RED LIST

THE STATUS AND DISTRIBUTION OF FRESHWATER BIODIVERSITY IN INDO-BURMA

D.J. Allen, K.G. Smith, and W.R.T. Darwall (Compilers)

INDO-BURMA

The IUCN Red List of Threatened Species™

SSC Species Survival Commission

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Executive Summary and Key Messages

The United Nations World Charter for Nature (1982) states that "every form of life is unique, warranting respect regardless of it's worth to man, and, to accord other organisms such recognition, man must be guided by a moral code of action." It also states that "…man must acquire the knowledge to maintain and enhance his ability to use natural resources in a manner which ensures the preservation of the species and ecosystems for the benefit of present and future generations." Most will recognise that, in the context of development planning, we now rarely respect nature, and we lack sufficient knowledge of biodiversity to inform decision making processes. This is certainly the case in the Indo-Burma region which is recognised as a global hotspot of biodiversity and has long been noted for the exceptionally high diversity of species within its inland waters.

Our knowledge of species diversity within the inland waters of Indo-Burma is poorly documented and the region remains relatively under-surveyed. Large scale development of water resources is also underway throughout the region with noted current and potential impacts on freshwater species. There is therefore an immediate need to collate, and make freely available, existing knowledge on freshwater species distributions, ecological sensitivities, and habitat requirements for input to the decision making processes. Without such information, development is unlikely to proceed in a sustainable way and the impact on freshwater species will be severe.

In this volume we aim to address this knowledge gap and present the most up-to-date information on the distribution and extinction risk of freshwater species in all inland water ecosystems across the Indo-Burma hotspot, and where appropriate, the reasons behind their declining status. This represents the most comprehensive assessment yet of freshwater biodiversity at the species level for this part of the world. For managers, this information will assist in designing and delivering targeted action to mitigate and minimise impacts to these species. From a policy perspective, the information presented is fundamental to meeting national obligations under the Convention on Biological Diversity (CBD); the Ramsar Convention; and the Millennium Development Goals (MDGs). Information on species status is particularly important for Targets 11 and 12 of the CBD that state: "By 2020, at least 17 per cent of terrestrial and inland water areas, … especially areas of particular importance for biodiversity and ecosystem services, are conserved…" and "…by 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained", respectively.

Biodiversity within Indo-Burma's inland waters is both highly diverse and of great importance to livelihoods and economies. This part of Asia is, however, embarking upon an unprecedented scale of development, in particular within its energy and water sectors. Such development is considered by many to be imperative if the region is to generate revenues and improve the livelihoods of this most densely populated region. Such development activities are, however, not always sustainable or compatible with species conservation in inland waters which is seldom adequately considered within the development planning process.

As a major contribution towards the provision of information on the region's freshwater species, IUCN's Global Species Programme, in collaboration with its partners, conducted an assessment of the status (according to the IUCN Red List of Threatened Species™) and distribution of all described species of freshwater fishes, molluscs, odonates, crabs, and selected families of aquatic plants from across the Indo-Burma hotspot. A total of 2,515 species were assessed and documented. Existing additional information for 468 species of freshwater dependant amphibians, birds and mammals was also utilised to present a more comprehensive overview of the status and distribution of freshwater species across the region. With species information compiled for each of 1,082 individual river or lake sub-catchments, this volume represents a major advance in knowledge for informing development actions at a scale appropriate for conservation management. The full dataset, including all species distribution files, will be made available through the IUCN Red List website (www.iucnredlist.org).

Thirteen percent of all freshwater species assessed here are globally threatened. This level of threat is similar to that for other taxonomic groups in the region (12% of water birds, and 12% of amphibians are threatened) and is predicted to increase dramatically unless the ecological requirements of freshwater species are provided for in future development planning, in particular for development of the energy and water sectors. Major threats are identified as Pollution (from agriculture and forestry runoff in particular), Biological Resource Use (direct exploitation and/or habitat loss through deforestation), and Natural System Modification (dam construction and other modifications such as river clearance for navigation). The majority of threatened species are found along the mainstream Mekong River and the central and southerly parts of the Chao Phraya River. This distribution largely reflects the overall pattern of recorded species richness and the parts of the region where our knowledge is most complete – other centres of threat may also be detected as further information becomes available.

Major centres of overall species richness include the lowland areas within the lower and middle Chao Phraya River, the main stem of the Mekong River between the Lao PDR border and the confluence of the Mekong and Tonlé Sap rivers in Cambodia. A number of river and lake basins are identified as a network of potential Key Biodiversity Areas (KBAs) most important for the protection of threatened and restricted range species. Those sub-catchments with the highest numbers of species meeting the KBA criteria are along the main stem of the Mekong river (in particular the region where Cambodia, Thailand and Lao PDR meet), the central Song Hong river system, the region surrounding Inlé Lake and the central Mae Khlong as it meets the Gulf of Thailand.

The IUCN Red List is one of the most authoritative global standards supporting policy and action to conserve species. We hope this analysis, based in large part on an assessment of species Red List status, will provide new information and insights, which will motivate actions to help safeguard the diversity of life within Indo-Burma's inland waters.

Key Messages:

- The inland waters of the Indo-Burma hotspot are confirmed to be one of the world's most species rich areas. For example, there is a higher diversity of species and genera of Odonata (dragonflies and damselflies) here than anywhere else in the Oriental Region, and the fish fauna is one of the richest in the world with more than 1,780 species known from the hotspot.
- Current levels of threat for Indo-Burma freshwater species (around 13% of species are threatened) are close to those of similar freshwater assessments in Asia, such as in the Eastern Himalayas (7% threatened), and Western Ghats (16% threatened). However, many areas remain poorly surveyed (for example, the Red River) such that 37% of all species assessed were classified as Data Deficient, meaning their extinction risk could not yet be assessed. As more data become available, undoubtedly a number of these species will be reclassified as threatened, and the overall number of threatened species will increase accordingly.
- Analysis of projected future threats suggests that, should current plans for construction of hydroelectric dams proceed as proposed, over the next decade the proportion of fish species threatened by dams will increase from 19% to 28%, and the proportion of mollusc species impacted by dams will increase from 24% to 39%.
- In this context the planned large-scale development of hydropower schemes, both on the Lower Mekong main stem as well as on its major tributaries, is of major concern – especially as the lower main stem in Lao PDR and Thailand, as far as northern Cambodia was found to be one of the areas with highest species biodiversity, and highest numbers of threatened species.
- Similarly, the Thai Government's recent announcement of a package of almost US$12 billion of (mostly) large scale water infrastructure investments in the Chao Phraya Basin in response to the devastating floods of 2011, gives cause for concern – especially as the middle and lower parts of the Chao Phraya are two of the most biodiverse areas, with one of the highest concentrations of threatened species.
- Pollution (largely from agricultural and residential run-off) is identified as a major threat affecting many species, that must be addressed through setting of improved standards and regulations together with monitoring and enforcement, application of the polluter pays principle, and through Payment for Ecosystem Services (PES) approaches.
- Over-harvesting is also a threat for some species and in certain locations. The recent suspension of 38 commercial fishing lot concessions in the Tonlé Sap (as well as concessions in other parts of Cambodia) for at least three years while stocks are assessed and more appropriate management can be developed, is a sign that governments are starting to recognise this issue and are willing to try to address it. To ensure that commercial concessions are not replaced by potentially even more damaging free-for-all "open-access" fisheries leading to a "tragedy of the commons", more effort must be applied to supporting the development of community-managed fisheries with agreed use rules and restrictions.
- Environmental Impact Assessments, Strategic Environmental Assessments, and Cumulative Impact Assessments should not be viewed as mere procedure and their recommendations must be taken into account. There must be follow-up after assessments are completed and the legal requirements of conducting them must be fulfilled. Such assessments should expressly require reference to the species data now made available through the IUCN Red List of Threatened Species. In the case of Mekong mainstream hydropower development, assessments must explicitly take into account trans-boundary impacts and, in the case of Thailand's Flood Management Master Plan, impact assessments should not be omitted or overlooked for the sake of political expediency in urgently preventing a recurrence of the 2011 floods.
- The overwhelming majority of protected areas in Indo-Burma have been designed and developed based on conservation needs (and opportunities) of terrestrial habitats and species. That freshwater habitats and species are protected at all is largely a result of their incidental inclusion within a forest protected area – and not as a result of a conservation plan specifically tailored to the protection of freshwater species. The protected areas systems of each country should be reviewed through the lens of freshwater species conservation priorities, gaps in the systems should be identified, and priorities established for extension of existing protected areas or designation of new areas to improve freshwater species conservation.
- Thailand has the most Ramsar sites of any country in the region, but almost all of these are additional designations applied to already existing National Parks or non-hunting

areas, and are not currently adding additional value to the conservation of freshwater species. In 2010–11 IUCN assisted the Government of Lao PDR to designate its first two freshwater Ramsar sites in Xe Champone and Beung Kiat Ngong, and assisted the Government of Viet Nam in designating Tram Chim (the most important area remaining in the Plain of Reeds in the Mekong Delta) as a Ramsar site. The process of identifying Key Biodiversity Areas started in this assessment should be built upon to help identify additional Ramsar sites (and other forms of conservation areas) within Indo-Burma.

- Monitoring of environmental conditions in inland waters must include focus on species diversity and not only on recording changes in species biomass and productivity (as is the case for most fisheries). The currency for measuring fish biodiversity is the number of species, not kilograms, dollars or catch per unit of effort. Without employing a species based approach many species will be lost, leaving in place species-poor and potentially unsustainable fisheries.
- Studies of direct interest to the local people should be translated into local languages and distributed freely. The results of too many studies are never made available and are therefore never used to benefit conservation.
- Finally, we must not forget the UN World Charter for Nature's statement that we respect all life regardless of its apparent worth to man. In other words we must still endeavour to protect those species that provide no obvious contribution to ecosystem services – including those smaller species of no apparent commercial value.

Chapter 1. Threats to freshwater biodiversity globally and in the Indo-Burma Biodiversity Hotspot

David Dudgeon[1]

1.1 Global status of freshwater biodiversity

Freshwater biodiversity is being increasingly imperilled by a range of factors globally (Dudgeon *et al.* 2006, Thieme *et al.* 2010, Vörösmarty *et al.* 2010). The vulnerability of freshwater biodiversity arises from the circumstance that fresh water is a resource that may be extracted, diverted, contained or contaminated by humans in ways that compromise its value as a habitat for organisms. Furthermore, the complex and often synergistic interactions between ecosystem stressors or threats to freshwater biodiversity will be compounded by human-induced global climate change, causing higher temperatures and shifts in precipitation and river runoff (IPCC 2007), increasing the difficulty of predicting outcomes for biodiversity and consequential extinction risks but, most likely, amplifying them (see Brook *et al.* 2008). Further complications arise from the urgent need to implement water resource developments to provide for ~0.9 billion people who do not have ready access to drinking water, and more than 2.5 billion people who lack adequate sanitation (WHO/UNICEF 2008). Because of a failure to address those needs, child deaths attributable to contaminated water number around 5,000 *daily* (~1.5 million annually). Self-evidently the matter is urgent, not least because halving the number of people without access to clean water and sanitation is one of the Millennium Development Goals, intended to stand as a major achievement of the UN-designated 'Water for Life' International Decade for Action (2005–2015).

Humans appropriate more than half of global surface runoff (Jackson *et al.* 2001), and anthropogenic water use and withdrawal are rising rapidly. Locally, especially in arid regions and some densely-populated areas, demand already exceeds supply and there is potential for humans to overstep planetary limits for 'blue water' runoff resources (Alcamo *et al.* 2008, Rockström *et al.* 2009). It is far from clear how the water needs of burgeoning human populations can be met in practical terms, but it is obvious that meeting them will have major implications for the supply of water required by ecosystems. The link between human livelihoods and freshwater biodiversity is made explicit in a recent global analysis which revealed that vast expanses of both the developed and developing world experience acute levels of imposed threat that compromise human water security and biodiversity (Vörösmarty *et al.* 2010). Sources of degradation in the world's most threatened rivers are broadly similar, but the highly-engineered hard-path solutions that are practised by industrialized nations to ensure human water security, and which emphasize treatment of symptoms rather than protection of resources, often prove too costly for developing nations. Thus human water security is threatened where governments lack the wherewithal to afford the technology that would protect their citizens. Moreover, the reliance of wealthy nations on costly

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Ang Tropeang Thmor is an artificial wetland northwest of the Tonlé Sap in Cambodia. It has been designated an Important Bird Area as the most important non-breeding site for Sarus Crane *Grus antigone* in Cambodia, as well as hosting many other wetland birds. © Jack Tordoff

technological remedies does little to abate the underlying threats, creating a false sense of water security, and the lack of comparable investments to conserve biodiversity accounts for the global extent of its imperilment. Unsurprisingly, then, there are virtually no places on Earth where the threat to human water security is high but the threat to biodiversity is low (Vörösmarty *et al*. 2010), and freshwater biodiversity is threatened by a combination of pollution, habitat degradation and water shortages everywhere that humans live in large numbers.

The midpoint of the 'Water for Life' decade coincided with the UN International Year of Biodiversity, when it became more evident than ever that the biosphere was undergoing an epidemic of human-caused extinctions (e.g. Butchart *et al*. 2010, Mace *et al*. 2010). Furthermore, a consensus has emerged that species population declines and losses from inland waters are greater than from their terrestrial or marine counterparts, so that freshwater ecosystems tend to have the highest portion of species threatened with extinction (see, for example, Loh *et al*. 2005, Dudgeon *et al*. 2006, Darwall *et al.* 2009, Strayer and Dudgeon 2010). Around 30% of the world's freshwater fishes (almost 40% in Europe and the United States) are threatened. An even higher proportion of the amphibians as well as many freshwater reptiles, and perhaps 20,000 freshwater macro-invertebrate species (especially crayfish and unionid mussels) are threatened. Iconic freshwater cetaceans are among the most threatened animals on Earth (e.g. Reeves *et al*. 2000) as exemplified by the functional extinction of the Yangtze River dolphin (Turvey *et al*. 2007). The fact that fresh waters are hotspots of threatened species demonstrates how exploitation and degradation of inland waters have outpaced our best attempts at management, and the degree to which current practices are unsustainable. Extinctions are likely to continue over the next few decades, regardless of actions taken now, due to an extinction 'debt' imposed by low-viability populations. (Strayer and Dudgeon 2010).

Stiassny (1999) co-opted Marshall McLuhan's phrase 'the medium is the message' (originally coined in a very different context) to encapsulate the notion that freshwater biodiversity faces unparalleled threats due to dependence on a resource subject to unprecedented and ever-increasing human demands upon it. Section 1.1.1 explains what makes the biodiversity associated with fresh waters particularly vulnerable to human impacts, while Section 1.1.2 discusses what the main threats are, why they are so severe, and the inherent features of freshwater environments which make their inhabitants particularly susceptible to changes wrought by humans. The consequences of this matter for Indo-Burma are considered in Section 1.2 where examples of the array of threats to freshwater biodiversity are given. Implications of the threat to freshwater biodiversity for ecosystem functioning and human livelihoods – representing one answer to the question of why threats to freshwater biodiversity matter – are addressed in Section 1.3.

1.1.1 Species diversity

The biota of fresh waters has yet to be fully inventoried, especially in tropical latitudes, but a recent – albeit incomplete – global assessment (Balian *et al*. 2008) demonstrates that it is very much larger than would be expected from the area occupied by inland waters. Of the ~1.32 million species thus far described on Earth, ~126,000 live in fresh water (Balian *et al*. 2008): almost 10% of the global total. Of these, 10,000 species are fish; approximately 40% of global fish diversity and one quarter of global vertebrate diversity. When amphibians, aquatic reptiles (crocodiles, turtles) and mammals (otters, river dolphins, platypus) are added to the fish, the total comprises one third of all vertebrate species. This is surprising in view of the tiny amount of fresh water that is actually available as habitat. Almost all (97%) of the Earth's water is in the sea, and the 3% that is fresh mainly comprises polar ice or is deep underground. Surface freshwater habitats contain only around 0.01% of global water (0.29% of all fresh water) and cover about 0.8% of the surface (Gleick 1996, Dudgeon *et al*. 2006). Rivers contain a mere 2% of surface fresh water (i.e. 0.006% of total freshwater reserves), although an additional 11% is in swamps of various types including floodplain water bodies. It is the absolute scarcity of surface fresh water, in combination with the number (and proportion) of species living in these inland waters, that makes them 'hotspots' for global biodiversity. This goes some way towards explaining why they are also hotspots of threatened species (see above). Identification of areas that support particularly high freshwater species richness has lagged behind efforts for the terrestrial realm. The first attempt at mapping global freshwater ecoregions and hotspots was unveiled relatively recently (Abell *et al*. 2008; see Figure 2.3). It is an important development given the lack of any confirmation that terrestrial and freshwater hotspots overlap (Strayer and Dudgeon 2010) although, based on a recent analysis at the scale of river catchments throughout Africa, it appears such overlap is low (Darwall *et al*. 2011).

Although knowledge of freshwater biodiversity is improving (Darwall *et al*. 2009), large gaps remain, particularly among invertebrates and especially in tropical latitudes where tens of thousands of species await description (Dudgeon *et al*. 2006, Balian *et al*. 2008). Accordingly, determination of invertebrate conservation status is problematic, and globally comprehensive IUCN assessments of extinction risk have only been completed for freshwater crabs (Cumberlidge *et al*. 2009) and crayfish, with a sampled assessment of odonates (Clausnitzer *et al*. 2009). Sixteen percent of freshwater crabs are known to be threatened, and the proportion increases to 65% if species classified as 'Data Deficient' (DD: species for which there are insufficient data to allow an accurate assessment of their conservation status; such species may be either threatened or not) are also assumed to be threatened (IUCN 2010). Similarly, the range of threat to crayfish and odonates is 25–46% and 9–40%, respectively. Even among vertebrates, many gaps remain with, for example, 25% of amphibians classified by IUCN as DD. Surprisingly, the relatively well-studied vertebrates are still incompletely known: between 1976 and 2000, for example, >300 new fish species, approximately 1% of known fishes, were formally described or resurrected from synonymy each year (Stiassny 1999, Dudgeon *et al*. 2006). Even more strikingly, ~40% of the global total of 6,695 amphibian species has been described during the last two decades (AmphibiaWeb 2010).

Why are fresh waters so rich in biodiversity? A few freshwater species have large geographic ranges, but the insular nature of freshwater habitats has led to the evolution of many species with small geographic ranges, often encompassing just a single lake or drainage basin (Strayer 2006, Strayer and Dudgeon 2010), which also tends to increase extinction risk (Giam *et al*. 2011). High levels of local endemism and species richness seem typical of several major groups, including decapod crustaceans, molluscs, aquatic insects such as caddisflies and mayflies, and fishes (Balian *et al*. 2008, Leprieur *et al*. 2011). The high endemism results in considerable species turnover between basins or catchments, especially in tropical latitudes that were not affected by glaciation during the last ice age (Leprieur *et al*. 2011). The fundamental point is that because of high species turnover, water bodies tend not to be 'substitutable' with respect to their faunal assemblages and this contributes to regional species richness. Local diversification within inland water bodies that function as 'islands' reflects the limited ability of most freshwater species to disperse through terrestrial landscapes or to migrate through saline habitats from river to river along the coast. Moreover, the hierarchical arrangement of riverine habitats means that the populations and communities they harbour are differentially connected to – or isolated from – each other, with abilities to disperse through networks that depend on the vagaries of confluence patterns, stream gradients, or the presence of barriers such as waterfalls. Geographic distance may appropriately reflect the degree of isolation among terrestrial habitats, whereas stream distance, which is often much larger than straight-line distance, reflects the degree of isolation among stream habitats. Thus headwater streams tend to be isolated habitats for fully aquatic species, even if they are in adjacent valleys and geographically proximate, because there can be large 'stream distances' between them (Clarke *et al*. 2007). Geographic distance is a more appropriate measure of isolation among lakes or other standing-water bodies, but the problem of overland dispersal remains. The hierarchical architecture and/or isolation of fresh waters can contribute to richness (through evolution of endemism), but also limits the rate at which recolonization proceeds following local extinction events that may be caused by droughts, contaminants, and so on. Thus, the features generating freshwater biodiversity also contribute to its vulnerability to the many threats generated by human activities, as described below.

1.1.2 Major threats to freshwater species

Fresh water is a resource that may be extracted, diverted, contained or contaminated by humans in ways that compromise its value as a habitat for organisms. Here, again, 'the medium is the message'. Additional threats that apply the world over are overexploitation of fishes and other animals, which is a global problem (reviewed by Allan *et al*. 2005a, Dudgeon *et al*. 2006, Thieme *et al*. 2010), and introductions of exotic non-native or alien species (reviewed by Strayer 2010), especially predators. The impacts of alien species often aggravate the physical and chemical impacts of humans on fresh waters, in part, because exotics are most likely to successfully invade habitats already modified or degraded by humans (e.g. Bunn and Arthington 2002). Once the invader has become established, introduction – like extinction – is forever. The ecological, economic, and evolutionary changes caused by alien species can be so profound that they have given rise to the suggestion that we are entering a new era, the Homogocene, where all continents (and water bodies) are connected by human activities leading to mixing of their biota (Strayer 2010). Although there are complex and often synergistic interactions between factors that threaten freshwater biodiversity, it is nevertheless instructive to consider the main threats to freshwater biodiversity individually, since their origins and modes of action are rather different. For example, both the largest and smallest species of freshwater fish appear to be at greatest risk of extinction globally, but the former are particularly impacted by overfishing while threats to the smallest species are particular to local circumstances and the species concerned (Olden *et al*. 2007).

The multiplicity of human impacts on freshwater biodiversity is a result of the tendency for the integrity and diversity of lakes, streams and rivers to be determined to a very significant extent by the condition of their catchment areas. Land transformation for agriculture or urbanization can lead to sedimentation, pollution by nutrients, changed run-off patterns and so on, leading to direct mortality of biota by poisoning and habitat degradation, and sub-lethal effects and physiological impairment that may cause extinction over longer time scales. Pollutants may result in eutrophication, toxic algal blooms, fish kills and so on that are associated with biodiversity losses. In short, lakes and rivers are landscape 'receivers' (Dudgeon *et al*. 2006) and catchment condition impacts biodiversity via multiple complex direct and indirect pathways. Furthermore, downstream assemblages in streams and rivers are affected by upstream processes, including perturbation, so that flowing-water habitats are 'transmitters' as well as 'receivers'. For example, pollution from upstream is transmitted downstream thereby spreading potential impacts to otherwise intact reaches. Disturbances that threaten riverine biodiversity can also be transmitted upstream against the flow of water. Examples include dams that impede upstream migration of fishes or shrimps that breed in estuaries, thereby resulting in the extirpation of whole assemblages in headwaters. The dams that block salmon runs in rivers along the west coast of North America, lead to reductions in 'uphill' transfer of marine-derived nutrients with major consequences for in-stream and riparian production in headwaters (e.g. Gende *et al*. 2002). In addition to salmon, other migratory fishes have likewise declined by as much as 98% from historic levels of abundance in rivers along the Atlantic seaboard due to the combined effects of dams and overfishing (Limburg and Waldman 2009).

An additional axis of river connectivity – between rivers and their floodplains – is mediated by seasonal inundation during high-flow periods, with many riverine or wetland species adapted to and dependent on such flooding (e.g. Dudgeon 2000a; Lytle and Poff 2004). Levee construction, channelization and flow regulation, degrades floodplains by limiting or severing their connection with the river channel which, in turn, impacts migration and reproduction of aquatic species. Changes to riparian zones or river banks have a number of effects including disruption of food webs and the reciprocal transfers of energy and nutrients between terrestrial and aquatic habitats (e.g. Nilsson and Berggren 2000, Fausch *et al*. 2010). Exchanges between surface and ground waters are also fundamental for maintaining the integrity of freshwater ecosystems although this connectivity is rarely acknowledged since, typically, surface and ground waters are managed as separate resources. In summary, the inherent connectivity between freshwater bodies and their surrounding catchments ensures that threats to biodiversity can originate well beyond lake or river banks, and within-river hydrologic connectivity allows impacts to be transmitted in both downstream and upstream directions. This is markedly different from the relatively localized effects of most human impacts in terrestrial landscapes.

It is a paradox that impacts can be transferred with efficiency throughout drainage networks (especially downstream), yet – as mentioned above – the complex architecture of such networks and the isolation of water bodies tends to constrain resilience and recovery from impacts. The consequences of the fragmented and insular nature of fresh waters are greatly magnified by the construction of dams. The extent of such dam-related impacts is very substantial: a global overview of dam-based impacts on large rivers revealed that over half (172 out of 292) were affected by fragmentation (Nilsson *et al*. 2005). Another indication of the extent of human alteration of global flow regimes is that dams retain over 10,000 km3 of water, the equivalent of five times the volume of all the world's rivers, and reservoirs trap 25% of the total sediment load before it reaches the oceans (Nilsson and Berggren 2000, Vörösmarty and Sahagian 2000), and this has had important consequences for rates of aggradation of the deltas around the world (Syvitski *et al*. 2009).

A fundamental reason why alteration and regulation of flow is so problematic is that all fresh waters are spatially and temporally dynamic systems, exhibiting variability in discharge, inundation or other aspects of water regime, on diurnal, seasonal and inter-annual timescales. Temporal variability in sediment and nutrient fluxes are also typical of biologically-diverse freshwater ecosystems, and interact with flow regime (including disturbances such as floods and droughts) to maintain habitat diversity and ecosystem processes. Such variability enhances the persistence and richness of native species, whilst making the habitat less 'invade-able' by non-native aliens (Bunn and Arthington 2002, Lytle and Poff 2004, Poff *et al*. 2007). Some of these species are adapted to ephemeral or intermittent systems, where water is present for part of the year only, whereas others require perennial inundation or flows. Seasonal peaks in the hydrograph and/or associated changes in temperature or turbidity may represent reproductive cues for fish and other organisms, whereas some species may recruit only during low-flow conditions (Bunn and Arthington 2002, Lytle and Poff 2004).

Humans treat flow variability as undesirable or – in extreme cases – disastrous (e.g. floods, drought), and therefore modify or engineer freshwater bodies to increase predictability and control variability. As well as leading to a loss of hydrographic cues for reproduction (Lytle and Poff 2004), a 'flattening' of peak flows limits the fluvial disturbance needed to rejuvenate habitat (Bunn and Arthington 2002, Poff *et al*. 2007). Maintaining the dynamic and variable nature of streams and rivers is a prerequisite for protecting freshwater biodiversity (Poff *et al*. 1997), but presents a formidable challenge given the context of a resource management paradigm aimed at controlling hydrological variability. Strategies to develop regionally-specific environmental water allocations (or e-flows) are the subject of considerable research (Arthington *et al*. 2006, 2010; Poff *et al*. 2010) and, although significant constraints on implementation remain, some 'proof of principle' modification of dam operations to mitigate impacts has been achieved (Olden and Naiman 2010).

Human-caused climate change represents a profound and insidious threat to freshwater biodiversity. Signs of global climate change in freshwater ecosystems include detection of a direct carbon dioxide signal in continental river runoff records (Gedney *et al*. 2006), as well as warmer water temperatures, shorter periods of ice cover and changes in the geographic ranges or phenology of freshwater animals in temperate latitudes (reviewed by Allan *et al*. 2005b, Heino *et al*. 2009). Temperature increases in the tropics are projected to be less than those farther from the equator (IPCC 2007), but the impacts of any rises could be considerable since tropical ectotherms ('cold-blooded' animals such as fish and amphibians as well as invertebrates) may already be close to their upper tolerance limits (Deutsch *et al*. 2008). The inverse relationship between temperature during growth and body size in amphibians and many aquatic invertebrates will lead to smaller size at metamorphosis, plus decreased body mass due to increased metabolism and hence reduced adult fitness (Bickford *et al*. 2010), but other demographic consequences are also possible in aquatic reptiles such as skews in sex ratios (e.g. Zhang *et al*. 2009, Bezuijen 2011). Nonetheless, it must be stressed that there has been very little research on the implications of climate change for freshwater biodiversity in the tropics.

Species that will be most vulnerable to climate change are likely to be those that are highly specialized, with complex life histories, restricted ranges/limited distribution and/or highly-specific habitat requirements. Assuming that such species lack the evolutionary capacity to adapt to rising temperatures (and leaving aside the effects of climate change on flow and inundations regimes), distributional shifts offer one option for persistence in a warmer world. Given the insular nature of freshwater habitats, adaptation to climate change by way of compensatory movements into cooler habitats farther from the equator or to higher altitudes are often not possible, especially for the many fully-aquatic species that cannot move through the terrestrial landscape (Dudgeon 2007). Even flying insects and amphibians might find their dispersal opportunities limited in human-dominated environments. Moreover, compensatory movements north or south are not possible where drainage basins are oriented east–west. One conservation initiative that could help address this problem would be translocation or aided migration of threatened species from warming water bodies to habitats within their thermal range (Dudgeon 2007, Hoegh-Guldberg *et al*. 2008, Olden *et al*. 2011). Such actions would be controversial and costly, requiring detailed information about the species (which is available for only a tiny fraction of freshwater species threatened by climate change), and pose the risk of transferring diseases or leading to ecological impacts of the type associated with alien species (Strayer 2010, Strayer and Dudgeon 2010). However, the option of doing nothing cannot be equated with adopting the 'precautionary principle' in a warming world, where climatic shifts may leave freshwater animals stranded within water bodies where temperatures exceed those to which they are adapted or to which they can adjust.

In addition to the direct effects of climate change, human responses to such change could give rise to further indirect impacts on freshwater biodiversity that will be as strong or even greater. Climate change will create or exacerbate water-supply shortages and threaten human life and property that will encourage hard-path engineering solutions to mitigate these problems (Dudgeon 2007, Palmer *et al*. 2008). These include new dams, dredging, levees, and water diversions to enhance water security for people and agriculture and provide protection from floods so altering flow and inundation patterns in ways that will not augur well for biodiversity. In addition, there is increasing impetus to install new hydropower facilities along rivers to reduce dependence on fossil fuels and meet growing global energy needs. The ecological impacts of such engineering responses will magnify the direct impacts of climate change because they further limit the natural resilience of freshwater ecosystems: for instance, they may limit the ability of animals to move northwards or to higher altitudes. A related problem is

The Na Hang hydropower dam under construction, Gam River, Tuyen Quang province, Viet Nam. © Jack Tordoff

Whilst the mainstream of the Salween-Nujiang has not yet been dammed, numerous dams have been built on tributary rivers in China, as shown here (Dima Lo, on the northern Nujiang). © Sabrina Harster / Ryan Moll

that hard-path solutions initiated in response to disasters (e.g. severe floods associated with rainfall extremes) may be permitted to circumvent environmental reviews and regulations because of the urgent need for project implementation. Offsetting the effects of dams will require assessment of environmental water allocations (= environmental flows) needed for affected reaches, and consequent modification of dam operations to mitigate their impacts. Some holistic methods have been developed in Africa and Asia that attempt to strike a balance between development and resource protection (e.g. King and Brown 2010), but their implementation at appropriate scales remains challenging.

Finally, in this global overview, it is important to stress that declines in freshwater species are not a new phenomenon. Declines in European freshwater fish from around 1000 AD have been attributed to a combination of siltation from intensive agriculture, increased nutrient loads and pollution, proliferation of mill dams, introduction of exotic species, and over-fishing leading to reductions in mean size and abundance (e.g. Hoffmann 2005). Essentially, these are much the same factors that threaten freshwater biodiversity today. Historical losses of salmon and other species occurred well before any stock formal assessments (Limburg and Waldman 2009), giving rise to a tendency to underestimate the extent of human impacts and mistaken expectations about what species should be present in fresh waters or, indeed, what pristine, unpolluted freshwater ecosystems should be like. Inevitably, this is accompanied by a reduced interest in conservation of aquatic biodiversity.

1.2 Situation analysis for Indo-Burma

1.2.1 General overview

Asia is the most densely populated region on Earth: its tropical forests are threatened by the highest relative rates of deforestation and logging in the world, and much of the landscape is disturbed and degraded (Hannah *et al*. 1994, Achard *et al*. 2002, Sodhi *et al*. 2004, 2009; Bradshaw *et al*. 2009). There are marked contrasts between the rural poor and the growing, increasingly affluent urban populations with higher per-capita rates of resource consumption (Corlett 2009). This is especially clear in Indo-Burma, the geographic limits of which are shown in Figure 1.1. World Bank estimates (data.worldbank.org) that annual (2009) per capita gross domestic product (GDP) of the 6.3 million population of Lao PDR is US$940; Cambodia is even lower where 15 million people average an annual GDP of only $706. Both are less than the more densely-populated nations of Viet Nam ($1,113; 87 million people) and, especially, Thailand ($3,893; 68 million). High levels of malnutrition and food insecurity in Cambodia and Lao PDR contrast with the relative prosperity of Viet Nam and, especially, Thailand; the latter two countries also reveal the disparity between conditions enjoyed by residents of, for example, Ho Chi Min City and Bangkok and those experienced by many rural people.

In view of the prevalence of the human footprint in Asia as a whole, anthropogenic impacts on biodiversity in Indo-Burma might be expected to be significant and there is considerable evidence to support this (e.g. Sodhi *et al*. 2004, 2009; Bradshaw *et al*. 2009). A full assessment of those impacts is, at present, limited by insufficient knowledge of the region's rich freshwater biodiversity; even inventories of vertebrate species are incomplete. For example, 31% of amphibian species known from Viet Nam, Lao PDR and Cambodia in 2005 had been described since 1997 (Bain *et al*. 2007). Species totals for river fishes in the region demonstrate the same point: for example, estimates of the richness of the Mekong prior to 2002 ranged between 450 and 1,200 species (see Dudgeon 2002), while one subsequent extrapolation suggested as many as 1,700 (Sverdrup-Jensen 2002). Even the current total of 781 species recorded by the MRC, which may be projected rise to 1,300 species (MRCS 2011), demonstrates that a considerable uncertainty remains. The present assessment recognises 1,178 species of freshwater fish for Indo-Burma as a whole (see Chapter 4). Nonetheless, the Mekong ranks third (after the Amazon and Congo) or second in the world in terms of diversity of river fishes depending on whether the verified species total or the higher estimate is accepted.

The importance of Mekong fishes in terms of global biodiversity is paralleled by its significance for humans: the annual yield from the Lower Mekong Basin (LMB: the portion of the river basin downstream of China) is the world's largest freshwater capture fishery at an estimated 2,200,000 t (Hortle 2009); it may reach 2.5 million t if freshwater shrimps, crabs, snails and frogs are included (MRCS 2011). This is one quarter of the global total inland-water catch of ~10 million t annually. Its first sale value is approximately US$2.2–3.9 billion; this sum rises to $4.3–7.8 billion when the secondary retail products of catch processing (mainly fish sauce and fish paste in the LMB) are taken into account (Hortle 2009). Other, ancillary economic benefits include over US$1 million in license fees collected by the Government of Cambodia. Large numbers of people (more

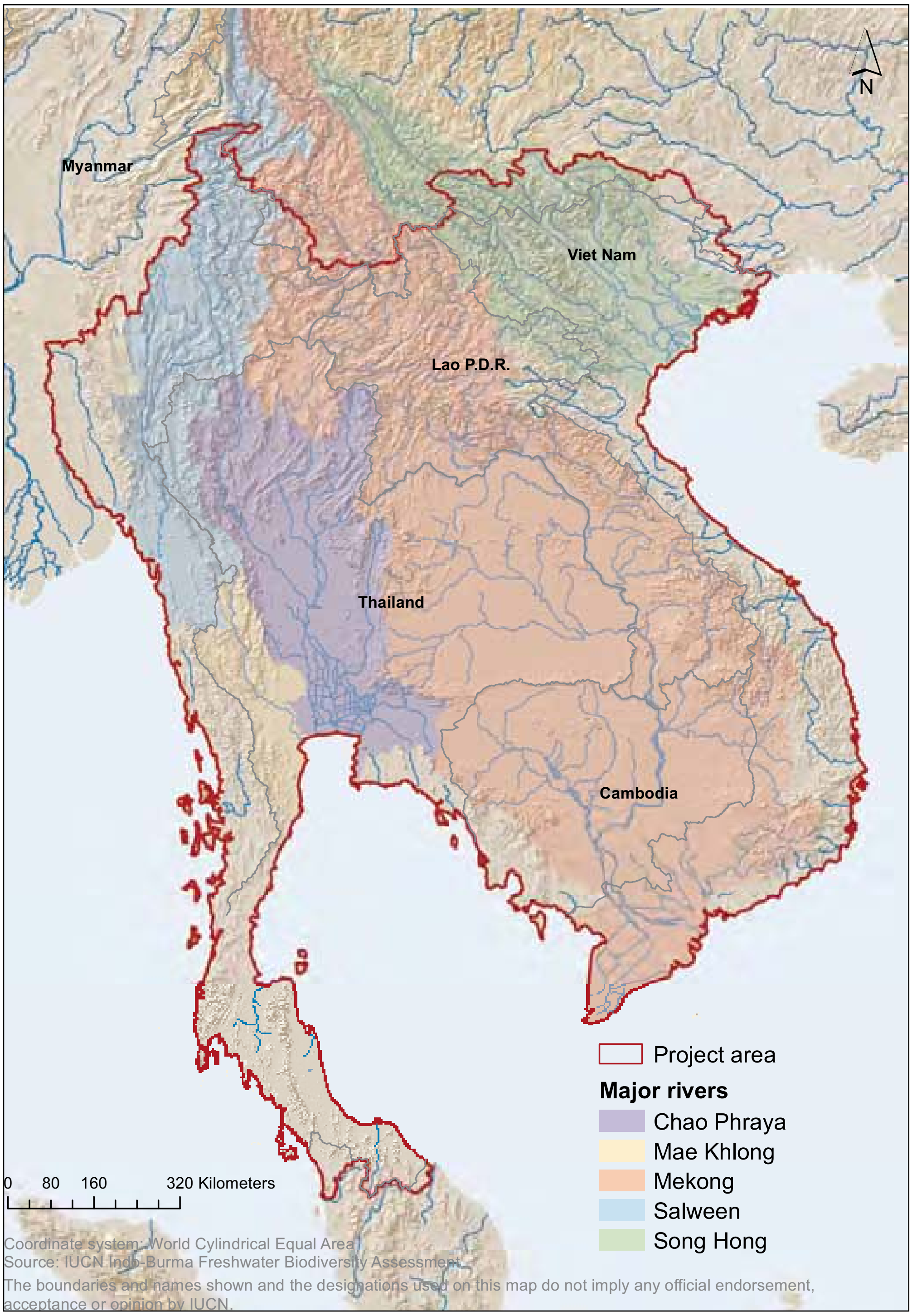


Figure 1.1 The Indo-Burma freshwater biodiversity assessment region and major river systems.

than half of them women) are involved in fishing on a small-scale, subsistence or *ad hoc* basis, amounting to around 40 million people in the LMB (MRCS 2011) with the catch contributing to family or local welfare and food security. In land-locked Lao PDR, for example, 83% of households engage in capture fishery at least some of the time, with 90% of the catch derived from rivers and streams, and fish provides 20% of animal protein consumed. The proportion is substantially higher in Cambodia where fish constitutes 47–80% of animal protein intake, or 29–39 kg per capita (Hortle 2007).

Despite our incomplete knowledge of the magnitude of freshwater biodiversity in Indo-Burma, the extent of threats to inland waters in the region is readily apparent from the recent global analysis of Vörösmarty *et al.* (2010) as shown in maps of threats to human water security and biodiversity in Southeast Asia (Figure 1.2). They summarise the combined intensity of threats posed by 23 weighted drivers within four categories: drainage-basin disturbance (4 drivers), pollutants (9), water-resource development (i.e. dams and flow regulation: 6), and biotic threats (4). For the purposes of this pixel-scale (0.5o) analysis, drivers were routed downstream (if their effects were not inherently local) or divided by annual discharge (if their effects were subject to dilution), and weighted according to their relative impacts. The weightings assigned to each driver within each theme, and to each theme, varied according to whether their impacts

Sorting the bagnet fishery catch on the Tonlé Sap, Cambodia. © Zeb Hogan were on biodiversity or on human water security. For instance, the weightings assigned to the number of dams and the extent of river network fragmentation in the context of an analysis of human water security were quite different from their weightings in calculations of impacts on biodiversity, because dams can benefit humans but have negative effects on aquatic biodiversity. Individual weightings of other drivers that were detrimental for both humans and biodiversity (e.g. pollutants such as mercury, pesticides, salinisation and so on) varied depending on the extent to which they threatened water security or biodiversity: e.g. high loadings of phosphorus and, especially, suspended solids, are relatively more detrimental to biodiversity (for details, see Vörösmarty *et al*. 2010). Despite differences in weightings used in the two analyses, remarkably, both maps of incident threat are almost the same for Indo-Burma and the surrounding areas (Figure 1.2). For example, pollution of the Chao Phraya basin tends to threaten both humans and nature, while the absolute scarcity of water in northeast Thailand likewise imposes similar patterns of aggregate threat in the two maps. By contrast, much of the LMB, with the exception of the delta where salinisation is widespread, generally experiences a low intensity of threat. The spatial variability within Indo-Burma contrasts dramatically with the relatively uniform and higher levels of threat in China to the east and India and Bangladesh to the west (Figure 1.2).

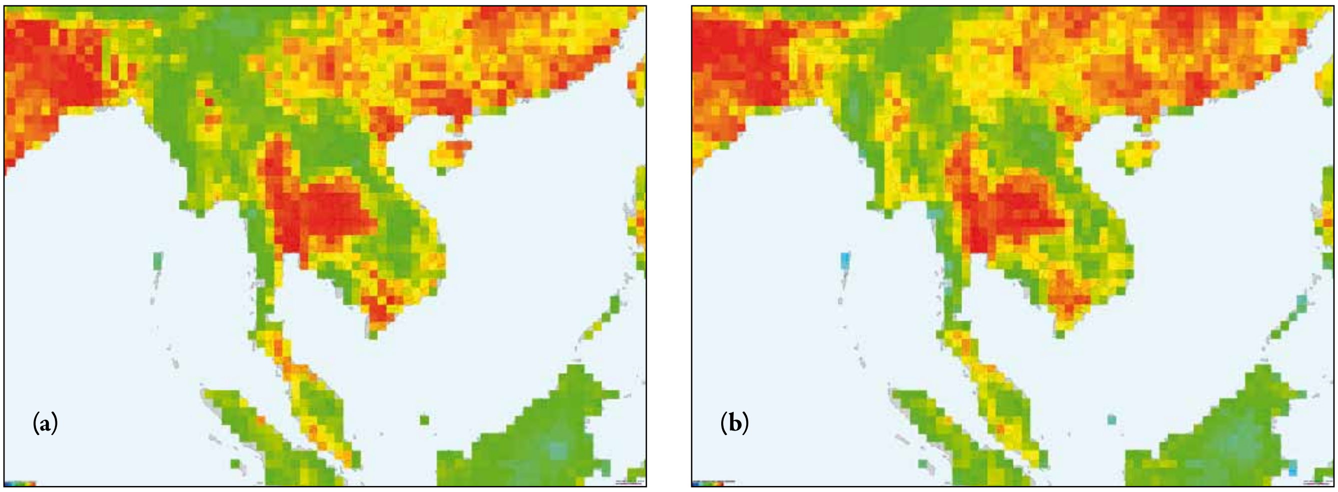
1.2.2 Threats to freshwater ecosystems

1.2.2.1 Drainage-basin transformation

There are two general categories of practices by which freshwater ecosystems can be degraded by humans. First, through transformation of the aquatic habitat itself, by contaminating it so that the water quality is reduced, or by draining it, damming it, and altering the flow or inundation regime. These topics will be considered under 1.2.2.2 (Pollution) and 1.2.2.5 (Dams and flow regulation). Second, because freshwater ecosystems are landscape 'receivers', modifications in vegetation cover or land use due to deforestation, agriculture or urbanization change run-off patterns, usually by way of reduced percolation or infiltration into the soil and increased surface flow. Both the amounts and timing of run-off and stream flow are altered, as well as the quantities of inorganic sediment, organic matter and pollutants or contaminants that are transported. This is a matter of great importance in Southeast Asia in general where loss of terrestrial habitats through deforestation and land-use change is occurring at higher relative rates than other tropical regions (Achard *et al*. 2002; Sodhi *et al*. 2004, 2009), with especially dramatic losses in forest cover in Indo-Burma between 1970 and 1990 (Bradshaw *et al*. 2009).

Transformations within a watershed far from the recipient river, lake or stream are augmented by changes that occur in riparian areas, where forest and vegetation clearance degrade habitat and are often combined with levee construction or bank engineering that can separate rivers and lakes from the areas that they inundate during the wet season. This has serious impacts on floodplain vegetation, riparian inundation or swamp forest plants, as well as fishes (especially blackfishes; i.e. species that make lateral migrations between the river channel and its floodplain), waterbirds, and other animals that make seasonal use of such areas for feeding or breeding. Such transformation also results in direct loss of habitat for species that have amphibiotic life cycles (most amphibians, Odonata and other aquatic insects with terrestrial adults) that depend on the riparian interface between land and water, and habitat loss is considered to be the preeminent threat to Southeast Asian amphibians, particularly those with restricted geographic ranges (Rowley *et al*. 2010). An additional threat category, related to habitat transformation, is mining of river alluvium to obtain sand for building. The combined effects of such threats are evident in Lao PDR, where river birds have been severely impacted by habitat alteration and

Figure 1.2 Relative intensity of incident threats to human water security (a) and freshwater biodiversity (b) in Southeast Asia attributable to the combined effects of 23 weighted drivers within four categories: drainage-basin disturbance (4 drivers), pollutants (9), water-resource development (i.e. dams and flow regulation: 6), and biotic threats (4). Intensity of threat within each 0.5o pixel is indicated from low (yellow) to high (orange and red). For more information, see Vörösmarty *et al.* (2010) and the associated website (www.riverthreat.net**).**



Habitat conversion and degradation impact wetlands throughout the Indo-Burma region. © Zeb Hogan

disturbance of breeding sites, with those nesting on sand bars being particularly vulnerable; some species have disappeared from large portions of their former range (Thewlis *et al*. 1998, Duckworth *et al*. 1999).

Much land-use change in Indo-Burma is associated with deforestation (Figure 1.3; see also Figure 1(a) in Bradshaw *et al.* 2009), as mentioned above, with control of logging in one part of the region (e.g. Thailand) resulting in an increase in the intensity of forest degradation in others, such as Cambodia. Both deforestation and conversion of land to agriculture result, to a greater or lesser degree, in soil erosion and increased sediment loads in receiving waters; in extreme cases, streambeds become choked with sediments. Organic-matter dynamics are also affected, both in the short term (when streams and rivers receive much organic debris during and after the forest clearance) and in the longer term since the provision of plant litter from the land is greatly reduced or ceases, and the contribution that dead trees in the form of log jams or 'snags' make to aquatic habitat complexity gradually diminishes. Previously shaded streams become exposed to the sunlight, and algae may proliferate, so the food web of the habitat shifts to dependence on aquatic autotrophic production rather than reliance upon detritus derived from the land. There are changes in temperature too with, for instance, cool shaded streams with rather stable temperatures transformed into habitats with warmer water and greater diurnal temperature range. Even partial logging or conversion of forest to plantation can have subtle ecological effects, since food sources for aquatic animals in shaded streams tend to be derived from the land in the form of leaf litter, and the variety of food types available will decline as terrestrial plant richness is reduced. In the case of Rubber (*Hevea brasiliensis*) plantations, the plant litter is, however, highly palatable to stream detritivores, and decomposes more rapidly

The clear waters of the Tonlé Sap River meet those of the Mekong River at Phnom Penh. © Zeb Hogan

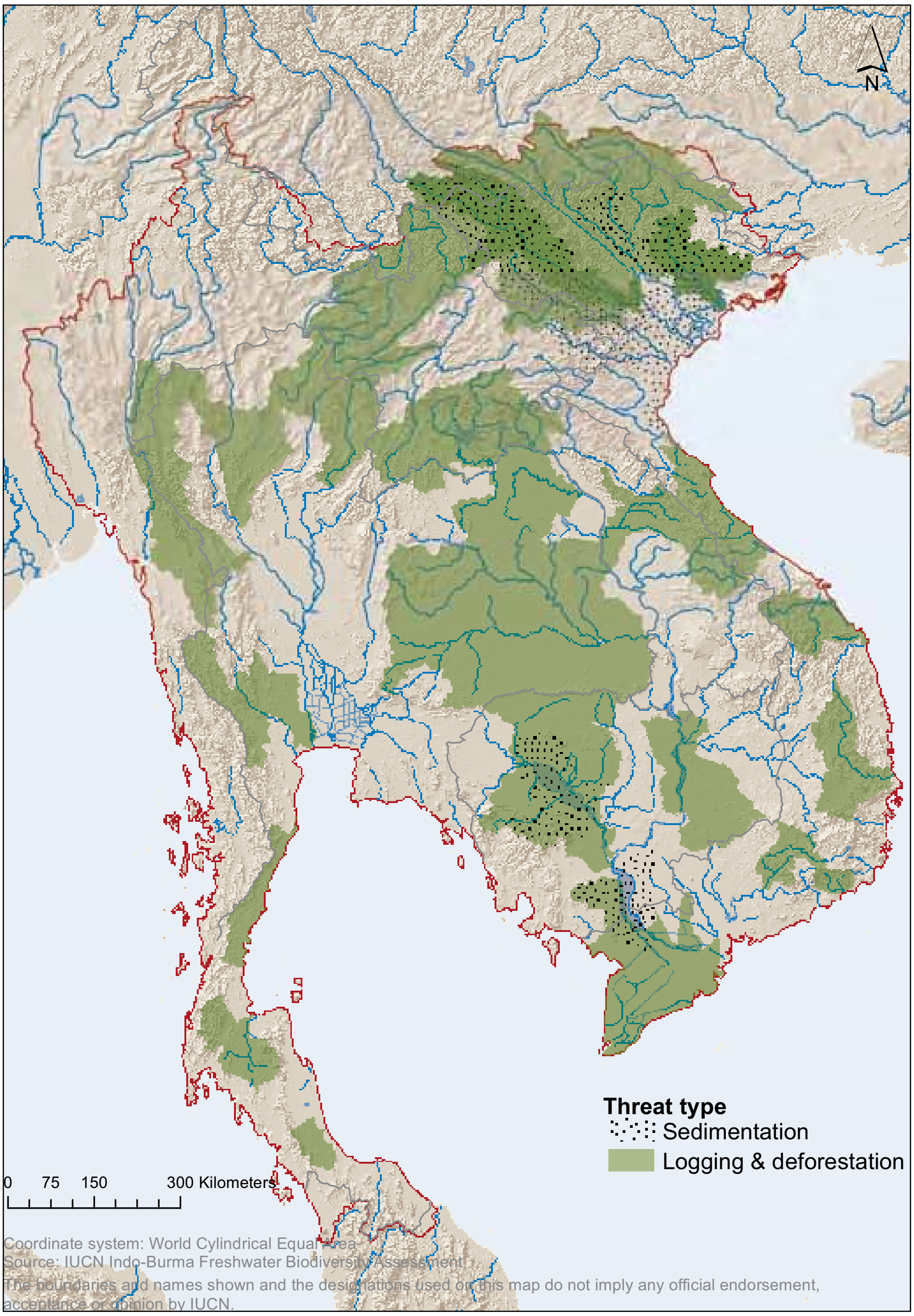


Figure 1.3 Map showing key areas of current deforestation and sedimentation in the Indo-Burma region. Note that the map was developed by participants at the project training workshop (see Chapter 2), based on their geographical areas of knowledge, and is not comprehensive.

than native species (Parnrong *et al.* 2002, Walpola *et al.* 2011), which may have implications for energy flow through aquatic food chains. Rubber is deciduous, with peak abscission during the dry season in Thailand, the timing of which is quite different from the year-round litter inputs that typify streams draining evergreen forest (Parnrong *et al.* 2002). The pulp and paper industry in Thailand has led to the development of huge monocultures of *Acacia* and non-native eucalypts with sclerophyllous litter that differs from that of native trees; pulp-mills constructed along rivers to serve these operations have added the insult of waste-water to the injury arising from the transformation of a diverse food-source into one that is inadequate to sustain native aquatic communities.

The ecological effects of land-use changes on freshwater biodiversity in Indo-Burma have not been investigated in detail (but for general reviews see Kottelat and Whiten 1996, Chapter 8 in Dudgeon 1999, Dudgeon 2000b), although fishes from streams associated with forests appear to be more extinction prone, in part because they have relatively restricted ranges (Giam *et al.* 2011). Land-use change tends to be associated with a loss of habitat complexity or heterogeneity in recipient fresh waters driving declines in biodiversity, and alterations in conditions that favour generalist species (including invasive aliens) at the expense of specialised indigenous species. The situation is exacerbated following conversion of deforested land to agriculture, since diffuse run-off of nutrients changes in-stream conditions and

In 2007, fishers reported the growth of dense mats of algae in the dry season channels of the Mekong River in the Stung Treng Ramsar site in Cambodia. Possibly caused by inflows of nutrients from agriculture, the algae disrupted fishing activities and impacted aquatic plants. © William Darwall / IUCN

can result in algal blooms or eutrophic conditions. Following land clearance, the substrata of recipient streams can become clogged with fine sediment from the land, which degrades the habitat of benthic animals. At times of high flow, this sediment is washed downstream where it accumulates along floodplains or lakes. For example, there have long been concerns over the rates of sedimentation in Tonlé Sap Lake with >70% of lake sediments (and the nutrients bound to them) derived from the Mekong River (Kummu *et al*. 2008). Thus land-management practices (and dam construction: see Section 1.2.2.5) that affect river silt loads could have profound effects on the nutrient supply and productivity of Tonlé Sap with implications for more than one million people who depend on its resources (Sverdrup-Jensen 2002). Forest clearance along the lake margins appears also to have impacted fish catches, and some additional potential threats to Tonlé Sap will be addressed in Section 1.2.2.5.

1.2.2.2 Pollution

Water pollution in Southeast Asia creates the same problems, has similar biological effects, and requires the same solution as in any other part of the world. Elevated nutrient loads and organic pollution are the major types of water pollution over much of Indo-Burma, reflecting the rather limited extent of industrial development in countries such as Cambodia and Lao PDR (Figure 1.4). Chemical and industrial pollution is a growing problem around urban centres especially in Thailand and, more recently, in Viet Nam where the economy is developing apace. Pollution from mining activities is also of importance in parts of Cambodia and Viet Nam. Apart from mining effluent, most of the pollution that affects inland waters in rural areas of Indo-Burma is not derived from industry or point sources, although the Chao Phraya River is a notable exception. Instead it has non-point source origins such as diffuse runoff from agriculture, and contamination of water by waste from villages and other dwellings not connected to sewerage systems, or by intensive aquaculture operations. Agrochemicals, especially those associated with intensive aquaculture, also pose an increasing threat. Their interactions with medical pharmaceuticals found in (but not restricted to) urban waste-water, as well as persistent organic pesticides and other more 'traditional' forms of pollution, present an array of lethal or sub-lethal threats to freshwater organisms, with impacts that depend on the concentration and mixture of contaminants, duration of exposure and so on. Over much of the region, detection or control of pharmaceutical release to freshwater environments is beyond the current capacity of authorities charged with environmental protection, and relevant new legislation may also be needed. However, general legislation to protect water resources already exists in most Southeast Asian countries. The fact that water pollution continues to be problem in the region, and appears to be increasing in magnitude and extent, reflects an inability or unwillingness to enforce such laws, especially pollution-control legislation requiring adherence to effluent standards (Dudgeon *et al*. 2000).

One of Indo-Burma's major rivers, the Chao Phraya, has already been severely degraded by all types of pollutants (Dudgeon *et al*. 2000), including industrial waste, and dam-building and a complex of other threats have degraded the river to the extent that perhaps only around 30 of the 190 indigenous fish species can reproduce in the river mainstream (Compagno and Cook 2005). It is this pollution that accounts for the significant threats to biodiversity and human water security in Chao Phraya drainage revealed in Figure 1.2, with dams and land-use change posing additional threats to biodiversity but not to humans. Unlike the Chao Phraya, urban and industrial discharges do not yet present a significant threat to fish biodiversity in the Mekong mainstream, although some local degradation of water quality due to saline intrusion, as well as acidification and eutrophication (mainly from aquaculture) are evident in the delta (MRC 2008). Biomonitoring at more than 50 sites in the LMB between 2004 and 2008 uncovered signs of degradation at scattered locations due to bank erosion, but most sites maintained excellent or good ecological health and a few (in the delta) even improved (Dao *et al*. 2010). While limited or localized pollution goes some way to explaining the low levels of relative threat to biodiversity in the LMB (see Figure 1.2), there are good reasons for concern about overfishing and dam construction here and elsewhere in Indo-Burma.

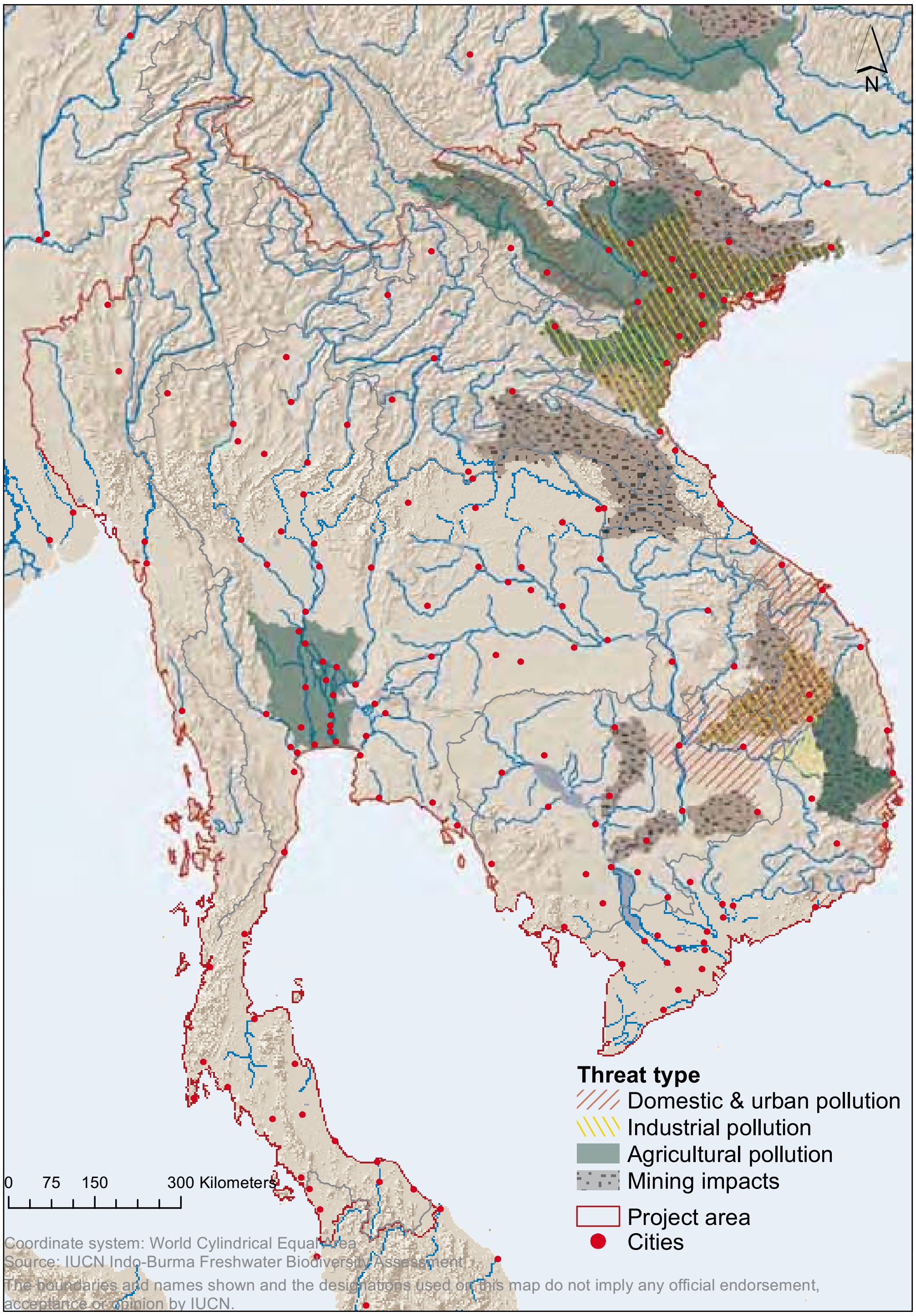


Figure 1.4 Map showing potential or actual sources of pollution as indicated by the distribution of cities, agriculture, mining and industries in the Indo-Burma region. Note that the map was developed by participants at the project training workshop (see Chapter 2), based on their geographical areas of knowledge, and is not comprehensive.

1.2.2.3 Overexploitation

Fishes

Freshwater fisheries the world over are exhibiting signs of overexploitation, with the effects being seen first in large or long-lived migratory species (Allen *et al.* 2005a, Dudgeon *et al.* 2006, see also Olden *et al.* 2007). Given its importance to the Indo-Burma Region, it is appropriate here to focus particular consideration on whether or not the Mekong fishery has been overexploited. Two major characteristics of this fishery are that it is based upon a large number of species, and that much of the catch (40–70%) is constituted by ~50 species that migrate within the Mekong (Barlow *et al.* 2008, Hortle 2009). The aggregate catch from the Mekong appears to be increasing although catch per fisher may be declining (FAO 2010): for example, the catch from Tonlé Sap floodplain lake in Cambodia doubled between 1940 and 1995; the number of fishers tripled over the same period. However, stability or increases in total catches can conceal the overexploitation of individual species in a multi-species fishery, with declines in the contribution of large, long-lived species to the overall catch being offset by increased capture of small, short-lived, fast-breeding species as the community is 'fished down'. This is quite evident from the Tonlé Sap example, where the 120,000 t annual catch in 1940 consisted mainly of large fishes while the 235,000 t caught during 1995 was almost exclusively small fishes (FAO 2010; see also Campbell *et al.* 2006). The *dai* (stationary trawl) fishery for Riel in the Tonlé

Sap River has been monitored since 1997, and catches of these small migratory cyprinids (mainly *Henicorhynchus* spp.) formerly showed a strong correlation with the height of the annual flood peak. Since 2004, this relationship has broken down (Campbell *et al*. 2006). Catches in 2010 were unusually low despite high water levels, perhaps due to scarcity of fry and poor recruitment success due to overfishing of adults in dry-season refuges (Sopha *et al*. 2010).

As detailed in Chapter 4, many fish species are directly threatened by overfishing with population declines of more than 80% recorded over the last 20 years. Many of these are the large migratory species. These include the endemic and Critically Endangered Mekong Giant Catfish (*Pangasianodon gigas*) that can grow to: ~350 kg (Hogan, 2011a), the Giant Barb (*Catlocarpio siamensis*; CR) (Hogan 2011b) and the Dog-eating Catfish (*Pangasius sanitwongsei*; CR), which are both reported to attain 300 kg (Roberts and Vidthayanon 1991, Roberts and Warren 1994), while the Freshwater Shark (*Wallago attu*; NT) – actually a silurid catfish – can grow to 2.4 m (Pethiyagoda 1991). All are affected by overfishing (Hossain *et al*., 2007), and the Dog-eating Catfish is apparently nearing extinction (Jenkins *et al*. 2007) Smaller fishes such as the migratory Laotian Shad is thought to be close to extinction due to overfishing (Blaber *et al*. 2003). Another Mekong endemic, the Small-scale Croaker (*Boesemania microlepis*; NT: up to 1 m length) has been reduced to no more than 20% of previous stock levels in Lao PDR, despite a law prohibiting their capture during the breeding season or sale at any time of the year (Baird *et al*. 2001). Notwithstanding the threats posed by overexploitation that particularly affect large species, it must be stressed that around 70% of the LMB catch (i.e. 1.8 million t; first-sale value US$1.4 billion) is based upon species that undertake long-distance migrations (Dugan 2008), and which are not *yet* threatened.

Frogs being cooked in Quang Nam Province, Viet Nam. © Jodi J.L. Rowley

Other vertebrates

The majority of Asian freshwater turtles are now at risk because of collection for trade (especially for food). The main consumers of turtle meat are in East Asia (China, Japan, and Korea) where the meat and shells are considered to have medicinal value and large numbers of species are imported (e.g. Cheung and Dudgeon 2006). Imports came initially from Viet Nam and Bangladesh and subsequently from Thailand and Indonesia. As wild stocks declined, these countries began acquiring turtles from neighbouring countries and transhipping them to East Asia. Thus turtles in India, Myanmar, Lao PDR and Cambodia became subject to intensive collection pressures (van Dijk 2000). Crocodilians and certain amphibians in the region are likewise threatened by overexploitation for skins (mainly) or as food (Campbell *et al*. 2006; Rowley *et al*. 2010), whereas declines in sand-bar nesting birds in Lao PDR appear partly attributable to egg collection (Thewlis *et al*. 1998). Elsewhere in the region, action by the Cambodian government to limit egg and chick collection appears to have reversed declines in the numbers of threatened colonial waterbirds around Tonlé Sap Lake (Campbell *et al*. 2006). One remarkable example of exploitation of wild animal populations involves five species of homalopsine watersnakes from Tonlé Sap, where daily market sales exceeding 8,500 individuals have been recorded, primarily as food for humans and farmed crocodiles (Campbell *et al*. 2006; Brooks *et al*. 2008, 2009, 2010). This probably represents the greatest exploitation of any single snake assemblage in the world and seems unlikely to be sustainable.

1.2.2.4 Dams and flow regulation

Effects of dams on fish and fisheries

The rivers of Indo-Burma have long been the subject of attempts by humans to control their flows and provide water for irrigation. More recently, they have come to the attention of engineers as potential sources of hydropower. While they are not yet subject to the degree of fragmentation, impoundment and regulation seen in China and India (e.g. Nilsson *et al*. 2005), the number of existing and proposed dams along the region's rivers is quite considerable (Figure 1.5). The deleterious effects of dams on river ecology are manifold, and include biophysical changes such as the reduction of aggradation rates of deltas attributable to sediment trapping within impoundments as evinced by the Chao Phraya delta in Thailand, where 'sinking' relative to sea levels has been accelerated by over-withdrawal of ground water such that the delta has been regularly inundated by sea water in recent years (Syvitski *et al*. 2009). The impacts of dams on the ecology and fisheries of north-temperate rivers and streams have been well established (e.g. Limburg and Waldman 2009, see Section 1.1.2) but there has been a general failure to apply any lessons learned from such experiences during planning of dams in Indo-Burma. An outstanding example is the devastation of artisanal fisheries caused by construction of the Pak Mun Dam (completed in 1994) on the Mekong's largest tributary in Thailand (Roberts 2001 and references therein). Reductions in fish diversity and fishery yields were attributed to obstruction of breeding migrations, habitat transformation (from flowing to standing water upstream of the dam), and periodic dewatering or extreme flow variation downstream combined with releases of warm, silty, oxygen-poor water from the impoundment (Roberts 2001). Dramatic declines in fisheries were also caused by construction of the Nam Theun-Hinboun Dam on a second Mekong tributary, the Theun River, in Lao PDR, despite prior knowledge that it would block fish migrations and degrade the aquatic habitat downstream greatly reducing dry-season flows (Dudgeon *et al*. 2000). The scheme generates electricity, some of which is sold to Thailand, by diverting water through a tunnel from a dam on the Nam Theun River downhill to the nearby Hinboun River. Further impacts on the 140 fish species known in the Nam Theun River are anticipated following construction of a second dam, the $1.3BN Nam Theun 2 scheme, which was completed in 2010. The dam

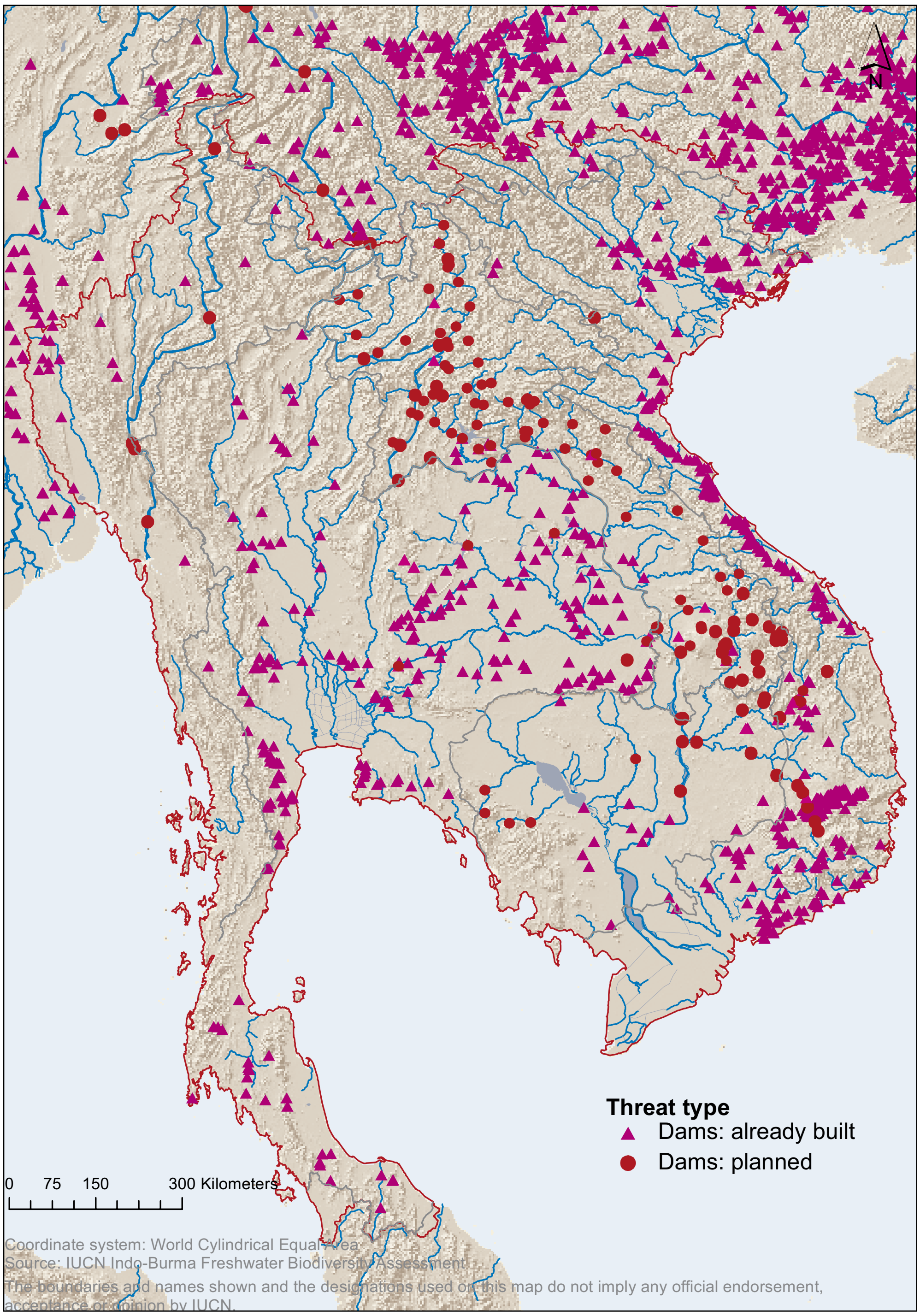


Figure 1.5 Known current (triangles) and proposed (dots) dams. The majority of the current dam records have been collated through the review of Google Earth images and the function of the dam can not be determined. It is thought that all proposed dams are for hydropower production. (Data sources: Indo-Burma training workshop participants, Mulligan *et al*. 2009, P.-J. Meynell pers. comm., M. Onial pers. comm., M. Kummu pers. comm.).

generates power during the process of diverting water downhill from the Nam Theun River to the Xe Bang Fai River 26 km away; most of the electricity generated is exported to Thailand. Impacts have yet to be assessed, but are likely to arise from blocked fish migrations, reductions in downstream flows and sediment loads in the Nam Theun, and changed flow patterns associated with water diverted into the Xe Bang Fai.

Elsewhere in the Mekong Basin, dam construction is ongoing on the Se San River in Viet Nam, close to the border with Cambodia, where the 69 m tall Yali Falls Dam that began operating in 2001 is the first in a cascade of six dams being constructed along the river. In most such instances of dam construction, the impact of the project is felt locally by fishers and those displaced by the impoundment (e.g. at Pak Mun and Nam Theun), while the benefits accrue elsewhere (for further discussion, see Dudgeon *et al.* 2000). In the case of the Yali Falls Dam and others in the cascade, this conflict is aggravated by national interests as the downstream impacts of these Vietnamese dams, which include dramatic water-level fluctuations, mainly accrue in Cambodia. Similar conflicts occur in the case of dams on the Lancang Jiang or Upper Mekong which affect countries downstream of China (see below).

Despite the concerns of scientists and non-government organizations about the impacts associated with dams, discussions about minimum flows needed to maintain ecosystem functions in reaches downstream of dams have scarcely begun (but see King and Brown 2010) and the design of fish ladders and passes suitable for indigenous fishes has received little attention. Where fish ladders have been built, they have been unsuccessful because they follow designs appropriate for salmonids, but few Asian river fishes jump. Observations at Pak Mun Dam suggest that scarcely one quarter of the 258 species in the Mun River could climb the fish ladder, and no gravid females of any species ascended it successfully (Roberts 2001). Downstream migration of adults comprises the same diversity of species that travels upstream, and occurs alongside eggs and larvae are carried by the current. Low water velocity in impoundments above dams compromises the drift of larvae, and may fail to provide adequate cues for adult migrants (MCRS 2011). In addition, downstream passage of large fishes through dam turbines would be virtually impossible even if upstream migrations were completely unhindered (Halls and Kshatriya 2009). It appears extremely unlikely that the direct impacts of dams on river fishes in Indo-Burma can be mitigated adequately, and continued proliferation of dams in the region is very likely to result in cumulative species loss.

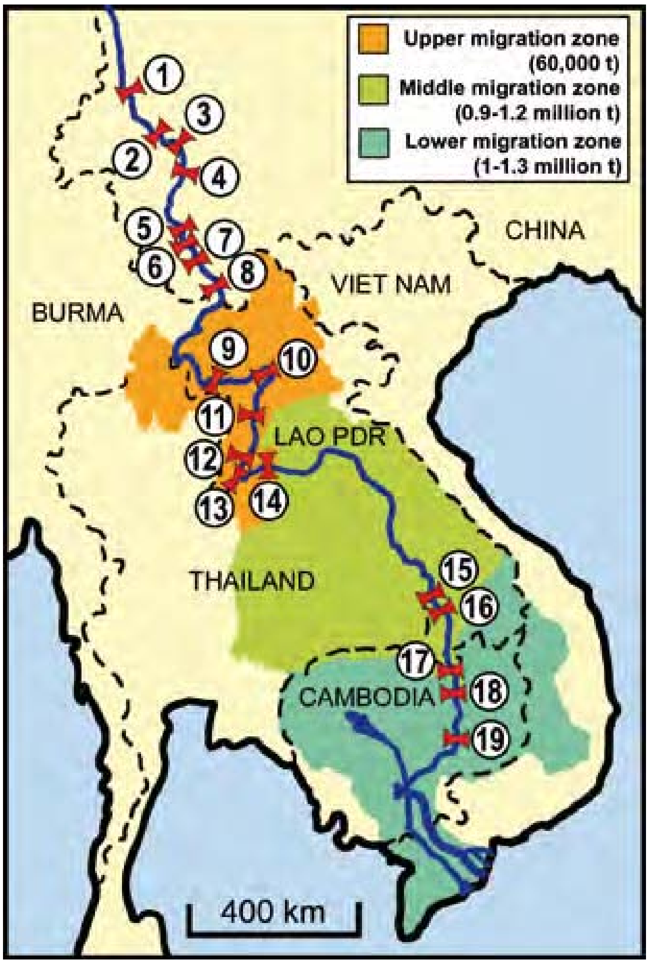


Figure 1.6 Map of the Mekong-Lancang Jiang showing the location of existing or planned dams. Estimates of total catch aggregated across all fish species in the upper, middle and lower Mekong migration systems are also shown, based on Halls and Kshatriya (2009). 1 = Gongguoqiao; 2 = Xiaowan; 3 = Manwan; 4 = Dachaoshan; 5 = Nuozhadu; 6 = Jinghong; 7 = Ganlaba; 8 = Mansong; 9 = Pak Beng; 10 = Luang Prabang; 11 = Xayaburi; 12 = Pak Lay; 13 = Sanakham; 14 = Pak Chim; 15 = Ban Koum; 16 = Lat Sua; 17 = Don Sahong (at Khone Falls); 18 = Stung Treng; 19 = Sambor. Dams 1 – 8 are situated on the Lancang Jiang.

Effects of dams on the Mekong mainstream

The local impacts of some dams on tributaries within the LMB have been substantial, but they might be assumed to be relatively minor compared with the likely effects of any dams on the river mainstream. This is not the case, and the cumulative impact of tributary dams cannot be ignored, since more than 70 (perhaps as many as 78) such dams may be operating by 2030 (MRCS 2011). A recent assessment by Ziv *et al.* (2012) projects that these 78 tributary dams would have catastrophic effects on fish productivity and diversity, even in the absence of any mainstream dam construction in the LMB. China has already set a precedent for mainstream dams on the Mekong (see Figure 1.6). Three dams on the Upper Mekong or Lancang Jiang were completed in 1995, 2003 and 2008, another is under construction, and four more are planned (Dudgeon 2005a, Barlow *et al.* 2008). The area of the Mekong drainage basin upstream of the border with China provides over 45% of the river's total sediment load (~160 million t annually). The three dams already completed have reduced sediment loads supplied to the LMB by 35–40% (i.e. to 60–65% of pre-dam conditions: MRCS 2011) and appear to be affecting aggradation of the Mekong delta (Syvitski *et al.* 2009). The reduction could rise to 45–50% by 2015 when the eight Lancang Jiang dams are completed (Kummu *et al.* 2010, MRCS 2011).

Khone Falls, the location of a proposed mainstream dam on the Mekong in southern Lao PDR. ©Jack Tordoff

These estimates are sensitive to assumptions about dam trapping efficiency and do not incorporate potential effects of changes in land use on sediment loads, or the possible incorporation of annual sediment flushing regimes into dam design and operation. Because the trapped sediments have nutrients bound to them, the Lancang Jiang dams have implications for the productivity of the LMB, with a 15–35% reduction in nutrient supply estimated to have occurred already rising to 15–40% by 2015 (MRCS 2011). Upon completion, the dam array is also projected to cause dry-season increases of up to 0.6 m in the level of Tonlé Sap Lake while decreasing the extent of wet-season inundation: flood duration would be shortened by two weeks, while the floodplain area, total flood volume, and amplitude would be reduced by 7% to 16% depending on scenario assumptions (Campbell *et al*. 2006, Kummu and Sarkkula 2008). There would be consequential reductions in gallery swamp forest and fishery yields with implications for the livelihoods of over 1 million people who depend on the lake's resources (Sverdrup-Jensen 2002). Note that these projections do not take account of predicted reductions in sediment loads in the LMB, but the effects on lake productivity may well be substantial given that >70% of Tonlé Sap sediments (and the nutrients bound to them) are derived from the river (Kummu *et al*. 2008).

Plans for mainstream dams in LMB date back to the 1950s (for details, see Dudgeon 2000a), but were stalled by regional conflicts and other constraints on development. Four decades later they appeared to be reaching fruition with a plan to construct 12 dams along the lower Mekong (Table 4 in Dudgeon 2000a). However, the projects were deferred in 2002, largely due to concerns about impacts on migratory fishes and fisheries raised by the Mekong River Commission (MRC), an inter-governmental organization established by four of the riparian states: Cambodia, Lao PDR, Thailand and Viet Nam (but not China or Myanmar: for more information, see Dudgeon 2005). National representation from each country provides a basis for prior consultation over water resource developments proposed for the LMB, followed by a process of review by MRC experts offering the potential to achieve consensus on whether or not particular developments would be beneficial for the region. Despite prior decisions of the MRC, 11 mainstream dams are under active consideration within LMB: 10 in Lao PDR and another in Cambodia (Figure 1.6). They include eight of the sites intended for the previous 12-dam scheme. Ten of the 11 dams will span the entire mainstream, with the other at Don Sahong in Lao PDR damming one of several branches of the mainstream at Khone falls. Two of the Laotian dams will be joint ventures between Lao PDR and Thailand, with the latter being the primary recipient of the electricity generated. Potential for conflict arises between the national interests of Lao PDR, due to the potential economic gains from selling electricity, and the concerns of other MRC member countries over impacts on fisheries. Thus far, Lao PDR has acceded to the wishes of fellow MRC stakeholders, and not proceeded unilaterally with dam construction, although preparations for construction of the Xayaburi Dam (Figure 1.6), the first in the array, are already complete. It is to be hoped that, despite the example set by China, Lao national interests will not trump transboundary concerns.

If it is built, the effects of the LMB dam cascade will be profound. At least 75% of the baseline sediment load would be trapped by the cascade dams plus dams planned for the Mekong tributaries, a considerable proportion of which would settle out in the 100 km-long Xayaburi Reservoir, with an associated decline in nutrients of up to 70% (MRCS 2011). However, the additional reductions in sediment flux and nutrient balance appear small compared with those attributable to Lancang Jiang dams (see above), and their indirect effects on productivity and fisheries will be much less than the direct effects of dams on fishes. Maintenance of the natural flood cycle and connectivity that allow unobstructed passage along the river is essential for fish reproduction and hence a productive fishery in the LMB, but both will be compromised by construction of mainstream dams. For that reason, virtually all evaluations predict that a large portion of fish production and its associated economic and social benefits would be lost if mainstream dams are built in the LMB (e.g. Dudgeon 2000, Barlow *et al*. 2008, Dugan 2008, MCRS 2011).

Prediction of the potential effects of dams must be predicated on knowledge of fish migration patterns. There are three main migration systems in the LMB: a lower zone below the Khone Falls; a zone between Khone Falls and Vientiane; and, a zone upstream of Vientiane (Poulsen *et al*. 2002a). While many species of whitefishes (i.e. those that migrate up- and downstream; *cf*. blackfishes) move within these three systems, they are interconnected as a number of commercially-valuable whitefishes migrate longer distances. Overall as many as 100 species may be affected by the mainstream dams, but the impacts will depend on the dam locations in relation to the migration zones. The six uppermost dams in the cascade (Figure 1.6) would convert almost 40% of the mainstream riverine habitat in the LMB into a chain of lacustrine water bodies – a loss of habitat representing 90% of the upper migration system (MRCS 2011). However, the predicted loss to the basin-wide capture fishery due to reductions in the area accessible to migrating fishes would be only around 6% (~66,000 t) of the basin-wide annual 2.5 million t fishery yield (MRCS 2011). This is because the impacts would be largely confined to the upper migration system which has a relatively small migratory biomass compared with the two downstream systems (Poulsen *et al*. 2002a; Barlow *et al*. 2008; Halls and Kshatriya 2009); thus the upper system has a migratory biomass of 36,000 t compared with 950,000 t in the lower system. However, the local loss of 66,000 t capture capacity in Lao PDR is equivalent to 73% of the floodplain fishery yield (Dugan 2008); if fully absorbed by the 2 million people living around the six dams in northern Lao PDR, the reduction in food security could amount to a substantial 33 kg fish/person/year (MRCS 2011). Many of the globally-threatened Mekong fishes are long-distance migrants and their movement between the three migration systems would be blocked by the Laotian dams. One view is that the Mekong Giant Catfish would likely become extinct because dams in Lao PDR would block access to spawning sites (MRCS 2011). Even if an engineering solution made upstream migration possible, it would be of no avail for this and other large fishes, such as Jullien's Golden Carp (*Probarbus jullieni*; EN), which reaches up to 70 kg and 1.5 m long (Roberts and Warren 1994, Baird *et al*. 1999), given the impossibility of return trips (Halls and Kshatriya 2009; see above).

The effects of dams as barriers to migration as well as the transport of sediments and nutrients will certainly be detrimental to fish and fisheries, and will interact with changes in flow and inundation patterns to profoundly alter aquatic productivity in the LMB. The proposed dams will also transform critical habitats such as deep pools, which are key dry-season refuges for many whitefishes (including Mekong Giant Catfish) and spawning sites of other species (Poulsen *et al*. 2002b). Changes in the quality of impounded water as well as water released downstream can be anticipated also. Environmental flow needs for downstream reaches will need to be addressed requiring, among other things, a post-construction monitoring programme in order to provide the data needed for adaptive adjustment dam operations to mitigate their impacts.

Mekong Giant Catfish, *Pangasianodon gigas,* Tonlé Sap Lake. ©Zeb Hogan

Mainstream dams on other major rivers

The Mekong-Lancang is not the only river in Indo-Burma that is hostage to the grandiose ambitions of dam builders. Preliminary site formation for some of a cascade of dams along the Nujiang – the upper course of the Salween River within China – began in 2003 but was suspended in 2004 after intervention by Premier Wen Jiabao in response to environmental concerns (Dudgeon 2005a). However, a stated goal of China's 12th Five-Year Plan (2011–2015) is to increase the proportion of energy generated from non-fossil sources. To achieve this, it was announced in the Chinese media (May 2011) that work on the Nujiang dams will be resumed, with a cascade of 13 dams (total capacity ~21 GW) envisaged along the mainstream. Details are scarce but, since 2007, at least eight dams have been proposed, including six on the Salween mainstream: the Upper Thanlwin (or Kun Long) Dam (2,400MW), the massive 228 m-tall Tasang Dam (7,110 MW), Ywathit Dam (600 MW), the Wei Gyi Dam (~5,000 MW), the Dagwin (or Lower Salween) Dam (792 MW) and Hat Gyi Dam (1,200 MW); Thailand will be the primary customer for the last three of these dams, and the Electricity Generating Authority of Thailand is a partner in their construction. The potential consequences of dams on the Nujiang-Salween cannot be predicted precisely, not least because the freshwater biota of these rivers is incompletely known. It is certainly diverse: at least 143 fish species are recorded from the Nujian-Salween representing 77 genera (Table 3 in Dudgeon 2000); Fishbase lists 147 species (Froese and Pauly 2011). A complicating factor is that there is uncertainty over which dams will be built, their configuration and the construction sequence. However, it seems hardly conceivable that construction of mainstream dams – especially the number planned for the Salween-Nujiang – will leave fish biodiversity unaffected, and a scenario of cumulative species loss and reduction of capture fisheries is more plausible. There is additional reason for concern over the region's rivers given that Chinese hydropower companies have entered into agreements to construct some of a series of dams within eastern Myanmar. At the time of writing, one of these (at Myitsone on the upper Ayeyarwaddy) was suspended by the Myanmar Government in an apparent response to public opposition to the project, and it is uncertain whether any of the planned dams will be completed.

1.2.2.5 Climate change

Climate change has already begun to affect rivers such as the Lancang-Mekong (He and Zhang 2005, Xu *et al*. 2009). Between 1960 and 2000, for example, mean annual air temperatures rose at a rate of 0.01–0.04oC at 12 stations along the Lancang Jiang in Yunnan Province. Significant changes in precipitation of 3–7 mm per year were also detected, with some sites increasing and others decreasing, but there was a notable trend for the most downstream sites (580–1,300 m elevation) to exhibit the greatest temperature rises and declines in rainfall, and thus a higher tendency to develop dry-season droughts (He and Zhang 2005). Other projections for the region as a whole include a general rise in mean annual temperature and greater duration of warm periods, as well as an overall increase in annual precipitation (and greater river flows) although the magnitude of this change will show marked spatial variation (Bezuijen 2011, and references therein). In the LMB, greater precipitation during the early monsoon and an overall increase in runoff with a higher frequency of floods has been projected (Xu *et al*. 2009, Bezuijen 2011), in general agreement with earlier predictions that extreme flow events in the LMB will become more common (Dudgeon 2000, and references therein). The Mekong delta region is expected to become highly vulnerable to increased storm and flood events, as well as saltwater intrusion and erosion due to rising sea levels (Cruz *et al*. 2007). This will be aggravated by reduced aggradation rates that have already been recorded in the delta (Syvitski *et al*. 2009). Sinking of the delta relative to sea levels will be further accelerated by trapping of sediment behind additional dams that are planned or under construction along Lancang-Mekong, and the same phenomenon has already affected the Chao Phraya (see Section 1.2.2.5). Elsewhere in the region, climate change projections suggest that monsoonal flows in the Nujiang/Salween are expected to increase, although annual discharge will fall initially (until ~2040) before exceeding present levels over the longer term (2070–2099: Xu *et al*. 2009).

There is a notable lack of research on possible impacts of climate change on freshwater biodiversity in Southeast Asia in general and Indo-Burma in particular (Bezuijen 2011), and the potential for thermal adaptation is unknown. Animals in rivers could, conceivably, adjust to rising water temperatures by making compensatory movements upstream to higher elevations or latitudes (Dudgeon 2007, Bickford *et al*. 2010). This may be especially important for species in the tropics that are relatively close to their upper thermal limits (Deutsch *et al*. 2007) and might be feasible for (say) fishes in many of the north-to-south flowing rivers of Indo-Burma, so long as such rivers remain free-flowing. However, the extent of movement needed to compensate for the upper bounds of the range of temperature rises predicted for the next century seems insurmountable for most freshwater species (see, for example, Bickford *et al*. 2010). Moreover, any such movements would be constrained by river topography, the presence of dams or other in-stream barriers, dispersal through a terrestrial landscape, availability of suitable habitats, or some combination of these (Dudgeon 2007). Here, as has been suggested for other regions (see Section 1.1.2), translocation or assisted migration of species at risk is one possible (albeit controversial) solution that may warrant further consideration for some species.

Determination of which freshwater species are most vulnerable to climate change, and might therefore warrant conservation intervention, is problematic due to the paucity of ecological data on freshwater species and their thermal tolerances (Bezuijen 2011). This information gap also makes it difficult to make detailed predictions about the effects of climate change, beyond extrapolations from the studies of temperate ectotherms (e.g. Heino *et al*. 2009). These suggest there could be shifts in the timing of recruitment and fish migration (driven by alterations in temperature and/or flow and inundation patterns), skews in sex ratios (in turtles and crocodiles), increases in metabolic costs and consequential effects on other components of energy budgets, and so on (e.g. Bickford *et al*. 2010). Increased scouring and washout associated with higher wet-season flows and flood events, lower oxygen levels in warmer water, and saline intrusion in coastal areas are potential sources of physical disturbance and stress on freshwater species.

A related issue is that existing protected areas of wetland within Indo-Burma (Figure 1.7) are static; climate space will alter over time and species will respond to this by shifting their distributions to a greater or lesser extent according to their dispersal ability, the availability of suitable and accessible habitat, and so on. Eventually, the boundaries of protected areas will no longer encompass the populations of species of conservation concern that they were established to protect, and thus their integrity and effectiveness will be compromised. Protected wetlands in the Mekong Delta (Figure 1.7) will be especially at risk from saline intrusion due to rising sea levels and reduced aggradation (Syvitski *et al*. 2009; see above). Furthermore, impacts arising from climate change in Indo-Burma will take place in the context of other threats to freshwater biodiversity, such as dam building, over-exploitation and habitat degradation, and their synergistic impacts could result in large-scale population declines or extinctions (Brook *et al*. 2008, Bezuijen 2011). Additional complexity is added by the possibility that changes in climate and, especially, warmer temperatures could facilitate the invasion of alien species and hence exacerbate the threats they pose to the indigenous biota, a matter which is considered in the following section.

1.2.2.6 Invasive alien species

Establishment of alien species is among the most important, poorly controlled and least reversible of human impacts on freshwater, and it can have profound ecological and economic impacts (see review by Strayer 2010). Despite this, the issue of exotics in tropical Asian fresh waters has been contentious. While some have expressed alarm over effects on indigenous species (e.g. Ng *et al*. 1993, Pethiyagoda 1994), others have championed the introduction of certain non-native fishes in particular circumstances. For instance, while the Tilapia *Oreochromis mossambicus* is categorised as one of the 100 worst invasive species by Lowe *et al*. (2004), Fernando (1991:28) concludes "… the drawbacks of tilapias are relatively minor compared to their contribution to the fisheries in Asia" and considers that there is no evidence that the introduction of Tilapias has adversely affected indigenous species. This view, which is in stark contrast to the concern over alien species expressed by authorities elsewhere, may indicate something about the difference in attitudes toward management of inland waters by workers in Asia, where human livelihoods and provision of protein from freshwater fishes is a paramount consideration.

A search of the Global Invasive Species Database (www.issg.org/database) reveals that a significant number of alien freshwater species have become established in Indo-Burma (Table 1.1); most are fish, but reptiles, amphibians, snails and aquatic plants – even a mammal – are also present although some are more widespread than others. A significant proportion of them are among the world's worst invaders (Lowe *et al.* 2004), and their potential effects on native species are quite various: predation on fishes (by, for example, Snakehead) and frogs (by American Bullfrog and Cane Toad), or their eggs and larvae (by Mosquito Fish); depletion of plankton and food-web alteration (by Silver Carp and Bighead Carp); bioturbation and increased siltation (by Common Carp and Armoured Catfish); habitat bioengineering and displacement of native fishes (by Tilapia, among others); competition with indigenous turtles (by Red-eared Slider); consumption of aquatic macrophytes (by Grass Carp and Apple Snails); shading or overgrowing submerged macrophytes (by Water Hyacinth, Floating Fern and Alligator Weed) or floodplain vegetation (Bashful Mimosa), and; transmission of fish parasites and disease (by Guppies and various carp species). Furthermore, dense growths of Water Hyacinth and Floating Fern reduce livelihood value of inland waters since they can prevent the use of boats, and tangle fishing gear, while the depletion of oxygen beneath floating mats is also detrimental to fisheries and other aquatic life. Apple Snails are economically important crop pests that are especially problematic in rice fields, which is ironic given that they were introduced in parts of Asia in order to enhance human food supply; their primary ecological effects are manifested through overexploitation of aquatic macrophytes and shifts in energy flow (Carlsson *et al*. 2004).

As the large proportion of fishes on Table 1.1 – which is certainly not exhaustive – indicates, many of the alien species originate from the aquaculture industry (e.g. various carp and Tilapia) representing escapes or, in some cases, deliberate releases. This is also the likely source of introduction of American Bullfrog, which are widely farmed for food in Thailand, while crocodile and turtle farms are a potential source of other invaders: for example, Chinese Softshell Turtles (*Pelodiscus sinensis*), Estuarine Crocodiles (*Crocodylus porosus*) and Cuban Crocodiles (*C. rhombifer*) have all been recorded from farms around Tonlé Sap Lake (Campbell *et al*. 2006), and this is the probable source of Caiman in Thailand (Table 1.1). Estuarine Crocodiles pose a particular risk to wild populations of the Critically Endangered Siamese Crocodile (*C. siamensis*) since the two species hybridise readily. Some alien fishes have become established after they were introduced to control mosquitoes (e.g. Guppies and Mosquito Fish) or have origins in the aquarium trade (e.g. Armoured Catfish). Other aquarium fishes, such as South American cichlids and Poeciliidae other than Guppies and Mosquito Fish (e.g. *Xiphophorus* spp.) have also become established but the long-term viability of many of these populations and their ecological effects have not been ascertained, and they may not be particularly invasive. Some of the non-fish species have become very widespread (e.g. Water Hyacinth, Apple Snails and Red-eared Sliders), and others may have the potential to become so (e.g. Bullfrog and Cane Toads), while larger species such as Caiman and Coypu are not yet widely established offering an opportunity for controlling their populations. The flooding-adapted Red Fire Ant (*Solenopsis invictus*), also among the 100 worst invasive species (Todd *et al*. 2008), is already established

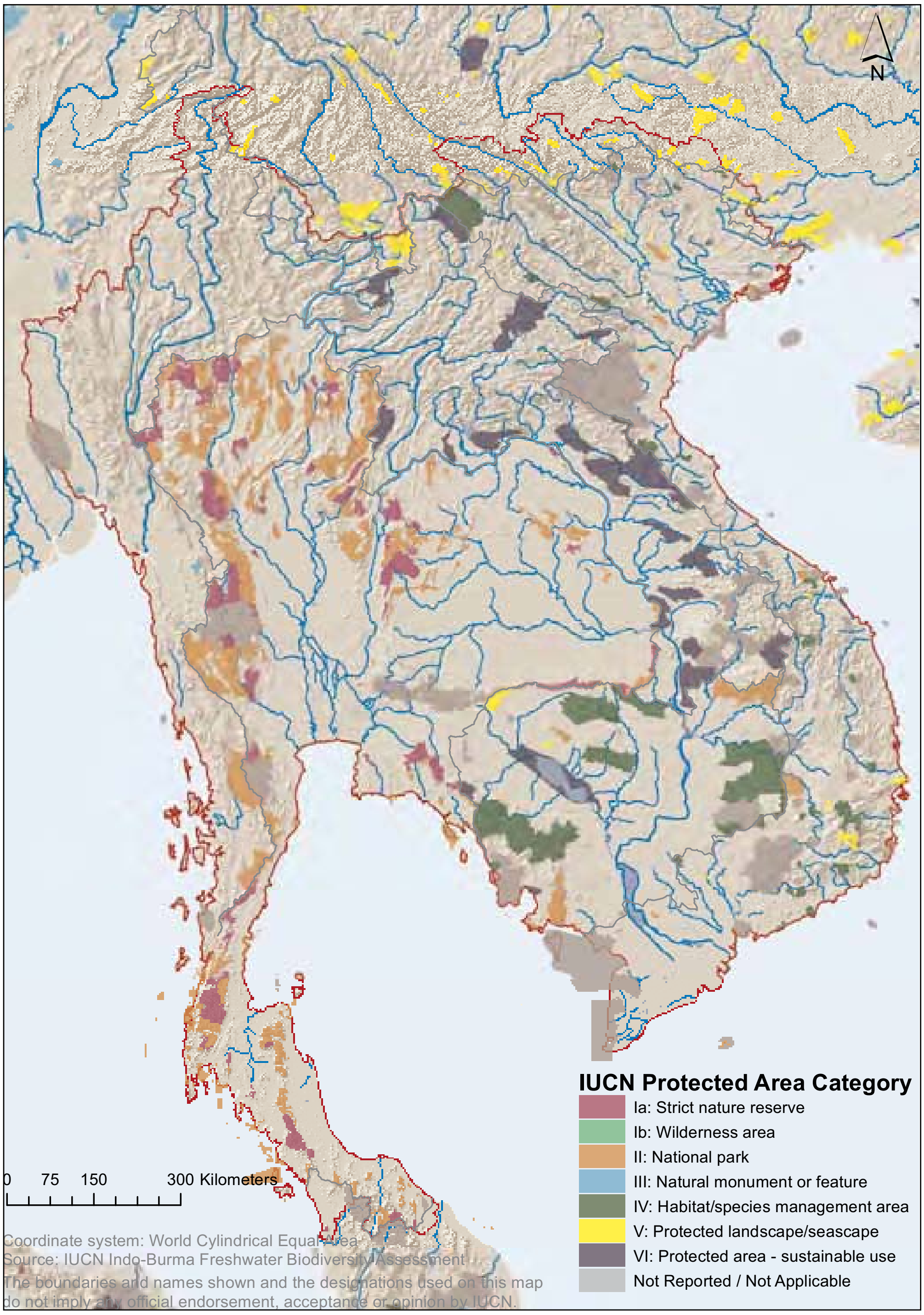


Figure 1.7 Protected Areas (with IUCN Category) found within the Indo-Burma region.

in wetlands in tropical East Asia (e.g. Hong Kong) and has the potential to become widespread in Indo-Burma wetlands where its impact could be substantial.

As in other regions (see Strayer 2010), aliens tend to gain an initial foothold in habitats that are disturbed or degraded by other anthropogenic factors; their potential impacts on native biodiversity are greatly magnified, however, if they can invade other, relatively undisturbed habitats. The ability to do so seems to be the primary attribute shared by the species in Table 1.1 that are categorised among the 100 worst invasive aliens (Lowe *et al*. 2004). Other species not thus categorised but which are of particular concern are obligate predators such as Snakehead, since their effects on the indigenous fauna can hardly be other than negative. Fortunately, there is thus far no indication that the invasive fungal pathogen *Batrachochytrium dendrobatidis*, responsible for the amphibian disease chytridiomycosis and implicated in population declines and extinctions globally, is present in Indo-Burma, nor have there been 'enigmatic declines' of amphibians in Southeast Asia of the type that have occurred in other parts of the world (Rowley *et al*. 2010).

1.3 Functions and values of freshwater ecosystems in Indo-Burma

Degradation of fresh waters and their component species is a matter for grave concern given the goods and services to be derived

Table 1.1 Sample list of alien freshwater species in Indo-Burma (Th, Thailand; Vn, Viet Nam; Ca, Cambodia; La, Lao PDR; My, Myanmar). Species classified among the 100 worst invaders are indicated (Lowe *et al.* 2004), and their demonstrated or inferred impacts on biodiversity and ecosystems are given.

Scientific name	Common name	Countries present	100 worst	Demonstrated or inferred impacts
Alternanthera philoxeroides	Alligator Weed	Th, My	No	Competition; overgrows other macrophytes
Eichhornia crassipes	Water Hyacinth	Th, Vn, Ca, My	Yes	Competition; shades submerged macrophytes; depleted oxygen under floating mats; blocks waterways; constrains human use of wetlands
Mimosa pigra	Bashful Mimosa	Th, Vn, Ca	Yes	Competition; displaces floodplain vegetation; reduces benefits gained from seasonally-inundated wetlands; rice-field pest
Salvinia molesta	Floating Fern	Th	No	Competition; shades submerged macrophytes; depleted oxygen under floating mats; blocks waterways; constrains human use of wetlands
Pomacea canaliculata	Apple Snail	Th, Vn, Ca, La	Yes	Consumes macrophytes and eggs/juveniles of other snails reducing wetland biodiversity; major rice-field and agricultural pest; *Pomacea insularum* also established.
Carassius auratus		Th, Vn	No	Preys on small fishes so indirectly precipitating algal blooms; may increase turbidity by disturbing bottom sediments.
Chana argus	Snakehead	Th, Vn, Ca	No	Voracious predator of fish and amphibians
Ctenopharyngodon idella	Grass Carp	Th, Vn, Ca, La, My	No	Voracious consumer of macrophytes; ecosystem engineer that alters food webs; carry parasites
Cyprinus carpio	Common Carp	Th, Vn, Ca, La, My	Yes	Ecosystem engineer: increases turbidity, disturbs macrophytes, and alters habitat conditions.
Gambusia affinis	Mosquito Fish	Th, Vn, My	Yes	Predator of small fish and amphibian eggs/larvae; alters food webs
Hypophthalmichthys molitrix	Silver Carp	Th, Vn, La	No	Eats zooplankton and competes with native fishes; alters food webs; transmits *Salmonella typhimurium*
Hypophthalmichthys nobilis	Bighead Carp	Th, Vn,Ca, La, My	No	Phytoplankton grazer that also eats zooplankton; alters food webs; transmits fish diseases
Oreochromis mossambicus	Tilapia	Th, Vn, Ca, My	Yes	Displace native fishes; alters food webs; other *Oreochromis aureus* also established.
Poecilia reticulata	Guppy	Th, Vn, La, My	No	Potential competitor of other small fishes; carries parasites
Pterygoplichthys spp.	Armoured Catfish	Th, Vn	No	Ecosystem engineer affecting food webs and siltation (bioturbation); at least two species established
Lithobes (= Rana) catesbeianus	American Bullfrog	Th	Yes	Predator and competitor of native amphibians
Rhinella (= Bufo) marinus	Cane Toad	Th	Yes	Predator and competitor of native amphibians and other small animals; toxic with impacts on native predators
Caiman crocodylus	Caiman	Th	No	Predator of native fishes, amphibians and other small animals
Trachemys script elegans	Red-eared Slider	Th, Vn, Ca	Yes	Competitor of native turtles; omnivore that alters food webs
Myocastor coypus	Coypu	Th	Yes	Consume macrophytes and wetland vegetation, degrading habitat conditions and reducing biodiversity

from them (Dudgeon *et al*. 2006). One estimate (Costanza *et al*. 1997) puts the value of ecosystem services provided by fresh waters at US$6.6 trillion annually, 20% of the value of all ecosystems combined, and in excess of the worth of all other non-marine ecosystems combined ($5.7 trillion), despite the far smaller extent of inland waters. While valuation estimates are subject to controversy, the general message that fresh waters have immense economic importance seems self-evident. Globally, at least two billion people depend upon rivers directly for provision of ecosystem services that can be characterised most simply as 'food', such as the benefits to be derived from fisheries, flood-recession agriculture, and dry-season grazing (Richter *et al*. 2010). Moreover, the value of fresh waters is bound to increase in future as ecosystems become more stressed and their goods and services scarcer.

Fish and fishing are the most obvious ecosystem goods and services to benefit humans in Indo-Burma. They have, for example, been central to Cambodian culture since ancient times, sustaining the Khmer civilization that gave rise to the temple complex at Angkor Wat (~800 AD). Present-day consumption of freshwater fishes and other aquatic animals (snakes, frogs, turtles, snails, shrimps and crabs) in Cambodia is in excess of 720,000 t annually. One regional estimate within Cambodia is that fish provides people with 80% of their animal protein (Campbell *et al*. 2006; see also Section 1.2.1). Arguably, given the magnitude of the catch and the dependence of livelihoods upon it, the national catch of Cambodia is one of the world's most important freshwater fisheries.

With respect to other benefits – aside from capture fisheries – that can be derived from intact freshwater ecosystems, the Millennium Ecosystem Assessment (www.maweb.org) offers a useful framework for their characterization. Four categories of ecosystem services can be recognized. First, *provisioning services* are goods produced or provided by ecosystems, such as water, animals for food, and plants for food, fuel, and medicines. Second, *regulating services* are the benefits obtained from water purification and regulation of floods and extreme events, as well as local climate and parasites or diseases. Third, *cultural services* are the non-material benefits derived from ecosystems, such as recreational, spiritual or educational benefits. Finally, *supporting services* are those necessary for the maintaining the three other categories of ecosystem services, such as soil formation, recharging groundwater, nutrient cycling, primary production, carbon sequestration. The first of these services can be thought of as providing a 'direct-use' value for humans, whereas the third represents a 'non-use' value; the second and fourth are 'indirect-use' values that nonetheless support livelihoods.

To what extent is provision of the four categories of ecosystem services dependent on biodiversity? It seems obvious that conservation of fish biodiversity is necessary to maintain a productive fishery, thus we would expect some relationship between biodiversity and ecosystem functioning. However, the exact form of the relationship between biodiversity (in terms of species richness) and ecosystem functioning (for instance, the provision of goods and services for humans) has not

Freshwater resources have sustained livelihoods throughout the region from earliest times, as shown here by a carving from the Bayon temple, Angkor Wat. © Jack Tordoff

been adequately characterised by ecologists and conservation biologists and thus is not fully understood, although it has been the subject of much recent research (as reviewed, for example, by Dudgeon 2010). While space does not permit elaboration of the matter here a summary of the competing possibilities must include the conventional view which states that ecosystem functioning is enhanced or stabilized in a near-linear fashion as species richness increases, and *vice versa* (this is the diversity-stability hypothesis). A second possibility is that loss of species has no effect on function until some critical threshold below which the remaining species can no longer compensate for loss of the others and complete failure may occur (the redundancy or rivet hypothesis). A third possibility is that the relationship is unpredictable: functioning may be unaffected by the loss of certain species, but greatly impacted by the loss of others. This idiosyncratic hypothesis holds that the identity of species lost is crucial (i.e. composition is key), and that the number remaining is of secondary importance.

Thus far, most studies suggest that the idiosyncratic hypothesis seems to provide the best description of biodiversity-ecosystem functioning relationships in fresh waters; i.e. species composition or identity – rather than species richness *per se* – is what matters, with the corollary that there may be a prevalence of 'redundant' species in some instances. Much remains to be learned however, and some compelling recent research suggests that nitrogen uptake (and the capacity to improve water quality) increases linearly with species richness of periphytic algae because more niches became occupied by different forms of algae (Cardinale 2011). Thus diverse communities function more effectively (in terms of nitrogen capture, in this instance) so long as the environment contains sufficient niche opportunities for the pool of potential colonists. The important implication here is that conservation of the forms of environmental heterogeneity that create niche opportunities and allow species to coexist may be necessary for sustaining ecosystem functioning. This finding suggests that flow regulation, channelization and habitat degradation that tend to simplify naturally-complex freshwater habitats will be detrimental to both biodiversity and ecosystem functioning (e.g. Bunn and Arthington 2002), and provides justification for restoration or management practices directed towards maintaining or enhancing heterogeneity. For this reason alone, it is obvious that the rich biodiversity of the LMB, for example, would be more likely to be preserved if the river mainstream and its variety of flow regimes and habitats remained intact rather than being transformed into to a chain of dams and associated impoundments.

1.4 Concluding comments

Given the extent of threats to freshwater biodiversity globally, and those that are now prevailing or can be anticipated within Indo-Burma, the prospects for sustaining healthy functioning freshwater ecosystems – and hence maintaining the goods and services that underpin human livelihoods – may appear limited. Constraints to conservation in the region include inadequate knowledge of freshwater biodiversity, and a lack of interest or awareness of its importance to humans in some sectors. This information gap can lead to 'inadvertance' whereby the impacts of human activities on biodiversity are overlooked. Convenience may also dictate that the likelihood of potential impacts is ignored due to economic, political or technical expediency that favour development. Alternatively, consideration of potential impacts may be set aside on the assumption they can be addressed later. This is particularly likely if proposed projects address pressing water-resource needs or where hydropower dams can be expected to yield significant economic benefits from selling electricity; as a result, they may be allowed to proceed without due accounting of the long-term environmental costs. Funding limitations can mean that governments are unable or unwilling to invest in monitoring or surveys that will yield information on the incidence of impacts or environmental degradation, and a shortage of trained personnel may hinder such research. Even where data on potential impacts are readily available, it may not be readily understood by decision-makers, or not perceived as relevant to local circumstances because it is too site-specific or sectoral. This is a particular problem for inland waters, since their integrated management usually requires incorporation and integration of different types of data gathered at various scales from a wide range of sources, including information on hydrology, water quality, vegetation cover, land-use, ecology, socio-economics, and so on.

Nonetheless, some opportunities for conservation gains remain, and the fact that construction of the first of a series of mainstream dams along the LMB at Xayaburi in Lao PDR has been suspended (at least for the time being) provides a basis for cautious optimism. Another positive development occurred in June 2010 when, in a landmark initiative for the International Year of Biodiversity, representatives of 85 nations met in Busan, South Korea, and agreed to establish an Intergovernmental Science policy platform on Biodiversity and Ecosystem Services (IPBES). The IPBES is intended to mirror the Intergovernmental Panel on Climate Change (IPCC) and will work to integrate data on biodiversity declines and ecosystem degradation with the government action required to reverse them. Like the IPCC, the IPBES will coordinate global-scale peer reviews of research on the status and trends of biodiversity and ecosystem services and provide 'gold standard' reports and policy recommendations to governments. The IPBES will also provide a conduit by which such reports can achieve wider currency and thereby inform conservation action.

It will be a colossal challenge to reconcile human needs for water without compromising provision of goods and services – and hence the support for livelihoods – that result from functioning ecosystems and the biodiversity that sustains them. This will require policies that 'legitimize' freshwater ecosystems as water users (e.g. Arthington *et al*. 2006), so that planning, management, and decision-making processes will need to take due account of the trade-off between environmental and human needs for water. To achieve this, provision of reliable information such as that found in this report, on the status and distribution of freshwater biodiversity – as well as the ecological conditions needed to sustain it – will be essential.

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Chapter 2. Assessment methodology

David Allen[1], Kevin Smith[1] and William Darwall[1]

2.1 Selection of priority taxa

Recent large-scale biodiversity assessments have focused on a limited range of taxonomic groups, most often those that provide obvious benefits to humans through direct consumption, or the more charismatic groups, such as mammals (IUCN 2008), birds (BirdLife 2012), amphibians (IUCN 2004), and reptiles (IUCN in progress). In the case of aquatic systems, it is wetland birds and fishes that have received most attention.

It is important that we take a more holistic approach by collating information to conserve those other elements essential to the maintenance of healthy functioning wetland ecosystems, and which are often vital to sustaining local communities through the provision of food and other ecosystem goods. As it is impractical to assess all freshwater species due to financial and knowledge constraints, a number of priority taxonomic groups were selected to represent a range of trophic levels within the foodwebs that underlie and support wetland ecosystems and livelihoods. Priority groups were selected to include those taxa for which there was thought to be a reasonable level of pre-existing information. The taxonomic groups selected for this assessment were: fishes, molluscs, odonates (dragonflies and damselflies), and selected families of aquatic plants. These groups are being comprehensively assessed by IUCN's Freshwater Biodiversity Unit (FBU) through a number of regionally focused assessment projects since 2004 (for example see Allen *et al.* 2010, Darwall *et al.* 2005, 2009; Molur *et al.* 2011). Other freshwater groups (for example, crabs (Cumberlidge *et al.* 2009), and freshwater shrimps (IUCN in progress) are being assessed comprehensively at the global scale.

Although fishes provide a clear benefit to the livelihoods of many people throughout the region, either as a source of income or as a valuable source of nutrition, benefits provided by the other taxa may be indirect and are often poorly appreciated but nonetheless equally important. Given the wide range of trophic levels and ecological roles encompassed within our four focal taxonomic groups, it is considered that information on their distributions and conservation status, when combined, will provide a useful indication of the overall status of the associated wetland ecosystems. Repeated assessment of these four groups, being relatively well-studied and easily surveyed, has the potential to serve as an indicator of the impact of environmental change within the region where pressures such as rapid development and high population growth have the potential to significantly impact wetland systems.

This report focuses on dragonflies and damselflies, molluscs, aquatic plants and fishes, with all four groups assessed through the Indo-Burma project, and freshwater crabs, for which all extant species were assessed in 2009 (Cumberlidge *et al.* 2009). Additional data for other key freshwater groups that have been comprehensively assessed for the IUCN Red List (www.iucnredlist.org) (i.e., all extant described species at the global scale) are included in the synthesis chapter (Chapter 9). These groups are wetland-dependent birds (220 species), wetland dependent mammals (14 species), and amphibians (231 species). The species in these groups were selected by querying the IUCN Red List by Taxonomy, Location (mainland Myanmar, Lao PDR, Viet Nam, Cambodia and Thailand), and System ('Freshwater').

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2.1.1 Fishes

Arguably fishes form the most important wetland product on a global scale, and are certainly the most directly utilised wetland resource across the region; Asia accounts for 63% of total fish production (Briones *et al.* 2004), and fish account for 30% of typical diets across Asia as a whole (WorldFish 2010). They provide the primary source of protein for nearly one billion people worldwide (FAO 2002) and food security for many more.

For the purposes of this assessment freshwater fishes are defined as those that spend all or a critical part of their lifecycle in fresh waters. Those species entirely confined to brackish waters are also generally included, however some species marginal to the project area, for example in the Malay Peninsula, have been excluded. There are an estimated 13,000 freshwater fish species in the world (Lévêque *et al.* 2008), but by 2009 only 76 species of fishes from the area covered by this project had had their risk of extinction assessed using the IUCN Red List Categories and Criteria at the global scale (IUCN 2011).

2.1.2 Molluscs

The value of molluscs to wetland ecosystems is poorly appreciated. Freshwater molluscs are essential to the maintenance of wetland ecosystems, primarily due to their control of water quality and nutrient balance through filter-feeding and algal-grazing and, to a lesser degree, as a food source for predators including a number of fish species. Within the Indo-Burma region they compose a food resource, especially for the rural poor, and are used in construction materials and for jewellery and decoration.

Molluscs are one of the most threatened groups of freshwater taxa (Kay 1995, Darwall *et al.* 2011). The impact of developments such as dams, and siltation caused by deforestation and agricultural clearance has not been adequately researched, and there is little knowledge of the complex life histories of some groups such as unionid mussels that rely on the maintenance of migratory fish runs to carry their parasitic larvae to the river headwaters. Many species are also restricted to microhabitats, such as the rapids and riffles (areas of fast current velocity, shallow depth, and broken water surface) between pools and runs (areas of rapid non-turbulent flow) which can be lost through habitat modification.

There are an estimated 5,000 freshwater molluscs for which valid descriptions exist, in addition to a possible additional 10,000 undescribed species (Balian *et al.* 2008). Of those molluscs from the area covered by this project, none had had their conservation status assessed for the IUCN Red List by 2009 (IUCN 2011).

2.1.3 Odonates

Larvae of almost all of the 5,680 species of the insect order Odonata (dragonflies and damselflies) are dependent on freshwater habitats, with only a few not utilising freshwater. Larvae that develop in water play a critical role with regards to water quality, nutrient cycling, and aquatic habitat structure, whilst also being voracious predators, often considered important in the control of insect pest species. Odonata are unique amongst the groups assessed in not being restricted to the aquatic environment for their entire lifecycle, and this gives them some mobility between habitat types, however they are susceptible to changes in wetland conditions (water flow, turbidity, or loss of aquatic vegetation; Trueman and Rowe 2009) and loss of terrestrial habitat and prey species.

Odonata are relatively easily surveyed (though some expertise is required for correct identification), and a full array of ecological requirements are represented within the group, which has led to their use as a bio-indicator for wetland quality. Whilst there are thought to be perhaps as many as 7,000 species of Odonata (Kalkman *et al.* 2008), only 5,680 species are currently extant and have been described. Of these, fewer than 24% (1,359) had had their risk of extinction assessed globally (only 98 species had been assessed within the Indo-Burma region) using the IUCN Red List Categories and Criteria by 2009. A baseline dataset is needed for the region to facilitate the development of similar long term monitoring schemes in Asia.

2.1.4 Aquatic plants

Aquatic plants are the building blocks of wetland ecosystems, providing food, oxygen and habitats for many other species. They are also a hugely important natural resource, providing direct benefits to human communities across the world. Numerous aquatic plants are highly valued for their nutritional, medicinal, cultural, structural or biological properties. They are also key species in the provision of wetland ecosystem services, such as water filtration and nutrient recycling.

An aquatic plant is defined here as a plant that is physiologically bound to water (a hydrophyte) or as a terrestrial plant whose photosynthetically active parts tolerate long periods submerged or floating (a helophyte) (Cook 1996). According to Cook (1996) aquatic plants represent between one and two percent of the approximately 300,000 species of vascular plants, equivalent to between 2,900 and 5,800 species (Chambers *et al.* 2008, Vié *et al.* 2008). Only five species of aquatic plants from the Indo-Burma region had been assessed for the IUCN Red List before this assessment began.

For this project, the conservation status of all aquatic plant species from 42 selected plant families was assessed (see Chapter 8). The selection of families was based on the following criteria: i) the family contains a relatively large proportion of aquatic species; ii) there is a reasonable level of available information on the relevant species; iii) the taxonomy is relatively stable; iv) the selected families would, when combined, cover a wide range of ecological niches and contain a substantial number of species; and v) the family is widely represented at the global scale.

2.2 Delineation of the Indo-Burma assessment region

To qualify as a 'hotspot', a region must contain at least 1,500 species of vascular plants (> 0.5% of the world's total) as endemics, and it has to have lost at least 70% of its original habitat (Conservation International 2010). This definition of a hotspot was developed using exclusively terrestrial criteria. The Indo-Burma Biodiversity Hotspot as defined by Myers *et al.* (2000) encompasses a wide extent; north-eastern India, the majority of Myanmar, all of Viet Nam, Cambodia and Lao PDR, parts of southern China, and all but the southern extent of Thailand in the Malay Peninsular (see Figure 2.1). As defined by Myers *et al.* (2000), the Indo-Burma biodiversity hotspot encompasses 528 endemic vertebrates (1.9% of the global total species) and 7,000 endemic plant species (2.3% of the global total).

This report describes the status and distribution of the freshwater biodiversity within a defined area of the Indo-Burma Biodiversity Hotspot. The freshwater biodiversity of the western extent of the Indo-Burma Hotspot has already been assessed by an earlier IUCN project covering the Eastern Himalaya Biodiversity Hotspot (Allen *et al.* 2011), which was earlier classified as part of the Indo-Burma Hotspot. The Eastern Himalaya assessment area encompassed the drainages of the Ganges, Brahmaputra, Kaladan and Ayeyarwaddy rivers. In addition, and in contrast to the approach taken in the Eastern Himalaya assessment, portions of the river drainages (for example, the Mekong-Lancangjiang, and the Salween-Nujiang) in southern China were excluded (see Figure 2.1).

2.3 Data collation and quality control

The biodiversity assessment required sourcing and collating the best information on all known species within the priority taxa (see Section 2.1). Regional and international experts for these taxa were identified by IUCN through consultation with the relevant IUCN Species Survival Commission (SSC) Specialist Groups. These experts were then invited to attend a training workshop (Phnom Penh, Cambodia, November 2009) where they were trained in use of the web-based IUCN species database

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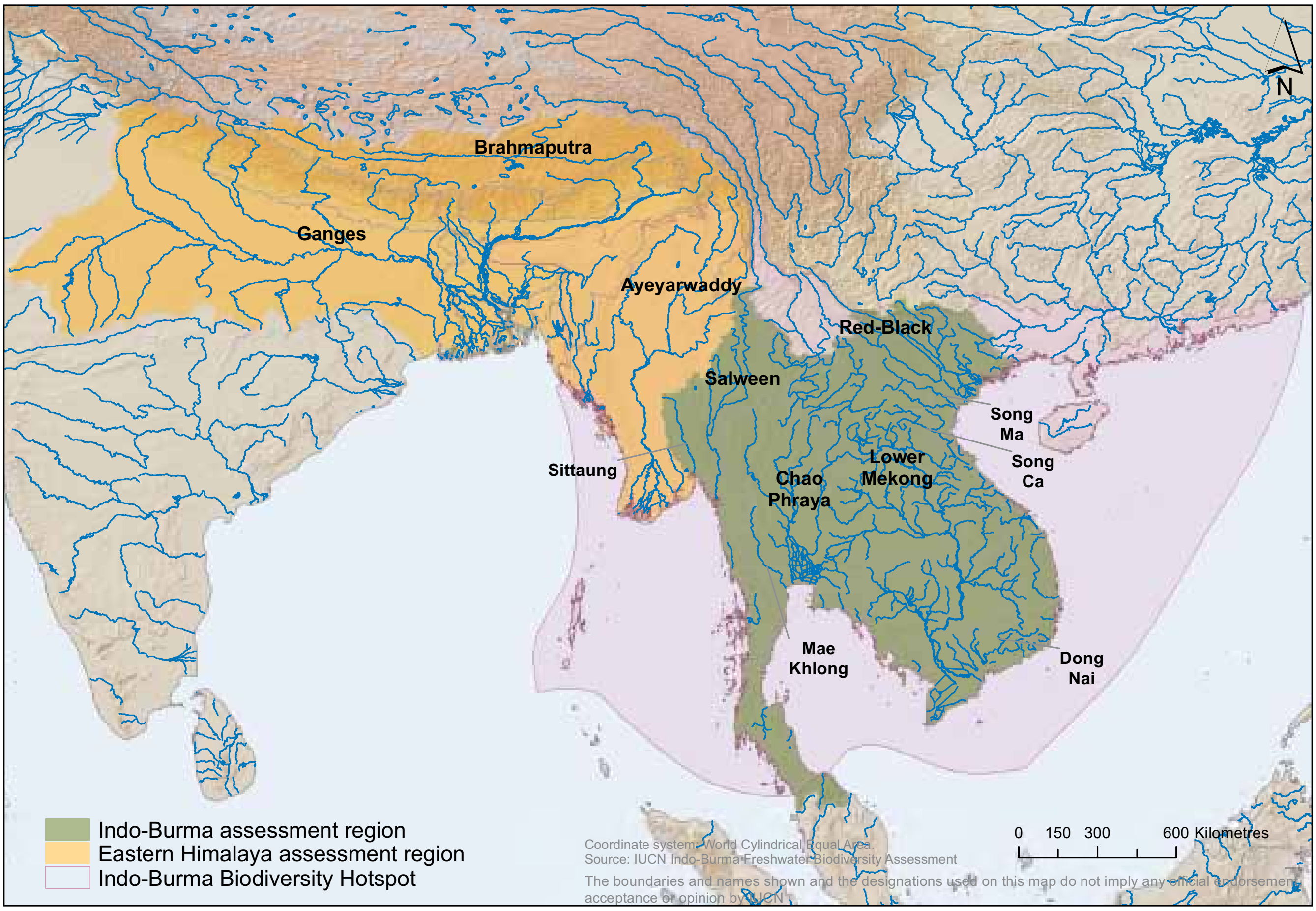
Figure 2.1 Map showing (i) the Indo-Burma Hotspot (in pink); (ii) the area selected for inclusion in the Indo-Burma assessment project (in green); and (iii) the area encompassed by the Eastern Himalaya assessment project (in orange).



Participating experts at the assessment training workshop in November 2009, Phnom Penh, Cambodia. © David Allen

Regional and international expert participants at the species assessment review workshop, Vientiane, Lao PDR. Photo: © David Allen

(Species Information Service; SIS), application of the IUCN Red List Categories and Criteria (IUCN 2001) to assess a species' risk of extinction in the wild, and in mapping freshwater species distributions using a Geographic Information System (GIS). Following the training workshop a number of participating experts were contracted to compile a list of all species of odonates, fishes, aquatic plants (within the selected families), and molluscs known to be present within the area of focus of the project. The taxon lists were then screened against those species already assessed against the IUCN Red List Criteria and published on the IUCN Red List. Those taxa that had not been previously assessed, or whose assessments were older than five years and needing to be reassessed (assessed in 2006 or earlier) were selected for assessment by the project. Experts were then asked to collate and input all available information on each of the priority taxonomic groups into the SIS database, and to assess each species Red List status. Participating experts were also asked to compile spatial data (species locality data, in decimal degrees latitude/longitude) for the production of species distribution maps (see Section 2.4). The taxonomy of each taxa was checked against current standard taxonomic references where available (e.g. Catalog of Fishes (Eschmeyer 2010) and the World Odonata List (Schorr and Paulson 2009)). The majority of species assessments were then reviewed at two further workshops (Vientiane, Lao People's Democratic Republic (January 2011), and Cambridge, UK (February 2011)) where each species assessment was reviewed by at least two independent experts to ensure that: i) the information presented was both complete and correct; and ii) the Red List criteria had been applied correctly.

Final analyses were based upon a merged data set combining the outputs from this current assessment with additional information on freshwater species as compiled through other IUCN assessments within the region.

2.4 Species mapping and analysis

Species global distributions were mapped to river sub-catchments as delineated by the HydroSHEDS (**Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple **S**cales) (Lehner *et al.* 2006) (Figure 2.2) using ArcMap and ArcView GIS software. River sub-catchments were selected as the spatial unit for mapping and analysing species distributions, as it is widely accepted that the river/lake catchment is the most appropriate management unit for inland waters. It is recognised that species ranges may not always extend throughout a river sub-catchment, but presence within the river sub-catchment is either 'known' or 'inferred' (either Extant: presence is known from field survey or recent literature, or Probably Extant: presence inferred based on expert opinion).

Point localities (the latitude and longitude where the species has been recorded), were used to identify which sub-catchments are known to contain the species ('known' sub-catchments). During the review workshop errors and dubious records were deleted from the maps.

Connected sub-catchments, where a species is expected to occur, although presence is not yet confirmed, are known as inferred catchments. Inferred distributions were determined through a combination of expert knowledge, course scale distribution records, and unpublished information. The preliminary species distribution maps were digitized and then further edited at the review workshop.

For many of the plant species maps, and for some mollusc species, inferred catchments were selected by extracting the 'sub-country units' and administrative boundaries (e.g. Indian states) from the SIS database in order to select the underlying river sub-catchments. These maps were then

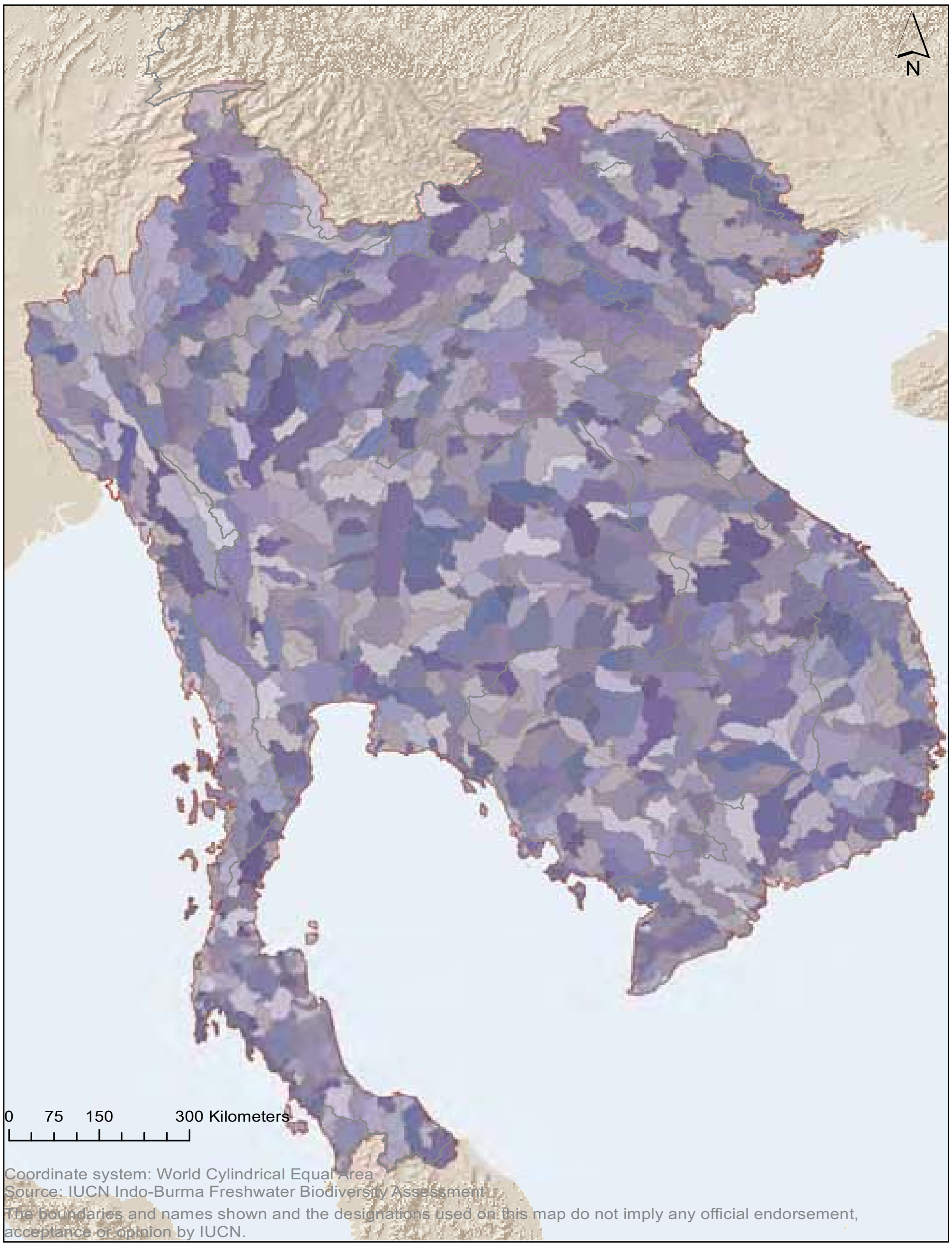


Figure 2.2 River sub-catchments as delineated by HydroSHEDS used to map and analyse species distributions.

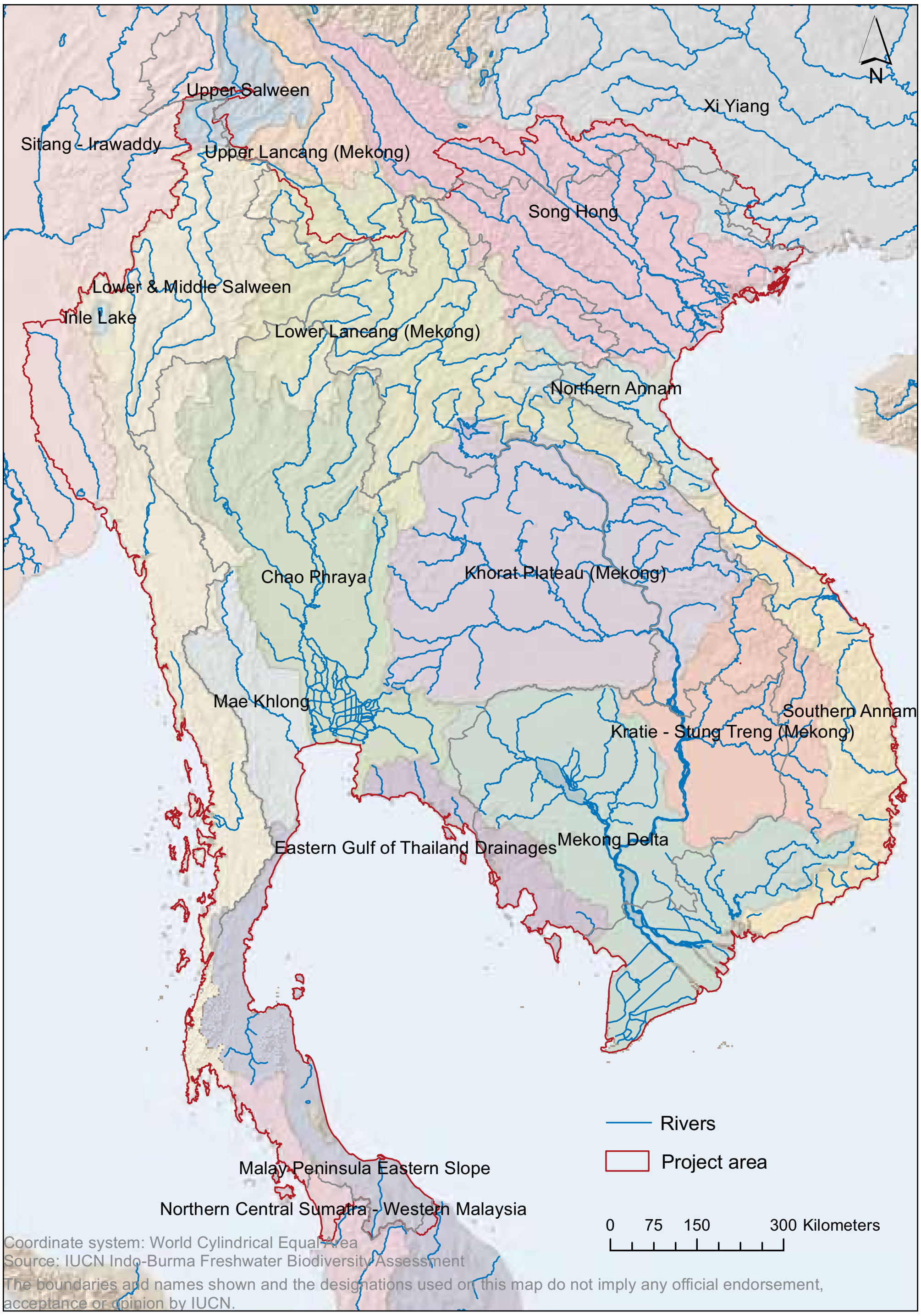
reviewed against the accompanying text on species distribution and ecology, and were reviewed again by the species assessor prior to submission to the Red List.

Species distributions were also described within the context of the Freshwater Ecoregions for Asia, as defined and delineated by WWF-US (Abell *et al.* 2008) (Figure 2.3).

Potential Freshwater Key Biodiversity Areas (KBAs) were identified for the project region and reviewed for correspondence with existing protected areas (World Database on Protected Areas; IUCN and UNEP-WCMC 2010) and terrestrial KBAs. KBAs are based on criteria relating to vulnerability and irreplaceability of the site for conservation (Langhammer *et al.* 2007). Vulnerability refers to the likelihood that species within a site will be lost over time, and irreplaceability refers to the spatial options available for conservation of particular species (Langhammer *et al.*, 2007). The IUCN Freshwater Biodiversity Unit has developed a series of criteria to identify river sub-catchments as Key Biodiversity Areas based on vulnerability and irreplaceability (Holland *et al.* 2012).

Based on these criteria we identified sub-catchments in the Indo-Burma project area that would qualify as potential freshwater Key Biodiversity Areas.

Figure 2.3 Freshwater Ecoregions within the project area (from Abell *et al.* 2008).



2.5 Threat mapping

Information on key threats across the region was gathered through a participative threat mapping exercise run at the project training workshop held in Cambodia in 2009. Workshop participants, including regional and international species experts, as well as experts from NGOs from within the region, produced maps of threats to freshwater biodiversity by drawing and categorising threats on large scale maps of the region. These maps were then digitised and distributed to species assessors to help inform the species threat assessments.

2.6 Assessment of species threatened status

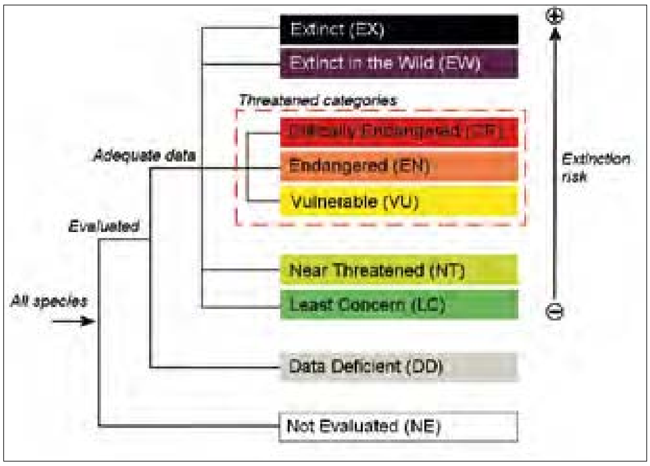
The risk of extinction for each species was assessed according to the *IUCN Red List Categories and Criteria: Version 3.1* (IUCN 2001; see Figure 2.4).

The categories of threat reflect the risk that a species will go extinct within a specified time period. A species assessed as "Critically Endangered" is considered to be facing an extremely high risk of extinction in the wild. A species assessed as "Endangered" is considered to be facing a very high risk of extinction in the wild. A species assessed as "Vulnerable" is considered to be facing a high risk of extinction in the wild. All taxa listed as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU) are described as "threatened". To distinguish between the three threatened categories there are five criteria with quantitative thresholds (Table 2.1).

A species is assessed as "Near Threatened" (NT) when it is close to meeting the thresholds for a threatened category either now or in the near future. A species is assessed as "Least Concern" (LC) if it fails to meet, or be close to meeting, any of the criteria for the threatened categories.

A species is "Data Deficient" (DD) when there is inadequate information to make a direct or indirect assessment of its risk of extinction based on the current knowledge of the species. Species assessed as DD are highlighted as priorities for additional research and are acknowledged as being potentially threatened.

Figure 2.4 IUCN Red List Categories at the global level.



For an explanation of the full range of categories and the criteria that must be met for a species to qualify under each category, please refer to the following documentation: The *IUCN Red List Categories and Criteria: Version 3.1, Version 3.0,* which can be downloaded from www.iucnredlist.org/technical-documents/categories-and-criteria.

The following criteria for the inclusion of a species in the assessment were agreed during the initial workshop and were applied in the completion of this Red List assessment:

1) Any species having less than 5% of its range within the project area should not be assessed through this project.
2) Species present in the project area prior to 1500 were treated as being "naturalised" and subject to a Red List assessment. Those species arriving in the region post 1500 were not assessed.

2.7 Overlap with other Red List assessment projects

Some species present within the Indo-Burma project region and therefore of interest to this project were assessed through other ongoing assessments in neighbouring or overlapping regions. These projects include the Eastern Himalaya and Western Ghats Hotspot assessments (Allen *et al.* 2011, Molur *et al.* 2011), the HighARCS project (ongoing; www.higharcs.org) and the Sampled Red List Index (SRLI) project (ongoing).

2.8 Nomenclature

The taxonomic placement of species and their higher taxonomy are constantly changing as results from ongoing studies, especially with the introduction of molecular techniques, are made available. Taxonomy is also a somewhat controversial field, and in many cases it is difficult to find a universally agreed taxonomic hierarchy. In the case of this project, the taxonomy followed is that adopted by the

Workshop threat mapping exercise. © David Allen

Table 2.3 Summary of the five criteria (A–E) used to determine the category of threat for a species.

SUMMARY OF THE FIVE CRITERIA (A-E) USED TO EVALUATE IF A TAXON BELONGS IN AN IUCN RED LIST THREATENED CATEGORY (CRITICALLY ENDANGERED, ENDANGERED OR VULNERABLE).[1]

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years). *[(a) cannot be used for A3]*

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

(a) direct observation *[Except A3]*

(b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

(e) effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented **OR** Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** area, extent and/or quality of habitat; **(iv)** number of locations or subpopulations; **(v)** number of mature individuals.			
(c) Extreme fluctuations in any of: **(i)** extent of occurrence; **(ii)** area of occupancy; **(iii)** number of locations or subpopulations; **(iv)** number of mature individuals.			

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) **(i)** Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km² or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

1 Use of this summary sheet requires full understanding of the *IUCN Red List Categories and Criteria* and *Guidelines for Using the IUCN Red List Categories and Criteria*. Please refer to both documents for explanations of terms and concepts used here.

IUCN Red List which, where possible, employs existing published world checklists. Fish classification generally follows the online Catalog of Fishes maintained at the California Academy of Sciences (Eschmeyer 2010). Odonate classification generally follows the World Odonata List maintained at the University of Puget Sound (Schorr and Paulson 2010). There is currently no widely accepted single taxonomy for molluscs, and we therefore follow the standards recommended by the IUCN SSC Mollusc Specialist Group. For plants, where appropriate, we follow the World Checklist of Selected Plant Families hosted by the Royal Botanic Gardens, Kew (WCSP 2010), but other more specialist lists are also followed, such as the Checklist of World Ferns (Hassler and Swale 2010) and Algaebase (Guiry and Guiry 2010). For more information on the taxonomic standards of the IUCN Red List, visit http://www.iucnredlist.org/technical-documents/information-sources-and-quality#standards.

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Chapter 3. The status and distribution of freshwater fishes of Indo-Burma

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3.1 Overview of the regional fish fauna

The Indo-Burma region includes all or part of the following freshwater ecoregions, as defined by Abell *et al.* (2008): Sittaung and Ayeyarwaddy (Irrawaddy), Lower and Middle Salween, Inlé Lake, Malay Peninsula Eastern Slope, Mae Khlong, Chao Phraya, Eastern Gulf of Thailand Drainages, Lower Lancang [lower stretch of Mekong in China, and upper stretch in Laos, Myanmar and Thailand], Khorat Plateau [middle Mekong], Kratie–Stung Treng [lower Mekong], Mekong Delta, Southern Annam, Northern Annam, Song Hong, and North Central Sumatra–West Malaysia (see **Figure 2.3**). Of the Sittaung-Ayeyarwaddy ecoregion, only the Sittaung drainage is considered here. The Ayeyarwaddy drainage was included in an earlier assessment of the Eastern Himalaya region (Allen *et al.* 2009).

3.1.1 Freshwater fish diversity

We recognise here 1,178 fish species in the Indo-Burma region. This includes all species of the primary freshwater families (families comprised exclusively of species spending their whole life cycle in freshwater (see Myers 1951); here 988 species), secondary freshwater families (families related to marine families but living in fresh or sometimes brackish water; here 58 species), vicarious species (species of otherwise largely marine families but spending their whole life cycle in freshwater; e.g. some gobies; here 110 species), diadromous species (which migrate between fresh and sea water but stay in freshwater for part of their life cycle; here 8 species), sporadic freshwater species (species that seem to be indifferent to salinity and usually occur in estuaries; here 14 species). Accidental species (normally marine species that are very occasionally caught inland) are omitted. For those species known only from brackish waters and estuaries we have preferred to be over-inclusive and they are retained in the analysis.

We include 151 species from the Salween drainage, 328 from the Mae Khlong–Chao Phraya drainages, 500 from the Mekong drainage, 253 from the Red River drainage, 160 from the streams draining the eastern slope of the Annamite range, and 221 from the Malay Peninsula (south of the isthmus of Kra). The Malay Peninsula south of Thailand is excluded, as are those parts of the Salween, Mekong and Red River drainages in China.

3.1.2 Zoogeography and faunal composition

Strictly freshwater fishes by definition cannot survive in marine waters and are therefore useful in helping to understand and describe the faunal units, their distribution and history. Current and past distributions of the various taxa are related to the geomorphological history of the river network. Natural alterations of the network such as river capture, changes of direction, desertification, fragmentation resulting from orogeny or karstification, likely explain much of the diversification at the species level (speciation).

The most salient physiographic feature of the Indo-Burma region is the group of three large rivers that flow in parallel

Example of the diverse river habitat in the Kratie–Stung Treng [lower Mekong] Ecoregion. Taad Fek waterfall on the Xe Namnoy in the Xe Kong drainage, southern Laos. In May 2009 35 species were observed immediately below the fall. © Maurice Kottelat from north to south: the Salween, Mekong and upper Yangtze. North of the Indo-Burma region, the Salween, Mekong and Yangtze flow very close together, in narrow gorges, for more than 300 km, sometimes separated by less than 20 km. Geomorphological studies (for example, Clark *et al.* 2004) have shown that these three rivers and the Ayeyarwaddy and Tsangpo were connected to a palaeo-Red River. See Box 3.1.

Throughout history the Mekong River and the smaller rivers of the Indo-Burma region have shared parts of their watersheds over time. As a result of this exchange of stream reaches these rivers now share parts of their faunas. For most of the shared faunas, sharing of species is, however, fairly rare because smaller populations of a species have smaller gene pools and will consequently show the results of natural selection and genetic drift more quickly than would the larger original population. So, sharing of species between rivers in neighbouring catchments may be more representative of recent than long-term connections.

Cyprinidae is the numerically most abundant primary freshwater family in the Indo-Burma region. A study on the cyprinid genera shared between rivers of east, southeast and south Asia, along with those of high Asia on the Tibetan Plateau (Rainboth, 1991b) demonstrated links that would not otherwise have been predicted, given that past connections between some rivers were still unknown at that time.

Within the Indo-Burma region, the Southeast Asian group of cyprinids included the Salween fauna (almost entirely an upland river with little or no delta and estuary), which most closely resembled that of the upper Mekong. The array of genera from the middle Mekong (from Myanmar to Kratié in Cambodia) most closely resembled the fauna of central Thailand (Chao Phraya and tributaries). The lower Mekong (Great Lake, Tonlé Sap and Mekong delta) was most like the fauna of the rivers of the eastern side of the Malay Peninsula.

With respect to the East Asian cyprinids, the Red River fauna was most similar to that of the Pearl River. The upper Yangtze fauna was somewhat similar to the middle Yangtze and lower Yangtze, but the fauna in all three parts of the Yangtze differed considerably from that of the Red River group.

To the west, the cyprinid genera of the upper and lower Ayeyarwaddy most closely resembled those of the Sittang and all three were part of the Gangetic fauna. Those of the Tsangpo did not resemble those of the Salween, upper Mekong or upper Yangtze, but instead clustered with the Tarim and Yarkand faunas of High Asia - these three faunas were linked with the East Asian fauna.

When all species are considered, the fish fauna of the Red River is quite similar to that of East Asia (from the Pearl River northwards) (122 of 253 species are shared) and has much less in common with that of the Mekong–Chao Phraya (21 species shared, mostly sporadic species). The earlier connection of the Chao Phraya and Mekong explains why most species of the Chao Phraya are also known from the Mekong, with only 50 of 328 of its species not shared. The reverse is not true such that 226 of the 500 Mekong species are not shared with Chao Phraya. The Nan drainage (a tributary of Chao Phraya) is inhabited by a number of species and genera otherwise known only from the Mekong (for example, *Sectoria*, *Yasuhikotakia nigrolineata*) suggesting an earlier past connection between these drainages.

The Salween shares most of its 151 species with the Sittaung–Ayeyarwaddy drainages and only a few (33) with the Mekong–Chao Phraya drainages, which likely reflects the lack of earlier connections. The Salween–Sittaung–Ayeyarwaddy fish fauna has more affinities with the Brahmaputra and North Indian fish fauna, which also reflects geological history. The Tenasserim area, although still poorly known, has a fauna related to that of the Salween–Ayeyarwaddy. Inlé Lake is an aquatic ecoregion of its own (Abell *et al.* 2008). See Box 3.2.

The fauna of the Mae Khlong is particularly noteworthy. It may be described as the fauna of the Chao Phraya, but with the addition of a number of genera and species otherwise known only, or mainly, from the Salween–Ayeyarwaddy–Tenasserim drainages (for example, *Batasio*, *Acanthocobitis*, *Badis*), again suggesting an earlier connection.

The composition and history of the fish fauna of the Malay Peninsula is somewhat more complex. The southern part of the peninsula has a clear Sundaic fauna (Sundaland: the south of the Malay Peninsula and the Great Sunda Islands (Sumatra, Java and Borneo)). The proportion of Sundaic fauna included within the total fauna decreases northwards. Several species and genera of that Sundaic fauna are also known from Southeastern Thailand (Chantaburi and Trat provinces) and coastal areas of Cambodia (for example, *Barbucca*, *Vaillantella*, *Silurichthys*). Along the western slope of the Malay Peninsula (Andaman Sea basin) several elements belong to the Ayeyarwaddy–Salween–Tenasserim fauna (for example, *Acanthocobitis*, *Batasio*, *Hara*) but their proportion of the total fauna decreases southwards. Along the eastern slope (Gulf of Thailand basin) it is the representation of the Mekong–Chao Phraya fauna that decreases.

3.1.3 Geographical factors affecting the distribution of freshwater fishes

Within these faunistic units the distribution of most species is shaped by their ecological requirements and the topography. Simply speaking, lowland species, those inhabiting large river mainstreams, swamps and slow flowing waters, and those with a large size, tend to have extensive ranges that may encompass several major drainages (for example, most species of

New fish species are still being discovered in the region. This species, *Schistura udomritthiruji* (LC) found in streams draining to the Andaman Sea in southern Thailand, was described in 2009. © Joerg Bohlen

Pangasiidae). On the other hand, those smaller species, inhabiting the upper parts of drainages, in faster waters, tend to have a small range and are often endemic to a single sub-drainage or a few headwaters (for example, most Nemacheilidae, Balitoridae and Sisoridae). As a result, although the number of species in the headwaters of any river is quite low, a significant portion of them are likely to be endemic to that drainage and the majority of small range endemics live in headwaters.

3.1.4 Taxonomic issues

The taxonomy of a significant portion of the fish fauna of the Indo-Burma region is still unsettled. New species are still being discovered, and many of those that have been collected are yet to be formally described in the scientific literature. The taxonomy of several groups is still not clear, with diversity patterns obscured by the large number of species, or by a perceived variability hiding "cryptic" species. This is understandable for the smaller species that often attract less scientific attention and may be more difficult to analyse, but it is also frequently true for the larger species some of which may also be significant for human consumption (for example, *Poropuntius*, *Tor*). Even the current taxonomy of some of the large or widespread species may change with future scrutiny.

It is notable that most of the largest species in the area have only been discovered, described or first reported in recent times. For example, *Aaptosyax grypus* was first described in 1991 (Rainboth 1991a), *Himantura polylepis* was first reported from the Indo-Burma region in the scientific literature as *H. chaophraya* by Monkolprasit and Roberts (Monkolprasit and Roberts 1991) (but was previously mentioned in travel reports by Aymonier as early as 1885, and was described from Indonesia in 1852). *Probarbus labeamajor* was first described by Roberts (1992). *Luciocyprinus striolatus* was first reported in the Indo-Burma region in 1996 (Kottelat, 1998; first described from Yunnan by Cui and Chu, 1986). The identity of some other large fishes described long ago (for example, *Labeo pierrei* by Sauvage in 1880), and of species to which the names of other well known species have traditionally been applied (for example, *Tor tambroides*), are still unsettled.

3.1.5 Limitations in data availability and reliability

The existing data present a number of problems in terms of availability and reliability. From an ichthyological point of view, large areas of the Indo-Burma region are still in the exploration and discovery phase, with 434 (37%) of the 1178 species described after 1989 and 285 of those (24%) after 1999. In the family Balitoridae, 128 (63%) of the 203 species have been described after 1989, 86 of these (42%) after 1999. The native fish fauna from Laos, as reported in the scientific literature, increased from about 220 to 465 species between 1996 and 2000 (Kottelat 2000, 2001). This high level of recent reporting in the literature is especially true for small-size species. This is, of course, largely a result of the earlier conflicts and political isolation of the country and its rapid opening to the outside world, but it also reflects differences in the methods and approaches employed for conducting fish surveys. Therefore, although the present analysis has included virtually all known species, it is expected that several hundred species are still to be discovered, in particular from the hilly areas where new discoveries are expected to confirm the species distribution patterns already described above. However, it is also likely that more detailed analysis of existing data will show that several of the best known and widespread lowland species may in fact comprise assemblages of several, less widely distributed, species each facing different threats due to their more restricted ranges. As such, the species distribution patterns described above may change as our knowledge increases.

Information on life history characteristics, especially migration patterns, feeding habits and reproductive season exists for some

Even in extensively surveyed areas, such as the Nam Theun River in Laos, new species are still being discovered. ©Maurice Kottelat

of the larger species of fisheries interest in the mainstreams of the largest rivers but, for the majority of species which are of medium to small size and that inhabit smaller waterbodies, there is limited, if any, information. For many species, the information that can be found is based on anecdotal observations by taxonomists at the time of surveys, or is extrapolated from information on similar species living in similar habitats elsewhere. Most of this information has been obtained in the dry season (between February and June) so we should be wary of some of the generalisations made – what may appear to be impassable rapids or even waterfalls in the dry season may be obscured in a flooded river in the wet season.

Information on species habitat and food requirements in the wet season for species inhabiting hilly areas is usually provided by the local fishermen since scientists rarely visit these areas at that time of the year (if the areas are accessible at all), and frequently information is only available for the larger species.

Precise distribution information is lacking for many species. Many species are known only from the taxonomic literature and their distribution is summarised by a few dots on a map representing the few sites where they have been collected by one or a few researchers. Distribution data may appear to be available from various sources but these are variously unreliable and often have to be rejected.

Various inventories, especially in relation to Environment Impact Assessments (EIAs) prepared for hydropower projects or fisheries studies, have been conducted, but mainly through market surveys and interviews. Unsurprisingly, therefore, the small-sized or commercially less valuable species are largely missing from these inventories. Such assessments usually focus on fishery productivity, although some claim to have investigated biodiversity. If such assessments are to be of any use for subsequent biodiversity analysis, the species inventories must be comprehensive (for example, recording the presence of all species present) and should be conducted by trained ichthyologists in the field.

A simple reliability test for the validity of a species assessment is to count the number of small-size species (such as Akysidae, Balitoridae, and Nemacheilidae) for comparison with earlier collections from the drainage. If, for example, a list of species in a mountainous area of Laos contains less than four species of *Schistura*, or includes species previously known only from another distant drainage, it is at best likely to be incomplete, or at worst, has been created without actually visiting the site in question.

The Critically Endangered Mekong Giant Catfish (*Pangasianodon gigas*) is one of the world's largest freshwater fishes and is endemic to the Mekong River. The species was once a highly valued food fish, but due to overharvesting populations have plummeted and now intentional capture of the species in the wild is banned. © Zeb Hogan

The Critically Endangered Giant Carp (*Catlocarpio siamensis*) is one of the largest fishes in Indo-Burma. Once an important food fish in the region, overharvesting, pollution and habitat loss has led to significant declines in its population. © Zeb Hogan

Checklists compiled through interviews, derived from collecting local names, or through showing pictures, contain little or no reliable information from a biodiversity perspective because the identities of many species (the small-size ones and those likely to have a restricted distribution) cannot be objectively confirmed; this also assumes that the fauna of the area has been subject to extensive research, which is rare. Information on unnamed species is not captured through these surveys, which is a serious problem since it results in a grossly underestimated biodiversity value. As a demonstration of the scale of this problem, in Laos, outside of the mainstream Mekong River at the Khone Falls, the best known drainages are the Xe Bangfai and Nam Theun which have both been extensively surveyed in connection with the construction of the Nam Theun 2 hydropower scheme. Surveys of these two drainages have resulted in a number of scientific publications (for example, Kottelat 1998, 2001), yet despite this level of survey, species are still being added to the list, and new species are also still being discovered.

Table 3.1 The number of Indo-Burma freshwater fish species in each IUCN Red List Category.

Category	Number of fish species
Extinct	1
Extinct in the Wild	0
Critically Endangered	21
Endangered	39
Vulnerable	52
Near Threatened	33
Least Concern	518
Data Deficient	514
Total	**1,178**
% Threatened (excluding DD and EX spp.)	**16.9**

3.2 Conservation status

This assessment considered the global risk of extinction for 1,178 species of fish found in the inland freshwaters of the Indo-Burma region, with the inclusion of some brackish or marine species where species dependence on freshwater for some essential life-history stages could be demonstrated. Of the extant species for which sufficient data are available to determine their conservation status (i.e., excluding Extinct and Data Deficient species), 16.9% (112 species) are considered threatened (assessed as Critically Endangered, Endangered, or Vulnerable), and 5.0% (33 species) are considered Near Threatened (Table 3.1, Figure 3.1). Of the 112 threatened species, only 17 are also found outside of the Indo-Burma region (species with very narrow ranges that cross the boundary of the assessment region are not included in the count of species considered endemic to the region). This current level of threat is similar to that observed in a similar assessment undertaken in the Eastern Himalaya (15.5% threatened; Allen *et al.* 2009). However, whilst high, it contrasts with higher levels of threat observed through assessments for Africa (26.7%; Darwall *et al.* 2011), the Western Ghats in India (37.0%; Molur *et al.* 2011), and

Table 3.2 Fish species omitted from the assessment in error, or due to lack of a formal description at the time of the assessment.

Omitted species		
Brevibora dorsiocellata	(Duncker, 1904)	Malay Peninsula
Badis juergenschmidti	Schindler & Linke, 2010	Sittaung
Lepidocephalichthys kranos	Havird & Page, 2010	Middle Mekong
Lepidocephalichthys zeppelini	Havird & Tangjitjaroen, 2010	Middle Mekong
Macrognathus dorsiocellatus	Britz, 2010	Sittaung, Salween
Kryptopterus hesperius	Ng, 2002	Mae Khlong
Recently described species		
Acanthocobitis pictilis	Kottelat, 2012	Tenasserim, Mae Khlong
Boraras naevus	Conway & Kottelat, 2011	Malay Peninsula
Clarias gracilentus	Ng, Dang & Nguyen, 2011	Phu Quoc Island
Schistura diminuta	Ou, Montaña, Winemiller & Conway, 2011	Lower Mekong
Scleropages inscriptus	Roberts, 2012	Tenasserim
Erethistoides luteola	Ng, Ferraris & Neely, 2012	Sittaung
Pseudeutropius indigens	Ng & Vidthayanon, 2011	Malay Peninsula

Europe (45.9% (regionally endemic species only; Freyhof and Brooks 2011)). This may reflect a lower current level of threat in some areas, but may also be a product of the large number of Data Deficient species (43.6 % here, versus 27.1% in the East Himalaya region).

Platytropius siamensis, the Siamese flat-barbelled catfish, is the only species of fish from the region considered to be Extinct at present (see below).

Five hundred and eighteen species (43.9%) are assessed as Least Concern and 514 species (43.8%) are considered Data Deficient (meaning there was insufficient information available to make an assessment of extinction risk), revealing the inadequacy of knowledge, for many species, of their ecological requirements, distributions, and levels of threat throughout the region.

Six species have been omitted from the assessment in error, and a further seven species have been described since the completion of the assessment (Table 3.2).

3.3 Patterns of species richness in the Indo-Burma region

3.3.1 All fish species

The lower and middle Mekong and Chao Phraya drainages have the most diverse fish faunas (Figure 3.2). This diversity is concentrated in the lowland areas, in the main rivers, and in the floodplain. This observation is, however, possibly biased as these areas are the most extensively studied, have the greatest subsistence and economic importance through their fisheries, and currently house, or formerly housed, the main research institutions of the region.

The fish fauna is least diverse in mountainous areas (for example, in northern Thailand and northern Laos). This can be explained by the lower diversity of habitats, being mainly headwaters, rapids, and rocky stretches. But these sites are also very remote and hard to access and, as a result, suffer from lack of sampling.

The low diversity recorded for the Tenasserim and the lower Salween is thought to be mainly due to lack of sampling. This is clear in the Salween drainage where the number of recorded species is higher where it forms the border between Thailand and Myanmar than further downriver in Myanmar; the highest diversity is expected to be in the lower part of the drainage.

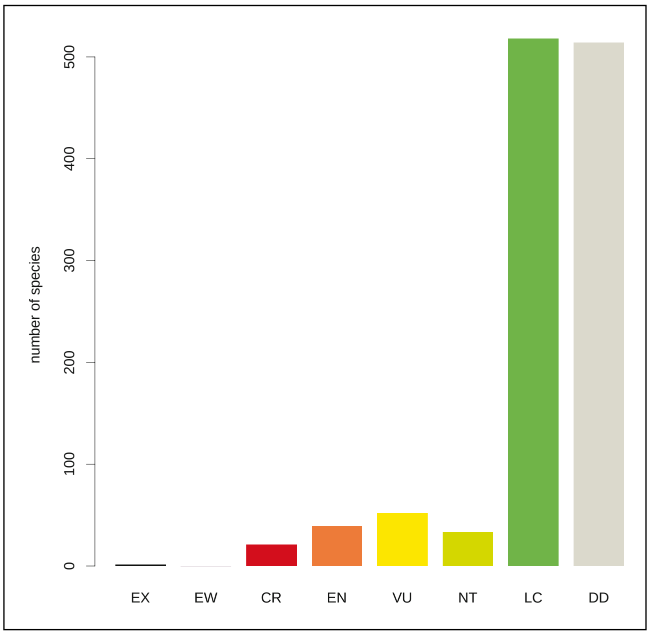


Figure 3.1 Numbers of freshwater fish species in each IUCN Red List Category in the Indo-Burma region.

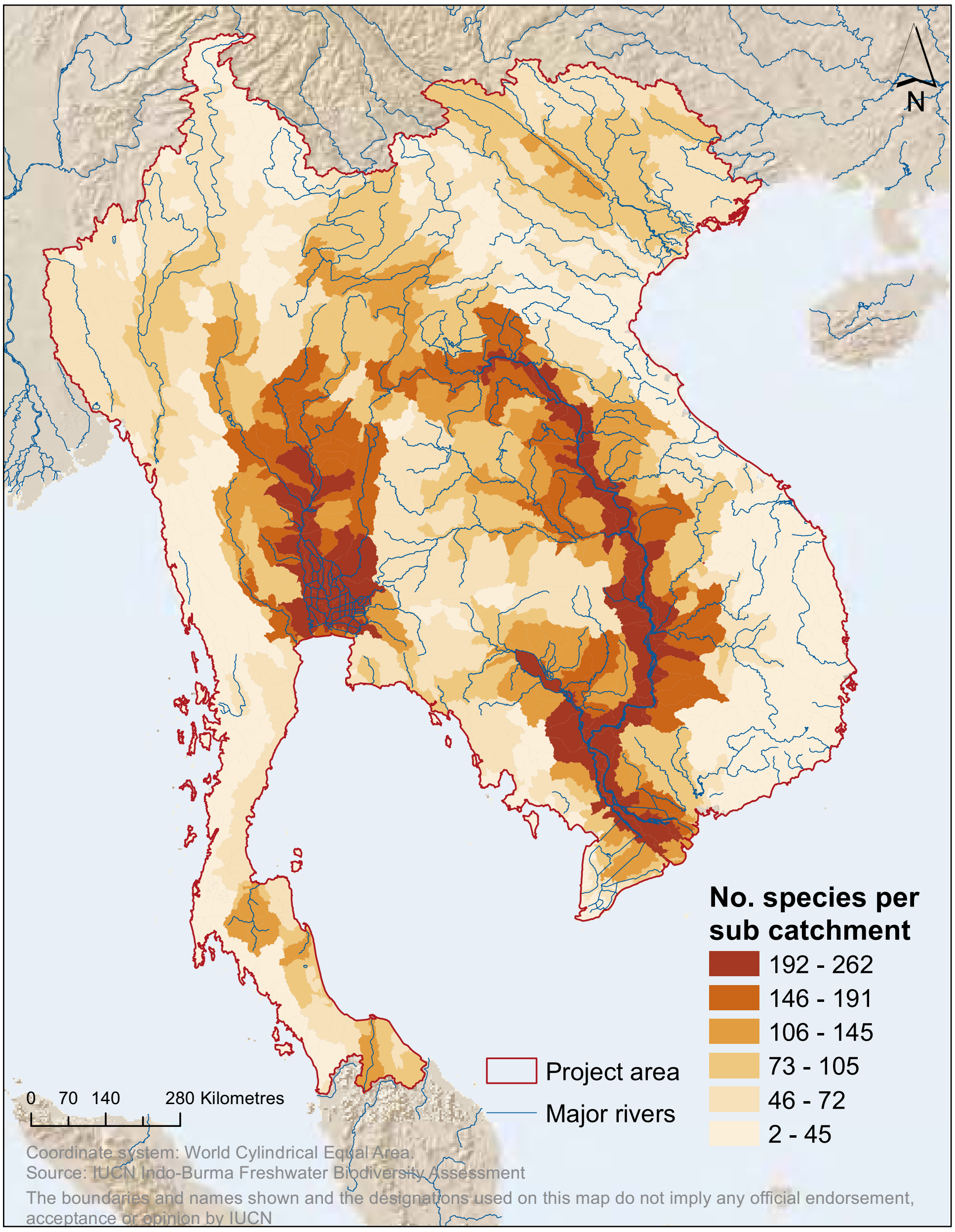


Figure 3.2 Patterns of freshwater fish species richness (number of species per river/ lake sub-catchment) in the Indo-Burma region.

3.3.2 Threatened species

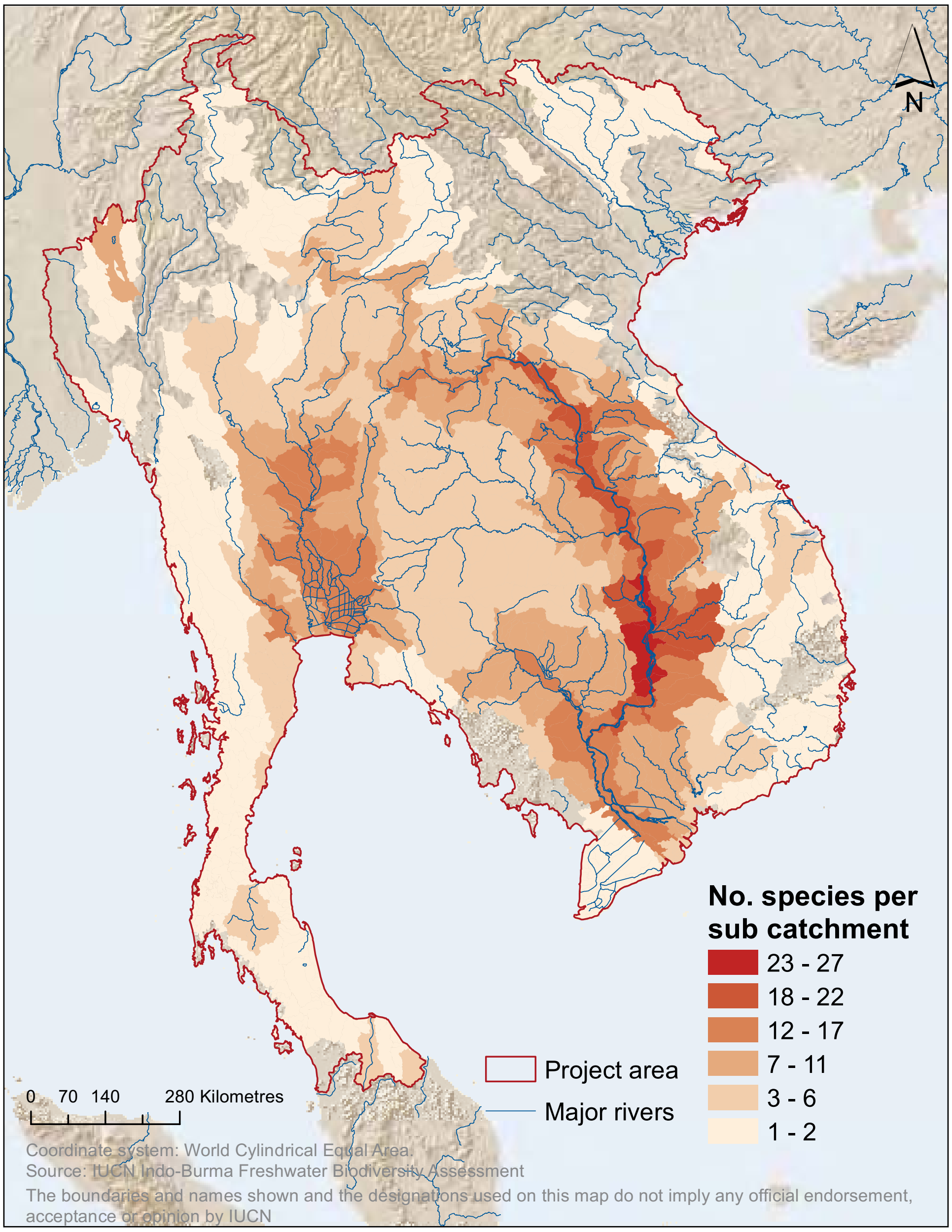
The distribution pattern of threatened species largely parallels that of species richness. The sub-catchments with the most diverse fish fauna have the largest numbers of threatened species. This largely reflects the reality that more studies have been conducted along the main rivers, and that the species identified as being threatened are in most cases species important for fisheries for which there is more available information.

The concentration of species with small ranges in Inlé Lake and their various threats is clear. The absence of threatened species in most of the Red River drainage reflects the assessment of most species as Data Deficient (compare with Figure 3.3). Species assessed as Data Deficient are assumed to be potentially threatened.

3.3.3 Restricted range and endemic species

The pattern of distribution of the restricted range and endemic species (Figure 3.4) largely duplicates that of species richness. As the region is partly defined by political boundaries and not by physiographic or faunistic criteria, patterns of endemism are particularly biased along the margins of the region. For example, species with a small range in northwestern Laos (for example, Nam Youan subcatchment) and Xishuangbanna (Yunnan, China) are not highlighted as being endemic to the region although their global range is much smaller than that of most of the endemic species in the Mekong and Chao Phraya flood plain (examples: *Sectoria heterognathos*, *Schistura macrocephalus*, *Schistura kloetzliae*, *Mystacoleucus lepturus*). The same observation is made at the southern margin of the region along the border between Thailand and Malaysia, and in the Red River drainage along the border with China.

Figure 3.3 The distribution of threatened freshwater fish species within river sub-catchments across Indo-Burma.



3.3.4 Data Deficient species

The pattern of distribution of the Data Deficient (DD) species (Figure 3.5) broadly duplicates that of species richness, with the largest density of species in the middle and lower Chao Phraya and Mekong. The Red River drainage and northern Vietnam, however, support higher than expected numbers of DD species.

Five hundred and fourteen (43.6%) of the 1178 assessed species are placed in the DD category. The main reasons species were assessed as DD are: (1) recent discovery or recognition as distinct species (often previously confused with other species); (2) known only from a single record or from a few individuals; (3) uncertainty about taxonomy (131 species), and (4) little or no information on their biology. For most species in this category there is no information on population trends, threats, etc. Most of these species are also of small size and have little commercial value. One hundred and sixteen of the 131 species assessed as DD because of uncertain taxonomy occur in Vietnam; most of these have been described in the last 15 years.

The taxonomy of northern Vietnamese fishes has evolved in relative isolation, with little knowledge of the work conducted in adjacent countries, and with different quality standards. As a result, the validity of a large portion of the species described in the last 20 years is open to question and many appear to be conspecific with species described from China and Laos. The true identity of these species can only be confirmed through direct comparisons of specimens of these species but, unfortunately, it is very difficult for foreign scientists to access material from Vietnam, both in the field and in research institutions. Reliable data on species populations and their threats are also scarce. The assessors who examined the Red River fishes may have a different perception of these issues.

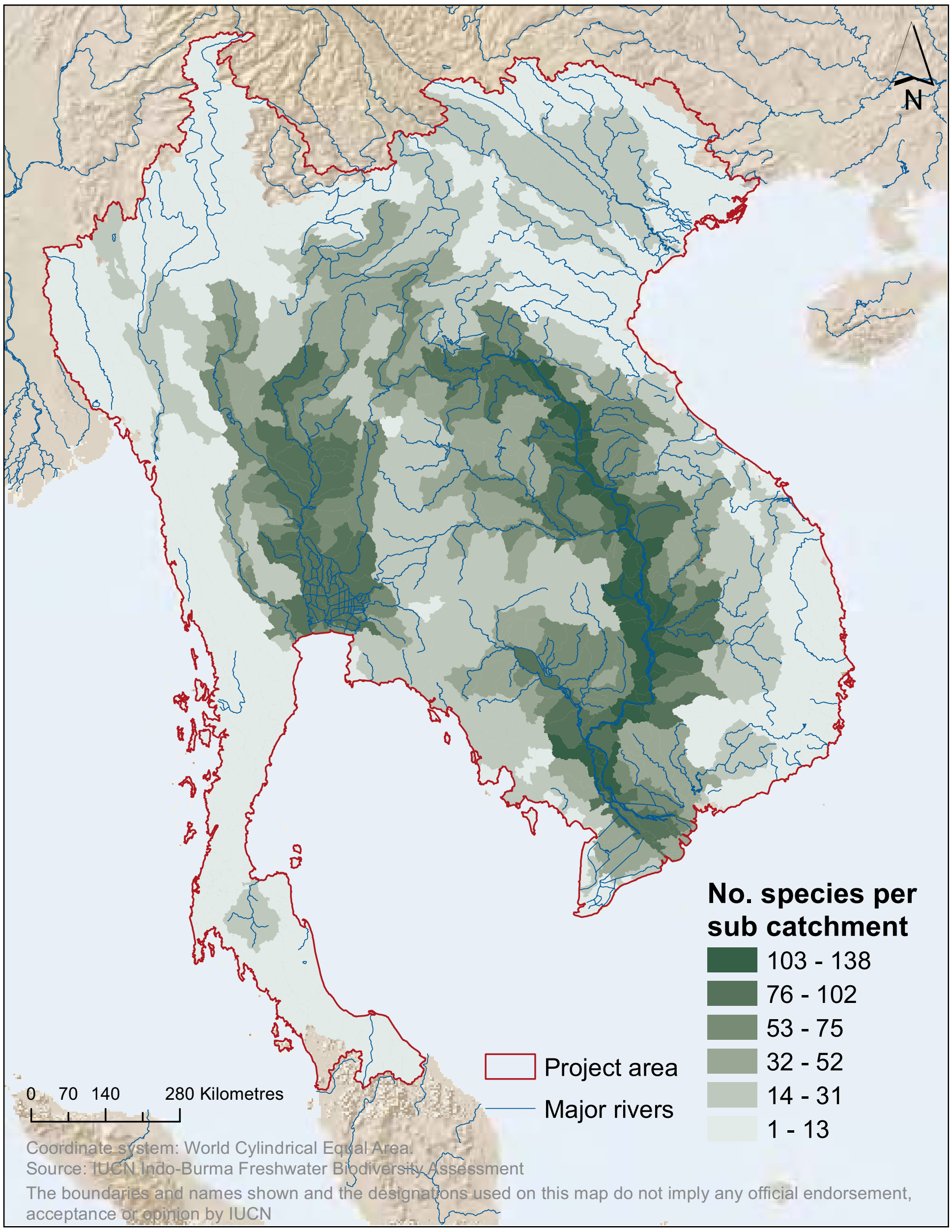


Figure 3.4 The distribution of freshwater fish species endemic to sub-catchments within the Indo-Burma region.

DD species, all of which are potentially threatened, will be re-assessed once sufficient information becomes available. The observation that many of the DD species have only been discovered recently already suggests that they have small ranges and are potentially at risk.

3.3.5 Extirpated/Extinct species

Platytropius siamensis, the Siamese flat-barbelled catfish, is the only species of fish from the region currently considered to be Extinct. The species was first described in 1883 and was known from the Chao Phraya and Bang Pakong river drainages in central Thailand. Not recorded in surveys since 1977, the species is thought to have been negatively affected by pollution, and habitat loss arising from wetland conversion, damming and canalisation. A further four species are considered 'Possibly Extinct' (Balitoridae: *Schistura tenura*, *Schistura nasifilis*; and Cyprinidae: *Puntius compressiformis*, *Balantiocheilos ambusticauda*); all are assessed as Critically Endangered (Possibly Extinct) and require additional survey to confirm their existence in the field. *Schistura tenura* is typical of species found in the upper parts of river catchments with probably restricted distributions, high vulnerablility to impacts from threats such as, in the case of this species, hydropower development.

Yasuhikotakia sidthimunki (the Dwarf Clown Loach) was previously recorded as present in the Mae Khlong and Chao Phraya drainages, and possibly the Mekong. It is now *thought* to still be present in two small streams in the Mae Khlong drainage, although this requires confirmation. It is, however, possible that the species has been extirpated in the wild. It is available in the aquarium-fish trade, but its survival in captivity relies entirely on cultivation in only a few farms in Thailand. It is generally understood that the captive stock went virtually extinct in the 1980s because the only breeder

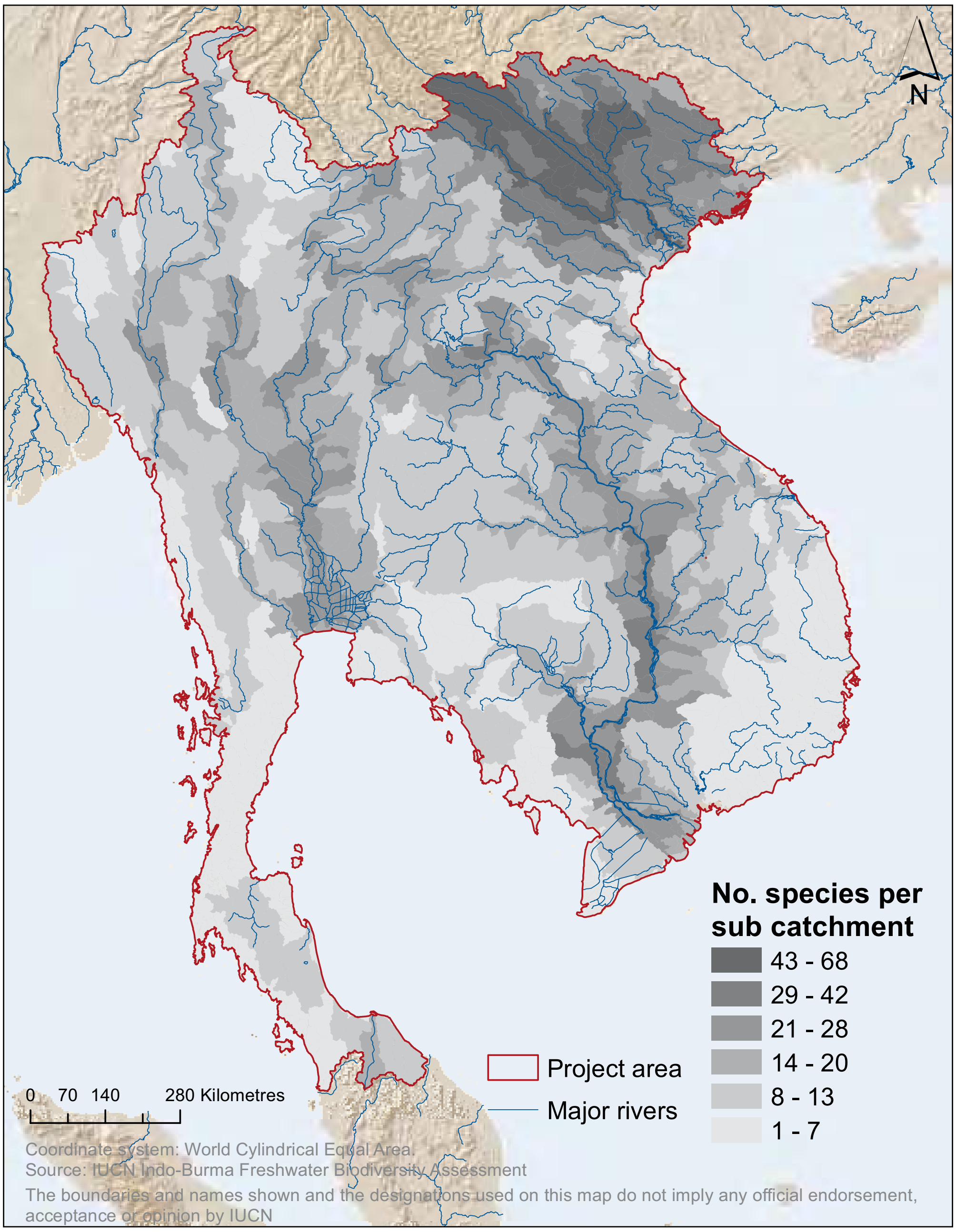
The Dwarf Clown Loach (*Yasuhikotakia sidthimunki*), currently assessed as Endangered, is possibly extinct in the wild, but is not uncommon in aquarium trade. © Gerhard Ott, www.sach-fach.de

at that time died; a stock was only reconstituted from ageing aquarium specimens. A species surviving solely through captive breeding by a few individuals leaves it at very high risk of extinction, relying on the goodwill and interests of these individuals, the market demand, fashion in the aquarium-fish trade, or the local or global political or economic situation. The situation of *Epalzeorhynchos bicolor* is quite similar except that it is more widely cultivated; it had long been considered as Extinct in the Wild but a small population has recently been rediscovered.

3.4 Major threats to freshwater fishes

There is hardly any type of terrestrial human activity that does not have an impact on freshwaters and thus on aquatic

Figure 3.5 The distribution of Data Deficient (DD) freshwater fish species within sub-catchments across Indo-Burma. Note: not all DD species could be mapped due to lack of information on their geographic ranges.



Luciocyprinus striolatus (EN), a large predatory fish known from rivers in Lao and possibly in China. It inhabits deep pools in the upper reaches of large rivers with naturally low, but decreasing, population numbers. © Maurice Kottelat

biodiversity. The main threats to the fish diversity in the region are the alteration of river morphology (especially by hydropower projects, and to facilitate navigation and water extraction for irrigation), habitat degradation (pollution, deforestation, agriculture, aquaculture, urbanisation), exploitation and species introductions. It is rare that a species is affected only by a single threat. More commonly, different categories of threats are interdependent and the synergy of the threats has much greater impact than the simple addition of impacts from individual threats. For example, mining involves not only the extraction of minerals, but also deforestation, road construction, settlements and increased exploitation, pollution, river modification, etc. Hydropower schemes usually imply deforestation, flow reduction or diversion, resettlement, increased exploitation, species introductions, etc. Some of the major threats are discussed here.

The main threats identified through the Red List assessments are agricultural and forestry effluents, affecting 402 species (including 63 threatened species), dams and other modifications of aquatic habitats, affecting 298 species (including 62 threatened species), and the over-harvesting of natural resources, affecting 313 species (including 59 threatened species).

The rare catfish *Silurus burmanensis* (Data Deficient) is endemic to Lake Inlé. This individual is only the second individual collected since the description of the species in 1967. © Ye Hein Htet

3.4.1 Alteration of river morphology

Among all factors threatening freshwater fish diversity in the Indo-Burma region, alteration of river morphology is the single most important threat since it modifies, destroys or suppresses the habitat of the fish or of its prey, its feeding and spawning grounds, and/or the hydrological features upon which it depends.

3.4.1.1 Hydropower

The development of hydropower dams throughout the Indo-Burma region is amongst the most crucial threats to aquatic biodiversity in the region. These projects are changing the fundamental hydrological and water quality conditions (including sediment flows) of many rivers, thus completely altering aquatic habitats with still little understanding of the impacts of these dramatic changes on fish biodiversity more generally. While there has been considerable media coverage given to the potential impacts on fish biodiversity of large mainstream dams such as the Xayaburi Dam on the Mekong River in northern Laos, much less attention has been given to larger tributary projects, and even less has been given to the impact on fish biodiversity in small tributaries and upland areas.

The Indo-Burma region is heavily influenced by monsoons, with long dry seasons with low precipitation and rainy seasons when the vast majority of rainfall occurs. The water levels vary considerably in different seasons. This leads to dramatic changes in aquatic habitats. For example, in the mainstream Mekong River near Pakse in southern Laos, there is approximately 30 times as much water at the height of the monsoon season in August–September than at the lowest part of the dry season in March–April. These hydrological conditions significantly influence the behaviours of fish, resulting in many species exhibiting some level of migratory behaviour to adapt to seasonal habitat changes. Some species are known to migrate long distances. For example, the large catfish *Pangasius krempfi* migrates many hundreds of kilometres from the South China Sea and the Mekong Delta up the mainstream Mekong as far as northern Laos where it spawns (Hogan *et al.* 2007). Several

The Endangered Giant Freshwater Whipray (*Himantura polylepis*) found in isolated populations from India to Indonesia is one of the largest freshwater fish in the world reaching 2 metres in disc width and is threatened by pollution and fishing pressure. This species requires further taxonomic research as it is possible that populations in the Mekong and other drainages may be distinct species. © Zeb Hogan

Chaudhuria caudata (Data Deficient), a tiny eel-like fish described from Lake Inlé in the Southern Shan State, Myanmar © Ralf Britz

species of small cyprinid also migrate hundreds of kilometres between the Tonlé Sap Lake in Cambodia and southern Laos and northeastern Thailand, some following lunar cycles (Baird *et al.* 2003).

Many large hydropower dams are likely to block these important fish migration routes, such as the planned Don Sahong Dam in the Khone Falls area of the mainstream Mekong River in southern Laos (Baird 2011), and the Lower Sesan 2 Dam on the Sesan River in northeastern Cambodia (Baird 2009), thus potentially having important impacts on fish diversity. Some fish species may have only a single spawning site, either in freshwater or at sea, and may become extinct if access to the site is blocked; a number of such cases are documented worldwide.

Many hydropower dams installed on large rivers belong to the category "run-of-the-river". In conventional dams, the water is stored in large reservoirs and is forced through turbines at some distance from the river; run-of-the-river dams are installed on the river and use its flow and natural drop. They are often misunderstood or misrepresented as being able to maintain the hydrological conditions of the river, which from the biodiversity point of view is not true. In most of these cases the river is still dammed, the water is channelled and the flow is reduced, with consequent impacts to the aquatic biodiversity. Run-of-the river dams may also be accompanied by one or more "regulation" or "extension" dams upstream; these maybe classical accumulation dams, with the same impacts, releasing a minimum steady flow for the run-of-the-river station(s) downstream. Run-of-the-river dams, by slowing the current, also threaten species whose eggs and larvae need to travel long distances before settling. For example, the eggs of *Hypophthalmichthys* species float and hatch after about two days; if the river is blocked, or if the current is slowed, or if the available stretch is too short, the eggs cannot drift long enough, fall to the bottom and fail to develop.

Several hydropower schemes divert the water from one drainage to another. For example, in Laos, most of the water of the upper Nam Theun is blocked by the Nam Theun 2 Dam and diverted to the Xe Bangfai; the lower Nam Theun and Nam Gnouang are blocked by the Theun-Hinboun Dam and most of the water is diverted to the Nam Hinboun. On the Bolaven plateau, the Xe Pian – Xe Namnoy project intends to dam these two rivers to produce a single reservoir.

Plans are also under consideration in Laos to transform whole rivers into successions of dams, euphemistically called 'cascades'. On the Nam Ngum, the Nam Ngum 1 reservoir extends up to the Nam Ngum 2 Dam, the Nam Ngum 3 Dam is planned at the upper limit of Nam Ngum 2 reservoir, with Nam Ngum 4 Dam planned further upriver, and Nam Ngum 5 Dam was constructed on one of the main tributaries.

There has been a huge amount of micro and pico hydropower development in the Mekong River Basin in Laos (see, for example, Baird and Shoemaker 2008), but there has been virtually no research conducted to study the impact of these projects on fish diversity. Typically, pico-hydro generators are small turbines placed directly in the streams. In small waterbodies, small weirs are built to create a short drop (commonly about 1 m). The weirs also create ponds that may be stocked with tilapias and carps (both non-native species). A single installation is usually not a serious concern, but thousands of these installations exist, often closely set and transforming small streams into a mere succession of ponds, leading to the extirpation of the native fish fauna and its replacement by ubiquitous and introduced species. In swifter streams, the turbines are installed in riffles and the flow may be narrowed and directed to the turbines, the impact being restricted to the dry season. In larger streams, the turbines are installed on posts, piles of stones or rafts and most seem to have no significant impact. Micro-hydro plants generally include a small dam, a penstock and a powerhouse, and their impact can be similar to that of large plants, although usually at a smaller magnitude; their construction is rarely preceded by a meaningful Environmental Impact Assessment.

3.4.1.2 Irrigation

The impacts of irrigation projects in the Indo-Burma region have been widely understudied and greatly underestimated, although some studies in the Mekong region indicate that even small-scale irrigation projects can have significant impacts on fish diversity (see Baird 2001a). Irrigation schemes often divert water from one drainage to another and there is ongoing discussion of large schemes diverting large tributaries of the Mekong from Laos to Thailand through 'syphons' under the Mekong. The rules set by the Mekong River Commission recommend against large-scale direct extraction from the Mekong without prior consultation with other countries in the basin, however, through distortion of the rules, the diversion of large tributaries immediately before they reach the Mekong mainstream is considered as not breaking this rule. The water put back into the river, if any, is usually warm, often of very poor quality being of low oxygen concentration, and loaded with organic matter, fertilisers and pesticides. Transfer of water from one drainage to another also transfers species, introduced as well as native, which may then become established or invasive in their new habitat, along with potential pathogens.

3.4.1.3 Navigation

The upper mainstream Mekong River has been significantly altered in China and northern Laos in recent years to facilitate large boat transport along the river. It is, however, difficult to know to what extent these changes have affected fish species, as fine-scale ecological studies of the niche-specific species are lacking.

3.4.2 Pollution

Currently, industrial pollution is of concern mainly in Thailand and Vietnam. It is currently very low but increasing in Laos and Cambodia, and is possibly still minimal in Myanmar. Urban pollution is especially important in Vietnam and Thailand, is more restricted in Laos and Cambodia, and is still very limited in Myanmar. Some Thai companies have set up factories on the Lao side of the Mekong so that they can disperse pollution into the river that is not allowed in Thailand, as was the case for the whiskey distilleries in the late 1990s.

Similarly, agricultural pollution is most problematic in Thailand and Vietnam, which both have intensive agriculture. Agricultural pollution comes mainly in the form of pesticides and industrial fertilisers, which, because the predominant crop throughout Indo-Burma region is rice, instantly enter the aquatic habitats. Increasing populations of water buffalo also have a significant impact on many water bodies, by destroying river banks and shallow water habitats, and through their excrement that significantly increases the organic loading and leads to local depletion of dissolved oxygen.

Recently, an increase in the number and extent of large-scale land concessions in Yunnan Province (China), Myanmar, Laos, Cambodia and northeastern Thailand has caused large-scale changes in landscapes. The increase in the number of rubber plantations is especially evident. The expansion of industrial agriculture has reportedly had significant impacts on water bodies near these plantations, both due to land conversion and the large amount of herbicides used. Fish populations and diversity in these areas has dropped significantly (see Baird 2010).

Pesticides are also used in antimalarial programs (in Thailand this is combined with introduction of the guppy, *Poecilia reticulata*). In Thailand these programs are considered to be

The hydroelectric dam on the Nam Ngum River, a major tributary of the Mekong River, which has created one of the largest water bodies in Laos. © Chaoborus Wikimedia Commons

Tor ater (VU) is a rare species restricted to the upper Nam Theun catchment, Lao PDR. It was considered possibly migratory and that construction of the Nakai Dam and reservoir would make migration impossible and therefore threaten the species. Surveys in 2003 found that its range is restricted to the drainages upstream of the reservoir and that in this case there is no indication that it undertakes migrations. Its entire known range is within the Nakai Biodiversity Conservation Area. © Maurice Kottelat

A confirmed spawning area for *T. ater*. Spawning occurs in wet season when water level is much higher." © Maurice Kottelat

responsible for a sharp decrease of fish populations, for example, in the hill streams of Loei and Nongkhai provinces.

Mining (see below), sugar refineries and sawmills are other known major sources of pollution.

3.4.3 Mining

In recent years, the rapid and widespread development of gold mining has destroyed large stretches of rivers by modifying their morphology, in particular through interrupting and diverting the flow in the dry season, increased siltation, and pollution with sodium cyanide and mercury (mercury has less immediate impact on fish diversity than does cyanide, but it also threatens the health of human populations by accumulation over very long periods). There are two main types of gold mining. The first is the large scale operation, which is generally better planned and is usually run by an international company (whose social and environmental record may receive some scrutiny in the countries from which they operate) with loans from international institutions and which is subject to more comprehensive EIA and monitoring (although imperfect). These larger scale operations tend to run standard mines involving excavation and disposal of rock, or transport of some 'concentrate' to a distant site – thus displacing some of the environmental cost.

The second types of gold mines are the small operations, some illegal, extracting gold from the river bed or soils. These operators have little or no planning, mitigation, monitoring, liability, or sanitary measures. Due to their illegal nature and the value of the metal they target, these extraction sites are difficult and dangerous to approach and are virtually impossible to monitor directly.

Gold is also extracted by dredging in large rivers, an action that destroys the river bed habitat for fishes. These operations, although conspicuous, are often illegal. Gold dredging operations have been allowed in the Xe Kong basin in Attapeu and Xekong provinces, despite the dissatisfaction of the local people (Baird & Shoemaker 2008). In 2012 dredging operations were ongoing in Xekong Province with local government approval. Typically, dredging is tolerated until the local population complains about fish losses by poisoning, destruction of habitat and fishing nets, and security problems (see Baird & Shoemaker 2008).

The impact of mining for other minerals is less well known, as is that of quarries, and sand and gravel extractions from the river beds.

3.4.4 Exploitation

The overexploitation of fish, especially for human and animal consumption, is a major concern worldwide and the Indo-Burma region is no exception. The fishing pressure is, of course, highest in the most densely populated areas of Vietnam and Thailand. In Laos, Cambodia and Myanmar, despite being less densely populated, the pressure is also high, the catches being partly exported to China, Thailand and Vietnam.

Almost all fish species are consumed with even the smallest and least conspicuous species, such as *Sundasalanx mekongensis*, the tiny venomous *Akysis* catfishes and some of the poisonous pufferfishes, being eaten. The subsistence fisheries for these small species, although providing a significant source

Road construction has devastating effects on streams in hilly areas throughout the Indo-Burma region. All excavated material is pushed downhill often burying streams, streams are blocked off when working in the river bed, and overfishing, employing electricity and explosives, is common where construction camps are established. © Maurice Kottelat

A small gold mining operation in the Gam River, Vietnam.
© Jack Tordoff

of protein for humans (especially the poorest), are virtually ignored in fisheries statistics (Kottelat & Whitten, 1996). More recent statistics from the Mekong Region have, however, taken them into account, thus resulting in dramatic increases in the recorded fish catches in the region. A few species may be avoided seasonally when their flesh becomes toxic (for example *Leptobarbus and Tor species*).

Throughout the region, the (illegal) use of electricity for fishing has become extremely common and of serious concern. In Laos this fishing method was virtually unknown in the 1990s, but it is now responsible for the absence of fish in many streams, especially near bridges. Typically, in stretches overfished with electricity only a few juveniles are observed.

With a large number of unexploded bombs remaining from the Vietnam war, and newer explosives becoming available with increasing mining and road and dam construction, fishing with explosives remains common in some remote parts of Laos. Fishing with chemicals, especially pesticides, cyanide and acetylene, and more rarely with local plants, is less frequently observed.

In addition to harvest for human consumption, fishes are also harvested in large numbers to feed animals, especially carnivorous fishes cultivated in cages. For example, the ranching of *Channa micropeltes* and the culture of *Pangasius* species consume large quantities of food fishes.

In the Indo-Burma region the ornamental fish trade is most active in Thailand, for both the local and export markets. Most of the fish species exported are cultivated; wild-caught fishes are also harvested but their share in the trade is not known. The ornamental trade is less well known in Vietnam, but the number of wild-caught species exported is thought to be quite low. In Myanmar, the trade has significantly increased in the last 15 years; it is based only on wild-caught species and all are exported. This trade is still very limited in Cambodia and Laos.

In theory, most species could be traded as ornamentals, but to be of viable commercial interest, a species has to be: 1) colourful or exhibit some special feature; 2) be sufficiently abundant to justify the expense of travel to the site of capture, other associated costs, and the expenses associated with the complex bureaucracy of obtaining sanitary certificates etc.; 3) be fashionable and available at an attractive price for the end buyer, or; 4) be expensive enough to justify prestige status (for example, *Scleropages formosus*, *Datnioides pulcher*). As a result, only a small number of species are caught and exported regularly. Most species are exported a few times, pictures then appear in the specialised literature but, unless they find a niche, their presence in the market is sporadic. The ornamental fish trade is likely to continue actively in Myanmar, but its future in Thailand is less promising as the fish's habitat quality and population densities continuously decrease.

There has been much debate as to whether the ornamental fish trade does, or could, threaten fish diversity. For most species, this trade alone is not known to have been a significant threat at the global scale. Some populations of particular species have been locally affected by overharvesting, but the population decline of a species in the ornamental fish trade is more often an indication of other threats (for example, *Yasuhikotakia sidthimunki*, *Trigonostigma somphongsi*). Species with very restricted ranges or sensitive habitats (for example, *Betta simplex*) could, however, become threatened by the trade. This is a particular concern for cave fishes, all of which have both restricted ranges and sensitive habitats. Although cave fishes have been occasionally harvested they have not yet found a significant niche within the trade.

The ornamental fish trade is extremely reactive. When attractive new species are described by scientists they may appear in the trade within days, leading to sometimes intense pressure on populations for which the precise location is reported. Scientists should therefore consider whether it is appropriate to divulge very precise information on species localities. The reverse situation can also arise where commercially important species have first been discovered by the ornamental fish

Artisanal fisher folks of Nan in northern Thailand. These subsistence fisheries provide a significant source of protein, especially for the poorest communities, but are often ignored in fisheries statistics. © Chavalit Vidthayanon

The Celestial Pearl Danio (*Danio margaritatus*) restricted to pools on the Shan plateau in Myanmar, first came to the attention of scientists due to its presence in the aquarium trade. The species is assessed as Data Deficient as more information is needed on its population status and the source of specimens found in the aquarium trade. © Ralf Britz

trade and subsequently brought to the attention of scientists; this now frequently happens in Myanmar (for example, *Botia kubotai*, *Danio margaritatus*). Incorrect locality information may also be provided in order to deceive competitors and keep the price high.

Large aquarium fishes (for example, *Scleropages formosus*, and large cichlids) are popular and locally can lead to the overexploitation of other juvenile fishes sold as live food for these predatory pets. Species most at risk from capture as "feeder fish" for these larger species are juveniles of the various *Channa* species and cyprinids. Even adults of small species such as *Boraras urophthalmoides* and *Rasbora* species in the Malay Peninsula and the Mekong Delta may also be at risk from this type of capture.

Although there are very few studies on the exploitation rates of fishes specific to the different types of use and their impact on fish populations, there is a general pattern of decrease in catches throughout the region, especially of larger long-lived species, indicating that current levels of exploitation are not sustainable.

3.4.5 Introductions, translocations, and invasive species

Introductions are often only recognised as such when a species is moved across national boundaries. However, transportation of fish species from one drainage to another, often within country boundaries, also constitutes an introduction and is potentially just as dangerous to biodiversity. Even the translocation of fish species within a drainage to an area where it was previously unknown is considered to be a potentially harmful introduction, although it is often euphemistically referred to as 'stocking' to increase, or expand, the range of a fish population already present within the drainage.

Introduced species of fishes and invertebrates may compete with, or prey on, native fish species, transport pathogens, and modify the habitats needed for a native species to feed and reproduce (Welcomme and Vidthayanon 2003). For example, the carp (*Cyprinus* spp., several species and hybrids may be involved) has become the dominant species in some parts of the mainstream Mekong in southern Laos in some seasons and has reportedly caused considerable riverbank erosion in areas where it is common (Baird 2001b)

Another danger that introduced fish species may pose is alteration of the genetic composition of native fish populations via hybridization. For example, the African clariid catfish *Clarias gariepinus* has been hybridized with *Clarias macrocephalus* (a species native to Indo-Burma) and cultured as a food fish in Thailand. These interspecific hybrids often escape and have been shown to interbreed with wild *C. macrocephalus* (see Senanan *et al.* 2004), and this introgression has been demonstrated to occur throughout a large area of Thailand (Na-Nakorn *et al.* 2004).

The guppy (*Poecilia reticulata*), a species native to northern South America, has been introduced in Thailand as part of antimalarial programs, with the hope that it would prey on the vector mosquitoes. Although the impact of these introductions has apparently not been evaluated it is known from other areas that the guppy has almost never had an impact on mosquito populations, but it has been observed to be competing with the local fish species and is itself a vector for a number of parasites and diseases (Nico & Neilson, 2012; www.issg.org). Despite the absence of demonstrated impact on mosquito populations, the stocking of guppies continues. See also under Pollution, above.

Pet-fish farms and accidental or voluntary release of oversize pets are not known to have impacted the native fish biodiversity, although some pet-fish may be a direct threat to humans (e.g. piranhas, South American stingrays, arapaima). Currently, this is mainly a concern in Thailand, which has a strong aquarium-fish industry, and to a lesser extent in Vietnam.

Pacu (*Colossoma* sp.), a relative of the Piranha, is a South American fish farmed in many areas in Indo-Burma but, following escapes from these farms, is now spreading in parts of the lower Mekong basin. © Ralf Britz

‘Fishing farms’ are ponds created specifically for recreational angling. They are populated with large fishes, mostly caught locally and then released into the ponds. The harvesting of the large native fishes for stocking in the ponds is not believed to have had a significant impact, especially when compared to the impact of other human activities, and their possible escape should not have an impact where they are part of the native fauna. There is, however, a potential for genetic pollution if local populations are mixed with populations of the same species from different basins. Of greater concern, exotic (non-native) species are also stocked and they may have an impact if they escape, especially if they reproduce and are predators (for example, the giant *Arapaima gigas*, and large South American cichlids of the genus *Cichla*). Any exotic species stocked in farms is likely to escape at some point, especially during floods. Most such farms in the Indo-Burma region are around Bangkok, Thailand, and in Vietnam. Most of the farms around Bangkok were flooded in 2011 with many fishes escaping into the wild (as did crocodiles from crocodile farms).

3.5 Conservation actions and recommendations

The survival of most fish species depends primarily on the continued maintenance of their natural habitats, especially stream morphology (bed characters, shape, heterogeneity, continuity), water quality (chemistry, temperature), hydrological conditions (current, sediment transport) and protection of the surroundings (riparian vegetation, forest, catchment). Conservation measures require the political will of the national and regional authorities and the participation of local people where possible.

3.5.1 Dams and hydropower

With the ever increasing demand for electricity, sparked by the increasing non-industrial consumption in Thailand and Vietnam (consumption peaks are moving from work days to week-ends), and with East and Southeast Asian countries increasingly becoming the source of manufactured goods consumed world-wide, it seems unlikely that concerns about biodiversity conservation alone could block the construction of many (if any) large hydro-power projects. Commonly, to affect such projects, the concerned biodiversity must be financially valuable or symbolically important for humans; to date, it seems that only commercial fisheries are likely to be valuated and receive significant attention (see, for example, Baird, 2009, 2011). Some funding agencies now pay attention to biodiversity values, but only to a limited extent. For example, the World Bank has a policy that projects with which it is involved should not result in biodiversity loss (that is, they should not result in the global extinction of a species) or in significant conversion or degradation of critical natural habitats (see Kottelat & Whitten, 1996). In reality, many such projects do entail such losses and local extirpation of species, and the policies may be implemented with much leniency.

Batteries of pico-hydro generators on the upper Nam Ou at Gnot Ou, Laos. © Maurice Kottelat

Because of their huge impact on river morphology and ecosystems, hydropower projects must include critical and competent pre-construction studies, explicitly addressing aquatic biodiversity and clearly distinguishing it from fisheries. These studies should not be restricted to a single season, but include at least two annual cycles. The impacts during construction should be included in the assessment. The period between the end of construction and start of commercial operation is often ignored although it may have dramatic impacts; technical tests of dam resistance, tunnels, power houses and canals are accompanied by dramatic fluctuations in the water discharge from zero flow to maximum flow within a short time, which may annihilate mitigation measures. Impacts of maintenance work must also be taken into consideration.

In cases where water is diverted to other rivers, or where water is removed and later returned to the same river, the minimum flow proposed by operators has so far never been sufficient to truly maintain biodiversity and functioning aquatic ecosystems. Downriver flows need enough water in the dry season for fish not only to survive, but to be physiologically fit for reproduction. Engineering measures such as locally narrowing the river bed to increase current and turbulence in stretches that were previously rapids have never been implemented and could be worth testing. Artificial rapids have never been envisioned as a mitigation measure to compensate for the loss of habitat for species specialised for that habitat. Artificial rapids are technically feasible, at least at a small to medium scale, and have, for example, already been constructed for kayaking on the effluents of nuclear power plants or in amusement parks, and for sporting competitions. Such techniques should be employed as part of the mitigation of the impacts of the dams producing the electricity to run these parks or events.

In the majority of hydropower projects rapids habitats are certain to disappear, or be severely affected. While measures to mitigate the impact of hydropower dams on better known, charismatic species such as birds and mammals and their habitats, are often attempted, little attention is paid to aquatic species directly dependent upon the condemned rapids habitats. The reservoirs created by dams are often presented as being beneficial to the conservation of terrestrial organisms, often through providing protected status to the basin, but with the main objective being a reduction in erosion and subsequent siltation, which would of course negatively impact financial operation of the dam itself. No study has yet compared the loss of aquatic biodiversity with that of terrestrial biodiversity, such that an informed decision might be made as to the best mitigations measures to put in place. Without such studies how do we weigh up the loss of aquatic versus terrestrial biodiversity when planning the appropriate and "best value" mitigation measures to put in place? For example, is the creation of one more wetland for the threatened white-wing duck an ethically acceptable compensation for the global loss of habitat and almost guaranteed extinction of a number of endemic species of fishes?

EIAs should not be viewed as mere procedure and their recommendations must be taken into account. There must be follow-up after EIAs are completed and the legal requirements of conducting them must be fulfilled. In the Mekong region the recommendations on aquatic biodiversity in EIAs related to hydropower dams are commonly ignored, or at best, addressed in partial and incomplete ways.

Environmental monitoring should be conducted during and after completion of dams by staff or external experts with relevant training. Ideally this should be conducted by independent experts or auditors mandated by an independent authority, and conservation bodies or non-government organisations (NGOs) should be permitted to enter impacted areas and to conduct their own studies. This is of course difficult to implement in countries where the independence of such authorities is structurally impossible, or where criticism of projects exposes one to political, monetary, or physical retaliation, but efforts should be made to improve this situation. The results of EIAs and of monitoring should be made public so that preliminary surveys and studies can be evaluated. Each hydropower project is effectively a large-scale ecological experiment, so the results of these experiments need to be disclosed in order to learn their lessons and avoid repeating errors.

Monitoring needs to focus on aquatic biodiversity and not only on biomass and productivity – the currency for measuring fish biodiversity is species not kilograms, dollars or catch per unit of ef ort. Biodiversity surveys should therefore be conducted by fish biodiversity experts and should include all fish species present. Surveys conducted by fisheries experts are unlikely to provide adequate, or correct, information as required for an effective EIA and for long-term monitoring. Voucher specimens should be kept for future examination.

Reservoirs are usually viewed as ideal new freshwater habitats and are commonly thought suitable for establishing new fisheries or aquaculture, especially since the first years after inundation may support high productivity. As these reservoirs are often established within biodiversity protection areas the concession agreements should include clauses specifying that freshwater species not previously known in the area will not be introduced. Experience shows that such clauses may be respected by those in charge of biodiversity, but that they are frequently ignored by individuals in charge of fisheries and that proposals or attempts to introduce, or translocate, species are made even before completion of the project.

3.5.2 Synergy of threats

Commonly, concessions for a range of activities impacting a site are granted by different authorities, without consultation and without consideration of the cumulative impacts of these varied activities on the site and for mitigation measures taken by or imposed on them. For example, a concession for a hydroelectric company may be granted in the same area as a logging concession and concessions for mining activities or industrial plantations, or two hydropower concessions may be granted on the same river. In these situations the EIA for one activity may conclude that a species is not globally threatened because it is present in another area, which is nullified if a second project is simultaneously granted a similar concession in that other area. It is therefore important that EIAs and subsequent mitigation measures take full account of all other activities impacting, or potentially impacting, the site, or species present.

3.5.3 Introductions and invasive species

Introduced and invasive species are not restricted to fish. Crustaceans, molluscs, plants and their parasites may also be invasive. Introductions of species should be controlled and subject to prior impact analysis and government authorisation, and should follow international guidelines, minimally those established by international agencies (ICES/EIFAC Code, Turner, 1988; see, for example, Coates 1995, Costa-Pierce & Soemarwoto 1990). Large and predatory species should not be introduced. Introduced species already present in the region should not be stocked in areas where they are not yet present. The decision to introduce species must not be in the hands of commercial companies but controlled by government or international agencies. This also applies to species imported solely for aquaculture. All cultivated fish species will eventually escape and we know of no case of successful eradication of an introduced and established fish species. Invasive species should be controlled and, to do so effectively, research on biological control is needed. When caught, invasive species should never be returned to the water.

3.5.4 Protected areas

The protection of key habitats in rivers, such as rapids and deep-water pools during the dry season, is rarely implemented but can be effective (Baird 2006; Baird and Flaherty 2005). See Box 3.4.

The protection of fish habitats is usually easier in headwaters, especially those in protected areas. Although the diversity in the headwaters is relatively low, a large portion of the species may be endemic. The protection of large areas in the lowlands where the

Releasing an Endangered Striped Catfish (*Pangasianodon hypophthalmus*) into the Tonlé Sap as part of a research programme on species migratory behaviour. © Zeb Hogan

diversity is higher is more difficult, especially because the impacts of fisheries and agriculture are high and the human population is dense. In areas where rice is the main crop, natural or ancient ponds and swamps are becoming rare and should be protected.

Fish diversity in protected areas must be valued as a conservation target in it's own right and should not, as is often the case, be viewed simply as food for water birds or as compensation for losses in local income. A decline in native fish populations should not be compensated for simply through stocking or culture of non-local species. In these cases efforts should be made to enhance the original native fish populations and habitats.

3.5.5 Species specific conservation programmes

Species specific conservation programmes may be justified but some kind of triage is needed to distinguish between programmes that would be nice to implement and those that are most likely to succeed. For example, conservation programmes based on protection of currently pristine habitats for the smallest species are most likely to succeed but could be difficult to justify politically or economically. Some highly localised species can, however, be the target of species-specific programmes, for example cave fishes. On the other hand quite significant resources have been invested in programmes to conserve large, charismatic species, but it is not yet known whether they will have real, lasting positive results for the species itself (for example, *Pangasianodon gigas*). In another example, construction of the Sambor Dam on the mainstream Mekong in Cambodia is being partially prevented due to the presence of the Irrawaddy dolphins (*Orcaella brevirostris*).

3.5.6 Education and community engagement

Local communities should be involved in the conservation of fishes and their habitats, and in the design of protection and management measures. Information, such as summaries of scientific studies, EIAs etc, should be translated into local languages and made widely available. Identification materials should be produced in local languages.

3.5.7 Implementation of domestic and international legislation

Existing legislation and international agreements to protect aquatic habitats, biodiversity and threatened species should be implemented.

3.5.8 Research and training

Training in fish ecology should be a priority. There is a desperate lack of basic information on autoecology: habitat requirements, feeding and reproductive modes, migration patterns, species communities. Descriptive ecology may not be fashionable, but it is important. The ecology of many large-size species has already been the object of large scale studies, several organised by the Mekong River Commission. There is, however, an urgent

More field surveys are required to fill significant information gaps but access to remote field sites, such as for this survey in a waterfall near Gnot Ou, upper Nam Ou drainage, Laos, is often a challenge. © Maurice Kottelat

need for similar studies of smaller species, especially since they represent the majority of the narrow endemic species of high biodiversity value.

There are great gaps in our documentation of the fish diversity of the Indo-Burma region and field surveys are needed to fill these gaps and to map with some accuracy the distribution of the known species. Unfortunately, while the basics of surveying can be trained, the most important tool, the explorer instinct, is needed and this is innate and no scientific education can train for it. The priority then is to ensure that those demonstrating this ability to conduct surveys be given opportunities to use that skill.

Although primary, descriptive taxonomic research is needed, the training of taxonomists is not a priority. One serious limitation to the training of taxonomists is that it takes years to produce a taxonomist, and a good taxonomist needs to have the ability to distinguish between normal and unusual patterns of variation. Some of this can be gained by training, but understanding comes only after years of practice. Most important: taxonomists need to be employed to do taxonomy (Carvalho *et al.* 2007); the corollary is also true: taxonomic work should be done by taxonomists. There is, however, a caveat. The kinds of taxonomic research needed for biodiversity documentation, management and conservation are not always compatible with the expectations of an academic career. In the current research landscape, geographically targeted research does not receive adequate recognition. Few researchers now study a flora or a fauna, but rather specialize in a particular group of organisms within a narrow taxonomic range (for example, family, genus, etc.).

More importantly in the context of biodiversity conservation is the urgent need to train specialists in 'secondary' taxonomy. We need scientists able to: 1) transform the output of primary taxonomic research into a usable taxonomy; 2) train others in identification, and; 3) write local identification tools (including their translation into local languages) and making identification of species possible for researchers in a variety of disciplines. Use of the correct species names is the most basic form of experimental control.

Finally, primary research should be facilitated, starting with the removal of "red tape". Research should be subjected to timely delivery of usable results, for example, for management or for the work of secondary taxonomy. Studies of direct interest to the local people should be translated into local languages and distributed freely. The results of too many studies are never made available, and are therefore never used to benefit conservation.

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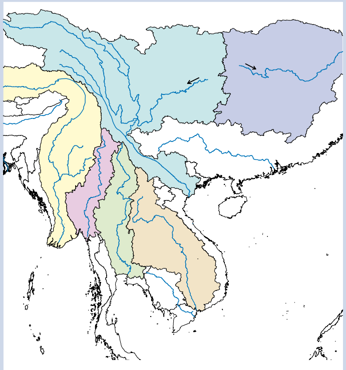
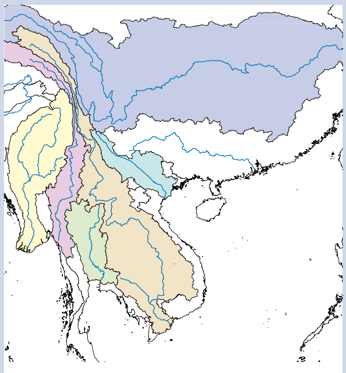
Box 3.1 Evolution of the river network in Southeast Asia

Walter J. Rainboth

The fish fauna of the Indo-Burma region is shaped by the geological history of its rivers. The Yangtze, Mekong and Salween, among the most important rivers of Asia, changed their course, at times were connected or disconnected, or part of them changed direction as the Himalayan range was rising. The following is summarized from Rainboth (1996, 2012).



Past river positions.



Present river positions.

Tectonic processes that modified the river basins of Southeast Asia extend well beyond the Indo-Burma region. The land surface of the Indochinese Peninsula and Myanmar has its origins in the closing of the Palaeo-Tethys (an ancient ocean). Southeast Asia represents remnants of ocean basins including various landmasses. As they increased size, these terrains developed their own drainage systems, which remain on them today.

When India collided with Eurasia, it deformed the land that had preceded it. Prior to uplift the Salween and Mekong flowed across a low relief landscape. As the Salween and Mekong began to rise in elevation, the rivers gained strength. This process of gradual uplift affects different eastern Himalayan areas differently. Along the southern margin of Eurasia, the recently attached areas have faults and suture zones which retain the capability of moving to relieve stress. These have been active in the Indo-Burma region. Much of the change in river basins affected the ancient Red River, which was formerly one of the great rivers of the world.

The most unusual physiographic feature of the region today is the close proximity of three deep, narrow, parallel gorges of three major rivers of Asia, the Yangtze, Mekong and Salween running over a reach of some 300 km and in places being separated by as little as 20 km. In the past, all of these river courses were part of the great paleo-Red River that may have included major reaches of today's middle and upper Yangtze, Mekong, Salween, Tsangpo and Ayeyarwaddy. The Tsangpo was captured by the Brahmaputra. The paleo-Tsangpo almost certainly was connected to the Ayeyarwaddy, but may also have been part of the paleo-Red River system for a period of time.

The first certain change in the paleo-Red River was the capture of the middle Yangtze as western Sichuan rose and tilted to the east, causing a reversal of flow in the middle Yangtze as it joined the lower Yangtze near today's Three Gorges Dam. The upper Yangtze was still connected to paleo-Red River after the capture of the Middle Yangtze took its flow eastward. Eventually the paleo-Red River lost the upper Yangtze watershed to the growing middle Yangtze, and the Mekong captured its headwaters from the paleo-Red River. The Mekong ultimately lost its western-most major branch to the Salween as the rivers formed their modern basins. However, the sequence of events after the flow reversal of the middle Yangtze is unclear.

The uplift of Tibetan Plateau margins in the north followed by uplift in the south while India forced its way into Eurasia caused the extrusion of the Indochinese Peninsula by ~1,000 km, while the peninsula rotated clockwise. In the early Pliocene (5 Ma [million years ago]), the origins of the Yangtze, Mekong and Salween rivers flowed across a gently undulating surface of an average elevation of ~1,000 m. By the beginning of the Pleistocene (2.5 Ma) the average elevation of the plateau was ~2,000 m. By the middle Pleistocene (1.5 Ma) the average elevation was ~3,000 m, and the climate was becoming markedly drier. By the late Pleistocene the average elevation was ~4,000 m, with landlocked basins becoming markedly salty. The uplift continued through the Holocene, which began 12,000 yrs ago, reaching an average altitude of ~4,500 m with a 300–700 m rise during the last 10,000 years. The rise in elevation has been the major cause of the increased rate of gorge incision in the Salween, Mekong and Yangtze.

It is thought that the Mekong did flow down through today's Chao Phraya until the Quaternary (2.5 Ma) and this almost certainly included rivers such as the Nam Tha in northern Laos. Much of the topography of northern Laos is due to earth movements from the late Pliocene through the Pleistocene. Rapid elevation of western parts of northern Thailand and Laos directed the Mekong to the east. The Khorat Plateau Basin of the northeast Thailand had a gentle slope away from the Annamitic mountains throughout the Mesozoic and most of the Cenozoic. During the Pleistocene it developed a slight incline to the east.

Downstream in Cambodia, the Mekong originally took a path to the south that formed a nearly straight line directly to the sea. However, during the Pleistocene extensive volcanism in the area of southeast Cambodia and adjoining areas of Viet Nam altered the river's course, deflecting it towards the Tonlé Sap which it joined and produced the river with multiple channels we see today. Some of the basalt outcrops are extensive and high.

Southeast Asia has an extraordinary feature in the extensive continental shelf that becomes exposed at regular intervals during sea-level retreat in glacial periods. This allows fish species from the lower courses of their watersheds to expand their ranges onto rivers passing over temporarily exposed continental shelf. Extended river basins on the Sunda Shelf can combine and allow fishes to expand their ranges to rivers that appear separate today.

The Mekong (before it flowed to the Tonlé Sap) would have passed directly into the South China Sea without joining any other rivers. In the past, the Tonlé Sap took a southwest path towards the Gulf of Thailand rather than the South China Sea. By flowing into the area that becomes the Gulf of Thailand during high-water periods, it would have come into contact with the extended Chao Phrya and rivers from the eastern coast of the Malay Peninsula.

Box 3.2 Inlé Lake

Sven O. Kullander

Inlé Lake near Taunggyi in eastern Myanmar is a warm polymictic lake about 22 km long and 6 km wide, and located at ca 870 m elevation in a limestone karst area, part of the Shan Plateau. It is only about 4 (dry season) to 7 (monsoon season) m deep, and the bottom is soft and largely overgrown with luxuriant vegetation. It is effectively a closed basin within the Salween watershed, but draining to the Balu River, a tributary to the Salween, intercepted by the Mobye Dam and hydroelectric power plants before reaching the Salween. The outlet has been reported to be initially endorheic, but is now superficial, probably as a consequence of the high water level of the dam. The tributaries are relatively few and to some extent intermittent. Inlé has crystal clear, alkaline (pH 7.8–8) water and a wide marginal belt of floating vegetation on which locals traditionally grow vegetables (Akaishi et al. 2006). The lake used to be fished mainly for the local carp *Cyprinus intha* which traditionally is captured with a special device consisting of a conical frame holding a gill net. Carp fishermen forage over the lake from canoes, standing at the prow and rowing with a long paddle manoeuvred with one foot and supported against the hip. The fisherman locates the fish by sight and places the frame over the fish, which is chased into the gill-net with a spear. Currently, however, monofilament gill nets are widely employed on the lake. Small fish are generally taken in traps set in the vegetation, or with a triangular push net.

Seventeen species of fish are endemic to Inlé Lake, its tributaries and its exit, viz., *Cyprinus intha* (EN), *Neolissochilus nigrovittatus* (DD), *Gymnostomus horai* (EN), *Physoschistura brunneana* (NT), *Physoschistura shanensis* (NT), *Yunnanilus brevis* (VU), *Sawbwa resplendens* (EN), *Microrasbora rubescens* (EN), *Danio erythromicron* (EN), *Devario auropurpureus* (EN), *Poropuntius schanicus* (DD), *Puntius compressiformis* (CR), *Garra gravelyi* (NT), *Silurus burmanensis* (DD), *Channa harcourtbutleri* (NT), *Macrognathus caudiocellatus* (DD), and *Mastacembelus oatesii* (EN). *Sawbwa resplendens*, a naked, minute cyprinid fish, the only member of its genus, is of uncertain relationships. *Silurus burmanensis*, *Cyprinus intha* and *Yunnanilus brevis* represent groups shared with the Yunnan Plateau, having their closest relatives in the lakes and rivers of Yunnan, within the watersheds of the Mekong, Yangtze and Pearl rivers. The first two genera also have a wide Palaearctic distribution. The relationships of *Poropuntius compressiformis* are uncertain and the species has a very provisional generic allocation here. *Microrasbora rubescens* or a very similar species is found also in small streams in the nearby He Ho plains, along with *Danio margaritatus,* the closest relative of *Danio erythromicron.* Remaining endemic species represent components of the Myanmar or Indo-Burmese fish fauna at large. In addition to those, 15 widespread species are reported from the lake. Of those, five were recorded after 1916 and are potentially introduced.

Inlé Lake is under considerable environmental stress from expanding marginal agriculture, leading to pollution, siltation and eutrophication, and rapidly diminishing open water surface. Pesticides are routinely used. Water hyacinths (*Eichhornia crassipes*) are expanding and further reducing open water. Overfishing is likely with the more recent use of monofilament nets and motorized boats. Several reports point to reduced fishery resources, but no precise numbers are available. At least two exotic aquaculture species have been reported from the lake, viz. *Labeo rohita* and *Ctenopharyngodon idella* but no specific adverse effects from these are known. Although regular inventories are not made, observations suggest that one major endemic predatory species, *Puntius compressiformis*, is no longer present. On the whole, the Inlé Lake habitat is under severe human pressure, affecting human health, a distinctive local culture, a unique wetland landscape, a unique animal and plant community, unique genetic resources, and a highly valuable national and international tourism resource. It is listed as a Vulnerable freshwater ecoregion by WWF.

Inlé Lake fisherman with traditional conical fishing net. © Shannon Holman

Box 3.3 Interdependent conservation of bitterlings and mussels

Maurice Kottelat

Bitterlings are a subfamily (*Acheilognathinae*) within the large freshwater family *Cyprinidae*. They are native to eastern Europe and East Asia. Bitterlings are most diverse in Japan and the Yangtze and Pearl River drainages, China. Several species are known from the Red River drainage and at east three are known from the Mekong drainage. Bitterlings have a distinct mode of reproduction. The female deposits the eggs in mussels of the family Unionidae through a tube-like ovipositor that she introduces in the exhalant syphon of the mussel while the male releases sperm at the opening of the inhalant syphon. The fertilized eggs are attached to the gills of the mussel; after hatching, the fry may remain up to 30 days in the mussel (depending on species). In turn, the larvae of the mussels (called glochidia) are obligate ectoparasites of fish. Bitterlings seem to be parasites of the mussels, whose growth they reduce while they avoid infection by glochidia. Several species of bitterlings may co-occur at a single site, and several species of mussels may co-occur. Individual species of bitterlings prefer or may uniquely use some mussel species and ignore others. The reverse is true for mussels, whose glochidia may prefer certain fish species. Some species of mussels are able to reject the eggs of some species of bitterling but not others. As a result, the survival of a species of bitterling is dependent upon the survival of one or a few specific host mussels. Their conservation must therefore be managed together. The survival of a species of mussel is dependant upon the survival of one or several specific host fishes, possibly other than the bitterling. The bitterlings may well be able to survive impacts to its habitat, but the mussels maybe more sensitive, as may the host of its glochidia. The fish may move but the mussel may not. Sedimentation is a threat to mussels, as is an anoxic zone at the bottom of a reservoir, or a dried riverbed downstream of a dam. Even if some of the mussel population is retained, mussels are known to have an extremely long lifespan (up to a recorded 120 years); some mussel species are known only from a few localized populations of aging individuals, apparently no longer able to reproduce - their extinction therefore seems certain. To manage a bitterling species for the medium or long term thus requires the identification of the host mussel(s) and of the host(s) of the mussel's glochidia, and the long term management of fertile populations of all.

Rhodeus laoensis (male and female with ovipositor) is endemic to the upper Nam Kading drainage in Laos. It is one of the few bitterlings known outside East Asia. Its mussel host is not yet known for certain but probably is Pseudodon vondembuschianus, a species widespread in Southeast Asia. Within the range of the bitterling, the mussel habitat has been much impacted by hydropower development. © Maurice Kottelat

Box 3.4 Deep-water fish sanctuaries in the Mekong River Basin

Ian G. Baird

Most governments in the Mekong region have adopted legal measures that limit or prohibit fishing during the rainy season, which is the main season when Mekong fish species spawn. Most fishermen in the region believe, however, that due to the dramatic differences in hydrological conditions between the high-water rainy season and low-water dry season, many fish species are particularly vulnerable to fishing pressure in the dry season, not the wet season when high waters frequently prevent fishing or make species less vulnerable to fishing pressures. In the dry season fish, especially large brood stock, tend to concentrate themselves in deeper waters. In large rivers, such as the mainstream Mekong, these pools can be over 50 metres deep in the dry season. But in small streams, even pools one metre deep can be crucial, especially if neighbouring areas almost entirely dry out at the height of the dry season. Fishermen tend to focus their activities in deep water when water levels are low. Many farmers also have more time for fishing during the dry season when farming is reduced, thus increasing fishing pressure. Local people have long implemented measures to protect deep-water areas during the dry season. Historically, cultural protections have often involved the adoption of taboos that have prevented or limited fishing in deep-water areas, or the fear of spirits believed to reside in these areas have sometimes prevented fishing, thus effectively leading to fish protection. This remains the case in some areas, although some cultural protections have become less effective due to modern influences (Baird 2006).

Since the early 1990s in particular, many villages in Laos and other countries in the region, often with non-government organization (NGO) and government encouragement or support, have increasingly established deep-water fish sanctuaries or Fish Conservation Zones specifically to reduce fishing pressure on a variety of large and medium-sized fish species during the dry season (Baird 2006; Baird and Flaherty 2005). Research conducted in southern Laos has indicated that a large number of species have benefited from this protection during the low-water season. Some deep-water fish sanctuaries are also believed to have been of benefit to migratory species passing through areas at different times of the year (Baird 2006; Baird and Flaherty 2005). While deep-water fish sanctuaries should certainly not be considered to be a panacea for all the complex fishing-related impacts affecting fish species, they do represent one potentially important measure for protecting fish species from overfishing (Baird 2006). In particular, some species that spawn during the dry season, such as the long-lived croaker *Boesemania microlepis*, have benefited greatly when their dry season spawning grounds in the mainstream Mekong River have been protected through the establishment of fish sanctuaries (Baird *et al.* 2001).

In the future, it would be wise to establish various types of fish sanctuaries to protect other key fish habitats in particular seasons, such as important rapids and critical wetlands. Decisions to establish fish sanctuaries should consider both ecological and social factors. Already some different types of aquatic habitats have been protected in southern Laos and other parts of the region (Baird 2006; Baird and Flaherty 2005), but much more could be done to ensure that important aquatic habitats vulnerable to human exploitation are effectively protected, in order to protect biodiversity, and sources of food and income for humans.

Deep water pools in the Mekong are critical for many freshwater species especially during the dry season. The Anlong Chheutal deep pool on Lao PDR-Cambodia border, shown here, is an important location for the threatened Irrawady Dolphin (*Orcaella brevirostris*). © William Darwall

Laos Xe Kong drainage Taad Fek waterfall on Xe Nam Noy River. © Maurice Kottelat

Chapter 4. The status and distribution of freshwater molluscs of the Indo-Burma region

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4.1 Biogeography of the freshwater environments in the Indo-Burma Hotspot

The Indo-Burma region is one of several biodiversity hotspots for conservation priorities as defined by the exceptional concentrations of endemic species and exceptional loss of habitat (Myers *et al.* 2000). The region covered here contains fourteen eco-regions according to the global map of biogeographic regionalization of Earth's freshwater systems (Abell *et al.* 2008; see (Figure 2.3, Chapter 2). These ecoregions were delineated based on the distributions and compositions of freshwater fish fauna and by reference to major ecological and evolutionary patterns, including borders of major river drainages.

Only a few larger natural lakes exist in the Indo-Burma region, with only Inlé lake being sufficiently large, deep or geologically old enough to support a significantly diverse and endemic freshwater mollusc fauna. The largest lakes are the Tonlé Sap in Cambodia and Inlé Lake in Myanmar. Both lakes vary dramatically in size according to season and have a maximum surface area of about 16,000 km^2. They are comparatively shallow, with only a few meters of average depth, dominated by macrophytes, geologically young and suffer anthropogenic pressures (for example, Akaishi *et al.* 2006, Ohtaka *et al.* 2011). Lake Inlé is an exorheic lake in the Shweyaung Rift valley, central Myanmar, about 22 km long and 6 km wide, with 17 known fish species endemic to the lake and its tributaries and a high diversity of gastropods. Its watershed boasts a diverse snail fauna consisting of 44 nominal species (30 thereof supposedly endemic) mainly from the families Viviparidae, Pachychilidae and Bithyniidae and four bivalves from the families Unionidae, Cyrenidae and Sphaeriidae (Annandale 1918, Annandale and Rao 1925, Strong *et al.* 2008). However, no recent comprehensive study of the molluscan fauna is available and thus the distribution and the taxonomic and conservation status of many of these taxa has remained unclear. By contrast, the Tonlé Sap harbours no endemic species of freshwater molluscs. In addition, a number of artificial lakes created by the construction of dams and reservoirs are scattered across the region. Most abundant are smaller habitats of stagnant and slow flowing freshwater habitats, such as rice paddies, irrigation canals, reservoirs and lower sections of larger rivers. Snail and bivalve species that are well-adapted to the characteristically low levels of oxygenation, high sediment loads, soft substrates, large fluctuations in water levels, partly ephemeral nature, and presence of macrophytes, such as many basommatophorans, thiarids, viviparids and ampullariids, are usually widely distributed across the region and found in large abundances in all sorts of habitats.

Lotic systems, such as rivers and creeks, account for the largest and most ecologically diverse freshwater ecosystems in the Indo-Burma region. Indo-Burma's rivers belong to a number of major drainage systems; most importantly the Sittaung, the Ayeyarwaddy, the Salween, the Chao Praya, the Mekong, and the Red River (Sông Hồng) in northern Viet Nam.

The drainage evolution of all these major river systems has significantly been shaped by two principal geological processes during the Cenozoic era: Tectonic uplift of the Tibetan Plateau over the last 40 million years or so and sea level fluctuations during the mid and late Tertiary (Clark *et al.* 2005, Köhler *et al.* 2010b, Peng *et al.* 2006). The beds of major rivers formed between 10 and 20 million years ago (mya) by cutting into the relict landscape (Clark *et al.* 2005). During younger stages of the Cenozoic, several river systems underwent dramatic changes due to tectonic processes, such as the uplift of areas and lava flows (Gregory 1925, Hutchinson 1989, Rainboth 1996). For example, the Ayeyarwaddy, Salween and Mekong drained into the bed of the Chao Praya until around 1.5 mya when volcanic activities separated the Ayeyarwaddy and Salween rivers from this system. The midstream of the Mekong had also become isolated from the Salween River and ran through the bed of the Ping River (Chao Praya drainage) until around 1.5 mya. Late Cenozoic faulting diverted the Mekong further eastwards along its present course towards Vientiane until, later in the mid-Pleistocene (c.1 mya), the Mekong once again drained into the Chao Praya, this time via the valley of the Loei and Pa Sak Rivers. Eventually, it changed its course again around 50,000 years ago towards the east where it has undergone further course changes. In addition, the Chao Praya lost its headwaters to the growing Mekong during the middle to upper Pleistocene. Since then, the Mekong changed its river bed repeatedly to successively more easterly directions. Further details on the evolution of the river network are given in Box 3.1.

While the details and exact timing of the geological history of the Mekong drainage are not fully understood (Gupta 2008), it is clear that the courses of many smaller rivers were similarly affected by tectonic processes. Some of them even reversed their original direction of flow due to uplifts that affected their upper or mid-streams, such as the Loei River that was once part of the southward-flowing proto-Mekong but today flows in a northward direction, or the Mun River that once drained in a westerly direction into the Chao Praya until it reversed its course towards the east due to the sinking of the Khorat Plateau during the mid-Pleistocene (Hutchinson 1989). These reconfigurations of drainage systems and river captures have occurred in the whole of Indo-Burma and evidence has emerged that they have influenced the composition of the freshwater biota, including snails and bivalves, by mediating contact or isolation of river faunas, which may have led to lineage differentiation or hybridisation on smaller geographic scales (Attwood and Johnston 2001, Köhler and Deein 2010, Köhler *et al.* 2010b).

Throughout the Tertiary and Quaternary periods, sea level fluctuations have constantly changed coastlines due to the marine incursions of vast inland areas. For instance, sea levels were apparently higher than today during the Miocene (+150–220 m, at 24–13 mya) and Pliocene (+100 m, at 5.5–4.5 mya) (Woodruff 2003), while they were considerably lower during the Pleistocene (up to 120 m below today's level) (Martinson *et al.* 1987). Elevated sea levels of 100 m or more would have resulted in a northward extension of the Gulf of Siam and the flooding of large parts of the Chao Praya river basin in central Thailand, as well as other low-lying coastal areas in Southeast Asia. These marine incursions would have wiped out the freshwater mollusc fauna of the lower floodplain river channels at the time.

However, the current river system configuration has been in place for several million years in all major drainage systems of Southeast Asia, allowing the evolution of a large number of endemic molluscan species. The development of catchment faunas in parallel with drainage-specific endemic species has generated an overall highly diverse and endemic fauna of freshwater snails in the Indo-Burma region. Amongst all rivers of the region, the lower Mekong stands out by supporting about 140 species mainly from the families Pomatiopsidae, Stenothyridae, Buccinidae and Marginellidae, of which 111 species are endemic. With such a large number of endemic species, the Mekong ranks amongst the global hotspots of freshwater snail diversity (Groombridge and Jenkins 1998, Bogan 2008, Strong *et al.* 2008).

Various molluscan species treated herein inhabit brackish water habitats, such as mudflats and mangroves in river estuaries or along shallow coastlines. These brackish water molluscs are not very diverse because of the unfavourable combination of heavy sediment load, acidic and anoxic soil, constantly varying salinity and inundation, and intense predation (Reid *et al.* 2008). However, particular families such as Potamididae, Neritidae and Iravadiidae have attained a close association with such intertidal habitats where some of them have radiated quite extensively (for example, Reid *et al.* 2008, Ozawa *et al.* 2009, Reid *et al.* 2010, 2012). The mangrove ecosystem has an ancient history. The earliest appearance of a modern mangrove genus, the palm *Nypa*, has been documented in the Late Cretaceous, and most genera of the Rhizophoraceae are known by the Early Eocene (Reid *et al*. 2008). By the Middle to Late Eocene most modern mangrove genera showed a worldwide tropical and subtropical distribution. Their once continuous distribution was disrupted by the closure of the Tethyan Seaways at the end of the Early Miocene, which initiated the vicariant separation of the Pacific and Atlantic mangrove-associated biota, including molluscs (Reid *et al.* 2008).

4.2 Overview of the freshwater molluscs of the Indo-Burma Hotspot

Freshwater molluscs (bivalves and gastropods) are found in a wide range of freshwater habitats, have varied life-history strategies and exhibit complex ecological interactions, all of which underscore their use as proxies for understanding our changing freshwater diversity. Freshwater molluscs fall into two main groups, the Bivalvia and the Gastropoda, with the latter dividing into two informal groups, the 'prosobranchs' and the 'pulmonates'. Ponder and Lindberg (1997) revised the higher phylogeny of Gastropoda, noting that 'Prosobranchia' could no longer be supported as a formal taxon designation, as it was polyphyletic. This view has been followed in the latest systematic treatment of the Gastropoda by Bouchet and Rocroi (2005). Currently there are two major clades, the Caenogastropoda and the Heterobranchia, along with smaller clades such as Neritimorpha. Within the informal group 'Pulmonata', similar problems have also been found (for example, Jörger *et al.* 2010), however most of the freshwater species lie in the Basommatophora, within the Eupulmonata. The Bivalvia, divided among nine families, are less numerous than the Gastropoda, with the 'pulmonates' containing a higher proportion of the widespread, more cosmopolitan species. Most research efforts in Asia in recent years have, however, concentrated on the freshwater unionid mussels and the gastropod Family Pachychilidae. However, we need to recognise that the tropical freshwater molluscs have not yet received the same level of attention as European and North American faunas, and that as taxonomic reviews continue – especially those utilising molecular systematics – the number of known species may well multiply, as has happened in studies of some genera already.

4.2.1 Freshwater Gastropods

The freshwater gastropod fauna of the Indo-Burma area comprises 325 currently known species belonging to 20 families.

The freshwater gastropod fauna is reasonably well known in large parts of the region, in particularly in Thailand. The first records of freshwater snails originate from colonial times in Myanmar (for example, Nevill 1877, 1885) as well as in Cambodia and Viet Nam (for example, Brot 1887, Dautzenberg and Fischer 1905, 1906, 1908, Morlet 1885, 1887, 1893). The fauna of Myanmar was summarized by Preston (1915) and more recently reviewed by Subba Rao (1989). In addition, the work of the Indian Zoological Survey in this area was included in works of Annandale (1918) and Prashad (1920, 1928).

More recent and comprehensive systematic treatments of mollusc fauna are available for Thailand (Brandt 1968, 1974), which list several hundred species for the country. No such overviews exist for the freshwater molluscs of Cambodia, Lao PDR, Viet Nam and Myanmar. In general our knowledge of the distribution, abundance and ecology of molluscs for most countries in the region remains limited.

However, some elements of mollusc fauna have been studied for particular geographical areas. The gastropod fauna of the Mekong is particularly well documented largely because certain species (for example, *Neotricula aperta*) act as intermediate hosts for economically important trematodes of humans and domestic animals (i.e., Mekong River schistosomiasis) (Brandt and Temcharoen 1971, Davis 1979, Davis *et al.* 1976, Hoagland and Davis 1979). Apart from these systematic works of 20th century authors, very few more recent taxonomic works are available and they usually cover single taxa and/or smaller areas (for example, Attwood *et al.* 2008, Đang and Ho 2007, Glaubrecht and Köhler 2004, Köhler 2008, Köhler and Glaubrecht 2006, Köhler *et al.* 2009, Liu *et al.* 2010).

4.2.2 Freshwater Bivalves

Early work on the descriptions of freshwater bivalves sent from southeast Asia by European explorers were described by naturalists including Lea, A. Morelet, Pfeiffer and Redfield, Rochebrune, Mabille, Prime and Brot. Lists of the freshwater fauna were compiled by Fischer (1891) and Fischer and Dautzenberg (1904). The work of the Indian Zoological Survey in this area was included in the works of Annandale (1918) and Prashad (1920, 1928). Higher classification of freshwater bivalves from southeastern Asia began with Lea (1836, 1838, 1852, 1870), was continued by Simpson (1900, 1914), and discussion of the fauna and descriptions of Asiatic unionids was initially monographed by Haas (1910–1920, 1924). The worldwide classification of freshwater bivalves continued with the work of Modell (1942, 1949, 1964) and more recently by Haas (1969a,b). An alternative classification was presented by Starobogatov (1970). Further refinements of the higher classification of bivalves and their relationships have been provided by Bieler *et al.* (2010) and Carter *et al.* (2011).

No recent overviews exist of the bivalve fauna of Cambodia, Lao PDR and Myanmar. However, the work of Brandt (1974) is based on fieldwork in Thailand, Myanmar, Lao PDR, Cambodia and west Malaysia. Fieldwork in the Mun River basin and lower Mekong River associated with water born diseases, including schistosomiasis, was carried out in the early 1970s (Heard 1974). The freshwater bivalve fauna of Myanmar was summarized by Preston (1915) and more recently reviewed by Subba Rao (1989). Nagachinta *et al.* (2005) documented the utilization of freshwater molluscs for food, jewellery and art work in Thailand and provided distribution maps for 15 unionids and three cyrenids. More recently, Jivaluk *et al.* (2007) provided an overview of the freshwater bivalve fauna of Thailand with colour pictures and a key to the 72 species recognized.

Early work on the freshwater bivalves of Viet Nam, included the description of new species and development of species lists, especially for the former Tonkin Province of north Viet Nam (Dautzenberg and Fischer 1905, 1907, 1908). Demange (1918) provided a list of land and freshwater molluscs of Indochina with information on species distributions and morphological characters. The freshwater bivalve fauna of Viet Nam was last monographed by Đang *et al.* (1980) but no maps were provided and limited species descriptions, with line drawings of the shells, were included.

The known freshwater bivalve fauna of the Indo-Burma area is comprised of 116 species in 38 genera belonging to ten families. Five families are each represented by a single species in freshwater (Arcidae, Cultelidae, Margaritiferidae, Pharidae and Solecurtidae). Two families contain the majority of the diversity; Cyrenidae (= Corbiculidae) with 20 species in two genera accounting for 17.4% of the species and 20.0% of the genera, and Unionidae with 79 species in 26 genera accounting for 68.1% of the species and 68.4% of the genera.

4.3 Knowledge gaps and taxonomic problems

The distributions and taxonomy of the molluscan fauna of the Indo-Burma region is poorly known and requires further study.

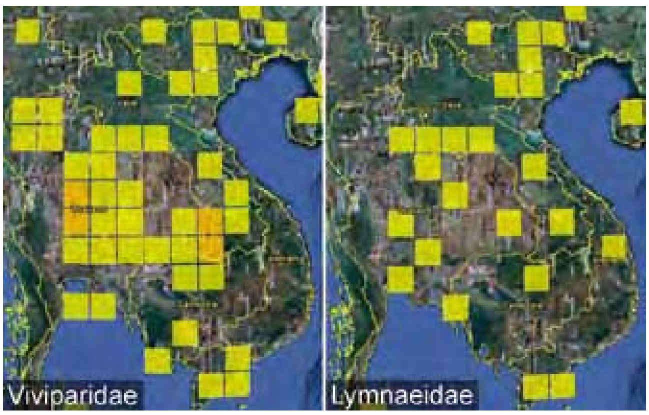
4.3.1 Freshwater Gastropods

Considerable gaps in the knowledge of gastropod fauna prevail, particularly in the more remote and less well studied regions of Myanmar, northern Lao PDR and, to some extent, in Viet Nam and Cambodia. While Brandt (1974) approximately doubled the number of species known from Thailand, similar comprehensive treatments are unavailable for Cambodia, Lao PDR, Myanmar and Viet Nam. As a result, the level of documentation of the freshwater snail fauna is patchy. Figure 4.1 exemplifies the extent of current knowledge gaps by displaying all records available in the international biodiversity database GBIF (www.gbif.org) for two of the most diverse and abundant snail families in the region, the Viviparidae and Lymnaeidae. This figure illustrates that the distributions of these two major gastropod groups are only patchily documented. Corresponding knowledge gaps exist for all other groups of freshwater gastropods in the region.

Available data records are predominantly based on digitised records from museum collections world-wide, which date back to the early collections undertaken in colonial times. The usefulness of these museum-based data to monitor faunal changes is limited by problems relating to unreliable or uncertain species identifications, imprecise locality information and historically outdated records. Even though these records represent only a fraction of all data available from scientific publications, including local species lists, it becomes apparent that distribution data in general are highly fragmented and incomplete.

Moreover, our current knowledge of many species, their distribution, ecology and taxonomy, is based on morphology-based works from the 19th and 20th century that reflect previous concepts of species delineation. More comprehensive, modern

Figure 4.1. Distribution data for two of the most diverse and abundant snail families in the Indo-Burma region, the Viviparidae and Lymnaeidae. (Source: GBIF www.gbif.org).



revisions employing more detailed morphological and/or molecular evidence to resolve taxon limits have remained scarce. Thus, even after almost 150 years of systematic work, we are far from having a comprehensive understanding of the diversity and ecology of the freshwater gastropod fauna in the Indo-Burma region.

Assessments of the conservation status of species have been hampered by the patchy distributional data as well as an incomplete understanding of their taxonomy. Many species names were introduced in late 19th and early 20th century – frequently based on identification of conchological characters, in some cases a few dry shells from one or few localities. The historic, predominantly shell-based taxonomy is particularly prone to errors due to misidentifications as the range of variation within species is still largely unknown. Recent studies have shown that due to such misidentifications, species of freshwater molluscs can be overlooked, as they are very similar in shell form to other species, and hence cryptic lineages may also exist, especially in regions with high endemicity. Conversely, some species have been named more than once by different authors.

The extent of the taxonomic confusion that results from such problems is highlighted by recent systematic revisions for various groups. Specifically amongst the freshwater gastropods in the Indo-Burma region, the Family Pachychilidae are the only group that has been comprehensively revised in modern taxonomic studies that employed a combination of morphological and molecular evidence (Köhler 2008, Köhler and Dames 2009, Köhler and Deein 2010, Köhler *et al.* 2010a, Köhler and Glaubrecht 2001, 2006, 2010; Köhler *et al.* 2009, Köhler *et al.* 2010b). In the previous taxonomic treatment, Brandt (1974) recognised 21 species or sub-species of pachychilids in Thailand. The recent studies have resulted in a changed taxonomic treatment of most of these species either with respect to their generic placement or the delimitation of species, such that, seven of these species were delimited differently while three species were recorded anew. Furthermore, eight new species from the Family Pachychilidae were described from parts of the Indo-Burma region not covered by Brandt (1974), demonstrating the level to which the region is under-recorded. Given that the Pachychilidae are represented by comparatively large and conspicuous animals, it is plausible to postulate that in other groups a similar or even higher proportion of species await taxonomic revision or discovery.

Brotia armata (LC), a species from the Family Pachychilidae from central Thailand. Typically, *Brotia* species are narrowly endemic having specific habitat requirements, making them particularly vulnerable to habitat loss or modification. © Andreas Helmenstein

Further confusion is caused by the arbitrary and inconsistent use of taxonomic names for snails that were identified by means of shell comparison only. While this practise is widely used for the compilation of local or regional species inventories or in ecological studies, such secondary literature records are notoriously unreliable in particular when species are known to be difficult to recognise by their shells or when they belong to taxonomically complicated groups.

4.3.2 Freshwater Bivalves

The identification of the freshwater bivalves of the Indo-Burma region has primarily been based on shell characters. Only recently has there been any work on the higher level relationships of some of the genera of this region using DNA sequence data (Bogan and Hoeh 2000, Graf and Cummings 2006, Hoeh *et al.* 2009, Whelan *et al.* 2011). The phylogenetic work on the relationships of species and genera is urgently needed for the unionid taxa. We have difficulties in assigning some species to the proper genus because of shell shape variation and convergence of shell characters. An example would be the confusion with the genera *Parreysia*, *Indonaia* and *Radiatula*. Some authors have considered these subgenera, genera and even synonyms.

The family Cyrenidae (formerly Corbiculidae; Bieler *et al.* 2010) contains the genus *Corbicula* which for Thailand alone has 28 recognized species and of these, five were introduced as new species (Brandt 1974). These species are differentiated on the basis of shell shape and degree of inflation. Electrophoretic analyses of representatives of 21 nominal species of *Corbicula* from Thailand across 24 allozyme loci proved to be identical and 20 Thai species were considered synonyms of *Corbicula fluminea* with another seven species considered possible synonyms (Kijviriya *et al.* 1991). Studies in Japan have documented some *Corbicula* species that are hermaphroditic and triploid (Komaru *et al.* 1997) or tetraploid in China (Qiu *et al.* 2001). Work on two species of *Corbicula* in Europe has found that there is hybridization between two different evolutionary lineages (Pfenninger *et al.* 2002, Pigneur *et al.* 2011). Evidence for two widely divergent clades within *Corbicula* has been detected, a freshwater and an estuarine clade. Taxa within *Corbicula* reproduce using diverse reproductive strategies (ranging from free–swimming larvae to incubation of larvae in gills) (Glaubrecht *et al.* 2006).

All of this evidence points to the problems of assessing what is a valid species within the genus *Corbicula* (see Glaubrecht *et al.* 2006). There appear to be several valid species but the conservation status of these taxa and the myriad of other named taxa must await a detailed phylogenetic analysis of both mitochondrial and nuclear DNA of all of the named taxa assigned to *Corbicula*.

4.4 Conservation status

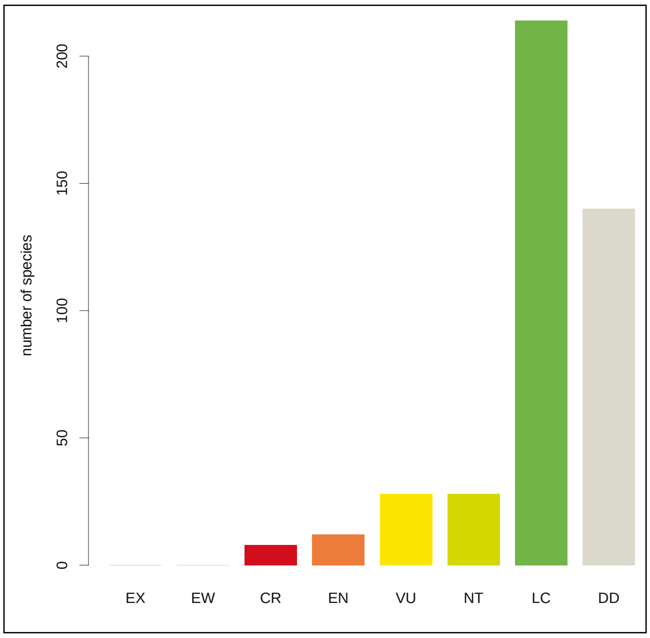
The summary presented here is based on the assessment, following application of the IUCN Red List Categories and Criteria (IUCN 2001), of 431 species of freshwater molluscs that we have identified as being present in the Indo-Burma Hotspot assessment region. This assessment includes 319 species of Gastropods and 112 species of Bivalves. Of the extant species for which sufficient data are available to assess the risk of extinction (one species, *Pila conica*, has not yet been assessed, and a further 25 species are awaiting review and have draft Red List assessments), 48 (16.6%) are assessed as threatened (Table 4.1, Figure 4.2).

Many of the gastropod species are poorly known, and much greater distributional data are required especially from the Mekong River system. However, given the level of threats through proposed major damming projects, assessments were made using the current data on distributions, so that a baseline conservation assessment is in place to allow an initial assessment of impact of threats to specific sites on these river systems.

Table 4.1 The number of species of freshwater molluscs under each IUCN Red List Category in the Indo-Burma region.

IUCN Red List Category	Number of species
Extinct	0
Extinct in the Wild	0
Citically Endangered	8
Endangered	12
Vulnerable	28
Near Threatened	28
Least Concern	214
Data Deficient	140
Total	**430**

Figure 4.2 The number of extant freshwater mollusc species for which sufficient data exist under each IUCN Red List Category in the Indo-Burma region.



Of the extant species for which sufficient data are available to assess the risk of extinction, nearly three-quarters are assessed as Least Concern (73.8%); many of these species have been reported over long stretches of river systems. Where there are three or four records over a long stretch of river, it was considered that the species may well exist in suitable habitat between these points, so the overall range took the species above the thresholds for qualification as threatened species.

There are an additional 140 species that are assessed as Data Deficient (Table 4.1) of which 94 are gastropods and 46 are bivalves, representing almost one-third of all known species in the region. Some of the DD species are known only from 19th or 20th century descriptions and have not been collected since, and further expert surveys across the region are required to determine the conservation status of these species, whilst other species have been considered DD due to taxonomic uncertainty. The level of Data Deficient species is somewhat higher than equivalent conservation assessment for freshwater molluscs in Europe (25%; Cuttelod *et al.* 2011) and Africa (18%; Darwall *et al.* 2011a).

4.4.1 Freshwater Gastropods

Of the 319 freshwater gastropods considered here to be present in the Indo-Burma region, 318 have been assessed according to the IUCN Red List Categories (Tables 4.2, 4.3; Figure 4.3). The majority of these species have been defined on conchological characters and the distribution of most species is not well known. Some of the species have not been recorded since they were first described over 100 years ago, the major reason for a species being assessed as Data Deficient.

The majority of the species assessed as threatened or Near Threatened are known to occur at fewer than five locations and these are potentially threatened by hydropower development. Some of the species listed as Near Threatened are known from very few sites and actually meet most of the criteria for listing as threatened species (i.e., range and number of locations), however at present the likely timing of the threat doesn't qualify the species for listing under the ten year limit rule hence, if a threat is established with likely impact within ten years, then these species would move straight to Threatened, in some cases to Critically Endangered or Endangered. For example, the waterfalls on the Mekong River near Khone Island (southern Lao PDR) are the location for the proposed Don Sahong dam which would have significant impacts on the flow regime of the river, and is likely to impact mollusc species that are found in rapids,

Table 4.2 The number of species of freshwater gastropods under each IUCN Red List Category in the Indo-Burma region.

IUCN Red List Category	Number of species
Extinct	0
Extinct in the Wild	0
Critically Endangered	2
Endangered	3
Vulnerable	27
Near Threatened	26
Least Concern	166
Data Deficient	94
Total	**318**

Figure 4.3 The number of extant freshwater gastropod species under each IUCN Red List Category in the Indo-Burma region

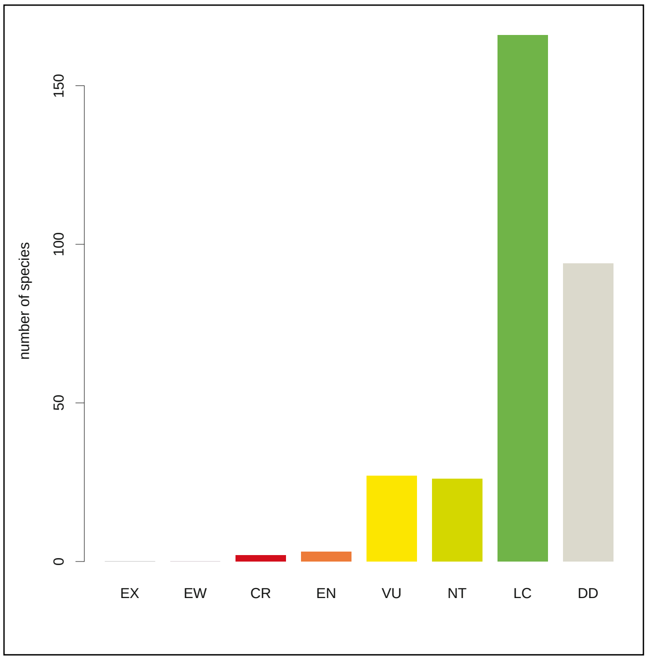


Table 4.3 The threatened freshwater gastropods of the Indo-Burma assessment region.

Family	Species	Category
VIVIPARIDAE	*Anulotaia forcarti*	EN
LYMNAEIDAE	*Lymnaea mimetica*	CR
PLANORBIDAE	*Gyraulus bakeri*	VU
BITHYNIIDAE	*Gabbia alticola*	CR
HYDROBIIDAE	*Hydrorissoia munensis*	VU
HYDROBIIDAE	*Paraprosothenia lynnei*	VU
LITTORINIDAE	*Cremnoconchus messageri*	EN
POMATIOPSIDAE	*Hubendickia pellucida*	VU
POMATIOPSIDAE	*Jullienia albaobscura*	VU
POMATIOPSIDAE	*Jullienia costata*	VU
POMATIOPSIDAE	*Jullienia flava*	VU
POMATIOPSIDAE	*Jullienia minima*	VU
POMATIOPSIDAE	*Jullienia prasongi*	VU
POMATIOPSIDAE	*Lacunopsis deiecta*	VU
POMATIOPSIDAE	*Lacunopsis globosa*	VU
POMATIOPSIDAE	*Lacunopsis minutarpiettei*	VU
POMATIOPSIDAE	*Lacunopsis munensis*	VU
POMATIOPSIDAE	*Pachydrobia bertini*	VU
POMATIOPSIDAE	*Pachydrobia levayi*	VU
POMATIOPSIDAE	*Pachydrobia zilchi*	VU
POMATIOPSIDAE	*Tricula conica*	VU
STENOTHYRIDAE	*Stenothyra decollata*	VU
STENOTHYRIDAE	*Stenothyra huaimoi*	EN
STENOTHYRIDAE	*Stenothyra laotiensis*	VU
PACHYCHILIDAE	*Brotia annamita*	VU
PACHYCHILIDAE	*Brotia citrina*	VU
PACHYCHILIDAE	*Brotia hoabinhensis*	VU
PACHYCHILIDAE	*Brotia laodelectata*	VU
PACHYCHILIDAE	*Brotia paludiformis*	VU
PACHYCHILIDAE	*Brotia solemiana*	VU
PACHYCHILIDAE	*Brotia subgloriosa*	VU
PACHYCHILIDAE	*Brotia wykoffi*	VU

such as *Lacunopis globosa*. Other species such as *Cremnoconchus messageri*, part of a genus otherwise known from the Western Ghats, India, occur in the fast-flowing river waters of Viet Nam, where pollution is impacting their habitats.

The Critical Ecosystem Partnership Fund ecosystem profile (CEPF 2007) noted that the family Pomatiopsidae has a remarkable centre for radiation in the Mekong Basin; the current assessment shows that this is the most threatened Family of mollusc in the Indo-Burma region. The other highly threatened families are the Family Pachychilidae. These two families have species that have extremely restricted ranges, often in specialised habitats, such as river rapids, requiring highly oxygenated unpolluted waters. By contrast the Family Viviparidae, have species that are more tolerant of pollution and disturbance, and these species are frequently used as food sources.

4.4.2 Freshwater Bivalves

One hundred and twelve freshwater bivalves are recognized from the Indo-Burma area. The greatest numbers of taxa fall into the IUCN Categories of Least Concern (48 species, 42.9%) and Data Deficient (46 species, 41.1%). Categories of conservation concern include Critically Endangered (six species, 5.2%); Endangered (nine species, 8.0%) and Vulnerable (one species, 0.9%). A total of 16 taxa (14.3%) are considered to be threatened (Tables 4.4, 4.5; Figure 4.4).

Table 4.4 The number of species of freshwater bivalves under each IUCN Red List Category in the Indo-Burma region.

IUCN Red List Category	Number of species
Extinct	0
Extinct in the Wild	0
Critically Endangered	6
Endangered	9
Vulnerable	1
Near Threatened	2
Least Concern	48
Data Deficient	46
Total	**116**

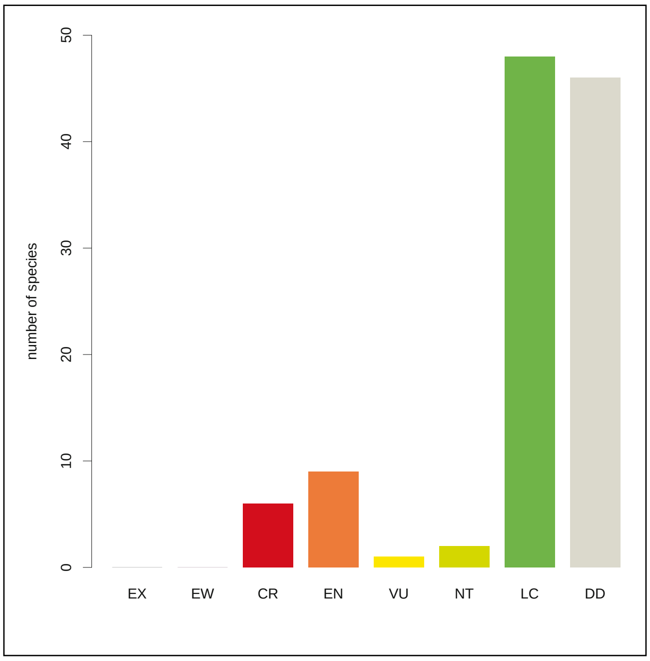
Table 4.5 The threatened freshwater bivalves in the Indo-Burma assessment region.

Family	Species	Category
MARGARITIFERIDAE	*Margaritifera laosensis*	EN
UNIONIDAE	*Cristaria truncata*	EN
UNIONIDAE	*Cuneopsis demangei*	CR
UNIONIDAE	*Lamprotula blaisei*	VU
UNIONIDAE	*Lamprotula contritus*	EN
UNIONIDAE	*Lamprotula crassa*	CR
UNIONIDAE	*Lamprotula liedtkei*	CR
UNIONIDAE	*Lamprotula nodulosa*	CR
UNIONIDAE	*Lamprotula ponderosa*	EN
UNIONIDAE	*Lanceolaria bilirata*	CR
UNIONIDAE	*Modellnaia siamensis*	EN
UNIONIDAE	*Oxynaia diespiter*	EN
UNIONIDAE	*Oxynaia micheloti*	EN
UNIONIDAE	*Physunio ferrugineus*	CR
UNIONIDAE	*Protunio messageri*	EN
UNIONIDAE	*Pseudodon resupinatus*	EN

All of the threatened species are from the larger freshwater bivalves in the Family Unionidae and the Margariferidae rather than the smaller bivalves (*Corbicula, Sphaerium, Pisidium* spp). All species in the Unionidae and Margaritiferidae have complex life histories requiring the presence of fish-hosts for the parasitic larval stage resulting in metamorphosis into juvenile mussels. However, in this region, our knowledge of the known fish host species is lacking for the majority of the species. The species are typically longer-lived than many of the Freshwater Gastropods, so the conservation assessment period of three generations will be more than ten years.

Some families, such as the Arcidae, Cultelidae, Solencurtidae, Pharidae, Mytilidae are largely marine, and the few species recorded are found in brackish water habitats along the coast, so have been included in the assessment, as it covers brackish waters. The major families containing the freshwater species are the Unionidae, Sphaeridae, Cyrenidae and the Margaritiferidae.

Figure 4.4 The number of extant freshwater bivalve species under each IUCN Red List Category in the Indo-Burma region.



4.5 Patterns of species richness

The Oriental biogeographic region with the Indo-Burma hotspot at its heart boasts a highly diverse and largely endemic fauna of freshwater snails (Strong *et al.* 2008) and freshwater bivalves (Graf and Cummings 2007, Bogan 2008). Within this region, the Mekong River basin stands out in terms of the diversity of species and the level endemism in freshwater molluscs (Figure 4.5).

In the first global assessments of the status of freshwater biodiversity (Groombridge and Jenkins 1998, McAllister *et al.* 2001), the Mekong River basin is listed as possessing one of the most diverse freshwater molluscan faunas in the world, second only to the Mobile basin in the southeastern United States (Neves *et al.* 1998, Bogan 2008, Groombridge and Jenkins 1998). This comprehensive assessment is the first for the region, and upholds the original findings from the overviews published in 1998 and 2001.

4.5.1 All molluscs

The species richness within the Indo-Burma region is shown in Figure 4.5, highlighting the diverse areas of the fauna in the central Mekong. In general, most larger catchments host between 14 and 34 species, but in parts of the Mekong catchment over 83 species are found, with replacement of taxa in similar habitats in different localities. Species are not evenly distributed across the course of the Mekong but most species are restricted to a relatively short stretch between Pakse in southern Lao PDR and Kratie in Cambodia where the river flows over a series of rapids.

4.5.2 Threatened species

The majority of threatened species (Figure 4.6) are found in the central Mekong River system, where there are a suite of endemic species located at sites which are proposed for dam construction in Lao PDR, Cambodia and Thailand. Other threatened species are found in the rivers draining northern Viet Nam, especially those with headwaters in China, where damming has impacted the flow levels of the rivers in Viet Nam and pollution from agricultural, industrial and urban sources impacts habitats. A further concentration is found at Inlé Lake in Myanmar.

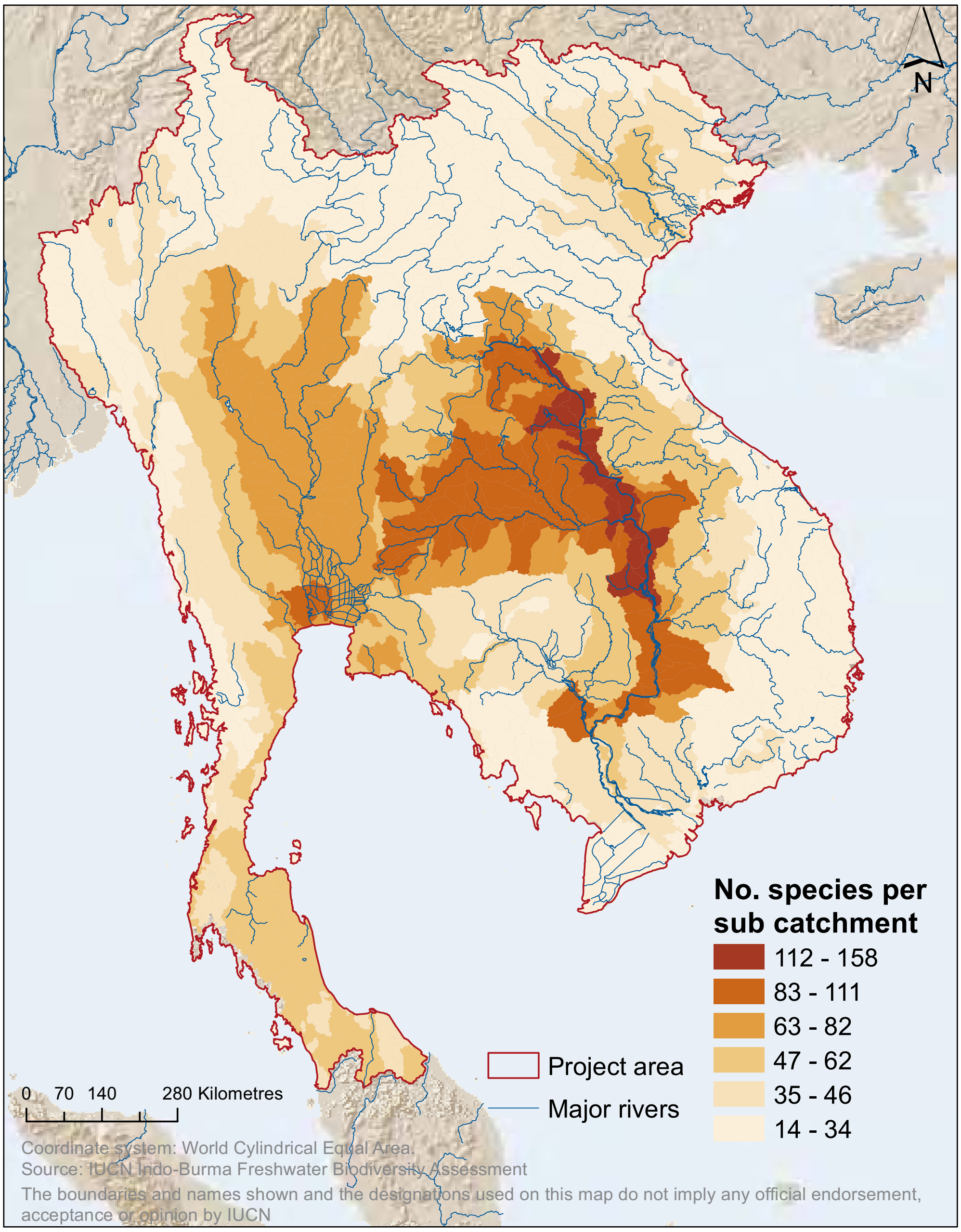
4.5.3 Endemic species

The endemic species, based on the current data, are mainly found in the central Mekong River and its sub-catchments, such as the Mun River in eastern Thailand. A smaller centre of endemism is found in the Kaek River, in the Chao Praya catchment, central Thailand (Figure 4.7).

4.5.4 Data Deficient species

The high level of freshwater bivalves assessed as Data Deficient is a result of the lack of detailed surveys and the lack of basic biological information for these taxa.

Figure 4.5 The distribution of freshwater mollusc species across the Indo-Burma region.



There are two key reasons for a species' assessment as Data Deficient:

a) Inadequate distributional data: Without accurate information on the distributions of the species, it is not possible to make a good assessment of the conservation status of these species. Some of these species have not been recorded for more than 60 years, such as *Diaurora aurorea*, and hence without new surveys, a conservation assessment is not possible. Other species, for example, *Chamberlainia hainesiana,* are listed as DD, but this species is already considered Vulnerable in parts of it's range in Thailand and Viet Nam, and it is known to be heavily collected across its range for food for consumption and sale locally, as well as for use in the production of decorative items and producing artificial freshwater pearls. The species is likely to be impacted by habitat modification and destruction due to dams, canalisation and pollution (siltation and contaminants associated with construction, agriculture, mining, and forestry practices). However, lack of data on levels of exploitation and decline in populations mean this widely distributed species cannot be confidently assessed as threatened.

b) Taxonomic status uncertain: for example, most of the species of *Corbicula* described from the region are poorly defined, and hence the species limits have been questioned for these taxa. Further data are needed on the status of the species and then new distributional data will be required to make an informed conservation assessment.

Other recent analyses of the number of Data Deficient taxa in crayfish, freshwater crabs and dragonflies showed that Data

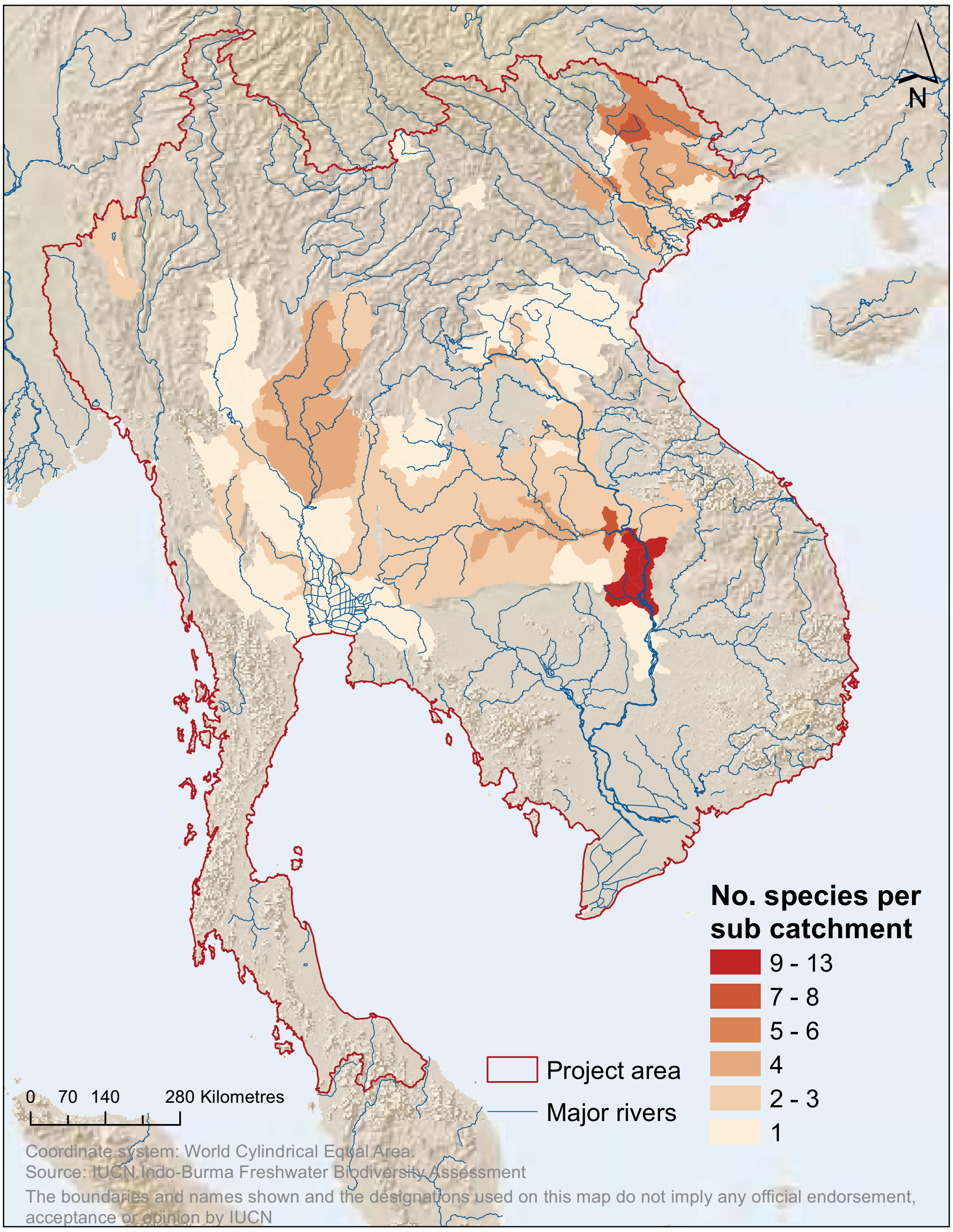


Figure 4.6 The distribution of threatened freshwater mollusc species across the Indo-Burma region.

Deficient species were globally non-randomly distributed in freshwater crabs and dragonflies and geographically non-randomly distributed in all three groups examined (Bland *et al.* 2012). They concluded that conservation priorities based on these data require more and better data obtained at a large expense. Since the Data Deficient taxa are so numerous and the biological characteristics and threats for extinction not easily determined these taxa should be given high priority to determine their conservation status.

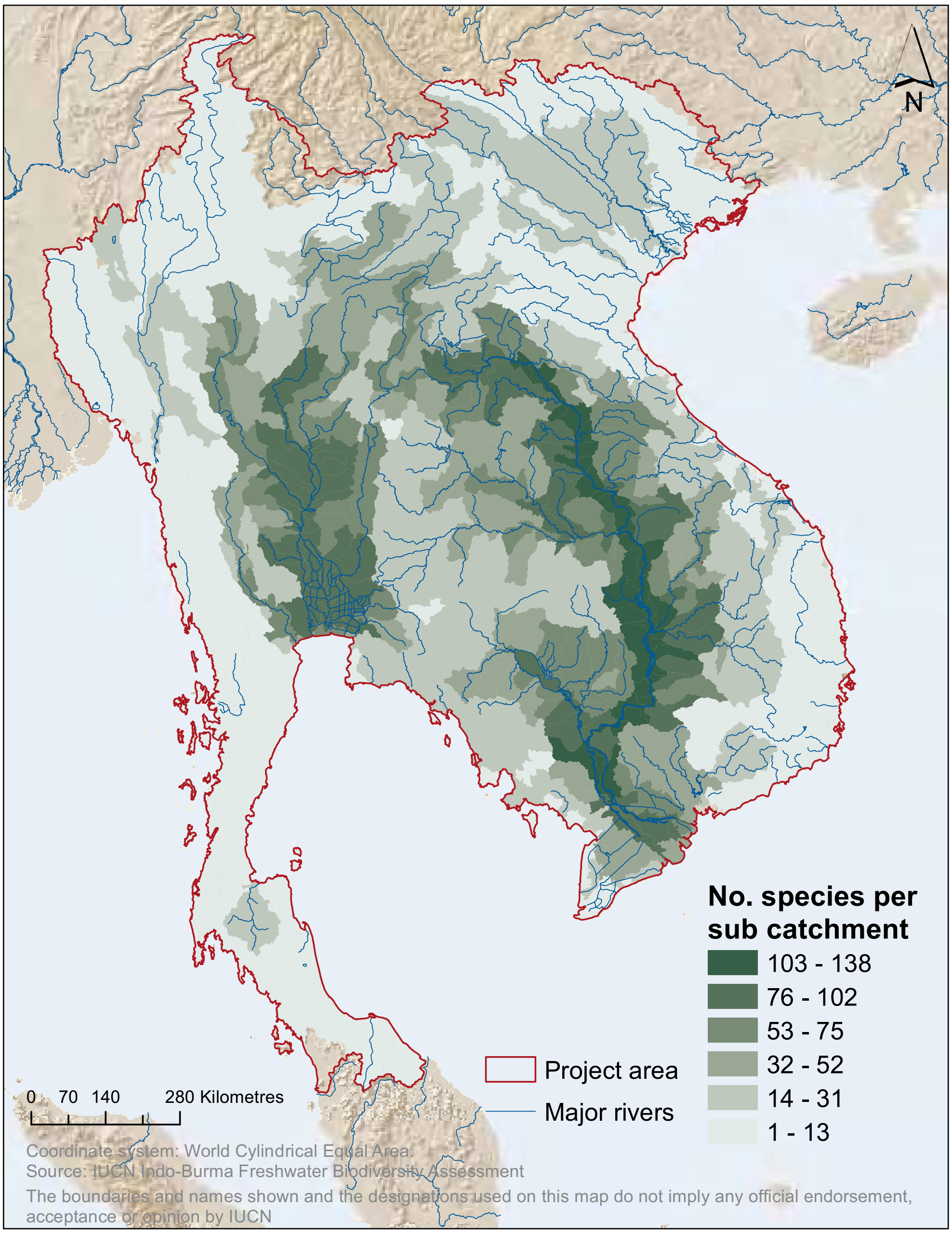
4.6 Major threats to freshwater molluscs

The Mekong River and its tributaries are increasingly vulnerable due to a wide variety of anthropogenic activities. Through this study the major threats to Indo-Burma freshwater mollusc faunas have been identified as river regulation and dam construction, water pollution from various sources (agricultural pollutants, domestic sewage, industrial effluents and mining waste) and over harvesting.

The rate and extent of environmental change in Asia are having impacts on the aquatic biota that may be greater than anywhere else on the planet. Large and growing human populations and the rapid pace of development have led to the degradation of freshwater ecosystems throughout Southeast Asia, including Indo-Burma, and many habitat types are under grave threat (Dudgeon 2000a).

On a global scale, the threats to freshwater biodiversity can be grouped under five interacting categories (Figure 4.8): overexploitation, water pollution, flow modification, destruction or degradation of habitat, and invasion by exotic species (for example, Dudgeon 1992, 1995, 2000a; Dudgeon *et al.* 2006, Malmqvist and Rundle 2002, Rahel 2002, Revenga *et al.* 2005). Environmental changes occurring at the global scale, such as changes in climate and nitrogen deposition (for example, Poff *et al.* 2003, Canfield *et al.* 2010), are superimposed upon these specific threats. Amongst these diverse influences on freshwater

Figure 4.7 The distribution of endemic freshwater mollusc species across the Indo-Burma region.



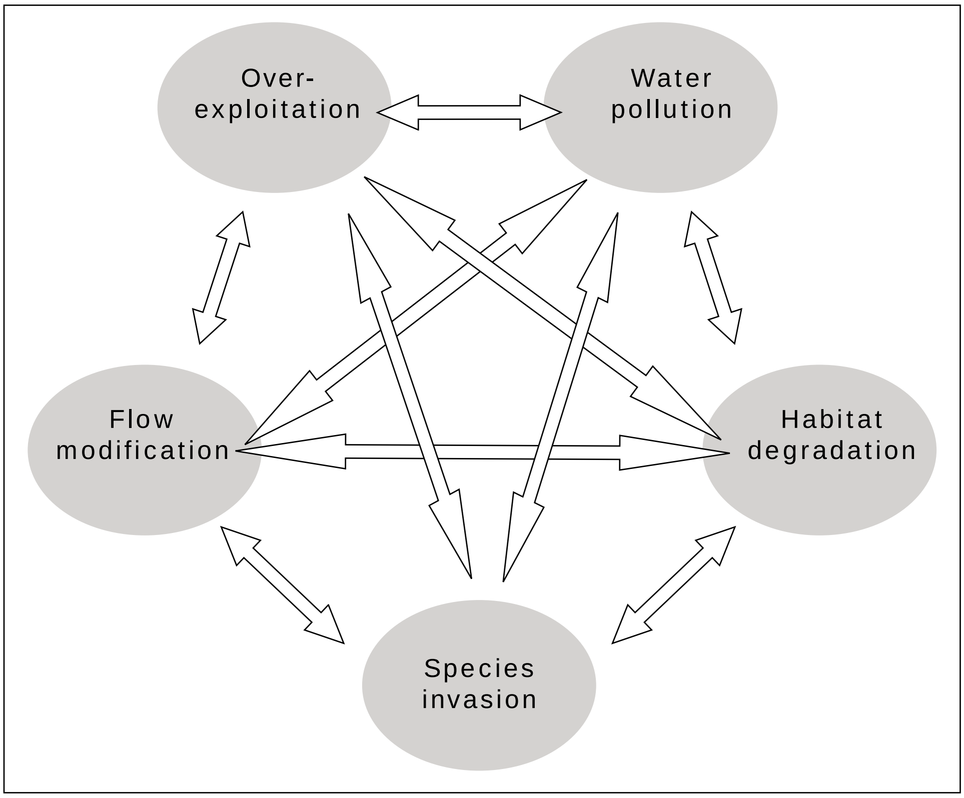


Figure 4.8 The five major threat categories and their established or potential interactive impacts on freshwater biodiversity. Environmental changes occurring at the global scale, such as nitrogen deposition, warming, and shifts in precipitation and runoff patterns, are superimposed upon all of these threat categories (redrawn from Dudgeon *et al.* 2006).

ecosystems, three major threats are considered particularly significant for the freshwater snails in the Indo-Burma region: (1) degradation of river drainage basins, (2) regulation and control of rivers and streams, and (3) pollution (Dudgeon 1992, Strong *et al.* 2008). How susceptible individual species are to these impacts, depends on their ecology, population structure and distribution.

From a conservation point of view, the most sensitive species are those that are characterised by particular life history traits, such as low vagility, strict habitat specialisation, restricted geographic range, long maturation time, low fecundity, obligate parasitic larval stage on gills or fins of host fish and longevity (Strong *et al.* 2008). These traits prevent species from adapting to significant alterations of the natural habitat, including but not restricted to changes in flow regimes, siltation and pollution, while ecologically more generalist competitors, such as introduced species, are going to benefit from the anthropogenic influence. This effect is going to contribute to on-going homogenisation of the fauna. Particularly vulnerable species are found especially in the endemic groups with localised distributions, for example, in the Mekong groups, the Pomatiopsidae (70 species) and Stenothyridae (40 species), but potentially also amongst the Pachychilidae and some Viviparidae, which are also known to occupy short distributional ranges. Many of these small range species are not assessed as threatened here for the absence of known, immediate threats. However, if such threats should emerge in the future, for example, the development of major dams, these species may also need to be considered threatened.

Spring snails are particularly vulnerable for most of them are narrow-range endemics, which can go from being unthreatened or Vulnerable to Extinct without any transitional level of threat due to the destruction of relatively small habitats. However, little information is available on the diversity of spring snails in Indo-Burma and on the imminent impacts to their extremely localized habitats.

4.6.1 River regulation and control

River regulation and control has been practised widely in the region for centuries but, with the planned development of massive projects throughout the region on both mainstream and tributary rivers, the potential for environmental damage has increased. Flow regulation reduces flood-season peaks, changing the magnitude and extent of floodplain inundation and land-water interactions. Fish breeding migrations may be disrupted, because dams block migration routes or changed flow regimes fail to stimulate reproduction, with potential impacts on mollusc reproduction in the case of species dependent on fish as part of their reproductive strategy. All countries in the region have embarked on major expansions of hydropower capacity, which is going to drastically transform most, if not all major river systems in these countries (Figure 1.5, Chapter 1). China has also proposed or already developed a large number of dam construction projects, so there is already a loss in the volume of water passing down the Mekong River. Hence in the Indo-Burma region, the most significant and imminent cause of declines in native mollusc populations is certainly dam construction for flood control, hydroelectric power generation

Waterfalls on the Mekong River near Khone Island, southern Lao PDR. The Khone Falls are one of the better surveyed locations within the Indo-Burma region. The proposed Don Sahong dam would have significant impacts on the flow regime of the river, and is likely to impact mollusc species that are found in rapids. © Frank Köhler

and water storage (for irrigation or drinking water supplies), which has converted species-rich riffle and shoal habitats into low-energy and often low-water bodies, greatly reducing and fragmenting suitable habitats and resulting in a cascade of effects both up and downstream. Hydroelectric power generation will have an increasing significance throughout the region in the next 20 years with a multitude of larger dams being operated, currently constructed or planned.

The impact of large dams on biodiversity is a key threat (McAllister *et al.* 2001), as they are frequently sited on species-rich rapids, and this is considered to be a major factor in the extinction of freshwater molluscs in North America (Bogan 1993, Hughes and Parmalee 1999) and as a threat to species in Africa (Seddon *et al.* 2011). Dams impact molluscan biodiversity both upstream and downstream of the structure (McAllister *et al.* 2001). Downstream, the water temperature and the flow levels are subject to variation. Increased water temperature impacts gamete development in the Unionidae (Galbraith and Vaughn 2009). Decreased water levels impacts sex ratios of species of freshwater mussels (Galbraith and Vaughn 2011). Unless potential biodiversity impacts are mitigated through the planned release of waters following construction, the subsequent low water levels can lead to a decline of populations and ultimately extinctions. Upstream, and especially within the extent of inundation, species may also be lost as the habitat quality declines, or if obligate hosts fish are lost. Increased standing water areas also has the potential to result in increased populations of species that act as vectors for disease, leading to a subsequent increase in levels of medical problems for the local human populations adjacent to the reservoir (Seddon *et al.* 2011). Attwood (1996) reported that the operation of the Pak Mun dam on the Mun River in Thailand resulted in an increase in the population density of *Neotricula aperta*, the snail intermediate host of *Schistosoma mekongi*, suggesting that the impoundment of the river created conditions favourable to the disease vector. Harinasuta *et al.* (1970) reported a high prevalence of intestinal and liver fluke infections following the construction of the Ubol Ratana Dam, Khon Kaen Province in Thailand.

Construction of a hydroelectric plant in Quang Ngai Province, central Viet Nam. Dam development can have significant impacts on mollusc species and their habitats both during and post-construction. © Do Van Tu

It is not just large dam projects that modify water flow patterns. Small-scale modification schemes, such as weirs, dams and canals, also have a ubiquitous presence in the region. Hundreds of multi-purpose reservoirs for water supply, irrigation, hydropower and fisheries have been constructed, as well as numerous barrages for water diversion and storage. These small-scale projects may also lead to a decline in native mollusc populations if environmental impact assessments (EIAs) are not carried out prior to the installation and if the presence of sensitive species is not taken into account in the subsequent release patterns for water flows.

Although most current studies on the impact of impoundment of rivers and anthropogenic modification of habitats on freshwater bivalves have been undertaken in North America and Europe, the results can be extended to the biodiversity hotspot of Southeast Asia.

The effects of these newly constructed dams on the biodiversity of so far generally unspoiled river systems is going to be dramatic as can be derived from the impact of already operational dams in the region and elsewhere (Dudgeon 2000b, Rosenberg *et al.* 2000, Carew-Reid *et al.* 2010). The influence of dams on biodiversity, including freshwater snails, are complex and grave causing, amongst other disturbances, habitat loss and fragmentation, impediments to species migrations and genetic exchange between populations, propagation of invasive species, deterioration of water quality, changes in flow regime and sedimentation. These factors are going to lead to a significant loss of riparian species. Narrow-range endemics with usually specific adaptations to well oxygenated, fast flowing riparian ecosystems are going to be particularly affected and many of them are at high risk of extinction. By contrast, a few ecologically tolerant snail species, including invasive species and some intermediate hosts of waterborne pathogens such as *Biomphalaria glabrata*, are going to benefit from the creation of artificial stagnant water bodies. In Lao PDR, a freshwater mollusc survey was undertaken prior to the construction of the Nam Theun 2 Hydroelectric dam. After construction of the dam in 2009, a subsequent survey was undertaken, which showed that the number of pomatiopsid snails had declined and more importantly more species of snails of medical importance were present and as well as the spread of invasive species of *Pomacea canaliculata* (Lohachit 1996, Sri-Aroon and Lohachit 2011).

Currently proposed dams or dams under construction will affect all major rivers and many tributaries across the region. The expected loss of species in the Mekong is considered to be significant as this river harbours speciose radiations of pomatiopsid and stenothyrid snails. The majority of these species are currently known from a relatively short (c.200–300 km) stretch between the Thai-Lao border and Kratie in Cambodia, where the Mekong flows over a series of fast-flowing rapids. Along this stretch there are five proposed dams, which if realised will significantly transform the fast flowing, seasonally fluctuating river into a chain of stagnant or slow flowing water bodies. These modified habitats are going to be uninhabitable for most riparian and narrowly endemic species, which are not adapted to live in largely lacustrine environments.

Dam development can also be a cause of the loss of the host-species required for the reproduction of the freshwater bivalves. Unionoids are unique amongst the bivalves in the adaptation of their larvae to the parasitic use of a host, usually fish, for development. This reproductive dependency on fish in some unionoid bivalves makes them vulnerable, as any modification or loss of the requisite host fish will be followed by extinction of the freshwater mussel taxa using that fish as a host. It is interesting to note that some species of bitterling fish (*Rhodeus* species of Cyprinidae) depend on bivalve molluscs as the intermediate host of eggs and larvae (for example, Reichard *et al.* 2007), with the relationship being species-specific.

4.6.2 Sedimentation due to deforestation and degradation of drainage basins

The degradation of drainage basins in particular caused by deforestation and agricultural use of vast areas is an on-going process in the region, resulting in an increased suspended sediment load and altered flow regimes, including more extensive flooding or running dry of water bodies in periods of drought.

A bitterling fish laying eggs inside a bivalve. Such relationships are species-specific and further research is required before conservation actions can be defined. © Oliver Lucanus / www.belowwater.com

Urban pollution in a stream in Viet Nam. © Frank Köhler

Excessive floodplain siltation alters habitats. Sedimentation can especially impact the juvenile stages of mollusc species, including the large mussels (Families Unionidae, Margaritiferidae), which cannot survive in the lower oxygen content where the river bed is smothered by sediment (Seddon *et al.* 2011). In many areas deforestation has taken place in the past, meaning that the fauna sampled in the present may simply represent a product of past habitat declines, such that we may be unable to reconstruct the earlier conditions of these affected habitats and the original composition of their faunas.

4.6.3 Pollution

River pollution is a serious problem throughout many parts of the region, especially in lower parts of river drainages, and constitutes the third major threat to freshwater molluscs. Pollution from point and diffuse sources is a major threat to the aquatic biota in general (Dudgeon 2000a). For example, current surveys in the Red River showed that in polluted areas, there were few mollusc species, often at low densities. Species tolerant of pollution (*Melanoides tuberculatus*, *Tarebia granifera* and invasive species such as *Pomacea canaliculata*) were prevalent, whilst almost all species of freshwater mussel were absent (Do Van Tu *pers. comm.* 2011).

Sources of water pollution in the Indo-Burma region include:

- Urban sewage: Untreated sewage is a particular problem in densely populated areas, and waste waters are largely untreated.
- Industrial sources of water pollution: pollution from industrial effluents and mining extraction and processing wastes is becoming significant (Dudgeon 1992), with mining activities often present in the upper, previously less impacted, parts of drainages.
- Agricultural sources of water pollution: intensive cultivation of vegetables and livestock rearing in cities, as well as diffuse pollution from nitrogen, phosphorus and pesticides from agricultural land (Dudgeon 2000a).
- Sedimentation: clearance of forests for agriculture and development resulting in high sediment loads, especially in hill areas.

4.6.4 Mining and aggregates extraction

There are two impacts from mining in the region. The first is water pollution, especially from the mine waste and ore processing (for example, cyanide use in gold extraction). In Viet Nam this is a recognised threat to some of the large unionid bivalves that require stable river bed habitats and fast flowing well oxygenated waters.

The sands and gravels from the river beds in part of the Indo-Burma region are used as sources of aggregates for building. This

Freshwater snails (Viviparidae) and mussels (Unionidae) for sale at a market in Viet Nam. © Frank Köhler

Sand and gravel exploitation in the Cầu River, northern Viet Nam. © Do Van Tu

disrupts the river bed habitats of the freshwater molluscs, as well as causing change in the flow regimes of the river.

4.6.5 Over-exploitation of molluscs

Many of the freshwater bivalves and larger gastropods are harvested throughout the region for food, jewellery, decorative and art work, and for construction materials, as Nagachinta *et al.* (2005) documented for the utilization of freshwater molluscs in Thailand.

However, the impact of use on species populations is not well documented. Organisms with a long lifespan and slow rate of reproduction are particularly vulnerable to over-harvesting. Throughout Southeast Asia, several larger species of freshwater gastropods and bivalves are widely used for human consumption. This applies particularly to species within the gastropod families Viviparidae, Ampullariidae and Pachychilidae, and the larger bivalves (Family Unionidae). These freshwater molluscs are mostly collected locally for subsistence use but throughout the region snails and mussels are also shipped in larger quantities to cities to be sold in markets. Most of the traded snail species are widespread and locally abundant and are therefore easy to collect in large quantities (Families Viviparidae, Ampullariidae) and, due to their generally ubiquitous life style and rapid reproduction, the volume taken for human consumption has apparently had little effect on populations of these snails. By contrast, many snail species of the Family Pachychilidae, in particular *Brotia* spp. (Köhler and Glaubrecht 2006), and certain species of the Family Viviparidae are potentially more susceptible to over-exploitation as they have narrowly endemic distributions. Some unionid mussels are probably most susceptible to over-exploitation for their endemism and complex life history.

One local study in Viet Nam (Table 4.6) demonstrated that the level of extraction or harvest for mussel species was such that the species may be potentially over-harvested in the Red River Basin.

Further studies of this type are urgently needed in order to understand the potential impact on populations and to identify species that may benefit from aquaculture to maintain populations.

At present there are no species known where harvesting has significantly impacted wild populations of snails, however, the question of whether regionally heavy utilisation of molluscs may be a local threat to some populations requires further research.

4.6.6 Climate change

At present few freshwater molluscs are known to be directly threatened by climate change in the Indo-Burma region. Increased frequency of drought events will in most cases be a secondary threat to those freshwater species where there are already problems, such as the over-abstraction of water for domestic and agricultural purposes. In the near future, these threats are likely to be exacerbated by the impact of changing climate, including altered rainfall patterns, more extreme weather conditions, and the increased frequencies of droughts or floods.

4.6.7 Untargeted use of molluscides

The control of waterborne disease vectors (for example, parasitic flukes that cause diseases such as angiostrongyliasis, echinostomiasis, opisthorchiasis, schistosomiasis, heterophyiasis, paragonimiasis, and fasciolopsiasis), can impact local populations of freshwater molluscs, with potentially severe impacts on range restricted species, which are often non-target species. In Africa such uncontrolled use was shown to be a cause in the decline of populations for range-restricted species to a level where they became threatened (Seddon *et al.* 2011). Control measures should prioritise education, health monitoring, improved water supply and sanitation, above molluscicide use or environmental management, which should generally only be used for pest/invasive species such as *Pomacea canaliculata*.

4.6.8 Invasive species

A future threat in some parts of the region is introduced mollusc species, such as *Pomacea canaliculata* and similar species. At present, the majority of species that are threatened

Table 4.6 Estimated stock of freshwater mussels in some branches of the Red River (Song Hong) in Viet Nam. (Source: Hoang 2010)

Tributary	Length of river (km)	Number of households	Yield/household /day (kg)	Days of harvesting/ year	Total yield (tonnes)	Estimated stock (tonnes)
Lo River (Viet Tri)	13	5	19.5	300	29,250	37.95
Da River (Thanh Thuy)	13	4	16.5	300	19,800	35.86
Thuong Tin (Ha Noi)	13	6	27	300	48,600	52.36
Ninh Co River	15	7	26	300	54,600	64.77
Mouth of Red River	5.5	9	7.5	300	20,250	23.86

in the region are primarily impacted by other threats. However, where *Pomacea canaliculata* has been widely found, native molluscs have declined, suggesting that the species may potentially impact range-restricted native species in the future.

4.6.9 Other threats

Additional sources of habitat degradation prevalent throughout the region include dredging and channelization, agrochemical and heavy metal loading, acidification, salinisation (from decreased freshwater flows in estuarine areas), fish and mollusc farming, wetland conversion through urban and agricultural development, and unsustainable water extraction for irrigation, livestock and urban use. However, it has frequently proven to be difficult to assess the significance of most of these factors for the global survival of individual species.

Table 4.7 Gastropod species and nematode disease hosts.

Species	Disease
Pila ampullacea	Angiostrongyliasis, Echinostomiasis
Pila angelica	Angiostrongyliasis, Echinostomiasis
Pila gracilis	Angiostrongyliasis, Echinostomiasis
Pila pesmei	Angiostrongyliasis, Echinostomiasis
Pila polita	Angiostrongyliasis, Echinostomiasis
Pomacea canaliculata	Angiostrongyliasis, Echinostomiasis
Filopaludina sumatrensis	Angiostrongyliasis, Echinostomiasis
Filopaludina martensi	Angiostrongyliasis, Echinostomiasis
Bithynia funiculata	Opisthorchaisis (*Opisthorchis viverrini*)
Bithynia siamensis	Opisthorchaisis (*Opisthorchis viverrini*)
Neotricula aperta	Schistosomiasis (*Schistosoma mekongi*)
Neotricula burchi	Schistosomiasis (*Schistosoma mekongi*)
Tricula bollingi	Schistosomiasis (*Schistosoma mekongi*)
Melanoides tuberculatus	Paragonimiasis, Echinostomiasis, Heterophyiasis
Tarebia granifera	Paragonimiasis, Echinostomiasis
Thiara scabra	Paragonimiasis, Echinostomiasis
Brotia costula	Paragonimiasis, Echinostomiasis
Indoplanorbis exustus	Cercarial Dermatitis, Echinostomiasis
Gyraulus convexiusculus	Echinostomiasis
Hippeutis umbilicalis	Fasiolopsiasis (*Fasciolopsis buski*)
Segmentina hemisphaerula	Fasiolopsiasis (*Fasciolopsis buski*)
Segmentina trochoideus	Fasiolopsiasis (*Fasciolopsis buski*)
Radix rubiginosa	Fasioliasis (*Fasiola hepatica*)
Radix swinhoei	Fasioliasis (*Fasiola hepatica*)
Radix viridis	Fasioliasis (*Fasiola hepatica*)

4.7 Understanding the impact of molluscs on human health and livelihoods

In Asia, many gastropods carry parasites that cause disease in humans (see Table 4.7). For example, several freshwater snails serve as intermediate hosts for the nematode *Angiostrongylus cantonensis* which, when ingested by people, penetrate the central nervous system and cause eosinophilic meningitis (Angiostrongyliasis).

The impact of diseases such as human schistosomiasis carried by molluscs is difficult to estimate in economic terms because of problems in accurately measuring the effects of subtle variables like absenteeism, childhood mortality, loss of productivity and reduced education on a continent-wide or even national scale (Seddon *et al.* 2011).

There are active disease control programmes in the region, involving health education and local participation in prevention and disease control campaigns run by government agencies though local government organisations. These concentrate on the detection and treatment of disease, improved sanitation and safe water supplies. The use of molluscicides or environmental management should only be used for pest/invasive snail such as *Pomacea canaliculata*.

Animal fascioliasis is known across the continent where it affects a range of stock animals and chronically infected animals show reduced growth, lower milk production and lower calving rates (Seddon *et al.* 2011), with consequential impacts on human food security and nutritional availability.

4.8 Conservation recommendations

Considering that even the more charismatic megafauna, such as river dolphins, have failed to trigger decisive and effective conservation actions in the region, it becomes clear that the conservation of freshwater invertebrates, including snails, faces particular challenges as a result of the lack of awareness of the magnitude of their importance to ecosystems and human livelihoods (Dudgeon 2000a).

This assessment of the impact of threats to molluscan biodiversity is complicated by limited knowledge of the freshwater mollusc fauna in the region. From the current assessment, we can anticipate a loss in biodiversity and gradual homogenization of the regional biota unless conservation actions are put in place. Reversal of these trends will require a change of focus by limnologists and water-resource managers, and the urgent adoption of a conservation agenda for freshwater science in Asia (Dudgeon 2000a, Dudgeon *et al.* 2006).

Whilst in North America and Europe, freshwater molluscs (such as the spring snails, river rapids species and the large Unionid mussels) have benefitted from the extension of protected areas as conservation actions for the species, in the Indo-Burma region there are, with the exception of Ramsar Sites, few protected areas designed specifically for protection of freshwater fauna. Protected areas for freshwater systems need to be designated to specifically protect upper catchments and to include entire river and lake systems within their boundaries, if they are to provide effective protection to freshwater species (Darwall *et al.* 2011b).

To our knowledge there are no current conservation actions in place to conserve freshwater molluscs in Thailand or Lao PDR, however, there are general education programmes aimed at raising awareness of environments and the biodiversity of the region. By contrast in Viet Nam, three gastropod species and 15 bivalves are listed as requiring conservation actions, and a project establishing inland water protected areas has commenced and by 2015 is intended to have 53 protected freshwater areas, although, the impact of this project in the field of conservation of aquatic resources is still limited.

Research capacity and the awareness of the value and ecological importance of molluscs needs to be improved in the region. Rarely do relevant governments or indigenous communities appreciate the value of their molluscan biodiversity, so capacity-building projects are recommended to raise awareness and facilitate monitoring of local mollusc populations, especially where they are utilised for food or other purposes. Some such initiatives are ongoing in Thailand and Viet Nam through community outreach and collaboration with local wildlife and fisheries departments (P. Sri-Aroon *pers. comm.*).

Environmental Impact Assessments (EIA) need to include assessments on the impacts to mollusc diversity, and should be mandatory for proposed developments such as dam construction, fish farm developments, large-scale timber extraction involving clear-felling of gallery forests, and mining developments. Monitoring after the completion of the project also needs to be incorporated into large project developments in the region.

Proposals to use molluscides need to be carefully assessed, as they can cause the decline of populations of non-carrier endemic species that do not provide a threat to human health or livelihoods. The loss of these species has two major effects; a) increase in the carrier species, filling the niche vacated by the non-carrier species; and b) decline of food supplies for the other native species that predate these molluscs, such as crabs, aquatic birds and fish.

Finally, sewage treatment needs to be improved, and there needs to be tighter control on the import of invasive species to reduce the impact on native species.

4.8.1 Species-specific conservation requirements

Species with small distributional ranges deserve particular attention through suitable management of habitats required for the survival of these species, especially those in riffle habitats susceptable to the impacts of dam construction.

Species that require a host-fish during their life cycle (e.g. the large Unionid mussels) may need to have a conservation plan

Snail survey in a polluted river in Cao Bang, northeastern Viet Nam, with Frank Köhler and Do Van Tu. © Frank Köhler

that includes the host fish's habitat requirements as well as their own requirements.

4.8.2 Research actions

At present, despite a few omissions from our species list and the number of Data Deficient species, we believe that the data presented are reasonably representative of the status of molluscan biodiversity and the threats to these species across the Indo-Burma region.

There are, however, certain key research actions that will improve our knowledge and allow better management of molluscan biodiversity:

1. **Improve general information on molluscs**
   For all freshwater molluscs in the region, there is an urgent need for a better understanding of their distributions, populations (where possible), fish-hosts, ecology, tolerance to pollution, impact of invasive species and habitat requirements, as well as better understanding of their taxonomic status, based on traditional systematic studies and the analysis of the mitochondrial and nuclear DNA sequences to establish species boundaries and species relationships. Such new information would potentially allow the large number of Data Deficient species to be moved into an IUCN Category for risk of extinction.
2. **Research on groups where current diversity is possibly under-recorded**
   There are likely to be cryptic species lying within some Families such as the Pachylidae, Lymneidae, Planorbidae, Cyrenidae and possibly other families. More research therefore needs to be focussed on known areas of high biodiversity, where these families have wide-ranging, but morphologically variable, species to determine whether such variability is masking a group of species, rather than a single widespread but variable species.
3. **Field surveys for Data Deficient species**
   Many freshwater molluscs in the region are known from only a relatively small number of specimens, and most of those have not been corroborated by recent collecting.
4. **Document traditional uses and establish volumes of species used in supporting local livelihoods**
   The scale of consumption and use of molluscs in supporting livelihoods (i.e., through direct consumption or utilisation in construction, jewellery, etc.) is not well understood. In southern India, some species are used as local remedies for human and animal diseases (Aravind *et al.* 2011). It is likely that similar knowledge is available in the Indo-Burma region, however, we haven't captured or collected this information in the current assessment. Hence the traditional uses of freshwater molluscs by people and the traditional knowledge associated with this use needs to be documented.

Corbicula species and *Nodularia dorri* molluscs sold in a market in Hai Duong Province, northern Viet Nam. © Do Van Tu

4.8.3 Legislation and policy

Legislation governing development and water resource protection varies across the region. In Thailand, the Office of Natural Resources and Planning (ONEP) determines if hydropower dam projects require an Environmental Impact Assessment. In this case an EIA is normally required if a dam or reservoir has:

- a storage volume of over one million cubic metres of water
- a storage surface area of more than 15 km^2
- an irrigation area of 12,800 ha or more

In general these EIA studies take a period of one to three years and should include surveys for freshwater molluscs and their parasitic diseases. The EIA report has to be approved by ONEP, and the Cabinet before construction starts, however after construction studies of the ongoing environmental impact are not generally required, except when serious impact occurs.

In contrast, in Viet Nam, conservation of freshwater molluscs has been initiated with the production of the Red Data Book of Viet Nam (MoSTE 2000) which includes 17 mollusc species: two gastropods and 15 bivalves- all of the threatened bivalves are in the family Unionidae.

Recommendations for Policy include: a requirement for all major developments to conduct Environmental Impact Assessments, and these should include surveys for all threatened and Data Deficient species of molluscs; mitigation plans to be put in place for sites of high biodiversity value, including restoration of habitats post-project and flow management to maintain biodiversity; and, implementation of water pollution management and prevention across river basins.

4.8.4 Freshwater molluscs and livelihoods

Freshwater molluscs are utilised throughout the region by local communities for direct consumption and for sale for a range of uses (see Section 4.8.2, above). Open-access freshwater resources such as molluscs can play a vital role in sustaining local livelihoods within the region (Allen *et al.* 2008), underpinning food security and providing a source of cash income. Cultivation (mariculture) of molluscs (primarily bivalves, for pearl and shell, occasionally for food) is not common, but has been promoted in some areas (for example, oyster cultivation in Viet Nam; Braidotti 2011).

However, at present although current harvesting levels do not appear to be impacting populations, further research is required on whether heavy utilisation of molluscs may be a local threat to some populations, especially those species considered to be narrow endemics.

4.9 Conclusions

The Mekong basin within the Indo-Burma region is considered to have one of the highest freshwater mollusc diversities in the world. However, in spite of this, there has been relatively little focus on research into the species and their distributions. In light of the number of the threats recognised in the region there is a need for better data to allow a more comprehensive assessment of the status of the Data Deficient species. If all of these taxa are later found to be threatened, with around 40 Percent of species threatened it would also become one of the most threatened freshwater mollusc faunas, second only to Europe (Cuttelod *et al.* 2011).

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Cristaria plicata in a market in Vietnam. © Arthur E. Bogan

Chapter 5. The status and distribution of dragonflies and damselflies (Odonata) in Indo-Burma

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5.1 Overview of the regional Odonata with reference to the freshwater ecoregions

Indo-Burma lies entirely within the Asian seasonal tropics. Much of the region, including eastern Myanmar, northwestern and southern Thailand, Peninsula Malaysia (the northern tip of which is in Indo-Burma), southern Lao PDR, eastern and coastal Cambodia and almost the whole of Viet Nam, was historically covered in broadleaved evergreen tropical rainforest (Primack and Corlett 2005). However, a large swathe of the Indo-Burma interior, comprising much of northern Thailand, northern Lao PDR and western Cambodia, is in a rain shadow cast by the surrounding uplands, and in this area the original vegetation would have comprised drier forest types (Primack and Corlett 2005). These highlands include the Shan Plateau and the Xianghoang Plateau to the north, the Annam Plateau to the east, the Dawna Range to the west, and the Chuor Phnum (Cardamom) Mountains to the south. Herbaceous swamps would also have been present on alluvial plains in the lower basins of the Mekong, Song Hong and Chao Phraya, now largely converted to rice paddy, where seasonal rainfall led to flooding conditions that precluded forest establishment (Corlett 2005). Most of the forest cover of Indo-Burma has been lost due to rapidly intensifying anthropogenic impacts in recent centuries. The largest tracts of evergreen rainforest that remain are in southern Myanmar, the Cardamom Mountains of southwest Cambodia, and the Annamite Mountains of central and southern Lao PDR and Viet Nam (Figure 5.1). Extensive tracts of broadleaved deciduous forest remain in eastern Myanmar, northern Thailand and northern and eastern Cambodia.

The region covers a wide altitudinal range, from sea level to 3,000 m. Much of the northern part of the region (eastern Myanmar, northern Thailand, northern Lao PDR and northern Viet Nam) is mountainous, while the southern half is predominantly low-lying with some exceptions, most notably the southern extension of the Annamite Mountains in Viet Nam (Figure 5.1). Drainage through the region is predominantly north-south and west-east and comprises three major catchments originating in uplands north of Indo-Burma: the Salween to the west, draining southeast Myanmar and extreme northwest Thailand, the Red River and Black River system draining northern Viet Nam, and the Mekong, draining most of the vast area in-between (Figure 5.1). A fourth river system, the Chao Phraya, is smaller, having an Indo-Burmese provenance, and runs from north Thailand south to Bangkok. The Mekong River system is by far the largest in Indo-Burma, occupying the rain shadow interior and including in its basin the Tonlé Sap Lake in Cambodia – the largest body of fresh water in Southeast Asia

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(CEPF 2007), which acts as a seasonal sump for the Mekong (Dudgeon 1999) – and the vast deltaic region of the southern tip of Viet Nam.

The Indo-Burma Hotspot, which includes tropical southern China in addition to the more narrowly defined area covered in this assessment, ranks in the top ten biodiversity hotspots in the world for 'irreplaceability' and in the top five for 'threat' (CEPF 2007). This high biodiversity value is reflected in the odonate fauna of the hotspot, with a higher diversity of species and genera than anywhere else in the Oriental Region (Kalkman *et al.* 2008), probably due to the combined effect of its size, mountainous terrain, large rivers and variety of forest types. The area encompassing the northern parts of Thailand, Lao PDR and Viet Nam, and tropical southern China, is particularly rich and was identified as a distinct subregion for odonate biodiversity by van Tol and Rozendaal (1995), a suggestion given further credence by Wilson and Reels (2003). As noted by Hämäläinen (2004), the area covered by the present assessment does not form a single zoogeographical unit, with an odonate fauna comprising Sondaic, Sino-Himalayan and Indochinese elements, in addition to Indo-Burmese.

The present assessment covers some 473 odonate species (in 150 genera), of which approximately 160 (34%) are thought to be endemic or near-endemic in Indo-Burma (the real figure for

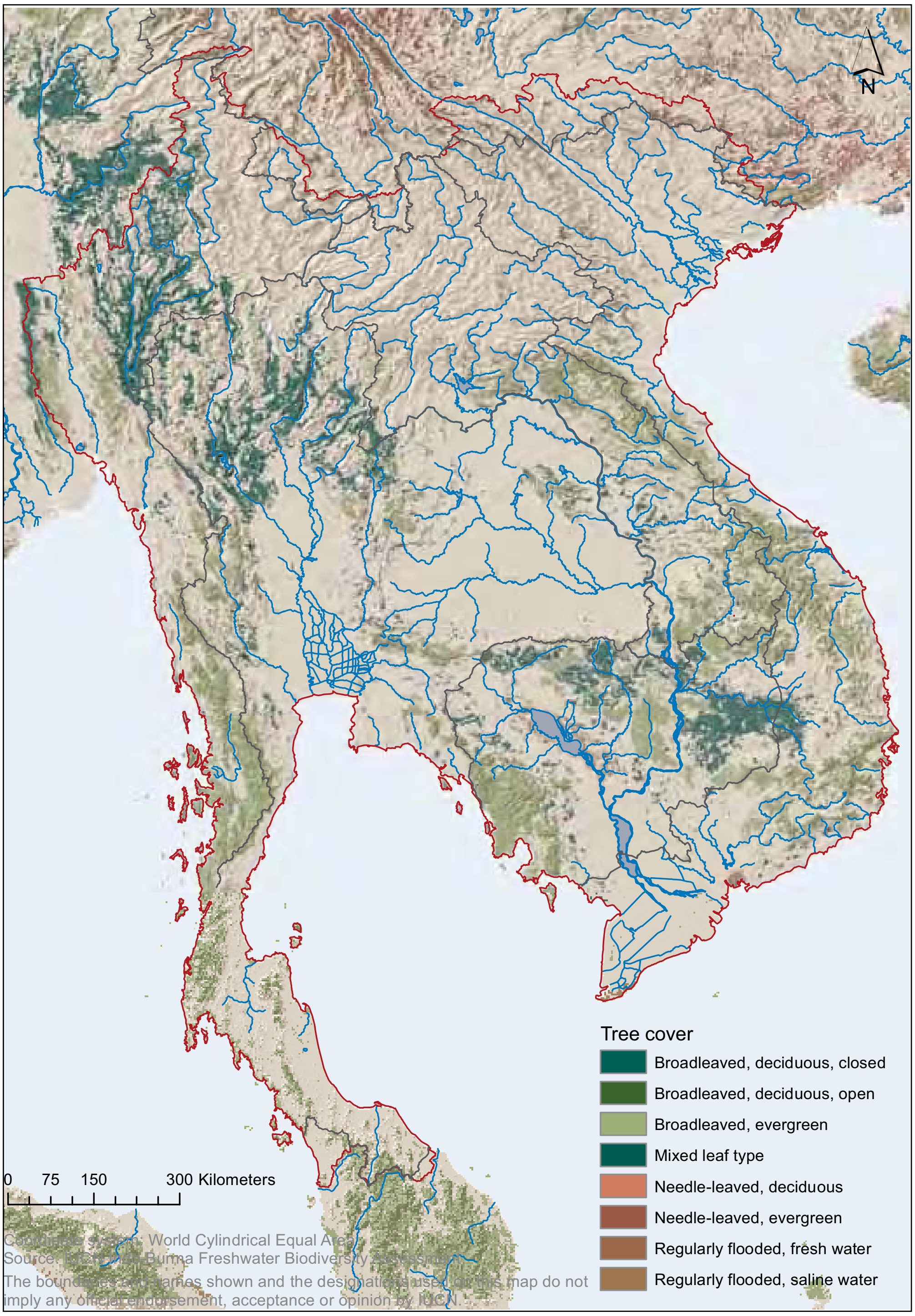


Figure 5.1 Forest cover and topography within the Indo-Burma assessment region, based on the Global Land Cover 2000 data (Stibig *et al.* 2003).

endemics is uncertain, given that the region impinges on, and is biogeographically contiguous with, parts of Myanmar, China and the Malay Peninsula). Fourteen species are considered threatened. The region has a low proportion (30.5%) of species in the cosmopolitan families Coenagrionidae and Libellulidae, most members of which are associated with open, lentic or slow-flowing waters. The majority of species are forest- and lotic-associated, reflecting the historical biogeography of the region. New species are still being described from Indo-Burma on a fairly regular basis (for example, Do 2011a, 2011b; Do and Karube 2011; Sasamoto *et al.* 2011) and it is likely that the real total exceeds 500 species (Hämäläinen 2004). Knowledge of Odonata across the region is very uneven. Hämäläinen (2004) briefly summarised the history of dragonfly studies in Thailand, Viet Nam, Lao PDR and Cambodia, noting that Thailand, the most accessible and best-studied country, had the most diverse odonate fauna (c.350 species), while Cambodia's odonate fauna was the most poorly known. This is largely still the case, with Cambodia and eastern Myanmar having the least-studied odonate faunas in Indo-Burma. Knowledge of the Cambodian fauna has however improved considerably in the last two years. Kosterin (2010, 2011) made two short surveys in the Cardamom Mountain foothills in southwestern Cambodia in April at the end of the dry season ('perhaps the worst time for Odonata') and November–December 2011, in which he made 29 new species records for that country – a powerful indication of how poorly known the Cambodian odonate fauna is. In combination with other recent work (Roland and Roland 2010, Day 2011, Kosterin and Holden 2011, Roland *et al.* 2011) this has brought the known total to 110 species, but there is clearly much still to be done. The Laotian fauna is rather better understood, mainly due to the efforts of Dr Naoto Yokoi, who added more than one hundred new species records over the period 1994 to 2003 (Hämäläinen 2004), bringing the Lao PDR total to in excess of two hundred species. Studies of Vietnamese Odonata have advanced considerably in recent years, to the point that a useful annotated checklist of 235 species was recently published (Do and Dang 2007), with maps showing species distributions at provincial level.

Indo-Burma comprises all, or part, of 16 'freshwater ecoregions' as defined by Abell *et al.* (2008) (Figure 2.3). These ecoregions are derived primarily on the basis of freshwater fish distributions (Abell *et al.* 2008); nevertheless they are used as the basis for the following discussion. It should be noted, however, that they are not necessarily as directly relevant to Odonata distributions as to other freshwater fauna, since most odonates can readily cross watersheds. Forest cover and topography are likely to be at least as important in shaping dragonfly species assemblages across the region. Forests contain the highest odonate diversity in the tropics (Dijkstra and Clausnitzer 2006:131); indeed, running waters in tropical rainforests support the greatest diversity of odonates across the world (Kalkman *et al.* 2008). Such forests contain a wealth of different aquatic habitats suitable for dragonflies (Orr 2006:61–69), especially in montane areas (Oppel 2005), which also act as regional refugia (Kalkman *et al.* 2008).

The 16 freshwater ecoregions fall into four broad 'Major Habitat Types': upland rivers, floodplain rivers and wetland complexes, coastal rivers, and large river deltas (WWF/TNC 2008).

5.1.1 Upland rivers

Two very different 'upland river' ecoregions have been identified in the Indo-Burma region.

The **Upper Salween** ecoregion extends in a long narrow curve from eastern Tibet, through Szechuan and Yunnan, and ends in northeast Myanmar, where it impinges marginally on Indo-Burma. This is a remote, mountainous and very poorly studied area of Indo-Burma, with peaks in excess of 2,000 m. *Calopteryx laosica*, a near-endemic Data Deficient (DD) species, occurs in this area, as well as in central Lao PDR and northern Viet Nam.

Although classed as 'upland river', most of the **Khorat Plateau (Mekong)** is below 500 m in altitude. It is an extensive, relatively low-lying ecoregion in the Indo-Burma rain shadow, covering much of eastern Thailand and southern Lao PDR. It is ringed by the higher Annam Plateau to the east, the Xiangkhoang Plateau to the north, the Dong Phraya Fai uplands to the west, and the uplands of the Thai-Cambodia border to the south, and is drained by the Mekong. The endemics *Sarasaeschna minuta*, *Onychogomphus kerri*, *Zygonyx immaculata* and *Protosticta trilobata* appear to be confined to this freshwater ecoregion. However, all four of these species are currently considered to be DD.

5.1.2 Floodplain rivers and wetland complexes

The upland northern part of Indo-Burma is largely dominated by ecoregions falling into this very broad habitat category.

The **Sittang – Irrawaddy (Ayeyarwaddy)** ecoregion covers much of Myanmar and impinges on Indo-Burma north of Yangon, in the Sittang (Sittaung) basin to the east of the Pegu Yoma uplands, draining into the Gulf of Martaban. The area is poorly known for dragonflies.

The **Lower and Middle Salween** ecoregion is a narrow corridor of very diverse topography, ranging along the western margin of Indo-Burma from the mountainous Shan Plateau in eastern Myanmar southwards through upland northwest Thailand and lowland southeast Myanmar, including Kayah, Kayin and Mon, the Salween estuary and the coastal plain of Tenasserim. The endemics *Anotogaster gigantica*, *Burmagomphus minusculus*, *Orientogomphus earnshawi*, *Paragomphus risi*, *Lestes angularis* and *Drepanosticta viridis* are currently thought to occur in this freshwater ecoregion and nowhere else. In addition, the Indo-Burmese distribution of the near-endemic *Palaeothemis tillyardi* is confined to the Lower and Middle Salween. All of these species are considered DD.

The **Lower Lancang (Mekong)** ecoregion covers mountainous areas of northeast Myanmar, northern Lao PDR and northern

Thailand, including the Louang Phrabang Range in Lao PDR and northern Thailand and the Xianghoang Plateau, with peaks reaching 2,800 m, north of Vientiane. It also includes the lower lying Mekong in northern Lao PDR, west of Vientiane. The endemics *Devadatta glaucinotata*, *D. multinervosa* and *Macromia vangviengensis* are thought to be restricted to this ecoregion, which also includes the Indo-Burmese range of the near-endemic *Indocypha silbergliedi*. All are DD.

The **Song Hong** ecoregion to the east of the Lower Lancang includes the Red River and Black River in northern Viet Nam, and a small part of northeast Lao PDR. It contains upland areas such as the Hoang Lien Son mountains, rising to above 3,000 m, and the Phou Sam Sao mountains in the west. *Planaeschna tamdaoensis*, *P. tomokunii*, *Echo maxima*, *Rhinocypha orea*, *Chlorogomphus albomarginatus*, *C. nakamurai*, *C. sachiyoae*, *Procordulia asahinai*, *Davidius monastyrskii*, *Macrogomphus rivularis*, *Merogomphus tamdaoensis*, *Nihonogomphus schorri*, *Calicnemia uenoi*, *Coeliccia hoanglienensis*, *C. onoi*, *C. pyriformis*, *C. uenoi* and *Protosticta satoi* are all thought to be endemic to this ecoregion. The near-endemics *Cephalaeschna aritai*, *Calopteryx coomani*, *Chlorogomphus takaguwai*, *Asiagomphus auricolor*, *Leptogomphus uenoi*, *Coeliccia satoi*, *Drepanosticta vietnamica*, and *Rhipidolestes pallidistigma* are thought to be restricted within this ecoregion in Indo-Burma. While most of these species are considered DD, *Calopteryx coomani* is Near Threatened (NT), *Chlorogomphus nakamurai* is Vulnerable (VU), *Rhinocypha orea* is Endangered (EN) and *Echo maxima* is Critically Endangered (CR).

Adjacent to Song Hong is the extensive **Xi Yiang** ecoregion of Guangxi and eastern Yunnan, which marginally impinges on Indo-Burma in the upland border areas of northeast Viet Nam. *Orientogomphus naninus* (DD) is possibly endemic in Indo-Burma, where it is found only in Xi Yiang and Song Hong. The near-endemics *Chloropetalia owadai* (DD) and *Watanabeopetalia uenoi* (VU) are confined to this ecoregion and to Song Hong in Indo-Burma.

The **Kratie-Stung Treng (Mekong)** ecoregion covers a fairly large area of the relatively dry lowland Indo-Burma interior, southeast of the Khorat Plateau, including southern Lao PDR, central-western Viet Nam and eastern Cambodia. The endemics *Chlorogomphus vietnamensis* and *Protosticta robusta* (both DD), are restricted to this ecoregion and one other (Mekong Delta and South Annam respectively).

Cryptophaea vietnamensis – a Least Concern species endemic to the Song Hong ecoregion. © Phan Quoc Toan

Merogomphus tamdaoensis female – a Data Deficient species, endemic to the Song Hong ecoregion. © Do Manh Cuong

Nihonogomphus schorri female – a Data Deficient species, currently considered endemic to the Song Hong ecoregion. © Do Manh Cuong

Chlorogomphus nakamurai, female – a Vulnerable species, thought to be endemic to the Song Hong ecoregion. © Do Manh Cuong

Occupying much of northern and central Thailand, the **Chao Phraya** ecoregion contains the entire catchment of the Chao Phraya, from the Chiang Mai area to Bangkok. It is bordered on the northeast by the Louang Pherabang Range and on the northwest by the Dawna Range. The southern part of the ecoregion is lowland. The endemics *Sarasaeschna pramoti*, *Planaeschna chiengmaiensis*, *Caliphaea angka*, *Mnais yunosukei*, *Cryptophaea saukra*, *Anisogomphus pinratani* and *Prodasineura doisuthepensis* are thought to be restricted to this ecoregion. *Cryptophaea saukra* is CR, and *Caliphaea angka* is EN. *Mnais yunosukei* is LC. The other species are DD.

Immediately to the west of the Chao Phraya is the **Mae Khlong** ecoregion, covering the relatively small catchment of the river of that name, which, like the Chao Phraya, drains into the Bight of Bangkok. It is bordered to the west by the Bilauktaung Range between Thailand and southeast Myanmar. The endemics *Idionyx iida* (LC) and *Burmagomphus johnseni* (DD) are apparently confined to this ecoregion.

5.1.3 Coastal rivers

Coastal river ecoregions occupy the coastal fringe of most of Indo-Burma, with the exceptions of northern Viet Nam, Tenasserim, the Bight of Bangkok area and the Mekong delta. They predominate in Viet Nam, on both sides of the Gulf of Thailand and along the Andaman Sea coast of southern Thailand and Kedah.

The **Northern Annam** ecoregion includes the coastal plain of north-central Viet Nam, and the east side of the Annam Plateau between Thanh Hoa and Dong Hoi. It continues inland to the mountainous northeast of Lao PDR. The remarkable endemic *Platycnemis phasmovolans* (DD) is currently known only from this ecoregion.

The **Southern Annam** ecoregion occupies central and southeast Viet Nam from Dong Hoi to Ho Chi Minh, with uplands in the southeast rising to above 2,000 m. *Planaeschna bachmaensis*, *P. owadai*, *P. viridis*, *Noguchiphaea mattii*, *Vestalaria vinnula*, *Rhinocypha seducta*, *Anotogaster klossi*, *Euphaea hirta*, *Protosticta caroli* and *P. linnaei* are currently thought endemic to this freshwater ecoregion. With the exception of *Vestalaria vinnula* and *Protosticta linnaei* (both LC), these species are all DD.

The **Eastern Gulf of Thailand Drainages** ecoregion covers coastal Thailand east of Bangkok, and coastal Cambodia. It is

Coeliccia doisuthepensis – a Least Concern species endemic to Indo-Burma, present in Chao Phraya, Lower Lancang and Lower and Middle Salween ecoregions. © Rory Dow

Caliphaea angka – a species currently assessed as Endangered and considered endemic to the Chao Phraya ecoregion. © Sami Karjalainen

Mnais yunosukei – known only from Doi Inthanon and Doi Hom Pok in Chiang Mai in the Chao Phraya ecoregion. Assessed as Least Concern. © Matti Hämäläinen

Noguchiphaea yoshikoae – a Data Deficient species, endemic to Indo-Burma, known from the Chao Phraya and Song Hong ecoregions. © Phan Quoc Toan

Rhinocypha fulgipennis – a Data Deficient Indo-Burma endemic, known from the Southern Annam and Kratie-Stung Treng ecoregions. © Do Manh Cuong

Rhinocypha seducta – a Data Deficient Indo-Burma endemic, known from the Southern Annam ecoregion. © Do Manh Cuong

Coeliccia yamasakii – a Least Concern Indo-Burma endemic, known from the Eastern Gulf of Thailand Drainages ecoregion. © Jeremy Holden

Devadatta cyanocephala – a Least Concern Indo-Burma endemic, known from the Mekong Delta, North Annam and South Annam ecoregions. © Do Manh Cuong

bordered to the north by the Chuor Phnum Kravanh uplands, which reach an altitude of 1,800 m. The endemics *Coeliccia yamasakii* (LC) and *Drepanosticta jurzitzai* (DD) are restricted to this ecoregion and one other (Song Hong and Mae Khlong respectively).

The **Malay Peninsula Eastern Slope** ecoregion includes most of lowland peninsular Thailand and also the eastern side of the Malay Peninsula, the extreme northern tip of which is considered to lie within Indo-Burma. The **Northern Central Sumatra-Western Malaysia** ecoregion impinges marginally on Indo-Burma, in extreme southwest Thailand and northwest Peninsular Malaysia, and comprises coastal lowlands. The endemics *Euphaea pahyapi* (VU) and *Drepanosticta khaochongensis* (DD) are thought to be restricted to these two ecoregions.

5.1.4 Large river deltas

The **Mekong Delta** ecoregion extends a considerable distance inland from the deltaic area of southern Viet Nam to as far north as the Chuor Phnum Dangrek uplands on the northern border of Cambodia. It is a lowland area that includes the Tonlé Sap lake as well as extensive coastal marshes. *Zyxommoides breviventre* (DD) is believed to be endemic in this ecoregion.

5.2 Conservation status

The summary presented here is based on a global species assessment applying the IUCN Red List Categories and Criteria. The compilation of the list of species considered to be present within the Indo-Burma region was led by Dr Rory Dow, in consultation with other experts participating in the assessment.

Of the extant species for which sufficient data exist, a total of 14 species (4.2% of the fauna) are assessed as threatened (Table 5.1; Figure 5.2), while 11 (3.3%) are considered Near Threatened (NT), and 312 (92.6%) are believed to be Least Concern (LC). Among threatened species, ten are assessed as Vulnerable (VU), two – *Caliphaea angka* and *Rhinocypha orea* – are Endangered (EN) and two – *Cryptophaea saukra* and *Echo maxima* – are Critically Endangered (CR). It should be noted that the assessments of *C. angka* and *C. saukra*, as well as *Bayadera hyalina* and *Protosticta khaosoidaoensis* (both VU) are several years old and will be due for review in the near future. A total of 136 species are so poorly known as to be considered Data Deficient.

The 14 threatened species are all in families that are essentially forest stream-associated, with the exception of the libellulid *Urothemis abbotti* (Table 5.2), as are the majority of NT and DD species. Conversely, most of the species in the cosmopolitan families Coenagrionidae and Libellulidae (118 out of 135) are listed as LC, reflecting the ubiquity of many of these species in open standing or slow-flowing water habitats (ponds, rice paddies, canals, ditches and unshaded low gradient natural watercourses) across the region. *Urothemis abbotti*, which is assessed as VU, is thought to be a mangrove species (Tang *et al.* 2010).

The high proportion of DD species in Indo-Burma, while somewhat lower than that for the neighbouring Eastern Himalaya region (Mitra *et al.* 2010) is essentially a reflection of the paucity of information on distributions of rare and uncommon forest dragonflies across the region. The underlying causes of this knowledge deficit are historical and physical. In the post-colonial era much of Indo-Burma was convulsed in conflict and political upheavals which rendered the pursuit of odonatology difficult if not impossible for locals and foreigners alike. In the last 20 or so years the situation has improved considerably, although home-grown odonatologists are still few in number (possibly non-existent in Lao PDR and Cambodia). However, much of the forested mountainous terrain which dominates large swathes of the region, especially in the north, is difficult to penetrate. The dragonfly field surveys of the last decade or so, particularly in Cambodia, Lao PDR and Viet Nam, usually

Table 5.1 The number of species of dragonflies and damselflies under each IUCN Red List Category in the Indo-Burma region.

Regional Red List Category	Number of species
Extinct	0
Extinct in the Wild	0
Critically Endangered	2
Endangered	2
Vulnerable	10
Near Threatened	11
Least Concern	312
Data Deficient	136
Total	**473**

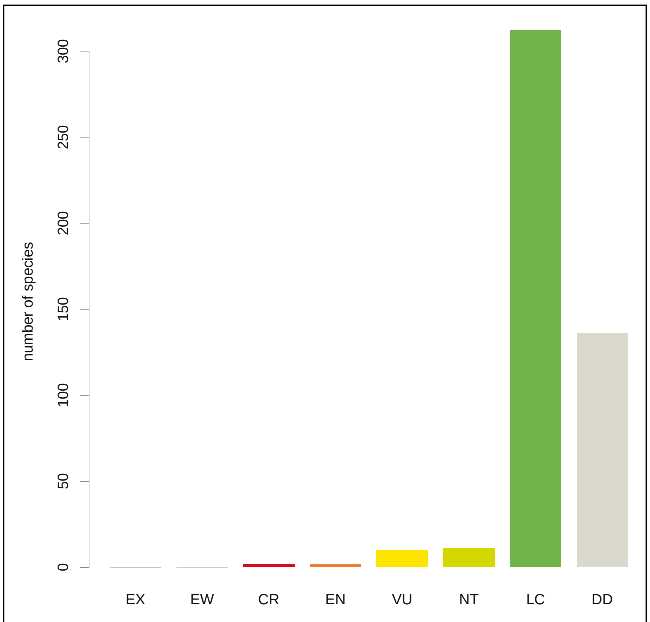


Figure 5.2 The number of extant dragonflies and damselflies species under each IUCN Red List Category in the Indo-Burma region.

Table 5.2 Threatened Odonata species in the Indo-Burma region.

Threat Category	Species	Range
Critically Endangered	*Echo maxima* (Calopterygidae)	N Vietnam [endemic]
	Cryptophaea saukra (Euphaeidae)	NW Thailand [endemic]
Endangered	*Caliphaea angka* (Calopterygidae)	NW Thailand [endemic]
	Rhinocypha orea (Chlorocyphidae)	N Vietnam [endemic]
Vulnerable	*Petaliaeschna flavipes* (Aeshnidae)	NW Thailand, N Vietnam [+ S China]
	Sarasaeschna niisatoi (Aeshnidae)	N Vietnam [+ S China]
	Chlorogomphus nakamurai (Chlorogomphidae)	N Vietnam [endemic]
	Watanabeopetalia uenoi (Chlorogomphidae)	N Vietnam [+ S China]
	Bayadera hyalina (Euphaeidae)	NW Thailand, E Myanmar [+ India, Bangladesh]
	Euphaea pahyapi (Euphaeidae)	S Thailand [endemic]
	Urothemis abbotti (Libellulidae)	S Thailand [+ PM, Singapore]
	Macromia katae (Macromiidae)	C Laos [+ S China, Hong Kong, Hainan]
	Philosina alba (Megapodagrionidae)	C Laos [+ S China, Hainan]
	Protosticta khaosoidaoensis (Platystictidae)	NW + E Thailand, W Cambodia, N Vietnam [endemic]

undertaken by Japanese or Western workers on constrained time budgets, have necessarily tended to focus on a small number of relatively accessible locations. It is likely that several of the species currently listed as DD in Indo-Burma will eventually fall into a defined threat category when their distributions and habitat requirements are more confidently understood.

5.3 Patterns of species richness and endemism

The known and inferred patterns of odonate species richness that are presented in Figure 5.3 are, to varying degrees, partially an artefact of uneven field survey efforts across the Indo-Burma region. For example, Chiang Mai Province in northern Thailand (covering the northern part of the Chao Phraya and southwestern part of the Lower Lancang freshwater ecoregions) is the best-studied province of Thailand (Hämäläinen and Pinratana 1999) and, by inference, the best-studied area of Indo-Burma; not surprisingly, it is also one of the most species-rich areas (Figure 5.3). Cambodia, the least-studied area, (lying mainly in the Mekong Delta freshwater ecoregion, with Kratie-Stung Treng in the northeast and Eastern Gulf of Thailand Drainages in the southwest) has lowest species richness (Figure 5.3). Of course, it is also the case that good areas for odonates become better-studied than other areas because they attract odonatologists, but it should be noted that Figure 5.3 almost certainly underestimates odonate species richness in much of Cambodia and in poorly known areas of Myanmar, Lao PDR and Viet Nam. Even in Chiang Mai, only a few upland and montane sites (mostly on Doi Inthanon and Doi Suthep) can be considered as close to being 'well studied'.

Notwithstanding the above caveats, the highest overall odonate species richness in Indo-Burma is in a swathe including northwestern Thailand, southeastern Myanmar and extreme western Lao PDR (Figure 5.3a), in the Lower and Middle Salween, Lower Lancang, Mae Khlong and Chao Phraya freshwater ecoregions. Overall species richness is also high in central and southern Thailand, western Lao PDR, northern Viet Nam and parts of southeast Myanmar (covering parts of the Song Hong, Xi Yiang, Khorat Plateau, Chao Phraya, Mae Khlong, Malay Peninsula Eastern Slope, Lower and Middle Salween, and Northern-Central Sumatra – West Malaysia freshwater ecoregions). The lowest overall species richness is in southern Lao PDR, southern Viet Nam and Cambodia (Mekong Delta, Kratie-Stung Treng, Southern Annam and Northern Annam). This pattern is very broadly replicated for endemic, threatened, and Data Deficient species (Figures 5.3b–d). It is notable, however, that there are two discrete, clearly discernible, hot-spots of endemicity, threatened species and data deficiency: in northwestern Thailand around Chiang Mai and adjacent provinces (Chao Phraya) and in northern Viet Nam, centred on the provinces of Cao Bang, Bac Can and Thai Nguyen (Song Hong). These are predominantly upland areas; historically thickly forested (although most of the forest is now gone, particularly in northern Viet Nam (Figure 5.1)). It is noteworthy that the interior rain shadow area of Indo-Burma, which has always been less forested than the rest of the region, is one of the poorest areas for odonates.

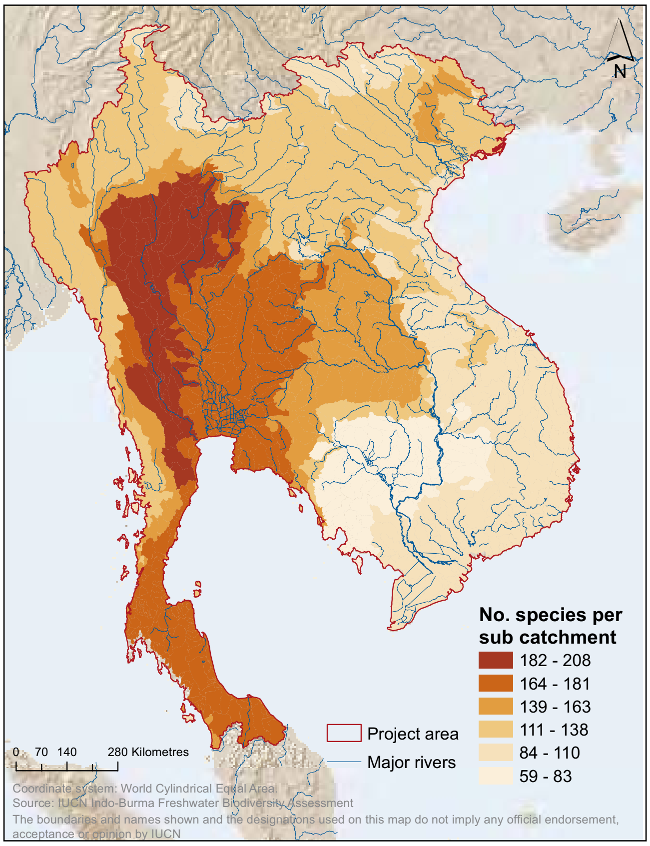
5.3.1 Threatened species

The freshwater ecoregion in Indo-Burma with the largest number of threatened species (seven) is the Song Hong (Figure 5.3c), which has essentially an Indochinese fauna, and is a rich centre of endemism. Five threatened species in Song Hong are endemic or near-endemic to Indo-Burma; three are endemic to the ecoregion itself, including the Critically Endangered *Echo maxima*, the Endangered *Rhinocypha orea* and the Vulnerable *Chlorogomphus nakamurai*. The area has been heavily deforested, with only scattered small patches of broadleaved evergreen forest remaining. On the other side of Indo-Burma, the Chao Phraya ecoregion supports five threatened species, of which four are endemic to Indo-Burma and two – *Cryptophaea saukra* (CR) and *Caliphaea angka* (EN) – are endemic to Chao Phraya. The Lower and Middle Salween ecoregion supports four Vulnerable species of mixed provenance, two (*Petaliaeschna flavipes* and *Protosticta khaosoidaoensis*) being endemic/near-endemic but quite widespread in Indo-Burma, while *Bayadera hyalina* occurs as far west as Bangladesh and *Urothemis abbotti* has a sondaic provenance. *P. khaosoidaoensis* also occurs in the Eastern Gulf of Thailand Drainages and Mekong Delta freshwater ecoregions, as well as Song Hong and Chao Phraya. Both the Xi Yiang and the Lower Lancang freshwater ecoregions support two threatened species of Indochinese provenance: the near-endemics *Sarasaeschna niisatoi* and *Watanabeopetalia uenoi* in Xi Yiang, and the more widely distributed *Macromia katae* and *Philosina alba* in Lower Lancang. The Malay Peninsula Eastern Slope and North-Central Sumatra – Western Malaysia freshwater ecoregions in peninsular Thailand, at the southern end of Indo-Burma, where the sondaic influence is greatest, support small populations of the endemic *Euphaea pahyapi*.

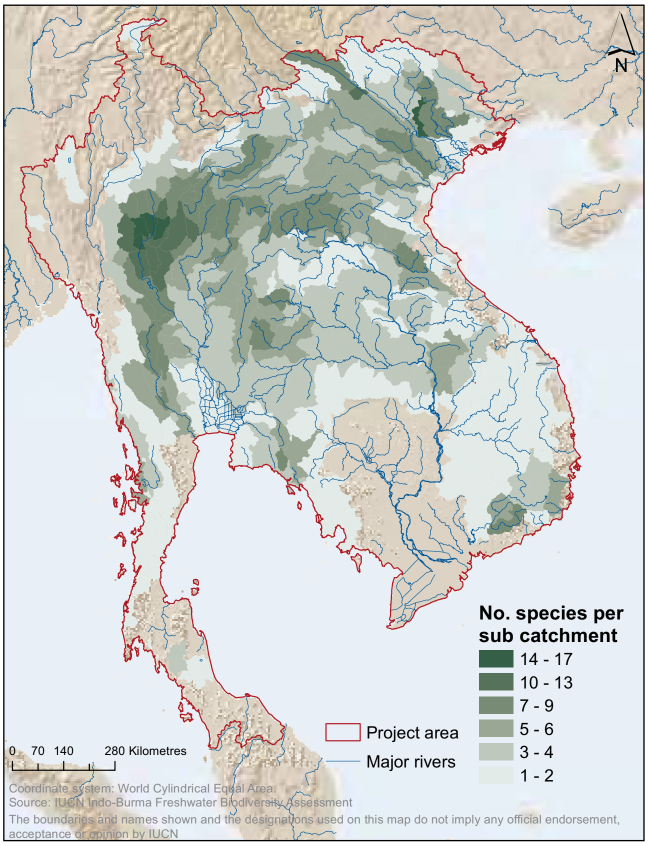
5.3.2 Data Deficient species

The high proportion (29%) of Indo-Burmese species that falls into this category, as compared with, for example, 18% in

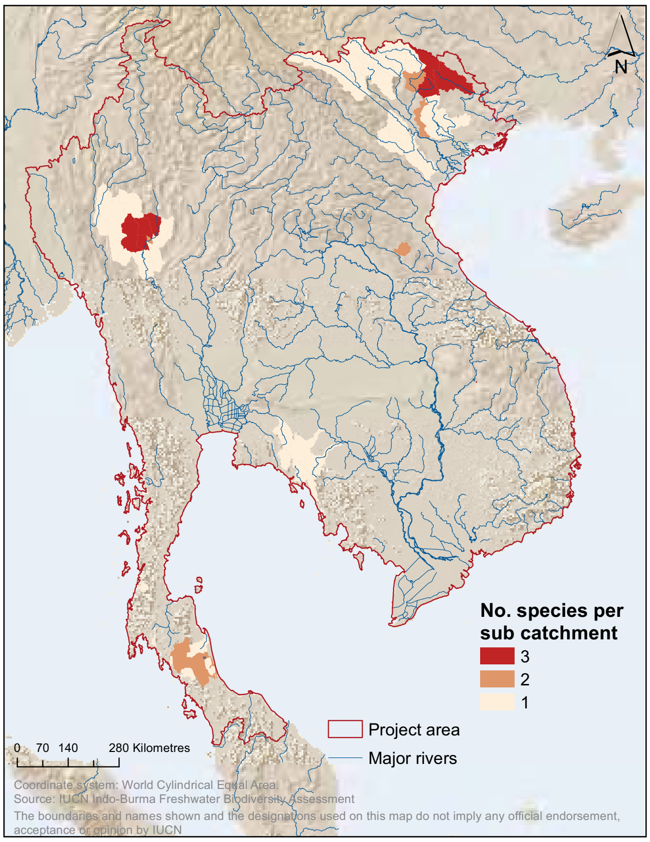
Euphaea pahyapi – a Vulnerable species endemic to the Malay Peninsula Eastern Slope and Northern Central Sumatra – Western Malaysia ecoregions. © Matti Hämäläinen



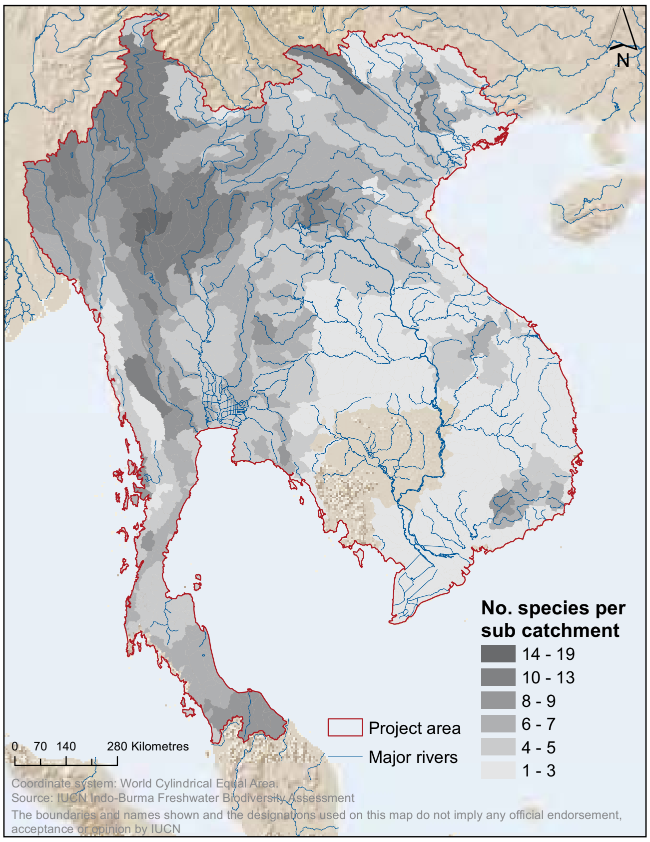
(a) Overall species richness



(b) Endemic species richness



(c) Threatened species richness



(d) Data Deficient species richness

Figure 5.3 Patterns of species richness in the Indo-Burma region based on known and inferred distributions.

Southern Africa (Suhling *et al.* 2009) and 14% in Central Africa (Dijkstra *et al.* 2011) is indicative of high local endemism and it is no surprise that the distribution mapped in Figure 5.3d so closely matches that for endemic species (Figure 5.3b). The areas of highest data deficiency are paradoxically also the areas that have been best studied, and it is clear therefore that much more concerted efforts will be required in these areas before the odonate fauna of Indo-Burma, the species ranges, habitat requirements and levels of threat, can be said to be thoroughly understood.

5.4 Major threats to dragonflies

Habitat loss, degradation, or modification, both in the aquatic and the terrestrial environments, represent the major threats to Odonata in Indo-Burma (and in the tropics worldwide). As indicated in Figure 5.4, the three most wide-ranging threats are residential and commercial development, biological resource use (including logging), and agriculture and aquaculture. All of which are particularly significant for threatened species (Figure 5.4). As noted above, a high proportion of species in Indo-Burma are forest-associated, with only 30.5% of species in the cosmopolitan families Coenagrionidae and Libellulidae, most members of which favour open unshaded habitats. This figure compares with 50% of species in the Afrotropics and > 40% in the Nearctic (Kalkman *et al.* 2008). The high proportion of forest-associated odonate species in the Oriental region generally (< 25% coenagrionids and libellulids; Kalkman *et al.* 2008) is possibly due to the fact that Southeast Asia differs from most other broad tropical regions by being overwhelmingly a region of forest climates (Corlett 2005). Since many forest odonates seem to be stenotopic and disturbance-sensitive, and reliant on the availability of shade (Dijkstra and Clausnitzer 2006), it is no surprise that activities which result in reduced forest cover in Indo-Burma will impact negatively on its forest-associated odonates, which tend to be out-competed by open land species such as libellulids and coenagrionids when the forest is opened up (Dijkstra and Clausnitzer 2006). Forest clearances may originally be for timber harvesting, but are often followed up by the establishment of coffee, oil palm or (in the past) rubber plantations, precluding any possibility of natural forest recovery. This is certainly an issue in Thailand and Viet Nam, which are among the world's largest producers of oil palm and coffee, respectively. For example, *Atrocalopteryx atrocyana* has apparently been extirpated from parts of its range in Viet Nam by recent habitat destruction in the form of hotel and road construction, logging and changing agricultural use. The main population of the threatened Indo-Burmese endemic *Euphaea pahyapi*, at Khao Phenom Bencha National Park in southern Thailand, has been much reduced not only by streambed clearance within the national park (by park staff to develop tourist facilities) but by forest clearance and development of oil palm plantations outside of the national park. The only confirmed locality of the Data Deficient endemic *Anisogomphus pinratani*, in northwest Thailand, has been seriously compromised by tourism facilities, forest clearance and agriculture.

The region has many protected areas. Hämäläinen (2004) gives figures for protected area coverage of 17%, 7.4%, 14% and 21% in Thailand, Viet Nam, Lao PDR and Cambodia respectively). However, degradation of nature reserves by encroachment, development of tourism facilities and illegal logging is probably a significant problem, particularly in Cambodia and Lao PDR, where enforcement is limited, and also in Viet Nam. An emerging threat is from the Chinese leisure industry. Kosterin (2011) noted that the Preah Monivong National Park on the Bokor Plateau in southwest Cambodia has been dramatically deforested by recent construction activities, conducted by and for Chinese, which will apparently culminate in a new leisure town of three thousand houses, complete with golf courses and casino, while even more extensive Chinese-led developments are in the pipeline at Botum-Sokor National Park.

Dam construction represents a significant threat to running water odonates in Indo-Burma. Damming is widespread in Thailand and Viet Nam and there are many new dams proposed for construction in Lao PDR. Kosterin (2011) reported on hydropower developments upstream of the Koh Por waterfalls in Cambodia, which have resulted in spectacular deforestation along the Koh Por River, and on a similar scheme on the Tatai

The habitat of *Rhinocypha orea*, an Endangered species endemic in the Song Hong ecoregion, at Tam Dao, Viet Nam. © Do Manh Cuong

The polluted main stream of Tam Dao town, which connects to the known *Rhinocypha orea* site. © Do Manh Cuong

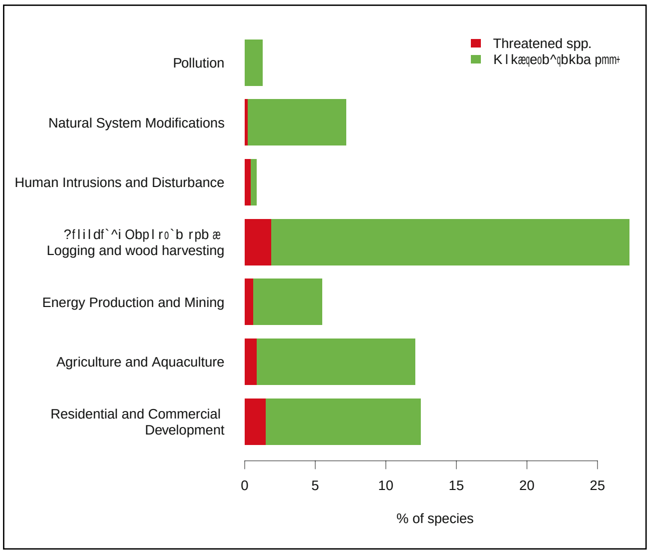


Figure 5.4 Percentages of species affected by each threat. Note that many species have more than one threat listed.

River that will convert possibly 7 km of the river into an energy producing channel. There is also a proliferation of hydroelectric dams in the bordering areas of south China. Some of these 'small-scale' Chinese dams are very large and presumably have an impact on discharge and flow rates in downstream areas across the northern part of Indo-Burma. The Chinese practice of channelling all the streams on a mountain or hill into one feed for the dam is an extremely destructive practice for forest stream Odonata, and a model that other countries should be heavily discouraged from following.

5.5 Conservation recommendations

5.5.1 Conservation measures

The effective conservation of Odonata depends entirely on conservation of their habitats. No other measures are of any real value. However, dragonflies do not need huge protected areas; in fact many small areas will probably serve them better than a few scattered big areas, as long as the protected areas are looked after properly. The degradation of dragonfly habitats arising from changing land-use can be ameliorated by appropriate development planning controls, such as maintenance of forest riparian corridors along streams running through logging concessions or agribusiness plantations, limits on water abstraction, and non-development buffer zones along or around natural water bodies. Effective stream buffers are rarely maintained in practice, even when touted as such, but they are an essential part of dragonfly conservation. It is important that at least some stream buffers are extended into conservation areas around the sources of streams (e.g. so that tiny seepages and trickles are included) to protect the substantial part of forest damselfly diversity found in these places. These streams are generally considered too small to deserve a buffer of their own.

Protected areas already exist in many of the best remaining dragonfly habitats in Indo-Burma, but the effectiveness of conservation policies and measures is often poor due to inadequate enforcement. Strict enforcement of regulations in nature reserves and national parks by the relevant authorities, together with expansion of existing protected areas and designation of new ones, particularly in forest areas, would undoubtedly enhance the efficacy of the protected areas systems as a means of conserving odonates across the region.

The downstream impact of dams on small and large rivers can be mitigated to some extent if a natural water regime with normal seasonal fluctuations, albeit much reduced discharge, is permitted by the dam design. This can reduce disturbance to the breeding and larval habitats of many riverine dragonflies.

5.5.2 Research actions required

Many species in Indo-Burma are only known from parts of protected areas that are relatively accessible. Concentration of efforts on a few high quality habitats in protected areas can in some cases create a biased view of a species' habitat requirements and/or scarcity. Much more work is needed in both protected and unprotected areas across the region. However there is a funding deficit for further research generally in the region, and for capacity building among local odonatologists, who are still few in number. To further facilitate effective research, unnecessary bureaucratic obstacles to the collection of specimens for research purposes should be removed, as many Odonata, particularly poorly known species, cannot be reliably identified without collection.

Some areas within the Indo-Burma region are clearly particularly poorly known for Odonata. One area that stands out as showing high promise is the Cardamom Mountains of Cambodia, which includes one of the largest remaining tracts of primary forest in Southeast Asia (Hämäläinen 2004). Myanmar is also very poorly known, with very little sampling of Odonata ever carried out and virtually no recent records. However, as noted above, even in relatively well-studied areas such as Chiang Mai, the number of actual locations that have been well enough sampled that their odonate fauna can be said to be well known, is very few. This is especially the case at higher altitudes across the region. As many forest dwelling odonates are very local in occurrence, a good picture of their distribution and true habitat requirements only emerges with intensive sampling at many locations in an area.

Taxonomic review is another issue that needs more attention, in order to reduce the confusion that surrounds species such as *Drepanosticta khaochongensis*, a taxon whose status is uncertain (it may in fact be a synonym of *D. sharpi*). The need for clarification of taxonomic status is a common problem among many groups of dragonflies. In addition, as yet unnamed species are either known to exist (for instance in the genus *Coeliccia* in Viet Nam) or very likely to exist in many odonate groups within the region. In many cases taxonomic revisions are needed before new species can be reliably described (to avoid further taxonomic confusion).

Taxonomic work suffers from the same lack of funding as fieldwork and is also hampered by restrictions on collection of specimens.

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Chapter 6. Freshwater crabs of the Indo-Burma hotspot: diversity, distribution, and conservation

Neil Cumberlidge[1], Peter K.L. Ng[2] and Darren C.J. Yeo[2]

6.1 Overview of the freshwater crab fauna of the Indo-Burma hotspot

Freshwater crabs are among the most important invertebrates inhabiting Asian inland waters and these large and conspicuous crustaceans are present in almost all freshwater habitats from mountain streams to large lowland rivers and smaller water bodies (Yeo *et al.* 2008). The present work focuses on the freshwater crabs of the biodiversity hotspot that is centred in the Indo-Burma region that lies in five countries: Thailand, Cambodia, Viet Nam, Lao Peoples Democratic Republic (Lao PDR), and the eastern part of Myanmar. A small portion of Malaysia (the northwestern states of Perlis and Kedah) falls within the southern tip of the Indo-Burma region (Figure 1.1); however, this contributes only four species (one endemic) to the region's richness, representing less than 5% of the country's freshwater crab fauna, as such Malaysia will be excluded from our discussions of country level patterns in this paper. Specifically, the Indo-Burma region as considered here extends from the Salween eastwards, and includes the Thai peninsula, coastal basins in Myanmar, Thailand, and Indochina, and the major river basins (Mekong, Chao Praya, Hong and Da, Mae Klong), excluding the Chinese parts of these river basins.

The number of species of freshwater crabs found in the Indo-Burma hotspot has grown steadily as the number of revisionary taxonomic studies in this part of Asia has increased (Rathbun 1902, 1904, 1905; Alcock 1909, 1910; Balss 1914, 1918, 1923; Bott 1966, 1968, 1970; Ng 1988, Ng and Naiyanetr 1993, 1995; Yeo and Ng 1997, 1998, 1999, 2003, 2004, 2005, 2007, 2010; Yeo *et al.* 1999, Yeo and Naiyanetr 1999, 2000, 2010; Ng and Yeo 2001, Yeo 2004, 2010; Yeo and Naruse 2007, Yeo *et al.* 2008, Ng *et al.* 2008, Naiyanetr and Yeo 2010, Naruse *et al.* 2011). These works have resulted in the description of large numbers of new species and new genera. The revisions at the family-level have included the revalidation of the subfamily Potamiscinae of the Potamidae Ortmann, 1896, to include all east Asian potamids, including those in the Indo-Burma hotspot (Yeo and Ng 2003), and the reassignment to the Gecarcinucidae Rathbun, 1904 of all species formerly assigned to the Parathelphusidae following the synonymy of these two families, with priority going to the Gecarcinucidae (Klaus *et al.* 2009).

In biogeographical terms the Indo-Burma hotspot lies in the Oriental zoogeographical region, an area that includes India, southern China, and Southeast Asia as far east as Wallace's line (Yeo *et al.* 2008). The Oriental region is the most taxonomically

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diverse part of the world with over 900 species of freshwater crabs in 154 genera and two families, totals that are markedly higher than those of the faunas of the Neotropical region (50 genera, 298 species, two families) and the Afrotropical region (18 genera, 133 species, two families) (Yeo *et al*. 2008, Cumberlidge *et al*. 2009).

The Indo-Burma hotspot hosts 182 known species of freshwater crabs in 55 genera and two families, the Gecarcinucidae (45 species, ten genera) and the Potamidae (136 species, 45 genera) (Ng *et al*. 2008, Yeo *et al*. 2008, Cumberlidge *et al*. 2009). This fauna is more diverse than previously assumed, and there are many more species still to be discovered. The freshwater crab genera of the Indo-Burma hotspot is highly endemic at the country level – 92% of the potamid species, and 76% of the gecarcinucid species endemic (Yeo *et al*. 2008, Cumberlidge *et al*. 2009).

6.1.1 Biogeographic patterns

The Indo-Burma hotspot shows a distinct north-south latitudinal trend that corresponds to the broader regional trend reported by Yeo and Ng (2003), whereby potamids dominate over gecarcinucids in the north, but gecarcinucids dominate over potamids in the south. For example, in China the ratio of potamids:gecarcinucids is 91:9, but this ratio changes further south, and is 73:27 in Indochina, and 51:49 in Peninsular Malaysia (Yeo and Ng 1998). In the Indo-Burma hotspot dealt with here, the Potamidae constitute approximately 75% of the known fauna, with the Gecarcinucidae making up the remaining 25%. In the northern part of this region gecarcinucids are poorly represented in Myanmar and Lao PDR (only 9% and 12%, respectively) but become increasingly more dominant in Viet Nam and Thailand (23% and 33%, respectively). In Cambodia the gecarcinucids are the dominant fauna (and no potamids are known from this country), but the figures for this country are almost certainly an artefact of under-collection (Yeo and Ng 1998). Further to the south of the Indo-Burma hotspot, in the Malay Peninsular and insular Sundaic Southeast Asia, the number of species of gecarcinucids increases and easily exceeds the number of species of potamids (Ng 1988). This dominance is already hinted at within the small portion of Peninsular Malaysia that falls within the Indo-Burma hotspot, with three out of the four species occurring there being gecarcinucids.

Freshwater crabs are found in all major habitat types in the Indo-Burma hotspot including floodplains, swamps, lakes, moist forest rivers, highland and mountain systems, large lakes, and large river rapids. Species diversity is highest in the rivers and streams of the major river basins, especially those that flow through lowland rainforest and drain forested highlands. Because of their widespread representation in Indo-Burma's aquatic ecosystems, freshwater crabs are also represented in most of the regions' freshwater ecoregions (for example, tropical and subtropical floodplain rivers and wetland complexes, montane freshwaters, tropical and subtropical upland rivers, tropical and subtropical coastal rivers, and large river deltas) (Thieme *et al*. 2005, Abell *et al*. 2008). However, with only a few exceptions, there is no close correlation between freshwater crab distribution patterns and freshwater ecoregion boundaries found in the Indo-Burma hotspot. The only instances where freshwater crab distribution coincides with ecoregion boundaries are those species that have a restricted distribution.

Most freshwater crabs are nocturnal scavengers or opportunistic predators, and some species have economic and ecological importance (Yeo *et al*. 2008). For example, some species are rice field pests, some are a source of protein for people, and other species have medical importance serving as the second intermediate host of the parasitic human lung fluke, *Paragonimus*. Some species of freshwater crabs also serve as bio-indicators of ecosystem disruption, some are threatened by collection for the aquarium trade, and some are even conservation icons, such as the Thai Royal crabs: *Phricotelphusa sirindhorn* (LC)*, Indochinamon bhumipol* (EN), and *Thaiphusa sirikit* (LC).

6.2. Conservation status

The conservation status of 173 Indo-Burma's known freshwater crab fauna was assessed as part of the global study by Cumberlidge *et al*. (2009) using the IUCN Red List Categories and Criteria at the global scale (IUCN 2003) and individual species assessments are available through the IUCN Red List website (www.iucnredlist.org). The conservation assessments of nine species, mainly recently described taxa, are in progress and are considered provisional. The Cumberlidge *et al.* (2009) study included information from specialists and as many literature sources as possible from the Oriental region, including national Red List assessments that focused on Viet Nam, Malaysia (Ng and Yeo 2007), Japan (Naruse 2008), and Sri Lanka (Bahir *et al*. 2005).

The results reveal current high levels of threat, with 26 (34%) of the assessed extant species for which sufficient data are available considered Threatened (Table 6.2, Figure 6.1). There was insufficient information to assess the status of 98 species, which

Indochinamon dangi, a recently described species of freshwater crab from northern Thailand, has not yet been formally assessed against the IUCN Red List Categories. © Darren C.J. Yeo

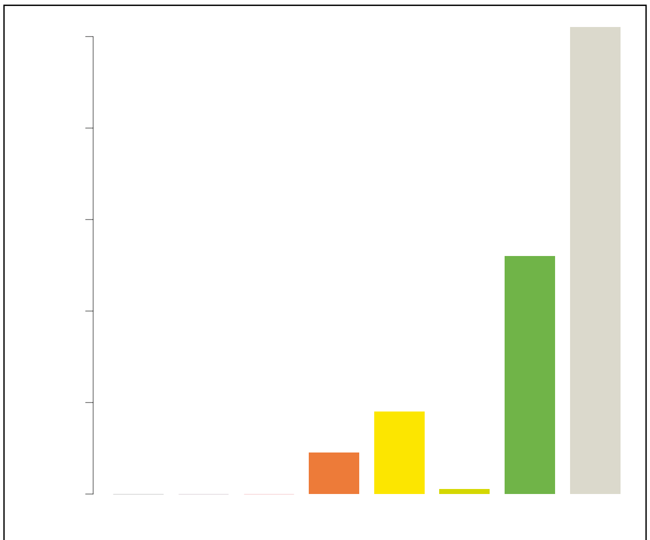
Table 6.1 **The 27 species of freshwater crabs found in the Indo-Burma hotspot that are threatened with extinction. * Indicates provisional Red List Category based on draft assessment.**

Family GECARCINUCIDAE		Family POTAMIDAE	
Heterothelphusa fatum Ng, 1997	VU	*Doimon doichiangdao* (Naiyanetr & Ng, 1990)	EN
Mekhongthelphusa kengsaphu Naiyanetr & Ng, 1995	VU	*Doimon doisutep* (Naiyanetr & Ng, 1990)	EN
Mekhongthelphusa tetragona (Rathbun, 1902)	VU	*Indochinamon bhumibol* (Naiyanetr, 2001)	EN
Phricotelphusa limula (Hilgendorf, 1882)	VU	*Indochinamon cua* (Yeo & Ng, 1998)	VU
Phricotelphusa ranongi Naiyanetr, 1982	VU	*Indochinamon dangi* Naruse, Nguyen & Yeo 2011	VU*
Salangathelphusa anophrys (Kemp, 1923)	EN	*Indochinamon guttum* (Yeo & Ng, 1998)	VU
Sayamia maehongsonensis (Naiyanetr, 1987)	VU	*Indochinamon mieni* (Dang, 1967)	VU
Sayamia melanodactylus Ng, 1997	EN	*Indochinamon villosum* (Yeo & Ng, 1998)	EN
Siamthelphusa holthuisi Naiyanetr & Ng, 1991	EN	*Iomon luangprabangense* (Rathbun, 1904)	VU
Stelomon erawanense Naiyanetr, 1992	VU	*Iomon nan* (Ng & Naiyanetr, 1993)	EN
Stelomon kanchanaburiense (Naiyanetr, 1992)	VU	*Nemoron nomas* (Rathbun, 1904)	VU
Thaksinthelphusa yongchindaratae (Naiyanetr, 1988)	EN	*Pupamon phrae* (Naiyanetr, 1984)	VU
		Stoliczia panhai Ng & Naiyanetr, 1986	VU
		Stoliczia perlensis (Bott, 1966)	VU
		Tiwaripotamon edostilus Ng & Yeo, 2001	VU

Table 6.2 The number of assessed freshwater crabs in the Indo-Burma region under each IUCN Red List category.

IUCN Red List Category	Number of species
Extinct	0
Extinct in the Wild	0
Critically Endangered	0
Endangered	9
Vulnerable	17
Near Threatened	0
Least Concern	49
Data Deficient	98
Total	**173**

Figure 6.1 The number of extant freshwater crab species for which sufficient data exist under each IUCN Red List Category in the Indo-Burma region.



were categorised as Data Deficient (DD) due to a lack specimens, and locality and population data (Cumberlidge *et al.* 2009, D.C.J. Yeo *pers. comm.* 2012). However, if all Data Deficient (DD) species also prove to be threatened, the level of threat could be as high as 72%. No species are currently thought to be Extinct or Extinct in the Wild.

Of the 73 species assessed in the Indo-Burma hotspot, 98 were found to be Data Deficient, of the other 75 species 49 species are Least Concern (LC) (65%), and 26 are threatened (35%) (Table 6.2). The 49 LC species comprised 26 species of potamids in 14 genera, and 23 species of gecarcinucids in seven genera, and most of these live in rivers, marshy lowlands, or mountain streams in the forested parts of the region (Cumberlidge *et al.* 2009). Twenty-six (37%) of the 75 species for which there was sufficient data were listed in one of two threatened categories, either as Endangered (EN) (four species of gecarcinucids plus five species of potamids) or Vulnerable (VU) (six species of gecarcinucids plus 11 species of potamids), but none were assessed as Critically Endangered (CR) or as Near Threatened (NT). No species of freshwater crabs from the region have been confirmed Extinct (EX) or Extinct in the Wild (EW). However, it should be noted that a species cannot be formally assessed as Extinct until exhaustive surveys have been carried out.

6.3 Patterns of species richness

The five countries that lie in the Indo-Burma hotspot collectively have a rich, highly diverse, and distinctly recognisable freshwater crab fauna with a high proportion of species endemic to this region (Cumberlidge *et al.* 2009: Table 2. Distribution data used here have been derived from all available specimen records but are still likely to be incomplete. Although many of the species

Described in 2011 from Phong Nha, Quang Binh Province central Viet Nam, *Indochinamon phongnha*, is still to be formally assessed for the IUCN Red List. © Darren C.J. Yeo

are quite well studied, there are still some that are known only from either the type locality or from just a few records, and in these cases further collections are necessary to ascertain their actual distributions. The available data indicate that the composition of the freshwater crab fauna in the Indo-Burma hotspot is not uniform, changes from region to region, and varies with ecosystem, aquatic drainage basins, and vegetation cover. For example, freshwater crabs are found in all of the major ecosystems in this region, but are noticeably more abundant in the rainforest, especially in highland regions (Cumberlidge *et al*. 2009). Species diversity appears to depend on vegetation cover and the availability of water, with the highest number of species occurring in rainforest ecosystems, especially in highland areas, and the fewest in lowland ecosystems.

The taxonomic diversity is highest in Thailand (107 species, 36 genera, two families), which is both the most species rich and most diverse country in the region. Next are Viet Nam (44 species, 18 genera, two families) and Myanmar (23 species, 16 genera, two families) while the diversity is lower in Lao PDR (17 species, 10 genera, two families), and lowest diversity is in Cambodia (two species, two genera, one family). Distribution patterns considered at the genus level indicate that although each of these five countries has genera with species that are found in more than one country, the vast majority of genera have species that have a restricted distribution. In the region as a whole, 19 out of 182 species have a distribution that encompasses more than one country. *Indochinamon* is found in four countries in the region (all except for Cambodia), *Esanthelphusa* is found in Thailand, Lao PDR, and Viet Nam, *Phricotelphusa* is found in Thailand, Myanmar and Cambodia, *Somanniathelphusa* is found in Viet Nam, Myanmar and Cambodia, and *Eosamon* is found in Thailand, Viet Nam, and Myanmar. In addition, the potamid genera *Hainanpotamon, Iomon, Pudaengon, Demanietta, Kanpotamon, Neolarnaudia, Quadramon, Stelomon, Thaiphusa, Pilosamon, Rathbunamon,* and *Villopotamon* and the gecarcinucid genera *Heterothelphusa, Mekhongtelphusa,* and *Sayamia* are all found in two countries in the region. In contrast, the vast majority of genera (35) that are found in the Indo-Burma hotspot have a relatively restricted range and are endemic to a particular country.

Demanietta khirikhan (LC), known from northern Prachuap Khiri Khan and Phetchaburi Provinces in southern Thailand. © Tan Heok Hui

6.3.1 All freshwater crab species: interpretation of distribution patterns

The most speciose genera found in the Indo-Burma hotspot are *Siamthelphusa* and *Demanietta* (nine species each); *Esanthelphusa* and *Eosamon* (each with eight species); *Thaipotamon* (with seven species), and *Phricothelphsa* (six species). All species of *Siamthelphusa* are found only in Thailand, except for *S. nan* which is also found across the border in Lao PDR. Six species of *Siamthelphusa* are relatively well known and were assessed as LC (*S. acutidens, S. improvisa, S. paviei, S. retimanus, S. transversa,* and *S. variegata),* while three species have a restricted distribution and were either assessed as DD (*S. faxoni* and *S. nan*) or as EN (*S. holthuisi*). The nine species of the potamid genus *Demanietta* are found only in Thailand, except for *D. tritrungensis* and *D. thagatensis*, which are also found across the border in Myanmar. Seven species of *Demanietta* are relatively well known and were assessed as LC (*D. huahin, D. khirikhan, D. lansak, D. nakhonsi, D. renongensis, D. suanphung,* and *D. tritrungensis*), while two species (*D. manii* and *D. thagatensis*) were regarded as DD. Six of the eight species of the Thai gecarcinucid genus *Esanthelphusa* are relatively well known and were assessed as LC (*E. chiangmai, E. denchaii, E. dugasti, E. fangensis, E. nimoafi* and *E. phetchaburi*), while two species have a restricted distribution and were assessed as DD (*E. prolatus* and *E. nani*).

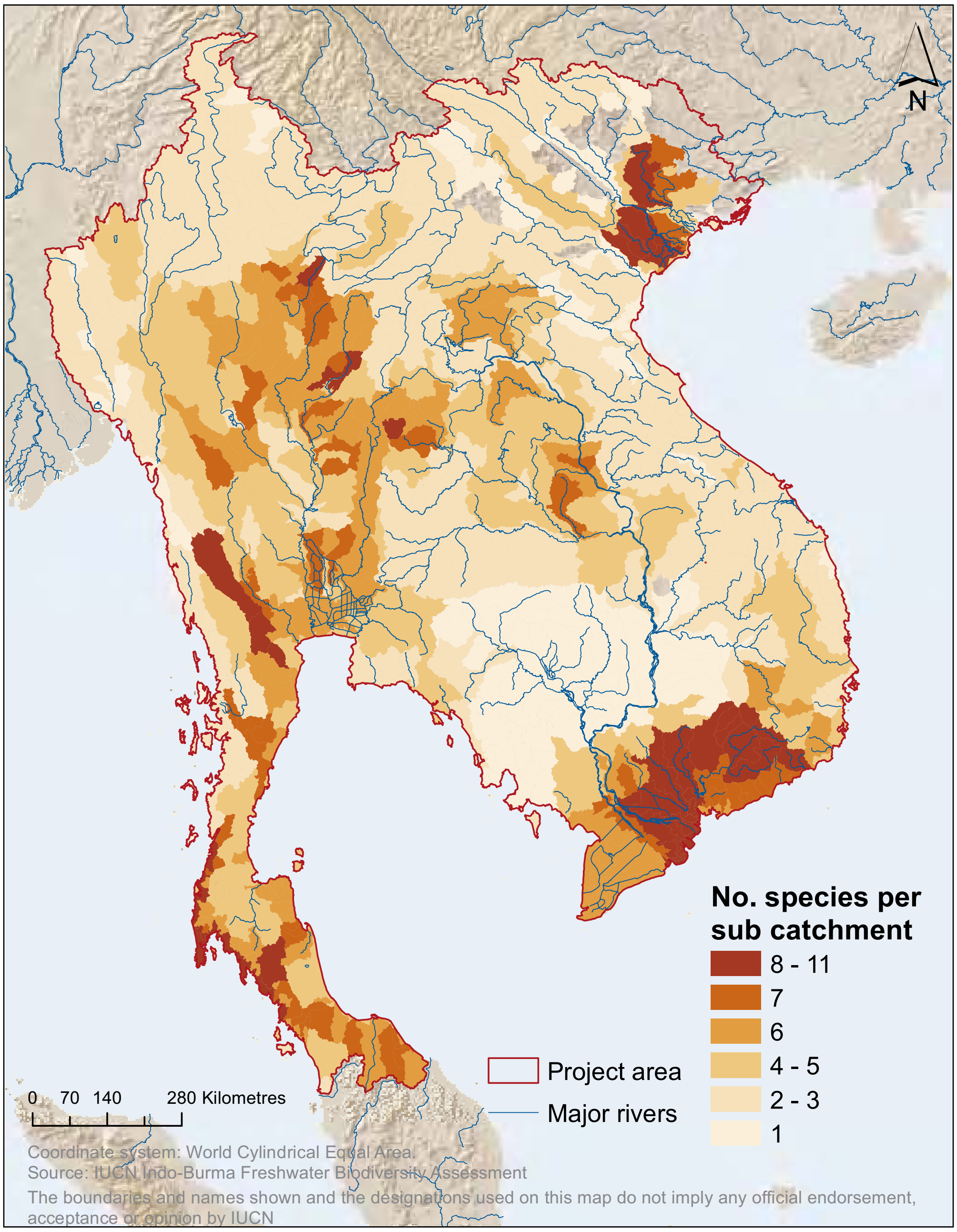
Two of the eight Thai species of the potamid genus *Eosamon* are relatively well known and were assessed as LC (*E. boonyaratae* and *E. smithianum*), while six species have a restricted distribution and were assessed as DD (*E. brousmichei, E. hafniense, E. nominothuis, E. paludosum, E. phuphanense,* and *E. yotdomense*). Two of the six species of the Thai gecarcinucid genus *Phricotelphusa* are relatively well known and were assessed as LC (*P. deharvengi, P. sirindhorn),* while two species have a restricted distribution and were either assessed as VU (*P. limula,* and *P. ranongi*) or as DD (*P. aedes*). Three of the seven species of the Thai potamid genus *Thaipotamon* were assessed as LC (*T.*

chulabhorn, T. dansai, and *T. lomkao*), while four species have a restricted distribution and were assessed as DD (*T. holthuisi, T. siamense,*T. *smitinandi,* and *T. varoonphornae*).

6.3.2 Threatened species distribution patterns

Some 35% (26/75 species) of freshwater crabs from the Indo-Burma hotspot were assessed as being in one of two threatened categories (EN, VU) (Cumberlidge *et al.* 2009; Figure 6.1; Table 6.2). Most of these (20 species) are found in Thailand (11 species of gecarcinucids and nine species of potamids). There are five threatened species of potamids (but no gecarcinucids) found in Viet Nam, three threatened species of potamids (but no gecarcinucids) found in Lao PDR, and there are no threatened species found in Cambodia or in the part of Myanmar included in this study. Of the threatened species, ten were assessed as EN, of which eight are from Thailand (four gecarcinucids: *Salangathelphusa anophrys, Sayamia melanodactylus, Siamthelphusa holthuisi,* and *Thaksinthelphusa yongchindaratae)* and four potamids: *Tiwaripotamon edostilus, Doimon doichiangdao, Indochinamon bhumibol,* and *I. villosum*), one from Viet Nam (*Iomon nan*) and one from Lao PDR (*Doimon doisutep*). None of the species from Myanmar was assessed as EN. A further seventeen species were assessed as VU, of which 12 are from Thailand (seven gecarcinucids: *Heterothelphusa fatum, Mekhongthelphusa kengsaphu, M. tetragona, Phricotelphusa callianira, P. limula, P. ranongi,* and *Sayamia maehongsonensis*) and five potamids: *Nemoron nomas, Pilosamon guinotae, Pupamon phrae, Stelomon erawanense,* and *S. kanchanaburiense*), four from Viet Nam (four potamids: *Stoliczia panhai, Indochinamon dangi, Indochinamon guttum,* and *I. mieni*), and two potamids from Lao PDR (*Indochinamon cua* and *Iomon luangprabangensis*). No species were assessed as CR or as NT. The main threats to these species were identified as urban, industrial,

Figure 6.2 The distribution of freshwater crab species across the Indo-Burma hotspot.



and agricultural development and the associated aquatic habitat degradation and pollution.

6.3.3 Restricted range species

Excluding DD species, 29 species have a restricted range (<20,000 km^2), and are irregularly distributed throughout the region (Figure 6.4). The limited distributions of these species are not simply a product of omission errors stemming from a lack of knowledge or under collection. These species are specifically recorded, through many surveys conducted over the years, as being absent in localities where they may have been expected to occur. Any disruption to the habitats of these species (either from development, pollution, or political unrest) could have serious consequences given that these restricted range species have been assessed as Threatened. Any species with a restricted range is potentially vulnerable to extreme population fragmentation and could suffer a rapid decline and even extinction in a relatively short time should dramatic changes in land-use suddenly affect its habitat. It is therefore of immediate concern that 29 of the 75 crab species that could be assessed are known from distribution ranges of less than 20,000 km^2 (and some of these have an estimated range of 5,000 km^2 or less). Despite the dangers of population fragmentation current population levels of stenotopic species assessed as LC or NT were estimated to be stable because they have been collected recently and there are no identifiable immediate threats that would impact the health of those streams and endanger their long-term existence. The reasons for the restricted ranges of the stenotopic species are largely unknown, but it is thought likely that they have speciated relatively recently in response to isolation in a specialised (marginal) habitat or through island colonization, rather than their being the remnant populations of formerly widespread species now in decline (Cumberlidge *et al*. 2009).

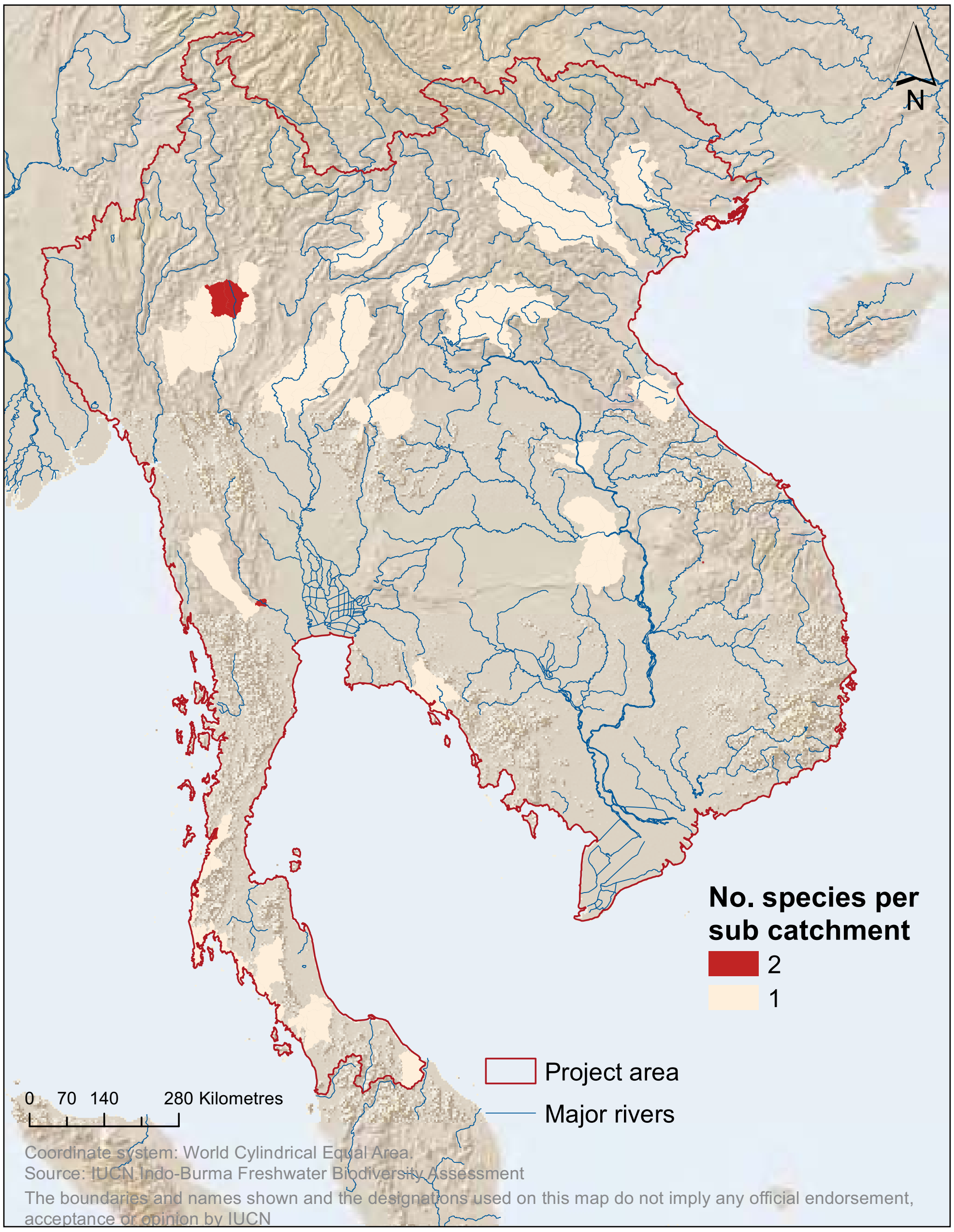


Figure 6.3 The distribution of threatened freshwater crab species in the Indo-Burma hotspot.

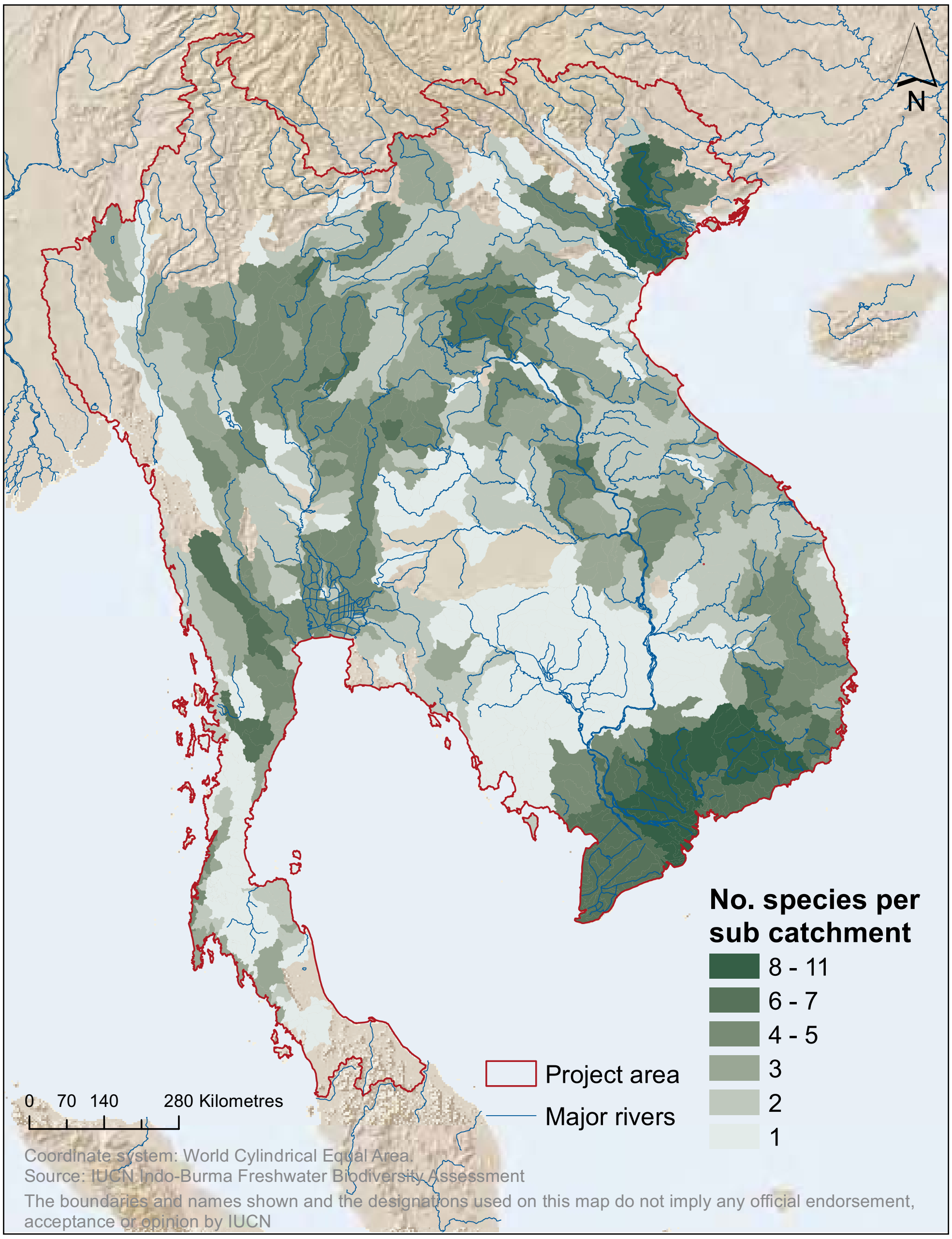
6.3.4 Data Deficient species

Ninety-eight (57%) of the 173 species assessed were judged to be DD (Table 6.1). Forty-seven DD species (five gecarcinucids and 42 potamids) are from Thailand, 19 DD species (all potamids) are from Myanmar, 29 DD species (six gecarcinucids and 23 potamids) are from Viet Nam, 11 DD species (all potamids) are from Lao PDR, and one DD species (a gecarcinucid) is from Cambodia (Figure 6.5). The high proportion of DD species reflects the general lack of specimens available, a scarcity that continues to fuel uncertainty about the distribution of these little-known species (Cumberlidge *et al*. 2009). It is of great concern that in many cases these DD species have not been found in recent years. These species have been listed as DD in view of the absence of recent information on their distribution ranges, habitat, ecological requirements, population size, population trends, and long-term threats (Cumberlidge *et al*. 2009). It is also of concern that many of these species are known only from a few individuals collected many years ago, and that no new specimens have been found

Pudaengon arnamicai, a Data Deficient species known only from the type specimens collected at Pakse in southern Lao PDR. © Darren C.J. Yeo

recently. The DD status is also assigned where there is insufficient information either on their taxonomic distinction, or where they are known from either only one or only a few localities and the full range

Figure 6.4 The distribution of freshwater crab species with severely restricted distributional ranges in the Indo-Burma hotspot.



extent is uncertain. It is possible that in some cases the DD status may be due to under-sampling but, as mentioned above, this is not thought to be the case for many of the DD species. Further research is needed on all of these species because, at least, they may prove to be restricted range endemics vulnerable to habitat loss.

6.4 Major threats

The main threats to the freshwater crabs from the Indo-Burma hotspot include water pollution, urban, industrial, and agricultural development, and habitat loss and deforestation resulting from human population and urban and agricultural expansion.

6.4.1 Habitat destruction

Threats to the endemic species include habitat destruction in the form of deforestation driven by timber extraction, mining, increasing agriculture, the demands of increasing industrial development, the alteration of fast flowing rivers for the creation of hydroelectric power, and the drainage of wetlands for farming and other uses. Destruction of the forests in many parts of the Indo-Burma hotspot is further exacerbated by logging roads that provide access to remote and previously undisturbed parts of the forest. Other threats that result in deforestation and habitat destruction include political unrest and refugee movements that are often accompanied by deforestation and soil erosion that contributes environmental damage to freshwater ecosystems. Potential future threats to aquatic communities in rivers associated with cities and towns in the Indo-Burmese region include pollution by sewage and industrial and general waste. Some agricultural pesticides used by farmers may prove to be lethal to freshwater crabs but more research needs to be carried out. All of the above factors combine to increase the overall level of threat to range-restricted endemic species, and the careful management of Asia's forests and water resources in the future will have the biggest impact on their long-term survival.

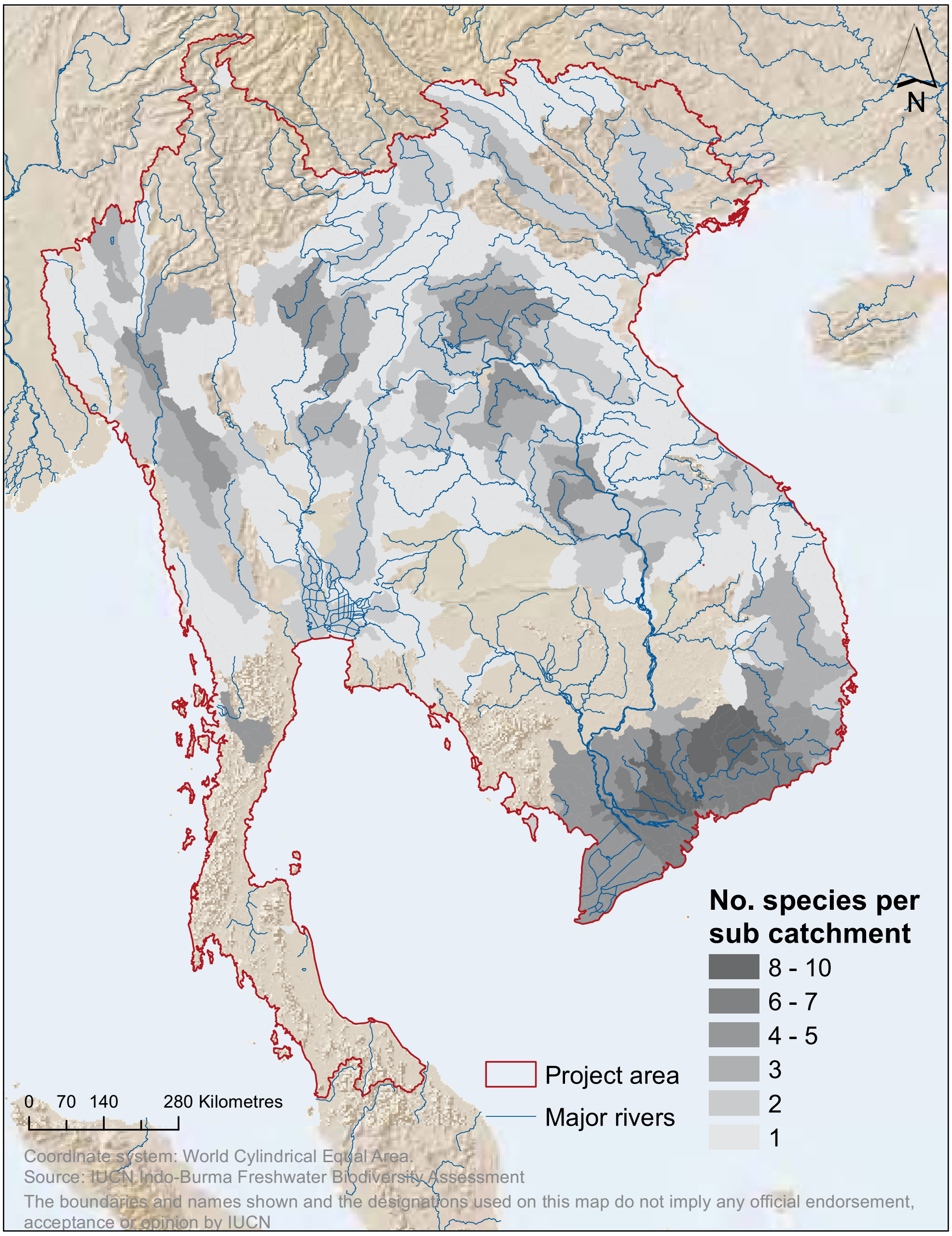


Figure 6.5 The distribution of Data Deficient freshwater crab species across the Indo-Burma hotspot.

Waterfall habitat for freshwater crabs in Thailand. © Darren C.J. Yeo

6.4.2 Pollution

Pollutants from mining activities for diamonds, gold, bauxite, and iron ore, and from organic wastes from leaking sewage systems in urban areas in Asia can accumulate in rivers and other freshwater bodies. These pollutants impact freshwater crab populations because they are benthic feeders that ingest other invertebrates and detritus that may contain high levels of contaminants. Immediate attention should be given to the improvement of the water quality in these areas not least because the bioaccumulation of metals in crabs could pose an increasing problem for the health of people that may eat them.

6.4.3 Natural predators and competition with introduced species

A large number of Asian predators including yellow-necked otters, water mongooses, civets, kites, egrets, herons, giant kingfishers, monitor lizards, and crocodiles depend on freshwater crabs as vital components of their diet. This is because freshwater crabs are the largest macro-invertebrates in Asian aquatic ecosystems and form an integral part of the food chain (Cumberlidge *et al*. 2009). The ecological importance of freshwater crabs in food webs has been underlined in studies on African carnivores (Rowe-Rowe 1977, Butler and Marshall 1996, Somers and Purves 1996). Such studies in Asia are still lacking, but it is likely that freshwater crabs would also constitute part of the diet of aquatic or semi-aquatic predators in Asia as well. In addition, freshwater crabs are also ecologically important for nutrient cycling through their role as macro-decomposers or as shredders of leaf litter and other allochthonous nutrient inputs (Ng 2004, Yeo *et al*. 2010). Potential competitors of freshwater crabs in Asia that are ecologically similar include exotic freshwater crayfish that have been introduced and established in subtropical/temperate parts of Asia (for example, North American *Procambarus clarkii*) (Xu *et al*. 2006) as well as in equatorial/tropical areas (for example, Australasian *Cherax quadricarinatus*) via aquaculture and ornamental trade (Ahyong and Yeo 2007).

6.4.4 Taxonomic issues

The evolving taxonomy of freshwater crabs is likely to be a challenge for conservation planning in the future because some taxa currently assumed to be widespread and common may prove to be complexes of several distinct cryptic taxa each with specific ecologies and distributions requiring specific conservation actions. There are a number of species that are currently assessed as LC primarily on account of their wide distributional ranges, however the distribution patterns of these species consist of many relatively isolated subpopulations that show a great deal of morphological variation. Further investigations may show these species to be species complexes as was the case for African species (Daniels *et al*. 2002).

6.5 Research actions required

Significant areas of this vast and biodiversity rich region still remain insufficiently explored, given that 56% of all species found in the region are Data Deficient. New species of freshwater crabs are sure to be discovered if collection efforts in remote areas are intensified and taxonomic advances become more readily available in the form of identification keys. Cambodia stands out as a country that is seriously understudied and its current total of only two species is almost certainly an undercount, given the outstanding species richness of the surrounding countries, and abundance and diversity of aquatic habitats within the country. Although taxonomic knowledge has advanced considerably recently, and museum collections of freshwater crabs have improved, a great deal of work still needs to be done. There is a need for further surveys to discover new species, refine species distributions, define specific habitat requirements, describe

Freshwater crabs are harvested for food throughout the region and often found in markets. © Charles Pieters

Demanietta khirikhan male. © Darren C.J. Yeo

population levels and trends, and identify specific threats to Asia's important and unique freshwater crab fauna. It is vital to the health of these ecosystems that fishery managers consider measures that specifically include the conservation and sustainable use of local populations of river crabs.

6.6 Conservation recommendations

The biology and distribution patterns of the freshwater crabs of the Indo-Burma hotspot are becoming better known as are the potential threats to their long-term survival. With 26 (35%) species of the 75 non-DD species of freshwater crabs from the Indo-Burma hotspot currently assessed as being at risk of global extinction, the long-term survival of the continent's largely endemic freshwater crab fauna is a concern. Nevertheless, it is hoped that conservation recovery plans for threatened species will be developed for those species identified to be in need of conservation action through this Red List assessment process (Collen *et al*. 2008, Cumberlidge *et al*. 2009).

The conservation of many species of freshwater crabs depends primarily on preservation of areas of natural habitat large enough to maintain water quality. Although it is not yet known exactly how sensitive the freshwater crabs of the Indo-Burma hotspot are to polluted or silted waters, there is evidence from elsewhere in Asia that similar crabs are not likely to survive when exposed to these factors (Ng and Yeo 2007). Development, agriculture and exploitation of natural products are necessary realities in developing economies, but compromises may have to be made if freshwater crab species are not to be extirpated in the future. Judicious and careful use of resources is unlikely to cause species extinctions as long as water drainages are not heavily polluted or redirected, some forest and vegetation cover is maintained, and protected areas are respected (Cumberlidge *et al*. 2009).

Common species assessed as LC have a wide distribution in the rivers, wetlands, and mountain streams of the region and so far have proved to be relatively tolerant of changes in land-use affecting aquatic ecosystems. It is encouraging that these more adaptable species can persist in the already disturbed and visibly polluted parts of the lowland rivers and streams. The increasing loss of natural vegetation and pollution as a result of land development and agriculture are, however, likely to affect the lowland rivers in the long term, and many of the wholly aquatic species that live there could eventually be vulnerable. Even species assessed as LC could suffer catastrophic declines should there be abrupt changes in land development, hydrology, or pesticide-use regimes. It is not known how the highland taxa will cope with habitat disturbance and pollution but, considering their specialised habitat requirements, it is likely that most of these species will not adapt as readily as the more widespread lowland species. In many countries with a rapid pace of development, often only a fine line separates a species assessed as LC from one assessed as VU, or a VU species from one that is assessed as EN. Development projects could have a dramatic impact on species with specific habitat requirements and a restricted distribution. Conservation activities should therefore be aimed primarily at preserving the integrity of sites and habitats while at the same time closely monitoring key freshwater crab populations.

The 98 species of freshwater crabs from the Indo-Burma hotspot judged to be DD were assigned to this category primarily as the result of insufficient field surveys. The scarcity of available specimens is in some parts of the continent due to the long-term poor security situation, and as a result little is known of the habitat needs, population trends, or threats to these species. When more information has been gathered, it is expected that almost all DD species will have a relatively restricted distribution and be endemic to the river basin where they are found.

The conservation assessment of freshwater crabs in Asia (Cumberlidge *et al*. 2009) represents a first step toward the identification of threatened species within the region and toward the development of a conservation strategy for endemic species. The restricted range of many species, together with the on-going human-induced loss of habitat in many parts of the region, are primary causes of concern for the long-term survival of this fauna. Asia's freshwater crabs have a high degree of endemism with many species living in specialised habitats such as river rapids, lowland marshes, forested highlands, and islands. Additional research is recommended to determine the minimum effective size and design of protected areas for freshwater species such as crabs.

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Chapter 7. The conservation of aquatic and wetland plants in the Indo-Burma region

Richard V. Lansdown[1]

7.1 Species selection

The aim of this study was to assess the conservation status of freshwater plants occurring in the Indo-Burma region and which are dependent upon standing or flowing fresh, or at most slightly salty water for their survival. There were two main difficulties with this process: the adoption of a definition of what constitutes an "aquatic plant" which would both include the target species and be unambiguous, and; selection of the species to assess. With regard to the notion of aquatic plants, one of the most important issues is that of obligation or tolerance. A large number of vascular plants, such as water naiads (*Najas* species) cannot survive out of water and may be considered obligate aquatics. Conversely many species including some trees and ferns can tolerate even quite long submersion but are not dependent upon wetlands and may be considered facultative aquatics or not aquatic at all. Clearly it was critical to include the former but exclude the latter from this assessment. However the situation is further complicated by taxa which germinate and initially grow under water but flower and fruit in the air (termed "emergent") and those which are dependent upon temporary or ephemeral water bodies, often remaining dormant beneath standing water and germinating as water levels drop. The following definition was considered the most clear and unambiguous available: "Vascular aquatic plants are interpreted as all Pteridophytina and Spermatophytina whose photosynthetically active parts are permanently or, at least, for several months each year submerged in water or float on the surface of water" (Cook 1996). The only ambiguous element of this definition is the duration of inundation, details of which are unknown for the majority of plants and any attempt to be more precise would require guesswork.

The growth forms of aquatic vascular plants include taxa which are:

- Always completely submerged (obligate submerged aquatics) such as the naiads (Najadaceae).
- Submerged with sexually reproductive parts emergent (held above the water or at the surface), such as *Hydrilla verticillata*.
- Emergent, the roots and base of the plant are submerged, but some photosynthetic parts and sexually reproductive parts are emergent, such as many species of the Scrophulariaceae, including *Limnophila* and *Lindernia* species.
- Floating, without roots or with roots hanging in the water column, such as rigid hornwort (*Ceratophyllum demersum*), floating fern (*Salvinia natans*) and duckweeds (Lemnaceae).
- Amphibious, growing from the land over the water or adopting a variety of the above forms, such as some *Persicaria* species.

The following taxa were excluded from the assessment:

- Taxa known or suspected to not be native to the region; although this distinction is not always straightforward, particularly when considering long-established cultivated plants.
- Hybrids and taxa below species level.

A fundamental principle of these assessments was not to pre-

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judge the conservation condition, such as by selecting species known or believed to be of conservation concern, as this approach is likely to support existing areas of concern but overlook taxa which are not already known to be at risk. The approach adopted for a similar study in Africa (Darwall *et al*. 2011) was to select and assess all species in a suite of families considered likely to serve as representative of wetland plants in the region; the same approach and families were selected for this project, with the addition of the Podostemaceae, for which an expert was available to provide input. The families included, as well as number of genera and total number of species assessed in each of these families are shown in Table 7.1, the number of species assessed in each genus is shown in Table 7.2.

Table 7.1 The selected families included in the assessment, showing the number of genera and aquatic plant species occurring in the region.

FAMILY	Number of genera	Number of species	FAMILY	Number of genera	Number of species
Acanthaceae	3	8	Hydroleaceae	1	1
Acoraceae	3	2	Isoetaceae	1	1
Alismataceae	6	11	Juncaceae	1	5
Amaranthaceae	2	2	Lamiaceae	1	3
Apiaceae	3	3	Linderniaceae	1	15
Aponogetonaceae	1	4	Nymphaeaceae	3	9
Araceae	10	24	Orchidaceae	1	1
Arecaceae	1	4	Phrymaceae	1	1
Asteraceae	12	14	Plantaginaceae	6	24
Ceratophyllaceae	1	2	Podostemaceae	10	55
Commelinaceae	2	3	Polypodiaceae	1	1
Droseraceae	1	3	Potamogetonaceae	3	14
Elatinaceae	1	1	Rubiaceae	2	2
Fabaceae	3	4	Salviniaceae	2	3
Hanguanaceae	1	1	Typhaceae	2	8
Hydrocharitaceae	7	18	Xyridaceae	1	3

Table 7.2 The number of aquatic plant species occurring in the region in each genus assessed.

Genus	Number of species	Genus	Number of species	Genus	Number of species
Acanthus	1	*Eclipta*	3	*Nymphaea*	6
Acorus	2	*Enydra*	1	*Oenanthe*	1
Adenosma	1	*Ethulia*	1	*Oldenlandia*	1
Aeschynomene	2	*Euryale*	1	*Ottelia*	3
Alisma	1	*Grangea*	1	*Oxystelma*	1
Alocasia	1	*Hanguana*	1	*Paracladopus*	2
Alternanthera	1	*Hanseniella*	2	*Pistia*	1
Aponogeton	4	*Hemisteptia*	1	*Pogostemon*	3
Azolla	1	*Hippuris*	1	*Polypleurum*	12
Bacopa	1	*Hydrilla*	1	*Potamogeton*	12
Barclaya	2	*Hydrobryum*	20	*Ranalisma*	1
Bergia	1	*Hydrocharis*	1	*Sagittaria*	5
Blyxa	6	*Hydrodyssodia*	1	*Salvinia*	2
Butomopsis	1	*Hydrolea*	1	*Sesbania*	1
Caesulia	1	*Hygrophila*	6	*Sparganium*	3
Calamus	4	*Inula*	1	*Sphaeranthus*	1
Caldesia	2	*Isoetes*	1	*Spirodela*	1
Centella	1	*Juncus*	5	*Stuckenia*	1
Centrostachys	1	*Landoltia*	1	*Terniopsis*	6
Ceratophyllum	2	*Lapsanastrum*	1	*Thawatchaia*	1
Cladopus	5	*Lasia*	1	*Typha*	5
Colocasia	2	*Lemna*	3	*Typhonium*	1
Commelina	2	*Limnophila*	19	*Vallisneria*	2
Cryptocoryne	11	*Limnophyton*	1	*Wedelia*	1
Curanga	1	*Lindernia*	15	*Wolffia*	2
Cussetia	2	*Microcarpaea*	1	*Xanthium*	1
Cyanotis	1	*Microsorum*	1	*Xyris*	3
Dalzellia	4	*Mimulus*	1	*Zannichellia*	1
Dentella	1	*Najas*	4	*Zeuxine*	1
Dopatrium	1	*Nechamandra*	1	*Zeylanidium*	1
Drosera	3	*Neptunia*	1		

Eriocaulon species in a species-rich flush, Doi Suthep, Thailand.

Table 7.3 The number of aquatic plant species assessed in each Red List Category in the region.

	IUCN Global Red List Category	Number of species
	Extinct	0
	Extinct in the Wild	0
Threatened Categories	Critically Endangered	1
	Endangered	2
	Vulnerable	2
	Near Threatened	5
	Least Concern	197
	Data Deficient	45
	Total	**252**

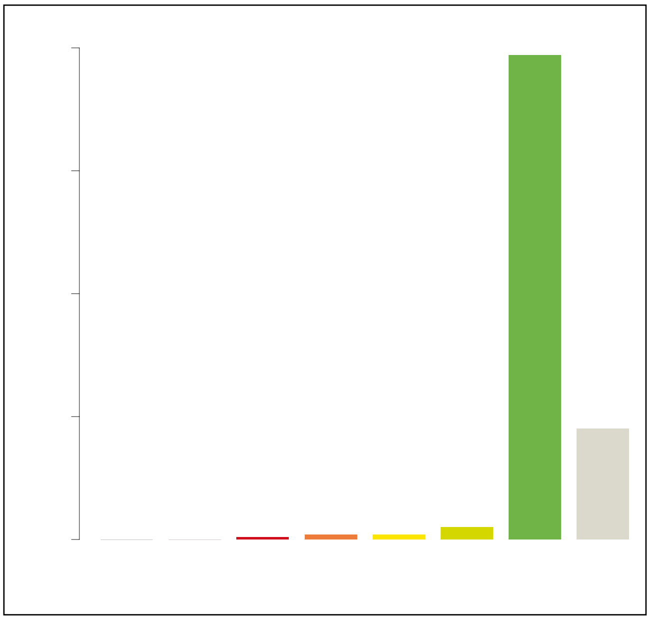

Figure 7.1 The number of assessed aquatic plant species in each Red List Category in the region.

Whilst this approach does enable assessment of a range of taxa, it is extremely selective and may present a distorted picture of the conservation status and requirements of freshwater plants in the region. Of particular concern is that adopting this approach precluded assessment of two of the most important wetland plant families, the sedges and allies (Cyperaceae) and grasses (Poaceae) as well as a number of other families, the inclusion of which could have given a completely different picture, such as the Eriocaulaceae. In addition, no trees were assessed and yet, particularly in this region, trees are a fundamental element of the wetland vegetation. It is likely that a comprehensive assessment covering all the wetland-dependent plants in the region could present a different perspective and show that there is a real need for concern regarding aquatic and wetland plant conservation in the region which is not the case with the taxa selected for this study.

There are many areas of taxonomic uncertainty affecting aquatic plants, for example, the taxonomy of the water-chestnuts (*Trapa* species) is very complex with at least 20 named taxa only one of which is widely recognised. Where the information was available, the taxonomic treatment by The Plant List (www.theplantlist.com) was followed. In cases where names had not yet been treated by this checklist, appropriate authorities, such as The Flora of Thailand (Hansen 1987, Hedge and Lamond 1992, Larsen 1972, Tagawa and Iwatsuki 1989 and Yamazaki 1990) were followed.

7.2 Conservation status

A total of 252 species had their conservation status assessed. The number of species assigned to each Red List category was calculated (Table 7.3, Figure 7.1) and the species assigned to each class presented in Table 7.4. The most notable points arising from this are the very small number of taxa assigned to a threatened category and the large number of species assessed as Data Deficient (DD). Of the species for which sufficient data are available, 2.4% (five species) are threatened (one CR species, two EN, and two VU). In many Data Deficient cases, such as for several species of Podostemaceae, as well as *Cryptocoryne annamica* and *C. vietnamensis*, the species are currently known from single sites and may be extremely vulnerable to local stochastic events. Equally, some species may not have been recorded for more than a hundred years, often not since they were described, and it is not unlikely that they are extinct. Because of this lack of information on threats or distribution, they have been assessed as Data Deficient.

The only species considered Critically Endangered is *Terniopsis ubonensis*, a member of the Podostemaceae (Box 7.1). *Crinum thaianum* and *Terniopsis chanthburiensis* are both assessed as Endangered. *C. thaianum*, the Water Onion, was historically widespread in low-lying areas below 150 m altitude on the coastal plains of southern Thailand but a combination of habitat degradation and over-exploitation have resulted in the loss of a number of populations. It grows in clear, fresh, flowing water typically in broad, unshaded streams and rivers which vary from a few centimetres depth in the dry season to two or more metres depth in the wet season. Much of the habitat degradation was caused by dredging of rivers and streams to improve drainage and to derive aggregate for construction, leading to increased scour which has uprooted whole populations. This has been combined with landuse changes in the catchments of rivers and streams which formerly supported this species, resulting in a decline in water quality and loss of a number of populations. Two species of Podostemaceae are assessed as Vulnerable and are discussed in Box 7.1.

Over half of the species assessed as Data Deficient are members of the Podostemaceae (see Box 7.1), others include members of the Araceae, Hydrocharitaceae and the Scrophulariaceae (including *Limnophila* and *Lindernia* species). Many of these species, such as *Pogostemon* species, *Ottelia balansae* and *Ranalisma rostrata* occur in marshy places and seasonally damp depressions and probably in flushes and seepages over bedrock, although some species such as *Limnophila polyantha* and *Lindernia rivularis* are more strictly aquatic, the former occurring in ponds or lakes and the latter in shallow streams. For most of these species, there is simply not enough information to assess whether or not they are threatened, and they are considered Data Deficient. Some, such as *Limnophila helferi*, are only known from the type locality (i.e. the specimen collected and then used to describe the species new to science), while other species such as

The Water Onion *Crinum thaianum* (EN), is now restricted to a few locations in the coastal plains of the Malay Peninsula in Thailand. © Somsak Soonthornnawapha

Table 7.4 Species assigned to threatened and Data Deficient Red List categories.

Critically Endangered	
Terniopsis ubonensis	
Endangered	
Crinum thaianum	*Terniopsis chanthaburiensis*
Vulnerable	
Dalzellia ranongensis	*Hanseniella heterophylla*
Near Threatened	
Cryptocoryne cruddasiana	*Polypleurum erectum*
Paracladopus chantaburiensis	*Polypleurum longicaule*
Polypleurum longifolium	
Data Deficient	
Barclaya motleyi	*Hydrobryum takakioides*
Blyxa quadricostata	*Hydrobryum tardhuangense*
Blyxa vietii	*Limnophila diffusa*
Cladopus fallax	*Limnophila hayatae*
Cryptocoryne annamica	*Limnophila helferi*
Cryptocoryne loeiensis	*Limnophila polyantha*
Cryptocoryne mekongensis	*Limnophila pulcherrima*
Cryptocoryne vietnamensis	*Limnophila siamensis*
Cussetia carinata	*Limnophila verticillata*
Cussetia diversifolia	*Lindernia khaoyaiensis*
Dalzellia angustissima	*Lindernia rivularis*
Dalzellia kailarsenii	*Lindernia succosa*
Dalzellia ubonensis	*Ottelia balansae*
Hanseniella smitinandii	*Pogostemon crassicaulis*
Hydrobryum kaengsophense	*Pogostemon quadrifolius*
Hydrobryum khaoyaiense	*Polypleurum longistylosum*
Hydrobryum minutale	*Polypleurum phuwuaense*
Hydrobryum phetchabunense	*Polypleurum pluricostatum*
Hydrobryum ramosum	*Polypleurum prachinburiense*
Hydrobryum somranii	*Polypleurum sisaketense*
Hydrobryum subcrustaceum	*Ranalisma rostrata*
Hydrobryum subcylindricum	*Terniopsis ramosa*
Hydrobryum taeniatum	

Limnophila siamensis, *L. verticillata*, and *Lindernia rivularis* are considered Data Deficient as, although they are known to persist at one or more sites, we have no information on their ecology, threats or conservation needs. Another example of a DD species is *Lindernia khaoyaiensis*, which is known from a restricted area of eastern Thailand and an adjacent part of Lao PDR; the only recent population has now been lost as the site where it occurred in Khao Yai National Park is now a radar installation (J.F. Maxwell *pers. comm.* 2011), however it has been recorded from a number of other sites where it may persist.

In contrast, Data Deficient species such as *Barclaya motleyi*, *Blyxa quadricostata* and *B. vietii* grow in flowing water. *B. motleyi* grows in forest streams and has been recorded from a wide area from southern Peninsula Thailand in the north, south through Malaysia and Indonesia to Irian Jaya. However, it has apparently

A species-rich flush including *Drosera*, *Utricularia* and *Eriocaulon* species, Doi Suthep, northern Thailand. © R.V. Lansdown

been recorded from single sites very widely spread through Southeast Asia with no obvious population centres and few recent records.

In most of the cases of Data Deficient species, there is a need to survey and document populations to establish whether they are, in fact, widespread or demonstrably threatened. In some cases, such as *Limnophila helferi*, there is a need to return to the area from which it was collected and establish whether it still occurs. However, there are two main conclusions from the assessments carried out:

1. The taxa assessed do not necessarily represent a sample which can be taken to indicate the overall conservation status of freshwater plants in the region. The inclusion of different or additional families may have presented a very different picture, however the families selected for inclusion were done so to allow comparison with other regional aquatic plant assessments (for example, Allen *et al.* 2010, Darwall *et al.* 2011) and to reduce potential bias towards species of families perceived to be more threatened and thereby present an alternative biased perspective.
2. The definitions employed and the limit on the number of species that could be assessed under the present study have excluded many of the taxa which are most vulnerable, such as those which are dependent upon flushes and shallow flow over bedrock, as well as many taxa dependent upon seasonal wetlands.
3. There is an urgent need to further document freshwater plants in the region to enable informed assessment of their conservation status.

Species richness maps (as presented for other taxonomic groups in this report) are not presented for aquatic plants as significant numbers of species were mapped at the country (or in some cases, sub-country units or provinces) level, due to a lack of information on detailed distributions or ecological preferences. For this reason aquatic plants are also not included in the richness maps shown in Chapter 8.

7.3 The freshwater vegetation of the region

The area treated in this report covers only a small proportion of mainland Asia, but includes huge climatic and landscape diversity. It ranges from some of the highest mountains in the world at the eastern end of the Himalaya to the humid tropics in Narathiwat Province in southern Thailand. Habitats for plants vary in a similar way, from more or less bare ground above the tree line in high mountains, through coniferous forests, deciduous and mixed forests throughout northern Thailand, Lao PDR, Cambodia and Viet Nam to rainforest in southern Peninsula Thailand; the habitats for wetland and aquatic plants lie within these and vary from montane flushes, seepages and high altitude bogs, through forested rivers and streams to lowland marshes, peat swamp forest and rice fields.

The most important wetlands in the region are the rivers, particularly the Lower Mekong River (Box 7.2), which touches on all the countries covered by this report, but also other large river systems such as the Salween River in Myanmar and the Mun / Chu river wetlands and the Khwae Yai River system in Thailand. Not only do these rivers support a wide range of aquatic and wetland plant species both in their channels and on the margins, which in some places spread over many kilometres, but in the wetlands formed by fluvial processes within their active floodplains. These rivers start as flushes and seepages in the mountains, often arising in small wetland systems characterised by a high diversity of bryophytes, including *Sphagnum* mosses, as well as vascular plants such as sundews (*Drosera* species), pipeworts (*Eriocaulon* species) and bladderworts (*Utricularia* species). They then flow down through forest, often very shaded and with very high humidity, dominated by species of fern and bryophytes, gradually slowing down and meandering, at which point aquatic plants specialised for shaded rivers such as *Cryptocoryne* (Box 7.3) and *Barclaya* species start to occur. Wherever these rivers cross harder rocks, torrents, rapids and waterfalls occur which support plants such as humidity demanding ferns, rattans of the genus *Calamus* and species of the Podostemaceae (Box 7.1), many of which are endemic to single rapids or short reaches of a single river.

In the larger river systems the high scour and turbidity of spate flows leads to opening of the canopy, braiding of channels and the consequent creation of mosaics of seasonal channels, *kai kum* areas (sensu Maxwell 2001), oxbow lakes, ephemeral pools and backwaters associated with rocky outcrops. It is these reaches of the river which create and maintain the widest range of wetland habitats and which probably support the greatest diversity of aquatic and wetland plants. Many of the ferns, *Cryptocoryne* and *Barclaya* species and rattans which occur upstream will also occur in these areas, as well as a wide variety of taxa typically found in lowland marshes and ponds. However, many of the species which occur in these wetland complexes are generalists, rather than the highly specialised species that often show a high degree of local endemicity and occur in torrents or in shaded forest streams.

Eventually, the rivers start to break up to form complex series of channels in deltas, in places flowing through extensive marshlands dominated by large monocots such as *Typha*, *Actinoscirpus grossus* and grasses, before reaching their tidal limits which are often indicated by the presence of *Nypah* palms and ferns of the genus *Acrostichum*. Where they reach the sea, deltaic systems may flow through a fringe of mangrove. The major deltas in the region, such as the Ayeyarwaddy and Mekong, which show a gradation from freshwater to brackish or saline conditions, probably once supported a wide range of aquatic and wetland plants, but much of this richness has been lost through drainage of marshes and their conversion to agriculture; mainly rice production.

Hydrilla verticillata, a species capable of forming extensive mono-specific stands covering the surface of the water. © R.V. Lansdown

The region also includes a number of very large lakes and associated habitats, including Inlé Lake (Box 7.4) in Myanmar, Beung Khong Long, Kwan Phrayao, Nong Han, Songkhla Lake and Thale Noi in Thailand, Tam Giang Lagoon in Viet Nam, and the Great Lake, Tonlé Sap (Box B7.5) in Cambodia. The number of medium-sized to large open bodies of water in the region has been significantly augmented by impoundment, mainly for the purposes of providing drinking water, agricultural irrigation water, or hydropower. However, only very few of these artificial impoundments, such as Bung Nam Ngum in Lao PDR, have any real conservation value and most support only the more adaptable and widespread aquatic and wetland plant species. Along with the upper reaches of estuaries and coastal deltas, natural lakes often originally provided the only extensive wet, non-forested areas which supported species now most often found in rice fields and seasonally inundated pasture.

Historically, large lake systems and extensive open water in freshwater marshes supported most of the true aquatics; species which grow in standing water and cannot tolerate extended exundation, particularly *Aponogeton* species, *Hydrilla verticillata*, *Monochoria hastata*, *Najas* species, water lilies such as *Nymphaea nouchali*, *N. pubescens*, *N. rubra* and *N. tetragona*, *Pistia stratiotes*, pondweeds (*Potamogeton* species) and *Vallisneria* species. The margins of these lakes; associated wetlands such as pools; seasonally inundated habitats and freshwater marshes will have supported most of the aquatic and wetland plants of the region not dependent upon forest streams, seepages and flushes or torrents. Extensive freshwater marshes once dominated the Fang and Chiang Mai basins in northern Thailand and spread across much of the Central Plains south from Phitsanulok and Itteradit to the vicinity of Bangkok. In the drier northeast, the swamps were more limited in extent and were chiefly confined to the valleys of the rivers Songkhram, Chi and Mun, meandering across the plateau toward the Mekong. By the turn of the twentieth century, virtually this entire habitat had been canalised, drained and converted to agriculture and urbanised areas. Today, no untouched freshwater wetland habitats remain in Thailand. What was not converted to agriculture was, like the swamps of Beung Boraphet north of Nakhon Sawan, dammed and turned unto lakes in order to enhance fisheries (Round and Graham 1994).

Extensive freshwater marshes in the region were originally mainly associated either with the upstream extremes of estuaries and deltas or with large lake systems. Most of these have been

Seasonally inundated marshland around the Tonlé Sap in Cambodia, showing the extent of land converted to agriculture. © Adrian Whelan

replaced by agriculture, often extensive areas of rice fields, which retain many of the former marshland species, but lack the great natural species diversity that once occurred. In many ways the vegetation of rice fields with sump ponds, canals and drainage ditches mimics that of former marshland systems, supporting many species formerly typical of freshwater marshes, including *Adenosma indianum*, *Alisma plantago-aquatica*, *Blyxa echinosperma*, *Caesulia axillaris*, *Curanga amara*, *Cyanotis axillaris*, *Dentella repens*, *Eclipta angustata*, species of *Limnophila*, *Lindernia* and *Marsilea*, *Microcarpaea minima*, *Mimulus orbicularis*, *Monochoria* species, *Oldenlandia diffusa*, *Ottelia alismoides*, *Sagittaria pygmaea*, *Salvinia auriculata*, *Spirodela polyrhiza*, *Typhonium flagelliforme* and *Zeuxine strateumatica*. These are mainly emergent or marginal species, with most of their bulk held above the water and so they are particularly well adapted to temporary water bodies, such as rice fields. Many of these species will also occur in small, low-lying wet areas outside active agriculture or other land-use, as well as in damp areas on waste ground and between fields. Weeds, that is more ephemeral herbs, include some species which are typically found in rice fields and can be seen when these places are wet. These include: *Dopatrium acutifolium*, *Utricularia bifida* var. *bifida* and *U. minutissima*, *Eriocaulon quinquangulare* and *Burmannia coelestis*. *Grangea maderaspatana*, *Sphaeranthus indicus* and *Ammannia baccifera* are species which flower and fruit when the fields are dry. Species found in sandy, often seasonally inundated areas, include *Spilanthes paniculata*, *Glinus lotoides*, *Polycarpon prostratum*, *Polygonum plebeium*, *Cyperus pygmaeus*; *Digitaria bicornis*, *Eragrostis amabilis* and *Eleusine indica*.

There are a number of different types of forested wetland in the region including swamp forests, *Melaleuca* forest and seasonally inundated forests. Swamp forests are permanently inundated and often grow over deep peat, often with a high proportion of palms in the taller vegetation and are restricted to southern Peninsula Thailand within the region. They often support a range of aquatic plants in channels, including species of *Cryptocoryne* and *Barclaya*. *Melaleuca* forest is typically seasonally inundated and forms a patchwork among more open swampy habitats which may support highly diverse wetland vegetation. There is only one *Melaleuca* species native to the region; *M. cajuputi*, with most species native to Australasia (WCSP 2012). Most of the forested wetlands in the region are seasonally inundated and occur along large river systems such as the Mekong (Theliade *et al*. 2011). Seasonally inundated swamp forest ecosystems also surround the Tonlé Sap Lake in Cambodia. Formerly these ecosystems were also extensive in the deltas and lower floodplains of the Mekong and Chao Phraya rivers but are now restricted to isolated fragments.

Wet grassland ecosystems range from small, seasonally wet meadows within dry forest landscapes, to the extensive, seasonally inundated grasslands that characterize the inundation zone of the Tonlé Sap Lake. Seasonally inundated grasslands, which support distinctive assemblages of species, including several globally threatened species, are one of the most threatened ecosystems in the region. They were formerly widely distributed in central Thailand and the Mekong Delta, and a few remain, some of which such as Tram Chim National Park, Lang Sen Nature Reserve, Tra Su, Hon Dat, Phu My and a few smaller areas in Viet Nam and Boung Prek Lapouv and Anlung Pring in the Cambodian part of the Mekong Delta. However, the majority have almost completely disappeared through conversion to agriculture, aquaculture and forestry.

One remnant grassland is Takeo grassland in Cambodia. In the wet season, the whole of this area is a floating mat of vegetation, supporting more than 30 aquatic plant species dominated

Eichhornia crassipes, an invasive aquatic originating in the New World and now a problem throughout the tropics. © R.V. Lansdown

A navigable channel through reed swamp in Tonlé Sap, where the only floating vegetation is the alien Water Hyacinth *Eichhornia crassipes*. © Charles Pieters

by *Echinochloa stagnina*, *Polygonum tomentosum*, *Ipomoea aquatica*, *Hymenachne acutigluma*, *Leersia hexandra* and *Pseudoraphis brunoniana*, with smaller populations of *Oryza rufipogon*, *Ischaemum rugosum*, *Salvinia cucullata*, *Cyperus iria*, *Monochoria hastata*, *Nymphoides indica*, *Sacciolepis interrupta* and *Paspalum scrobiculatum*. When floodwaters recede, the floating mats come to rest on the ground. In dry and hot conditions, biomass from the previous year quickly decomposes and provides nutrients for new shoots that re-sprout from old stems. The new shoots mainly root in the loose semi-decomposed mats and not in the soil, the whole mat then floats again when the site is next flooded (Tran 2003).

7.4 Major threats

Wetlands in the region and the plants which depend upon them are under threat from a wide range of direct and indirect anthropogenic actions. The biggest single threat worldwide and no less so in the region, is drainage, simply the removal of standing or flowing water to enable the land to be used for other purposes. One of the first actions usually undertaken by people when they settle to exploit an area is to modify the drainage. This may simply involve relatively minor tinkering by redirecting and locally damming small streams to manage the availability of water for stock but more often involves drainage of any low-lying depressions, pools and ponds together with canalisation of larger flowing water-bodies. Thus, the first thing that typically happens when an area is opened up for exploitation is the loss of marginal habitats and seasonal wetlands which support the greatest diversity of freshwater plants.

Most river systems in the region are threatened by plans for dam construction. Construction of dams on rivers modifies the hydrological regime, divorcing floodplains from the river so that floodplain wetlands loose connectivity and are often more vulnerable to drainage and conversion to other land-uses; inundation regimes and the erosion-deposition balance change such that taxa dependent on particular niches are lost and some taxa cannot survive under the modified regime. This applies both to small scale dams, which often destroy diverse and sensitive springhead and flush communities and to the large dams which inundate kilometres of river with previously wide amplitude of inundation variation, leading to sediment deposition upstream, but often starving downstream areas of the sediment needed to support species-rich wetlands. Disruption of the erosion-deposition balance can also mean that plants such as some of the more vulnerable *Cryptocoryne* species may be buried beneath sediments deposits. There is a significant increase in the number of dams in the area, varying in scale from large international or national projects on rivers such as the Mekong, to the installation of bunds on small streams to provide water during the dry season.

Even in the upstream reaches of rivers, where most catchments are still forested, uncontrolled or poorly controlled conversion to agriculture, as well as slash and burn forest clearance, usually results in increased erosion and sediment loading in upland rivers, whilst increasing the flashiness of the river leading to increased scour, simultaneously reducing the water retention capacity of the catchment and increasing the risk of flooding. Similar issues result from the blasting of bars and rapids, which result in greatly increased flow and reduced water retention, increasing the risk of flash-flooding downstream. The destruction of rapids and torrents also destroys the habitat of plants such as members of the Podostemaceae, which, because most are endemic to a single torrent, are immediately extinct.

All wetlands in the region are threatened by pollution, from small-scale untreated sewage and waste water to large-scale industrial effluent and poorly buffered run-off from agriculture. Increased nutrient-loading, often derived from a combination of sediment inflow and poorly buffered agriculture within the catchment, can lead to hyper-eutrophication in backwaters and pools during low flows with consequent algal blooms followed by die-back and eventually dissolved oxygen depletion, at which point most submerged vegetation will die. Other forms of pollution include untreated sewage and household and industrial waste which can build up in the sediment and lead to similar conditions. Even small streams are under threat from casual modification and untreated sewage.

Small floodplain wetlands, such as pools, as well as the seasonal wetlands associated with larger wetland complexes are extremely vulnerable to drainage and conversion to agriculture. This has happened throughout much of Thailand and it is difficult to quantify the effect on some of the wetland plants such as *Lindernia* species. Lakes and ponds are becoming shallower due to a combination of build-up of decayed vegetation and litter, sedimentation, abstraction and diversion of inflow streams (Laongsri *et al.* 2009). Many small floodplain pools and pools in marshland complexes have been modified for lotus cultivation, which typically involves bunding to make seasonal waterbodies permanent, accompanied by eradication of competitive natural vegetation. Intensification of traditional agricultural practices reduces the potential for non-crop species to survive in the habitat further reducing habitat availability, at the same time agricultural intensification brings an increase in the use of fertilisers and pesticide which enter the system and disrupt the functioning of ecosystems. These and larger wetlands are also threatened by burning during the dry season which is intended to promote growth of grasses for livestock.

All wetlands are also affected, to some extent, by small-scale and largely uncontrolled modification, including embankment to protect roads, houses or crops from flooding, diversion of small streams for irrigation, local drainage of seasonal wetlands and low-lying depressions around settlements. This is exacerbated by the spread of industrial and urban areas, which have a knock-on effect on wetlands. A recent study found that wetlands close to villages, grazed by cattle or which were seasonally burned were the most likely to become badly degraded (Seng Kim Hout *et al*. 2002). This is a particular problem for seasonal wetlands which can be grazed and burnt during the dry season without the need for expensive or labour-intensive drainage. Equally, the vegetation of the channel of the Mekong is dramatically over-grazed during the dry season by water-buffalo and other livestock, and cleared for river bank vegetable cultivation.

Invasive species are an increasing problem in the area, including the well-known and obvious species such as Common Water Hyacinth *Eichhornia crassipes* and *Mimosa pigra*, but also grasses introduced as fodder and even ornamental species. All of these species displace native vegetation and in some cases rendering large areas unsuitable for native plants.

7.5 Conservation

There is little conservation action undertaken in the region that is specifically targeted at wetland plants. Most wetland conservation initiatives are directed at vertebrates and such actions rarely benefit plants. Sites protected for vertebrates often either support the simplified and low-diversity communities that are associated with rice fields or reservoirs, or they gradually loose specialist plant species. This is because protection and management focus on factors which directly affect the target organisms rather than bottom-up conservation which looks to safeguard diverse vegetation associations on the basis that these will support animals.

It is clear that the main priority arising from this limited suite of assessments is the need for critical identification of freshwater plants, determination of species distributions through survey, and a better understanding of threats, enabling accurate documentation of their ecology and distributions. For example, Maxwell (2009) found 23 taxa new to the country during a single survey along a 55 km stretch of the Mekong and associated habitats in Kratie and Stung Treng provinces in Cambodia. It is very likely that such detailed survey will recognise new freshwater taxa to science, as well as new regional records, many of which will be shown to be rare or conservation dependent. Such documentation would also almost certainly show that some taxa currently considered Data Deficient are sufficiently abundant not to need active conservation. However, it is equally likely that some taxa would be shown to be threatened and in need of conservation action. For example, from available data, it is not possible to show that *Barclaya motleyi* still occurs throughout its range and recent records suggest that it has been lost from large areas of its former range. In all likelihood, data exist that are more up to date than that available for these assessments, but this information is either unpublished, available only in "grey" literature or published to provide context for different taxa. For example much of the information published on aquatic plants is in descriptions of habitat for birds or fishes.

Due to the limited number of specialist wetland botanists in the region, it has been very difficult to be certain that no wetland-dependent taxa have been omitted from the families covered by these assessments.

The following actions would make a significant contribution to the conservation of aquatic and freshwater plants of the region:

1. Compile and publish information from the "grey" literature, anecdotal evidence, and studies targeting other taxa.
2. Document the occurrence of aquatic and wetland plants, particularly their representation in protected areas.
3. Assess the wetland-dependent plants not covered by this assessment and re-assess Data Deficient taxa as information becomes available.
4. Identify areas where data are lacking and plan surveys.
3. Develop and publish identification guidance, for example guidance on the identification of *Cryptocoryne*, *Limnophila* and *Lindernia* species could improve recording and thereby enable more informed conservation assessment.
4. Where taxa are genuinely threatened, there is a need to better document their ecology, so that work toward their conservation is effective.

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Box 7.1 The Podostemaceae – riverweeds

Masahiro Kato and Richard V. Lansdown

The Podostemaceae are an unusual aquatic flowering plant family of alga- or moss-like plants of approximately 300–320 species in 54 genera. They occur in the tropics and subtropics of the world, with the greatest species diversity in the Americas. Approximately 135–155 species belonging to 21 genera occur in South and Central America, one of which also occurs in eastern North America and is scarce. Approximately 80 species belonging to about 16 genera occur in tropical and southern Africa and Madagascar and approximately 80 species of 18 genera occur in southern and southeastern Asia, some of which occur in temperate eastern Asia and northern Australia where they are scarce. All the Asian-Australian genera, like almost all African-Madagascan and American genera are endemic to the superregion, which suggests that each genus underwent diversification in its own region. They are absent from regions outside the tropics and areas which lack rivers with torrents.

Hydrobryum species. © Masahiro Kato

Molecular phylogeny shows that the Podostemaceae are close to the Hypericaceae. Taxonomically, the family comprises three subfamilies; Podostemoideae is the largest subfamily (c. 300 species in 47 genera), the Tristichoideae (six genera with 18 mostly Asian species) and the Weddellinoideae (a single South American species). Twenty-two or two-fifths of genera are monotypic, while the remaining genera are mainly small, comprising fewer than ten species, indicating that morphological variation is discontinuous and unique. Associated with this, species endemism is high. For example, in the well-documented Podostemaceae of Thailand, three-quarters of the 42 species (and three genera) are endemic to Thailand and most are known from very few sites, often a single population on one rapid complex or waterfall. Of the 56 species recorded from Southeast Asia (of which ten have yet to be formally described), only six species are known from more than ten sites and 21 are known from single sites. Many rivers and torrents or waterfalls support only a single species, although a few or occasionally several species may occur together in a river system or even in single torrents.

Description

Members of the Podostemaceae are structurally reduced, they lack the cuticular layer and vascular tissue typical of terrestrial vascular plants which may be an adaptation to growth in highly oxygenated rocky torrents and which make them unable to survive if permanently exposed. The morphology of the Podostemaceae is markedly diverse in contrast to their apparently uniform environment. The vegetative parts of *Hydrodiscus koyamae* comprise only a leafy branched shoot, lacking the apical meristem which is essential for vascular plants. In the genera *Hanseniella* and *Thawatchaia* and most species of *Hydrobryum*, the plant comprises a foliose root with usually reduced shoots or tufts of leaves on the dorsal surface, a body plan common in other Podostemaceae. In a few other species of *Hydrobryum*, the root is subcylindrical or ribbon-like and repeatedly branched. The vegetative parts of *Dalzellia* comprise a rootless foliose shoot with scaly leaves on the dorsal surface, while those of *Indotristicha* comprise a branched subcylindrical root with elongate branched leafy shoots on the flank and those of *Indodalzellia* comprise a foliose shoot adventitious to, and borne on the flank of the branched subcylindrical root. A few species are monocotyledonous even though the family is a member of the dicotyledons.

Hydrodiscus koyamae. © Diego Juffe-Bignoli

Habitat and ecology

The vegetative parts of plants grow exclusively submerged in torrents during the rainy season, tightly attached to water-worn rock surfaces by creeping organs, either the root or stem, with sticky rhizoids on the ventral surface. They tend to grow on granitic or volcanic rocks such as basalt and lava, or exceptionally limestone and sandstone and only occur in open, sunlit areas. In rivers with suitable rocky riverbeds or torrents along a considerable length, Podostemaceae grow in long interrupted populations. Thus, they may occur in single or multiple torrents on one river.

In the dry season when water levels drop, the plants are exposed to the air and set flowers and fruits for a short time. The seeds have a sticky coat; they are dispersed and settle at appropriate sites and then germinate and grow under water. Thus, Podostemaceae are amphibious in the sense of submerged growth in the rainy season and aerial propagation and dispersal in the dry season. The small seeds (usually 0.2–0.5 mm long) are dispersible to long distances, but nonetheless actual long-distance dispersal is rare. This is probably partly because suitable torrents and waterfalls are rare and sparse, and partly because the exalbuminous seeds have low establishment capability. The seeds may be dispersed by wind, but dispersal by birds, to whose feet seeds adhere, is also a possibility.

Box 7.1 The Podostemaceae – riverweeds, cont'd

Threats

The extremely restricted distribution of Podostemaceae populations means that most species are extremely vulnerable to local, small-scale and even temporary changes in their environment. It is reported that approximately one third of South American species are threatened by human activities, especially large dams. The greatest threat to all species is the modification of river hydrology, particularly construction of dams. This assessment has shown that more than half of the species in the region are similarly threatened or simply too poorly known to be assessed. Rocky torrents are often used to construct dams for hydropower, water storage and flood control. Dam construction mainly affects them:

- When the rock on which they grow is damaged or destroyed by blasting to enable construction of dam infrastructure.
- When construction covers the surface of rocks supporting populations.
- When impounded water precludes flowering leading to the gradual decline and eventual extinction of populations because they become permanently submerged and unable to flower.

Typical Podostemaceae habitat. Tad Xai Falls, Phou Khao Khouay National Park, Lao PDR. © Diego Juffe-Bignoli

Deforestation of watersheds and the slopes of headwater streams will often lead to increased deposition of sediment onto rocks, making it inhospitable to Podostemaceae. Similarly, water pollution and consequent eutrophication can compromise Podostemaceae populations by allowing other plants and algae to out-compete them. Populations of Podostemaceae are also extremely vulnerable to agricultural encroachment into areas adjacent to or upstream of populations, where factors such as increased turbidity, herbicide run-off and water abstraction can impact populations. Tourist pressure can also lead to loss or degradation of habitat through the effects of walking or climbing on the rocks which support populations, as well as pollution.

Conservation

There are currently no conservation actions being undertaken in the region specifically to protect Podostemaceae populations. Only one species occurring in the region, *Terniopsis ubonensis*, is assessed as Critically Endangered. It is known from a single locality in a small area of the Mun River in eastern Thailand. The river passes through the city of Ubon Ratchathani (capital of the province with the same name) upstream of the population and pollution, probably derived from this city, has been observed to affect the known population. There is an urgent need to assess the nature of the threat to this species and identify practical action for its conservation.

A single species; *Terniopsis chanthaburiensis* is assessed as Endangered, the only known population covers an area of less than 500 m^2 in the Klong Yai, Pong Nam Ron District, Chanthaburi Province in eastern Thailand. There is a small dam located downstream of half of the known population which is causing water to back up beyond the population, such that only half of it is able to flower, the remainder being permanently submerged. The site supporting the species is not protected, but there is a need to assess whether the dam can be relocated or removed before this species becomes extinct.

Two species are assessed as VU. *Dalzellia ranongensis* is known from a single location near Haew Long waterfalls in Chumphon Province, peninsula Thailand. The site is a popular site visited by tourists and local people and consequently it is threatened by habitat degradation and water pollution. *Hanseniella heterophylla* is known from three sites in Thailand. Despite all known populations being within protected areas, one is close enough to agricultural land to be vulnerable to pesticide spraying or water pollution, whilst the other population is threatened by tourism. Four species (*Paracladopus chantaburiensis*, *Polypleurum erectum*, *P. longicaule* and *P. longifolium*) are assessed as NT; they are all known from single localities and all are potentially threatened by habitat degradation resulting from local and international tourism. Available information is inadequate for a further 17 species and they are considered DD.

In situ conservation is essential for the preservation of these ecologically unique plants as they are difficult to cultivate without special equipment and controlled environments. However, in a few cases some small dams or artificial barriers, which control soil erosion have been colonized by Podostemaceae suggesting both that *ex situ* conservation may be possible and that management could be carried out to protect populations in the wild using artificial or imported substrate.

Many species no doubt will be discovered from torrents and waterfalls in the rainy and dry seasons in subtropical and tropical Asia by future exploration. This discovery is very likely given the results of recent field studies that revealed the remarkable diversity of Podostemaceae in Thailand and very recent detailed local field exploration that is uncovering a number of unrecorded species from a single province of Thailand. Prior to actions for conservation, taxonomic information on Podostemaceae, in particular badly underexplored Asian species should be increased by field research.

Box 7.2 The vegetation of the Lower Mekong

Richard V. Lansdown

At nearly 5,000 km long with a catchment of 795,000 km^2, the Mekong is the world's tenth longest river and the seventh longest in Asia. It rises on the Tibetan Plateau together with the Yangtze and Salween Rivers and then flows through Yunnan province in China, Myanmar, Lao People's Democratic Republic, Thailand, Cambodia and Viet Nam, where it divides into nine channels of the Mekong Delta and discharges into the South China Sea. The Mekong Basin can be divided into two parts: the Upper Basin in Tibet and China and the Lower Basin from Yunnan downstream to the South China Sea. The Upper Basin is mainly characterised by narrow gorges among high mountains and over this length the river drops 4,500 metres before it enters the Lower Basin where the borders of Thailand, Lao PDR, China and Myanmar come together in the Golden Triangle.

For much of its length the Mekong flows through bedrock and the features normally associated with the alluvial stretches of mature rivers, such as meanders, oxbow lakes and extensive floodplains are restricted to a short stretch of the mainstream around Vientiane and downstream of Kratie. The Mekong basin is one of the richest areas of biodiversity in the world; estimates suggest that it supports 20,000 plant, 430 mammal, 1,200 bird, 800 reptile and amphibian and an estimated 850 fish species. In 2009, 145 new species were described from the Mekong Region, comprising 29 fish, two new birds, ten reptiles, five mammals, 96 plants and six new amphibians (www.mekongriver.info/biodiversity).

Landuse

Throughout the region, forest cover has been steadily reduced by shifting and permanent agriculture, and loss of forest cover in the Thai areas of the Lower Basin has been the highest in all the Mekong countries in the last 60 years. More than half of Cambodia is still under mixed evergreen and deciduous broadleaf forest, although forest cover declined from 73 to 63% between 1973 and 1993. Shifting cultivation is common in northern Lao PDR where it is reported to account for as much as 27% of the total land under rice cultivation. Most of Lao PDR lies within the Lower Mekong Basin, while Cambodia is entirely dependent upon the river for food and much of its economy. The annual floods provide much needed water for wet rice which is the main crop and is grown in the inundation zone of Tonlé Sap.

Covering an area of roughly five million hectares, the Mekong River Delta is a vast wetland complex, consisting of many different types of wetland ecosystems, from coastal salt and brackish to inland freshwater wetlands. Of the total area of land and water surface, approximately four million are in Viet Nam and one million in Cambodia. Wetlands of the Mekong Delta have long been used and altered by people. Most of the seasonally inundated grasslands of the Viet Nam part of the Mekong Delta have been turned into farmland, mostly rice paddies. The Mekong Delta in Viet Nam is farmed intensively and has little natural vegetation left.

Riverine vegetation of the Lower Mekong Basin

The greatest diversity of channel vegetation occurs in the Siphandone wetlands (Daconto 2001). In this area, Maxwell (2000) divided the vegetation into six major zones; sand-bars, *boong* areas, *Kai Kum* zone, the Acacia-Anogeissus zone, seasonal and perennial channels and aquatic habitats. Sand bars generally support amphibious trees, shrubs and large grasses such as *Saccharum spontaneum* and *Phragmites vallatoria* and parts are also cultivated during the dry season. The term *boong* refers to rocky places with permanent river flow with dense tufts or small islands of rheophytic vegetation on sandstone bedrock where there is a general absence of sand. *Kai Kum* refers to *Phyllanthus jullienii*, a shrub, which is the dominant species in the region below the *boong* area and above the falls. This area involves flat, rugged sandstone bedrock which is completely exposed from December to May. There are channels through the bedrock and patches of sand in some places. Amphibious herbs such as *Hygrophila incana* and *Cryptocoryne* species are also present. The Acacia-Anogeissus zone is a unique area below the falls which is the deepest zone of submergence in the wetlands and supports current-bent, deciduous trees up to 10 m tall.

Seasonal and perennial channels support a range of emergents and aquatics, including the free-floating alien *Eichhornia crassipes* which is uncommon in the Mekong River since it is washed away each year during the rainy season, *Ipomoea aquatica* which is cultivated for food, *Nymphaea nouchali* and *Nymphoides indica*, *Hydrilla verticillata*, *Ottelia alismoides*, *Marsilea quadrifolia*, *Potamogeton crispus* and *Ceratophyllum demersum*. *Utricularia aurea*, *Lemna perpusila* and several species rooting in the bottom of ponds and wet ditches, such as *Cyanotis axillaris*, *Monochoria vaginalis* and *Typhonium flagelliforme* are found in mostly seasonally dry areas away from the Mekong River. *Hydrocera triflora* and *Hydrolea zeylanica* are found in scattered wetlands in Dry Lowland Dipterocarp forest. There is also a filamentous green alga which is very dense in the Mekong River during February-March, but is absent by April-May.

Lotus (*Nelumbo nucifera*) and water lily (*Nymphaea* spp.) swamps occur commonly in seasonally inundated habitats in the delta region of the basin, or along the floodplain of the lower basin, mostly in Southern Lao PDR and in Cambodia. These are low-lying areas that hold water in the dry season. Many are connected by small streams that form a network of dry season water bodies. Seasonally inundated grasslands mainly support emergent vegetation including acid-tolerant plants such as *Eleocharis dulcis*, *E. ochrostachys*, *Lepironia articulata* and *Xyris indica*. Due to the connection with the sea, the downstream areas also have plants that are saltwater-tolerant such as *Paspalum vaginatum* and *Scirpus littoralis*.

The channel of the Mekong at Don Khone, Lao PDR. © T. Idei

Box 7.2 The vegetation of the Lower Mekong, cont'd

Threats

The most significant threats to wetland plants along the Mekong are habitat loss and degradation, especially from the construction of dams and habitat clearance. A number of dams have already been built on tributaries of the Mekong, notably the Pak Mun dam in Thailand, while China is engaged in an extensive program of dam building with three already completed and another 12 under consideration and the Lower Mekong basin countries are planning the construction of 12 more dams on the main channel (Tran Triet pers. comm.). Dams disrupt the natural hydrological cycle of the river, leading to an overall lowering of water levels, for example since the first Chinese dam was completed water levels have dropped causing problems for ferries and ports downstream. In addition there will be a reduction in the amplitude of variation in water levels, with consequent changes to the extent and nature of the active floodplain, the sediment erosion-deposition balance and scour. It is very likely that changes in the nature and extent of the active floodplain of the Mekong will not only result in loss of floodplain wetlands, but it will change the pattern of inundation enough to enable expansion of agriculture into areas which currently include wetlands. It is also very likely that they will have knock-on effects on Tonlé Sap (Box 7.5). Changes in the flow and water levels will have consequential effects both on threatened taxa instream, such as *Cryptocoryne loeiensis* and *C. mekongensis* and on taxa more typically associated with floodplain wetlands, such as *Limnophila* and *Lindernia* species. It is also extremely likely that the scale of impacts will increase with every dam constructed.Another significant threat to wetland plants on the Mekong system is the blasting of sand bars, rocks, gorges and rapids to facilitate navigation, which is causing increased flashiness and scour in the rivers, as well as the loss of habitat for species such as *Podostemaceae* (Box 7.1) and *Cryptocoryne* (Box 7.3).

The channel of the Mekong at Don Det, north of Don Khone, Lao PDR. © T. Idei

Invasive alien plants now pose a severe threat to the native wetland vegetation. *Eichhornia crassipes* is a particular problem as it is free-floating and can rapidly spread to cover large areas of the water surface, blocking out sunlight and precluding growth by other species. *Pistia stratiotes* and *Salvinia* species have a similar free-floating growth form but do not appear to have such a significant effect. Among emergent vegetation, grasses such as *Brachiaria mutica* and *Echinochloa stagnina* can dominate to the exclusion of more specialised native taxa (Tran 1999). On land, *Mimosa pigra* is a particular problem as it quickly becomes established in areas of disturbed ground, precluding re-colonisation by native species.

The floating mats of wetland plants which are such a peculiar feature of seasonally inundated wetlands in the area are unable to survive in the face of hydrological modifications. When canal systems are constructed to facilitate movement of water, this results in water-level changes that are too rapid to allow the establishment of these floating mats and they are quickly lost.

The Mekong Delta has been badly affected by the rate of development in the area. Governmental support for the production of rice led to a massive surplus, which became a financial burden when the international price plummeted. Much new development within the delta has been carried out with little or no regard to potential impacts on the natural wetlands of the delta and few intact areas now remain.

Conservation

There are as yet no direct actions for the conservation of aquatic and wetland plants in the Mekong system, in fact there is very little widely available information on the vegetation of the Mekong. The main conservation work needed for plants on the Mekong and associated water bodies involves:

- Documenting the vegetation of the main channels and associate wetlands in the way that has been applied by Maxwell (2009).
- There is a need to document the distribution and ecology of all taxa, but particularly rare or Data Deficient wetland-dependent taxa such as *Cryptocoryne loeiensis* and *C. mekongensis*.
- There is a need to establish the distribution and conservation status of Podostemaceae on the river.
- There is a need to document the distribution and vegetation of seasonal wetlands, to establish critical areas for the conservation of plants dependent upon these habitats.

Box 7.3 The *Cryptocoryne* genus

Richard V. Lansdown

The genus *Cryptocoryne* belongs in the large and diverse family Araceae and it is one of the larger genera of aquatic plants in the region. Globally, *Cryptocoryne* is a genus of about 60 known species and several naturally occurring interspecific hybrid combinations. Within *C. cordata* five, *C. crispatula* seven, and *C. spiralis* two varieties have been recognized (WCSP 2012).

The genus is restricted to Asia and Australasia, from Sri Lanka through India and Bangladesh to southern China, then south through Mainland Asia, the Philippines, Sumatera and Borneo to Papua New Guinea, with *C. beckettii* and *C. wendtii* established as non-native in the USA. All except around a dozen species have a rather restricted distribution and only four can be described as widespread, of which *C. albida* and *C. crispatula* occur from eastern India eastwards to southern China and south into mainland Asia, *C. cordata* occurs in southern Thailand, Peninsula Malaysia, Sumatra and Borneo, while *C. ciliata* occurs from India through Bangladesh, Thailand and Viet Nam south through Indonesia to Papua New Guinea. Three islands support nearly half the world's species; nine species are endemic to Sri Lanka, 13 species are endemic to Borneo, and five species are endemic to the island of Sumatera, in Indonesia. Ten species occur in the Indo-Burma region, including six varieties of *C. crispatula* and two varieties of *C. cordata* (Table C1).

Table C1. Distribution of the *Cryptocoryne* species and varieties occurring in the region.

Species	Distribution
C. albida	Myanmar and southern Thailand
C. annamica	Central Viet Nam
C. ciliata	India to New Guinea, including Thailand and Viet Nam
C. cordata	Thailand to Malesia
var. *cordata*	South-eastern peninsular Thailand, eastern and southern Peninsular Malaysia
var. *siamensis*	South-western peninsular Thailand to north-western Peninsular Malaysia
C. crispatula	India to southern China, Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam
var. *crispatula*	North-eastern India to south-eastern China, Cambodia, Lao PDR, Thailand and Viet Nam
var. *balansae*	China (Guangxi), Lao PDR, Myanmar, Thailand and Viet Nam
var. *yunnanensis*	China (Yunnan), Lao PDR, Thailand and Viet Nam
var. *tonkinensis*	Thailand and Viet Nam
var. *flaccidifolia*	China (Guangxi) and southern Thailand
var. *decus-mekongensis*	Lao PDR
C. cruddasiana	Myanmar
C. loeiensis	Thailand (the Mekong), and Lao PDR
C. mekongensis	Lao PDR and Thailand
C. retrospiralis	SW and S. India to Myanmar
C. Viet Namensis	Central Viet Nam

Description

Cryptocoryne species form tufts or swards of leaves arising from irregularly thickened creeping rhizomes which spread through the substrate and often develop runners. The leaves are extremely variable, with the variation at least partly influenced by whether they are submerged, emergent or entirely exposed and more than one form may occur on the same plant.


Cryptocoryne loeiensis on the Mekong at Chiang Khan, Loei Province, northern Thailand. © T. Idei

The leaves may have no defined petiole and blade and be more or less linear, or even terete or they may have a clear distinction between a petiole and blade. When petiolate, the leaves generally have a narrow, almost linear to broadly ovate more or less elongate, cordate or cuneate blade on a long petiole with entire or slightly toothed margins that may be flat or undulate; the leaves are usually green or brownish often with some red or purple coloration. They are generally flaccid when growing submerged but may be erect or drooping in emerged plants, in most species they are usually flat but they may be strongly undulate or bullate with entire or irregularly denticulate margins.

The flower is a typical Aroid spathe with a basal tube that opens upward with a flap extending to a limb. The limb may be ciliate,

Box 7.3 The *Cryptocoryne* genus, cont'd

smooth or warty, short or long to very long and attenuate, it may be more or less straight, curved or spirally coiled. The spathe often has a white background with pink or yellow parts and may have dark purple, brownish or black spots.

Habitats and ecology

All the *Cryptocoryne* species that occur in the region will grow in rivers; some such as *C. cordata* will also grow in peat swamp forests and in forest pools with some flowing water. *Cryptocoryne loeiensis* is only known from the margins and bars in the Mekong River, where it grows in the lea of boulders and bedrock outcrops; other species growing in similar habitats are *C. crispatula*, *C. retrospiralis,* and *C. mekongensis*. These last three will also grow in small forest streams, often where sunlight is able to reach the channel, although some species will tolerate shade. *C. annamica* and *C. vietnamensis* are both known from a few sites apparently on small rivers in central Viet Nam, while *C. cruddasiana* is known from forest streams and rivers in north-eastern Myanmar and *C. ciliata* is a species occurring in the inner parts of the mangroves.

Most species appear to require shade, possibly as few other aquatic plants will grow in such habitats and there is therefore less competition. However, some species, such as *C. cruddasiana*, have been shown to grow where openings in the canopy allow sunlight to reach the river (N. Tanaka pers. comm. 2011) and a few, such as *C. griffithii*, *C. longicauda* and *C. striolata* can cope with opening of the canopy and have re-colonised rubber plantations (Jacobsen 1986).

Most species typically grow in sand or gravel, although some will grow on mud or silt. Some species, such as *C. crispatula* will grow in firm substrates including travertine. Particularly in large rivers, they usually grow in sites where they are deep-submerged throughout much of the year, becoming exposed as water levels drop, when they flower. Plants or populations are often found largely buried in the substrate with only the upper parts of the leaves and flowering spathes exposed.

Threats

The habitats of *Cryptocoryne* species in the region can be split into large or very large rivers systems such as the Mekong, small forest rivers or swamp forest; the nature of the threats affecting these is very different. The threats affecting the Mekong are discussed in Box 7.2, however those which are most significant for *Cryptocoryne* species are the disruption of the erosion-sedimentation balance as a consequence of dam construction and the blasting of rapids and torrents to facilitate navigation. These are likely to lead to the loss of habitat suitable for the species particularly in the *boong* zone (*sensu* Maxwell 2001). Another particular problem affecting *Cryptocoryne* populations on the Mekong is dry-season over-grazing. During the dry season, large numbers of water-buffalo are left to graze more or less uncontrolled on the channel and floodplain of the river (J.F. Maxwell pers. comm. 2011). This is the period when *Cryptocoryne* species flower and this overgrazing will not only denude, break up and kill vegetative parts, but will compromise sexual reproduction.

The small forest streams on which most populations of most species in the region depend are extremely vulnerable to human activity. The most severe impacts arise from clear felling and subsequent conversion to other habitats, which normally results in the loss of all natural aquatic and wetland plant species and their replacement by taxa tolerant of high nutrient levels and disturbance. However other actions, such as logging or slash and burn agriculture in the catchments can lead to a massive increase in sediment, burying populations or conversely can lead to increased scour with the loss of sand banks and silt deposits in which these species normally grow. Another common cause of loss of aquatic plants in small forest streams is the construction of small dams for irrigation or domestic water, which reduce seasonal variation in flow, permanently submerge populations in turbid water and are often accompanied by pollution.

Species of *Cryptocoryne* are very popular aquarium plants; in general this involves only a few species, such as *C. crispatula*. However there are a large number of people with a particular interest in the genus who could place the rarer species at risk. For example, *C. annamica* is known from two occasions, the original collection from which the species was named and a photograph taken by an anonymous aquarist with an interest in the genus. All that it would take is for one irresponsible individual to over-harvest a population to bring it into trade and the known population could become extinct. Thankfully there appears to be a well-developed awareness of conservation among enthusiasts and this seems unlikely.

Conservation

Whilst there is currently no active in-situ conservation for *Cryptocoryne* species, some taxa will occur in protected areas and gain some protection. There is an urgent need to document the distribution and extent of all taxa, including information on ecology, to facilitate or enable conservation where needed. Some species have very restricted ranges and this, combined with the few known populations, means that some species are possibly vulnerable to local or stochastic events. For this reason *C. annamica*, *C. cruddasiana, C. loeiensis*, *C. mekongensis* and *C. vietnamensis* are assessed as Data Deficient.

Although many *Cryptocoryne* species are popular aquarium plants there is no formal collection of members of the genus as a living resource. The only known significant collection is a private one maintained by Niels Jacobsen at the Royal Veterinary and Agricultural University, Copenhagen. Conservation of the genus would be greatly enhanced by the development of a collection including all currently recognised taxa, particularly those at sub-specific level, to representation of genetic variation.

Box 7.4 Inlé Lake, Myanmar

Richard V. Lansdown

Description

Inlé Lake is the second largest lake in Myanmar, it lies about 420 km northeast of Yangon in the southern Shan State. It is tertiary rather than glacial in its origin and occupies the deepest part of the Yawnghwe basin, which has an average length of 65 km and at its widest is about 13 km wide. The region is characterized by a large, flat valley running north to south at an average elevation of 1,000 m above sea level, which is surrounded by mountain ranges averaging 1,300 m in elevation (Butkus and Su 2001). The whole basin was once occupied by a very large lake with an area of nearly 500 km^2. The present Inlé Lake is the remnant of this lake, with an average length of 14 km from north to south and at its widest, only 6 km from east to west (Nath 1960). In 1935 it was estimated to have a net open water area of 69 km^2, however this had declined by 2000 to 47 km^2, a loss of 32% during this 65-year period (Sidle *et al*. 2007). The depth of the lake fluctuates with the seasons; the average depth in the dry season is four meters and in the rainy season is around seven meters (Butkus and Su 2001), although there are extensive shallow margins (Sidle *et al*. 2007). The lake bed is comprised of fine silt deposited by approximately 30 streams entering the lake from the surrounding hills and flowing through the limestone plateau (Butkus and Su 2001), increasing carbon levels in the lake, it has one outlet which flows to the south entering the Thanlwin River (Butkus and Su 2001); it is eutrophic, with high concentrations of phosphate, nitrites and nitrates probably originating from domestic and agricultural inflows.

Land use

Land use in the area is dominated by agriculture with over 200 villages around the lake and within the watershed (Butkus and Su 2001). While there is some forest in the hills, this is being lost through slash and burn to shifting agriculture. In the valley the main crop is rice, but other crops such as wheat, grams and maize are also grown, while tomatoes which are the primary cash crop comprise two-thirds of the region's agriculture, the remaining one-third consists of flowers, vegetables, and sugarcane. However, a great variety of fruits, vegetables, ornamental flowering plants, especially for cut flowers, as well as the staple and cash crops, such as potatoes, sugarcane, tobacco, squash, pumpkins, melons, eggplants, peppers, spinach and other greens, beets, turnips, tomatoes, peas, beans, maize, okra, peanut, onions, strawberries, mangoes, custard apples, pineapples and cabbages as well as oranges, bananas and papayas are grown and sold at the various markets in the Southern Shan States (Nath 1960). The Inlé region is also well-known for its textile products; in eight villages, major textile industries use chemical dyes as well as natural dyes.

The lake itself supports two major sources of food; the native Inlé Carp (*Cyprinus carpio*) is a staple of the people who live around the lake, as well as being a cultural symbol of the ethnic Intha people. The carp breed year-round in clean and clear water; however, because of poor water quality, the population has become increasingly scarce (Butkus and Su 2001). In addition to fishing, the people of Inlé Lake construct floating vegetable gardens which they establish in the margins of the lake by constructing mattresses of *Typha* or other tall aquatic monocots. Submerged aquatic plants are spread over these and black silt from the eastern shores of the lake spread on the top, weighing them down without sinking them. When there is enough soil for a seed bed, the gardens are anchored by bamboo poles. On these vegetable gardens, people raise millet, peas, beans, lentil and sesame; bamboo sticks or reeds are also tied to them parallel to the ground, making trellises to support beans, peas or cucurbits, thus adding to the effective area of the garden (Nath 1960). Inlé Lake is a major tourist attraction and the government became aware of the problems caused by pollution when it began to promote tourism in 1996 (Butkus and 2001).

Natural vegetation

Much of the surface of the lake is covered by floating vegetation, both as the floating gardens, but also extensive stands of native plants, including *Azolla pinnata*, a *Lemna* species recorded as *L. minor* but probably *L. tenerum*, *Ottelia alismoides*, *Nymphaea nouchallii*, *Nymphoides indica* and *Salvinia cucullata*, as well as *Eichhornia crassipes* and *Nelumbo nucifera* which have been introduced. The submerged vegetation is diverse, including *Ceratophyllum demersum*, *Elodea canadensis*, *Hippuris vulgaris*, *Hydrilla verticillata*, *Myriophyllum verticillatum*, *Najas graminea*, *Potamogeton alpinus*, *P. crispus*, *P. lucens*, *P. nodosus*, *P. obtusifolius*, *P. perfoliatus*, *Ruppia maritima*, *Stuckenia pectinata*, *Utricularia aurea* and *Vallisneria spiralis*. In areas without floating gardens, the margins support extensive stands of tall monocots, dominated by *Phragmites karka* and *Typha angustifolia*, with species such as *Arundinella decempedalis*, *Cyperus cyperoides* subsp. *cyperoides*, *C. digitatus*, *Echinochloa crus-pavonis* and *Schoenoplectus lacustris*. Marshy areas support a diverse range of plants, among which there may be a range of smaller marginal plants including *Ammannia baccifera*, *Colocasia esculenta*, *Dichrocephala integrifolia*, *Fimbristylis aestivalis*, *Gahnia javanica*, *Lasia spinosa*, *Lythrum salicaria*, *Monochoria vaginalis*,

Establishing floating gardens on Inlé Lake. © Jonas Merian

Established floating gardens with young crops. © fabulousfabs

Box 7.4 Inlé Lake, Myanmar, cont'd

Rotala rotundifolia, *Schoenoplectiella supina*, *Sagittaria sagittifolia* and *Salix tetrasperma*. Marginal areas, shallow water, seasonal pools and occasionally the water gardens support a range of aquatic and marginal plants such as *Eclipta alba*, *Elephantopus spicatus*, *Eryngium foetidum*, *Hygrophila auriculata*, *Ludwigia octovalvis*, *Phyla nodiflora*, *Plantago major*, *Polygonum aviculare*, *Polygonum plebejum*, *Veronica anagallis-aquatica* and *Xanthium strumarium*.

Aquatic and marginal plants which occur in rice fields in the area include *Alisma plantago-aquatica*, *Cyperus difformis*, *Eriocaulon quinquangulare*. *Fimbristylis dichotoma*, *Hypericum japonicum*, *Ipomoea aquatica*, *Ludwigia repens*, *Monochoria hastata*, *Ottelia alismoides*, *Sagittaria sagittifolia* and *Utricularia flexuosa*. Common vegetation of the floating islands includes *Cyperus digitatus*, *Cladium jamaicensis*, *Cephalanthus occidentalis* and the ferns *Adiantum edgeworthii* and *Thelypteris interrupta*.

Threats

The main threats to Inlé Lake are siltation, leading to succession from open water to marsh or dry land, eutrophication and pollution of various sorts. Many factors, such as timber removal and slash and burn agriculture in the watershed have been blamed for the increased rate of siltation. However, in an intensive study, Sidle *et al*. (2007) found that the main cause of the decline in surface area of the lake was the on-going development of floating gardens which they considered to be responsible for 93% (i.e. 21 km^2) of the recent loss of open water. They also concluded that other impacts due to the floating gardens and agriculture in the margins of the lake include sedimentation, eutrophication, and pollution from pesticides which are routinely used on the floating gardens. Waste and garbage from households, lack of proper sanitation, and livestock breeding contribute to poor water quality. *Eichhornia crassipes* was introduced to the lake about 60 years ago as an ornamental plant and has become so abundant that it obstructs many waterways along the lake. Other threats to the lake include: extensive use of fresh water for agriculture, over-fishing, over-extraction of timber and fuel woods, overgrazing, development of dams and unsustainable agricultural practices in wetlands, hunting, trapping and poisoning of birds, panning for gold, illegal settlement and deforestation in catchments.

Conservation

In 1985, just under 65,000 ha of the lake was notified as the Inlé Wetland Sanctuary. In 1997, the government of Myanmar initiated the Inlé Lake Preservation Project, of which the executive committee includes members from Shan State Peace and Development Council, Nyaungshwe Township local authorities, and government staff from the Irrigation, Agriculture, and Forestry Departments. This project enables national, regional and local interests to influence management of the lake (Butkus and Su 2001).

There is currently no comprehensive account of the vegetation of the lake, taking into account the national and international conservation status of species present. Without this, effective conservation of wetland plants will be impossible. The conservation of the wetland plants of the lake system requires documentation of the existing vegetation, with particular reference to national and international conservation status, and the integration of wetland plant communities into management throughout the lake system.

Dense growth of aquatic plants in Inlé Lake, with *Stuckenia pectinata* in the foreground. © Marina & Enrique

Box 7.5 The Tonlé Sap Great Lake

Richard V. Lansdown

The Tonlé Sap (the Great Lake) is the largest permanent freshwater lake in Southeast Asia (Scott 1989) lying over silts and clays in the centre of the Cambodian plain. It is connected to the Mekong River by the Tonlé Sap River at Phnom Penh, some 120 km to the southeast. Shortly after the onset of the rainy season, the strength of the Mekong discharge begins to act as a dam on the Tonlé Sap River. Initially, this causes the river to spread laterally but subsequently its current reverses and carries the Mekong floodwaters into the Tonlé Sap basin. At low water level the Tonlé Sap floodplain is about 120 by 35 km, covering an area of 250,000–300,000 ha and less than one metre deep, however under peak flood conditions it expands to over a million hectares with a mean depth of 8–10 m. Water levels fall rapidly between January and March and the lowest levels occur in April and May (Scott 1989).

Inundated forest, Tonlé Sap © Petre

The principal economic activities of the communities living on the lake and surrounding the floodplain are rice cultivation, collection of wood for fuel and aquaculture (chiefly fish), as well as subsistence and commercial fishing. Fishing is the mainstay of communities situated closer to open water and major waterways, while rice cultivation and other agriculture are economically more significant to communities in the outer floodplain. Rice cultivation traditionally involved deepwater (floating) rice and historically about 200,000 ha was grown in the Tonlé Sap inundation zone, but by 2000 only c.70,000 ha remained. The most recent and accurate estimate is of approximately 470,000 people living within the 10 m inundation zone and approximately 1.19 million in all zones including urban centres. A small out-migration of people from all provinces surrounding the lake (except for Kompong Chhnang) has recently been reported, due to decreasing fish catches, droughts and unpredictable flooding which is affecting rice yields, and reduction in river water quality due to increased sediment loads (Davidson 2006).

Episodic cultivation of deepwater rice created a mosaic landscape of great biodiversity importance in parts of the floodplain, and has probably been instrumental in the creation and maintenance of grasslands in the floodplain. The Tonlé Sap Biosphere Reserve supports the largest remnant tract in the region of a unique seasonally inundated freshwater swamp forest formation, which although relatively species poor is highly distinctive and rich in both regional and narrow endemics. This swamp or gallery forest has an understory of lianas, made up of a group of species that form their own distinctive formation, in the absence of the larger species in the middle floodplain. It also supports what may be the largest remaining area of seasonally inundated grasslands of diverse structure and community composition in Southeast Asia (Davidson 2006).

Vegetation

The vegetation of Tonlé Sap is defined by centuries of exploitation by man but fundamentally is dictated by the peculiar hydrology of the lake. Its floodplain supports a low overall diversity of plant species, but is rich in species that are unique to the Indochinese floristic region (Rundel 2000), some of which are entirely restricted to the Tonlé Sap floodplain (McDonald *et al*. 1997). The floodplain vegetation can be crudely differentiated into irregular concentric bands radiating out from the dry season low water mark of Tonlé Sap. At the centre is the area which is inundated each year, this is surrounded by a band of swamp forest generally some 20–30 km wide but extending for 65 km west from the west end of the lake, containing numerous small rivers and streams and innumerable lakes and ponds. The belt of swamp forest is in turn surrounded by a broad belt of rice paddies up to 25 km wide which borders on extensive forested areas.

The open water of Tonlé Sap does not support rooted aquatics possibly because they are unable to tolerate the massive seasonal change in water level of the lake and its strong turbidity. The shallow shoreline of Tonlé Sap and patches within the gallery/swamp forests support dense mats of herbaceous vegetation, 1-3 m tall, that may be emergent from shallow water but are more typically floating. These large, often clonal assemblages float freely over the lake, colonising large openings and gaps within the swamp forest. The wet-season floating rice field agro-ecosystem near Roluos in Kompong Thom supports vegetation very similar to the floating aquatic vegetation mats of the open lake and gallery/swamp forest clearings. Grassland areas within and around the Tonlé Sap floodplain may cover more than 2,000 km^2 (Davidson 2006). Wild rice *Oryza rufigpogon* is the dominant grassland type within the inundated forest-scrub of the inner and middle floodplain, occurring in homogeneous dense mats mixed with *Leersia hexandra*. Burning promotes species diversity in these grasslands: *Oryza* dominated swards burnt during the

Extensive irrigated rice field, Tonlé Sap. © David Allen

Box 7.5 The Tonlé Sap Great Lake, cont'd

previous dry season often support a wider range of species. Further from the lakeshore, these species become less common, merging into *Paspalum*-type grasslands. A distinctive aquatic community occurs in isolated ponds in the outer floodplain, in which grasses and sedges are important, while *Phragmites karka* is a local dominant at the mouth of Tonlé Sap and at other river inlets and exits (Davidson 2006).

Houses on the Tonlé Sap among extensive carpets of *Eichhornia crassipes*. © David Allen

Threats

The two main direct threats to aquatic and freshwater plants in Tonlé Sap are the direct destruction of wetland habitats, mainly due to changes in agricultural practices and clearance of seasonally inundated forest for agriculture and settlements. Endorsement by the Cambodian Government of commercial production of dry season paddy in the inundation zone has led to an increase in the extent a rate of loss of seasonally inundated grasslands around Tonlé Sap. Similarly, the area of forested habitat in the Tonlé Sap Biosphere Reserve has declined over the past five decades. Significant areas of inundated forest-scrub have also been destroyed through clearance and conversion to rice cultivation, burning, harvesting of wood for fuel and construction materials and collection for firing brick kilns (Davidson 2006).

Agricultural intensification is a major cause of biodiversity loss in the area, particularly conversion to irrigated rice production with associated high levels of chemical inputs and the loss of dry season stubble and fallow habitats. Rapid expansion of dry-season irrigated rice now presents a serious and immediate threat to landscapes of the outer Tonlé Sap floodplain and at the same time, abandonment of deep water rice cultivation and reversion to tall scrub due to low economic returns from deep water rice harvests represents a substantial concern. In 2004–05, at least 15 dams were constructed to irrigate over 60 km^2 for intensive rice production within and surrounding two sites in Kompong Thom. This is expected to greatly reduce habitat suitability for grassland dependent species due to reduced structural diversity, high pesticide inputs and greatly reduced opportunities for non-crop species to survive, as well as reducing access to natural resource such as grazing and fishing by local communities (Davidson 2006).

There is also an increasing risk of effects due to pollution; untreated urban and domestic solid and liquid waste especially from floating villages, are discharged directly into water bodies associated with Tonlé Sap. Impacts on water quality are most severe during the dry season when shallow waters quickly become stagnant and temperatures can be high. Oils spills pose a threat to waterways and associated habitats around ports and waste oil, sludge and bilge are often discarded into the water in these locations.

Invasive, non-native species are an additional threat to aquatic and wetland plants in the Tonlé Sap. *Eichornia crassipes* appears to be increasing greatly in abundance along the shore of Tonlé Sap (McDonald *et al*. 1997). *Mimosa pigra* invades fallow fields and disturbed ground; once established it forms dense impenetrable thickets, provides very little value as wildlife habitat, and is detrimental to fisheries. Two grass species have also widely invaded wetland margins of Tonlé Sap; *Brachiaria mutica* and *Echinochloa stagnina* were introduced in the past from Africa (Rundel 2000) as high quality species for grazing and have become dominant in many areas of the lake.

In addition to all of these factors which directly affect Tonlé Sap, all of the actions adversely affecting the Mekong River (Box 7.2) have potential for secondary impacts on Tonlé Sap. Certainly, the combination of dam construction, enabling regulation of flows and blasting of rapids to facilitate navigation could disrupt the hydrology of the river to the extent that the annual flooding of Tonlé Sap is significantly disrupted.

Conservation

In 1997 Tonlé Sap Lake and most of its floodplain were designated as the Tonlé Sap Biosphere Reserve under the UNESCO Man and the Biosphere Program (UNESCO 2005); recognised within Cambodia in 2001 by the Royal Decree for the Establishment of the Tonlé Sap Biosphere Reserve. The Biosphere Reserve consists of a core area which is strictly protected, although subsistence and commercial fishing are permitted within it. Surrounding this are buffer and transitional areas where sustainable extraction and human occupancy are permitted (Davidson 2006). In 1999, 28,000 ha of the Boeung Chhma Core Area was designated as a site of international significance under the Ramsar Convention (Ramsar 2012), one of only three Ramsar sites in Cambodia (Davidson 2006).

There is no conservation action specifically for wetland plants in Tonlé Sap. There is an urgent need to document the distribution and status of species of conservation concern, combined with data on their ecological requirements, to inform conservation action.

Chapter 8. Synthesis for all taxa

Smith, K.G., Allen, D.A, and Carrizo, S.

In this synthesis chapter we combine all data sets from Chapters 3 to 7 (freshwater fishes, molluscs, odonates, freshwater crabs and aquatic plants) and consider the status and distribution (overall species richness, endemism, data deficiency and threatened species richness) of these taxonomic groups across the Indo-Burma region, finally incorporating additional data from previous Red List assessments for wetland birds, amphibians, and mammals. The factors driving threats to the freshwater biodiversity in the region are discussed and potential freshwater Key Biodiversity Areas (globally important sites for conservation of freshwater species) identified. The contribution by freshwater species to provisioning ecosystem services in the region is also presented and discussed.

The objective of this analysis (and the accompanying data) is to provide outputs to inform conservation and development planning for wetland ecosystems and species at the national, state, catchment and site scales.

8.1 Red List status

The core of the Indo-Burma Biodiversity Hotspot covered by this assessment supports globally significant numbers of species dependent on wetland habitats (Table 8.1); nearly 10% of wetland-dependent mammals and birds, more than 8% of the currently known species of dragonflies, damselflies and freshwater molluscs, nearly 8% of freshwater fish species, and over 5% of amphibians.

Of the 2,515 currently known extant species of the priority taxonomic groups selected for this project (fishes, molluscs, damselflies and dragonflies, aquatic plants and crabs), for which sufficient data are available to assess their conservation status, 13.1% are considered threatened (Table 8.2. Figure 8.1). Only one species is currently considered to be Extinct (*Platytropius siamensis,* the Siamese flat-barbelled catfish, which has not been recorded in surveys since 1977). Of the 32 Critically Endangered species eight (four each of freshwater fish and molluscs) are considered Critically Endangered (Possibly Extinct); these species are of especially high conservation concern and require intensive surveys to confirm their continued presence and current distributions.

When compared with the level of global threat for selected taxonomic groups that have been comprehensively (i.e. all known species) assessed (amphibians 41.0% threatened; mammals 24.9% threatened; birds 13.3% threatened) (IUCN 2012), this figure of 13.1% for freshwater species in Indo-Burma is relatively low. However, when compared with other regionally focused freshwater biodiversity assessments in Asia (Eastern Himalaya, 7.2% threatened (Allen *et al.* 2010); Western Ghats 15.8% threatened (Molur *et al.* 2011)), this level of threat is similar.

Table 8.1 Estimated numbers of extant inland water-dependent species in Indo-Burma by major taxonomic groups.

Taxon	Global number of described species	Number of species in Indo-Burma assessment region	% of species found in Indo-Burma assessment region
Fish	>15,000[1]	1,178[3]	7.9%
Molluscs	>5,000[1]	430[3]	8.6%
Odonates	5,680[1]	473[3]	8.3%
Plants	21,411*	252[3#]	n/a
Amphibians	4,290[2]	234[2]	5.5%
Mammals	145[2]	14[2]	9.7%
Turtles	256[4]	42[4]	16.4%
Birds	2,196[2]	220[5]	10.0%

Data sources: [1]Balian *et al.* (2008); [2]2012.1 IUCN Red List - filtered by 'system = freshwater' and 'location-Cambodia, Lao P.D.R., Thailand and Viet Nam'; [3]Species lists generated by experts for this project; [4]Turtle Taxonomy Working Group (2011); [5] 2012.1 IUCN Red List (as [2]) edited by Christophe Zöckler, UNEP WCMC for species that are particularly dependant on freshwater (see Box 8.1); *Total species for the families listed by Balian *et al.* (2008) that are comprehensively assessed; #Not all families comprehensively assessed by this project are listed in Balian *et al.* (2008), therefore this is the total number of species identified by this project that are in the families listed by Balian *et al.* (2008); n/a not applicable, as only a selected sub-set of families were assessed through this project.

The percentage of Data Deficient (DD) freshwater species in the Indo-Burma region (37.3%) is, however, higher than in both these regions (31.3% DD Eastern Himalaya; 10.5% DD Western Ghats), and significantly greater than the comprehensively assessed groups (amphibians 25.5% DD; mammals 15.2% DD; and birds 0.6% DD (IUCN 2012)). Many of these DD species are likely to be threatened and when more information becomes available these species will need to be reassessed.

Of the projects priority freshwater taxonomic groups assessed in the Indo-Burma region, the crabs have the highest level of threat (33.8%), followed by the fish and molluscs (16.9% and 16.6%, respectively), with the odonates and aquatic plants having relatively low levels of threat (4.2% and 2.4%, respectively) (Figure 8.1 and Table 8.2). Of the other taxonomic groups previously assessed, the freshwater dependent mammals (14 species) demonstrate by far the highest level of threat at 76.9%. The proportion of species that are Data Deficient is much higher within the project priority freshwater groups (for example, crabs and fishes are 56% and 43.6% DD, respectively) than for the mammals and birds (both with 0% DD), reflecting the historical focus of research upon large vertebrates.

Flooded forests of the Mekong River, Stung Treng Ramsar Wetlands Site in northern Cambodia © Paul Stewart http://mouthtosource.net/portfolio/

Figure 8.1 Summary of IUCN Red List Category classifications for the Indo-Burma assessment region for: (a) taxa assessed through this project (Odonata, fishes, molluscs, crabs and selected families of aquatic plants, and; (b) all taxa including other previously assessed key freshwater groups (freshwater dependent amphibians, birds and mammals).

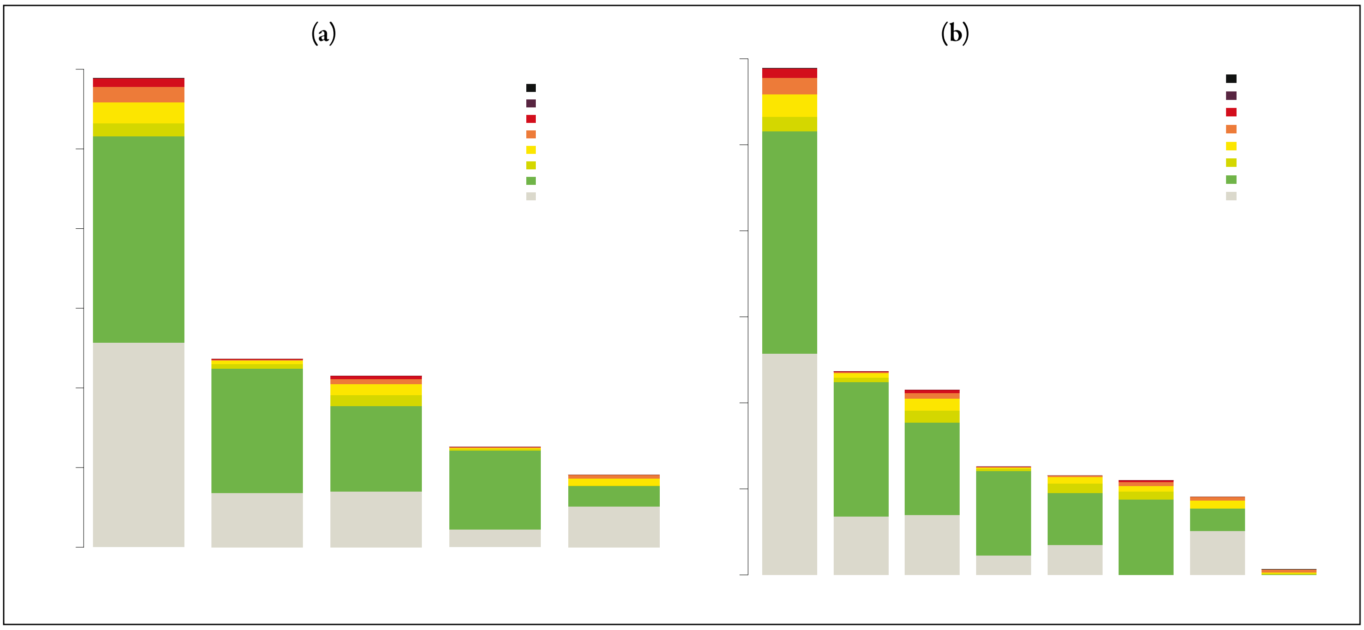


Table 8.2 Summary of Red List Category classifications for the Indo-Burma assessment region by taxonomic group.

	Project focus groups							
Category	**Fish**	**Odonata**	**Molluscs**	**Plants**	**Crabs**	**Amphibians**	**Birds**	**Mammals**
Extinct	1	0	0	0	0	0	0	1
Extinct in the Wild	0	0	0	0	0	0	0	0
Critically Endangered	21	2	8	1	0	0	4	0
Endangered	39	2	12	2	9	3	9	7
Vulnerable	52	10	28	2	18	16	13	3
Near Threatened	33	11	28	5	1	21	19	2
Least Concern	518	312	214	197	52	120	175	1
Data Deficient	514	136	140	45	102	74	0	0
Total	**1,178**	**473**	**430**	**252**	**182**	**234**	**220**	**14**
% Data Deficient	**43.6**	**28.8**	**32.6**	**17.9**	**56.0**	**31.6**	**0.0**	**0.0**
% Threatened*	**16.9**	**4.2**	**16.6**	**2.4**	**33.8**	**11.9**	**11.8**	**76.9**

* % Threatened is calculated using only species that are extant and have sufficient data to assess their conservation status (i.e. excluding EX, EW and DD species)

8.2 Patterns of species richness

Species richness is presented as the number of species contained within river sub-catchments, as derived from HydroSHEDS hydrographic data (Lehner *et al.* 2008), mapped to include all the species within the priority taxonomic groups of this project. However, as all plant species could not be mapped to river sub-catchments but only to presence within countries (see Chapter 7) we have not included the plants in the multi-taxa analyses.

As with many species richness maps they have the potential for bias due to sampling intensity and mapping methodology. For example, some parts of the region have benefited from more intense survey and taxonomic study, either historically (i.e. the colonial era), or more recently, due to their close proximity to research centres. Conversely, some areas are likely to support greater numbers of species than are apparent here as they have been historically under-surveyed, often because of political instability or difficulty of access.

8.2.1 Centres of species richness

The highest level of species richness (416 to 526 species present per sub-catchment) is found in lowland areas within the lower and middle Chao Phraya River, the main stem of the Mekong River as it flows along the Lao P.D.R-Thailand border into northern Cambodia (Khorat Plateau and Kratie-Stung Treng ecoregions) (Figure 8.2). Lower levels of species richness are found in mountainous areas across the region such as in the Salween catchment, the Tenasserim mountain range and the eastern Gulf of Thailand. The lower recorded numbers of species associated with highland areas, as might be expected due to their lower diversity of habitats, may be partly a reflection of the reduced intensity of survey and research undertaken in these areas.

8.2.2 Distribution of threatened species

The distribution pattern of threatened species (Figure 8.3) broadly matches that of overall species richness (Figure 8.2). The greatest numbers of threatened species (28 to 40 species per sub-catchment) are within the main channel of the Mekong River between the very southern tip of Lao PDR around Khone Falls and northern Cambodia north of Stung Treng. The next highest numbers (20 to 27 species per sub-catchment) are within the main stem of the middle (lowland) Mekong River as it flows along the Lao PDR-Thailand border from the confluence with the Namkading/Theun River into Cambodia to the north of the confluence with the Tonlé Sap River. The low numbers of threatened species recorded in some places, in particular in the Red River catchment, may not represent the true picture of the overall level of threat as there was often insufficient information available to assess the threatened status of many potentially threatened species (Data Deficient species) (see Figure 8.4).

8.2.3 Distribution of Data Deficient species

The distribution pattern of Data Deficient (DD) species (Figure 8.4) highlights those areas where more research is needed to

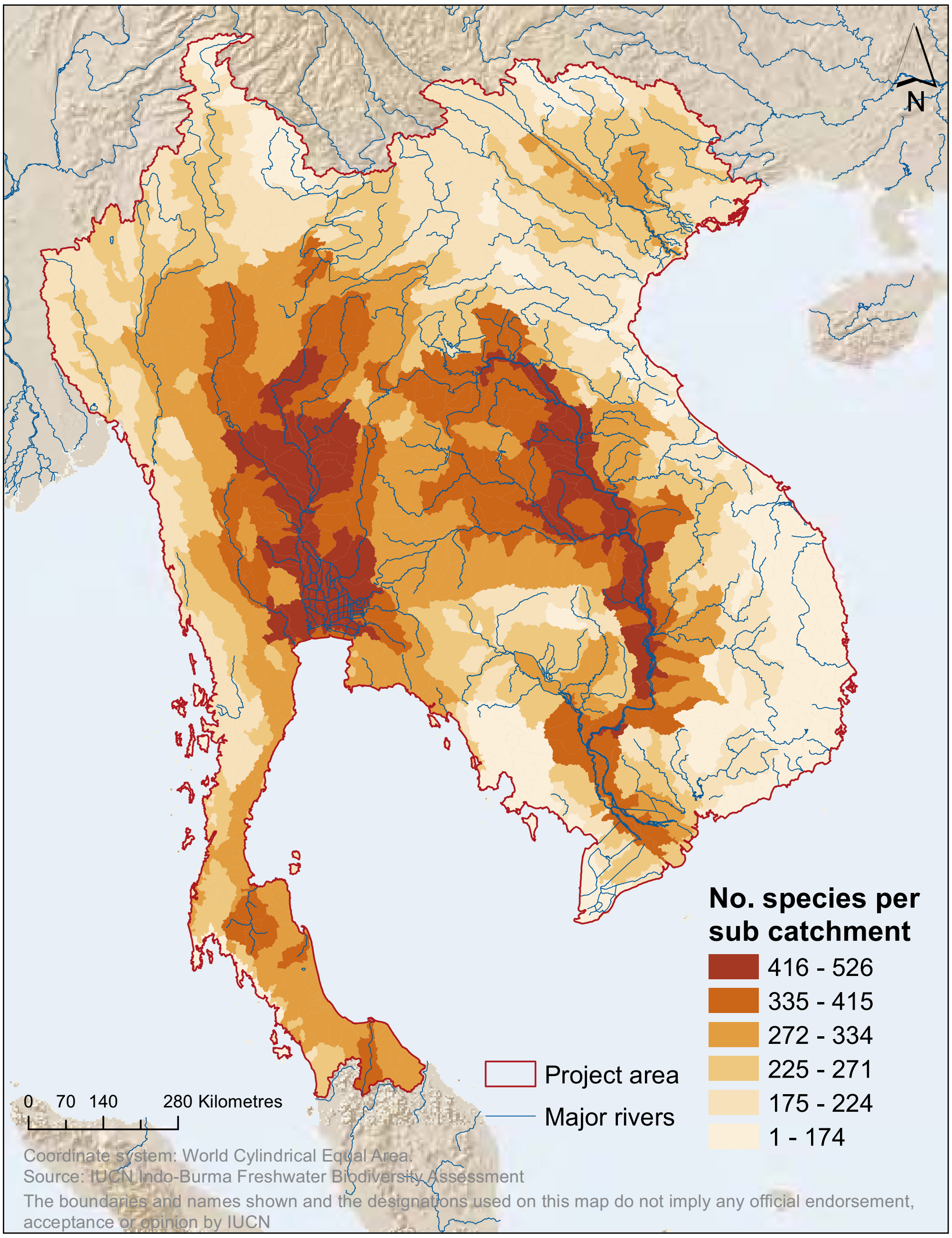


Figure 8.2 The distribution of all freshwater fish, mollusc, odonate and crab species within river sub-catchments across Indo-Burma.

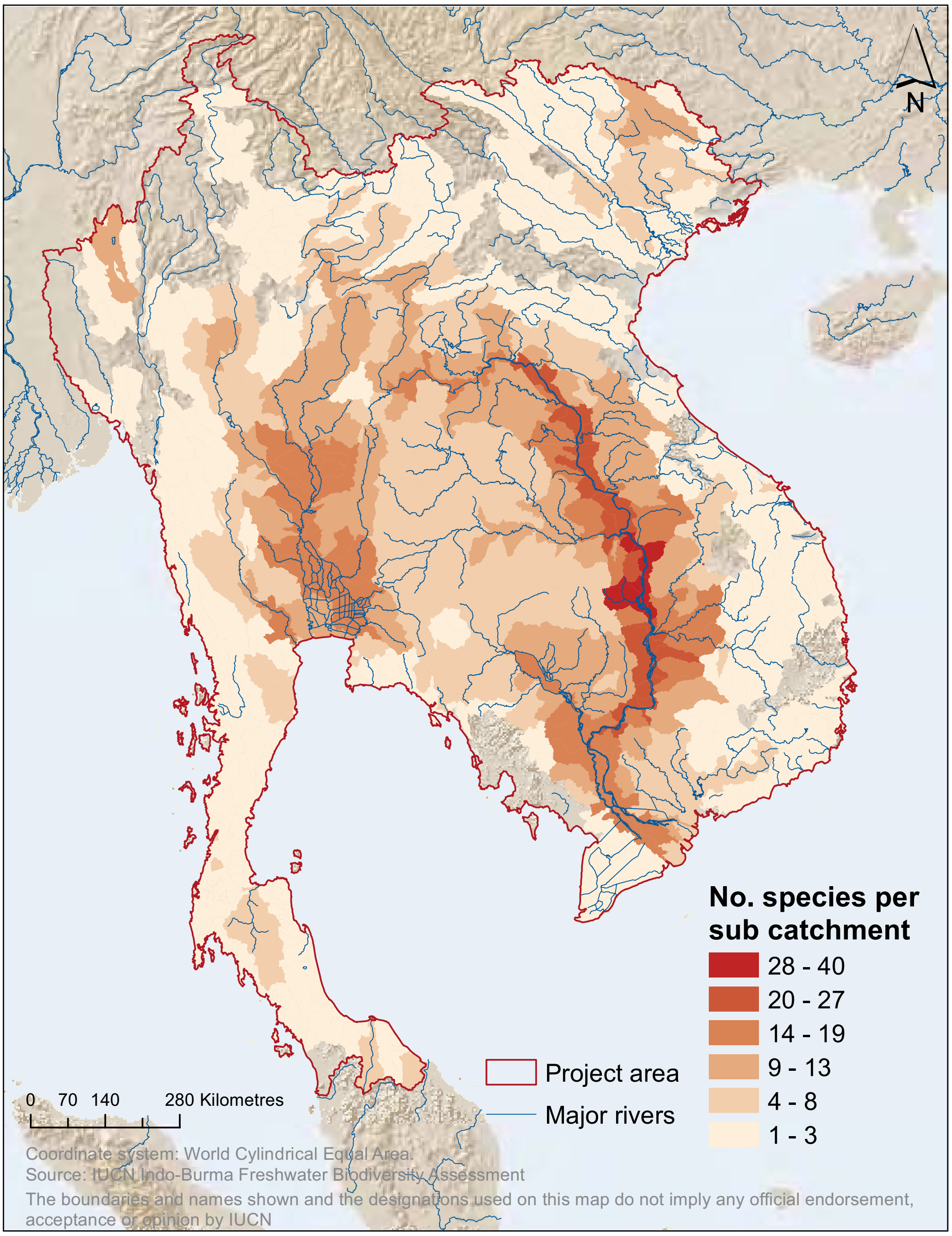
determine the threatened status of species present. However, as not all DD species can be mapped, it only provides a partial picture for the distributions of DD species. Almost the entire Red River catchment in northern Viet Nam is included within the highest category of DD species richness (58 to 86 species per sub-catchment), as is a small section of the Mekong River from Stung Treng near Kratie in northern Cambodia to southern Lao PDR (Figure 8.4).

8.2.4 Restricted range species

Restricted range species are those that have a distribution (based on the combined area of sub-catchments where recorded) of less than 20,000 km^2 for fish, crabs and molluscs and less than 50,000 km^2 for odonates. These area thresholds are compatible with those used to identify freshwater Key Biodiversity Areas under Criterion 2 (see

Khone Falls, on the Mekong River in southern Lao PDR, supports exceptionally high levels of freshwater species and threatened species © Hiroo Yamagata

Figure 8.3 The distribution of all threatened freshwater fish, mollusc, odonate and crab species within river sub-catchments across Indo-Burma.



Section 8.4). The areas containing the highest number of restricted range species (23 to 31 species per sub-catchment) are the Mekong River around Khone Falls at the very south of Lao PDR, and Inlé Lake in eastern Myanmar (Figure 8.5). The sub-catchments containing the second highest numbers of range restricted species (17 to 22 species per sub-catchment) are the upper Namkading/Theun River and the upper Kong River (Sekong) in Lao PDR (both eastern tributaries of the Mekong River).

8.2.5 Inclusion of freshwater dependant mammals, birds and amphibians

Species distributions of previously assessed freshwater dependant mammals, birds and amphibians are combined here with those of the fishes, molluscs, odonates and crabs in order to provide a more comprehensive picture of the overall geographic patterns of freshwater and species and threatened freshwater species.

The cause of death of this young Irrawaddy Dolphin (Critically Endangered *Orcaella brevirostris*) near Kratchie in Cambodia is unknown © William Darwall

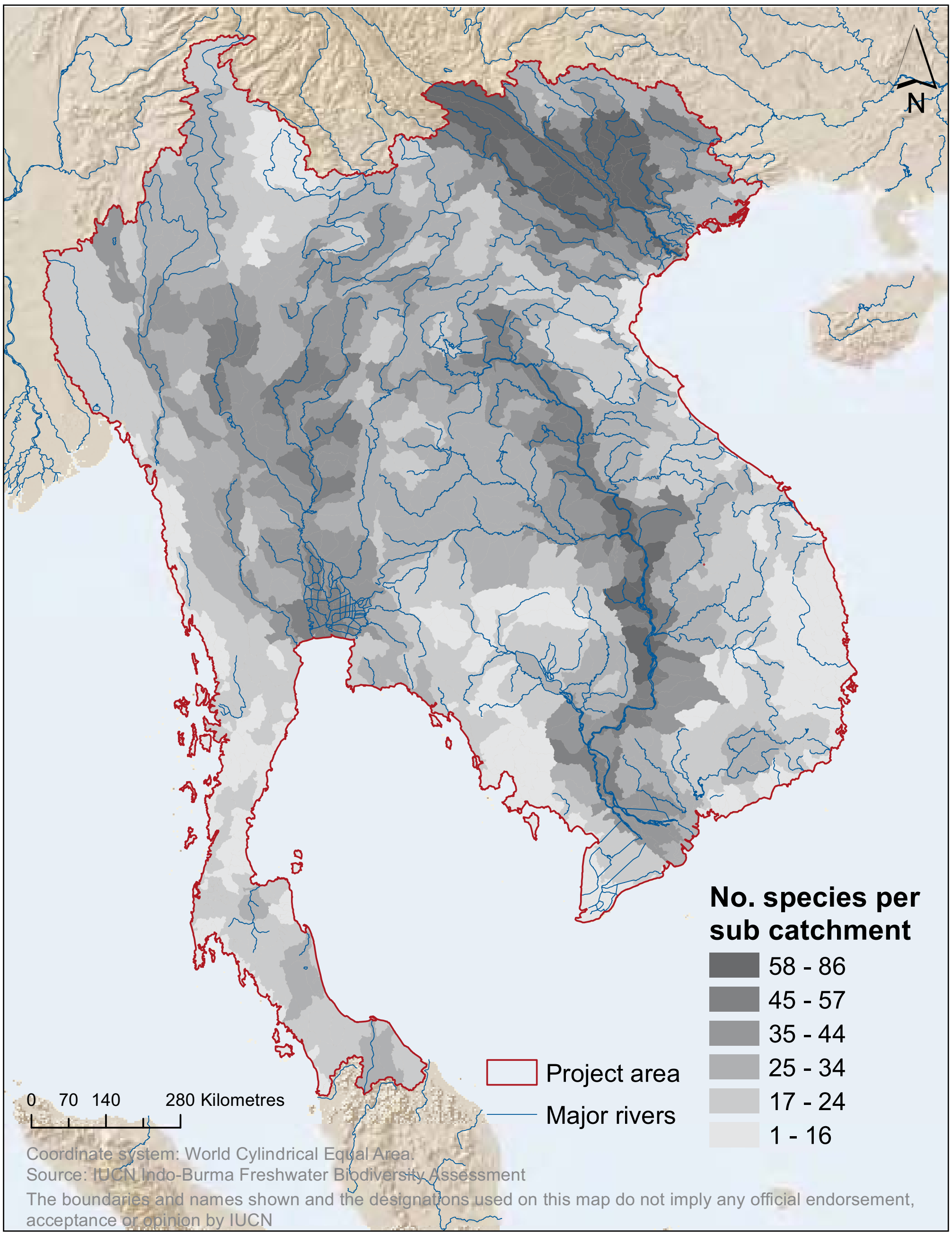
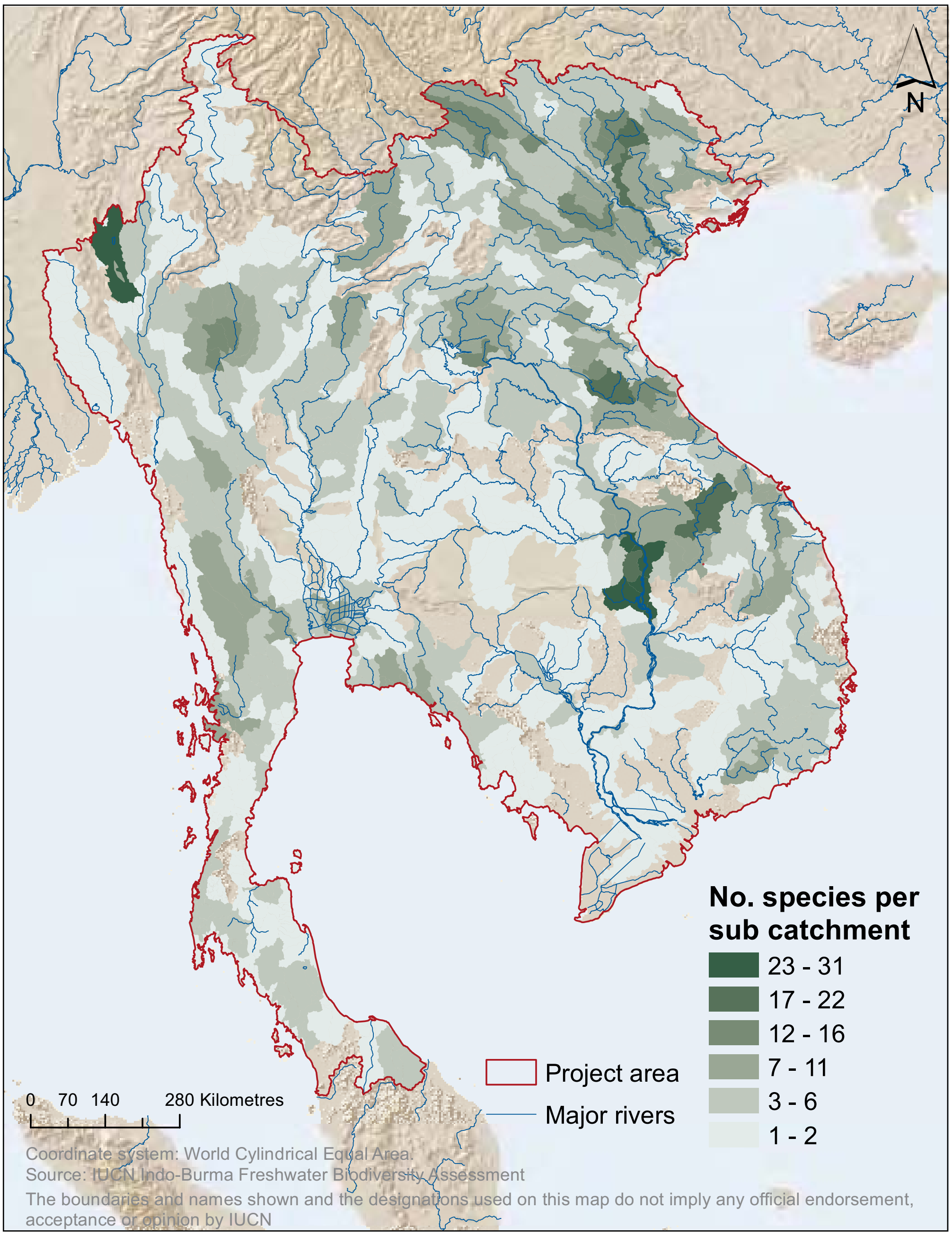


Figure 8.4 The distribution of all Data Deficient freshwater fish, mollusc, odonate and crab species for which maps could be created within river sub-catchments across Indo-Burma.

The River Lapwing (*Vanellus duvaucelii*) is a Least Concern bird found throughout the Indo-Burma region. © Patty McGann

It is, however, important to note that these additional species groups were not originally mapped to sub-catchments but to species extents of range, so there may be commission errors (i.e. a catchment that falls within a species range may not contain the species). No sub-catchment was found to contain at least 15% of species within each of all seven taxonomic groups (Figure 8.6). However, an eastern tributary to the Mekong in southern Lao PDR, the lower Mae Khlong, and two tributaries in the lower Chao Phraya in Thailand contain at least 15% of all known species within six of the seven taxonomic groups. Sub-catchments meeting this 15% threshold for five of the seven taxonomic groups cover almost the entire Chao Phraya catchment and the main stem of the middle and lower Mekong from northern Thailand to the Tonlé Sap in Cambodia. No sub-catchment contains more than 5% of threatened species recorded within all seven taxonomic groups (Figure 8.7).

Figure 8.5. The distribution of all restricted range freshwater fish, mollusc, odonate and crab species within river sub-catchments across Indo-Burma.



Rubbish below houses on the bank of the Mekong near Phnom Phen © William Darwall.

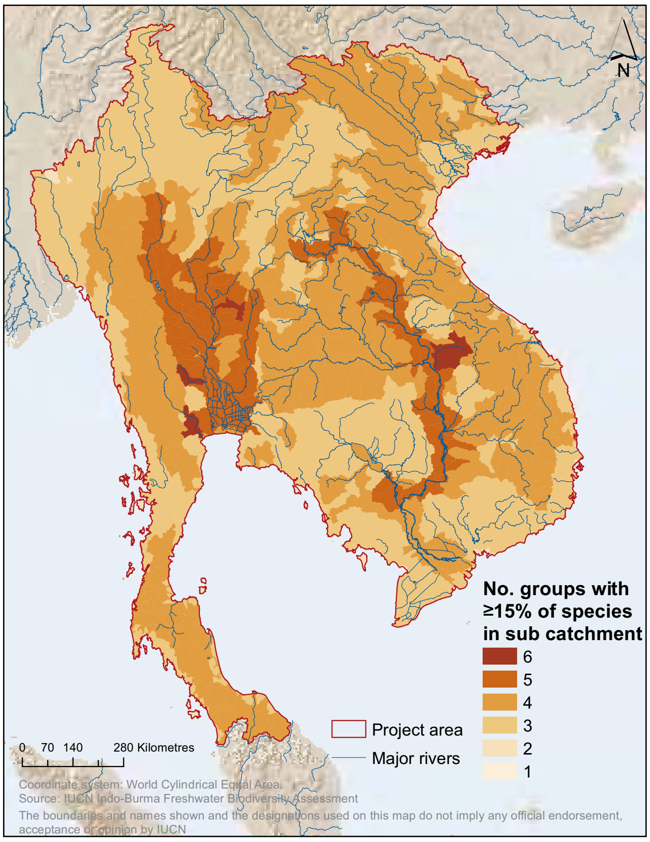


Figure 8.6 Sub-catchments containing high proportions of species from across all taxonomic groups (fish, molluscs, odonata, crabs, amphibians, birds and mammals). The map represents the number of taxonomic groups for which at least 15% of their total numbers of known species are recorded as present within each sub-catchment.

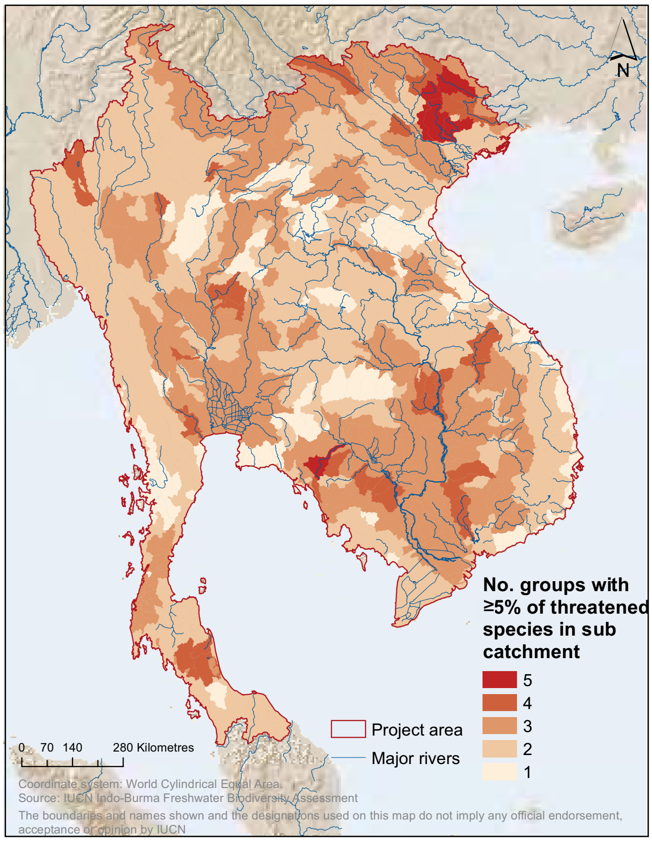


Figure 8.7 Sub-catchments containing high proportion of threatened species from all taxonomic groups (fish, molluscs, odonata, crabs, amphibians, birds and mammals). The map represents the number of taxonomic groups for which at least 5% of their total numbers of threatened species are recorded as present within each sub-catchment.

However, an eastern tributary of the Red River and the upper Pearl River in northern Viet Nam, and a western tributary to the Tonlé Sap in Cambodia all contain over 5% of the threatened species recorded for five of the seven taxonomic groups. A number of sub-catchments contain 5% of threatened species for four of the seven taxonomic groups, including Inlé Lake in eastern Myanmar, the Khone Falls area of the Mekong, and the Thai peninsular.

8.3 Threats to freshwater biodiversity in Indo-Burma

8.3.1 Ongoing threats to freshwater biodiversity in Indo-Burma

Each species has been coded against the IUCN Red List threats classification scheme, to record the threats impacting the species. This scheme is a hierarchical system (with some threats having three levels of breakdown), is comprehensive and exclusive at the upper levels of the hierarchy, and is expandable at the lower levels (Salafsky *et al.* 2008, see www.iucnredlist.org for the full classification scheme). Figure 8.8 shows the proportion of species in each taxonomic group impacted by each of the upper level threats, whereas Table 8.3 shows the number of species impacted by each of the upper and second level threats.

There are three major threats to freshwater fishes. *Pollution* is the greatest threat, impacting over a third of all fish species (36%), followed by *Biological resource use* (impacting 26% of species), and *Natural system modifications* (impacting 25% of species). Table 8.3 shows that *Agricultural and forestry effluents* (impacting 402 species, of which 63 are threatened) is the major type of pollution threat followed by *Domestic and urban waste water* (120 species, of which 26 are threatened). Under *Biological resource use* the major threat to fishes is *Fishing and harvesting of aquatic resources* (264 species, of which 55 are threatened), and under *Natural system modifications* 222 species, of which 59 are threatened, are impacted by *Dams and water management/use*.

Freshwater molluscs are heavily impacted by *Pollution* (40% of species) and *Natural system modifications* (25% of species). *Biological resource use*, and *Energy production and mining* also pose serious threats to molluscs with 11% and 9% of species impacted, respectively. *Agricultural and forestry effluents* (142 species, of which 23 are threatened), *Dams and water management/use* (103 species, of which 14 are threatened), and *Mining and quarrying* (39 species, of which 16 are threatened) are the major second level threats to molluscs (Table 8.3).

The odonates (dragonflies and damselflies) are primarily threatened by *Biological resource use* (27% of species). However, it is the indirect impact of habitat loss and degradation through *Logging and wood harvesting* (20 species, of which 11 are threatened) that represents the major threat, in contrast to the direct *Harvesting of aquatic resources* as recorded to be a major threat for fishes and molluscs (Table 8.3). *Residential and commercial development* and *Agriculture and aquaculture* also represent significant threats to the odonates of Indo-Burma, both impacting 12% of species. Under *Residential and commercial development*, it is *Tourism and recreation* that impacts the greatest number (six species) of threatened species (Table 8.3).

Freshwater crabs are threatened by both *Residential and commercial development* (14% of species) and *Biological resource use* (13% of species). *Pollution* and *Agriculture and aquaculture* are significant threats, each impacting 9% of species. All the second level threats nested under *Residential and commercial development* impact crabs, with *Tourism and recreation areas* impacting the most threatened species (six species) (Table 8.3). Within *Biological resource use* it is *Harvesting of aquatic resources* that impacts the most species (20 species are impacted), although *Logging and wood harvesting* affects the most threatened species (five species are threatened). In contrast to fishes, molluscs, and odonates the major pollution threat is *Domestic and urban waste water* (12 species, of which 11 are threatened) with *Agricultural and forestry effluents* threatening eight species, five of which are threatened. Under *Agriculture and aquaculture* it is *Annual and perennial non-timber crops* that represents the major threat to crabs impacting 16 species, of which 11 species are threatened.

Aquatic and wetland plants are currently the least impacted of the priority taxonomic groups assessed here, with *Biological resource use* impacting the greatest proportion of species (8% of all species) (Figure 8.8). *Agriculture and aquaculture, Pollution* and *Residential and commercial development* all impact around 4% of species. Under *Biological resource use* it is *Logging and wood harvesting* that impacts the most species (14 species impacted) (Table 8.3), however, *Gathering terrestrial plants* impacts the only those species assessed as threatened. *Dams and water management/use* impacts the most threatened species (two species).

The IUCN Red List threat classification scheme also allows for past and future threats to be identified for each species. One of

Freshwater gastropods for sale at a market in Cambodia. © William Darwall.

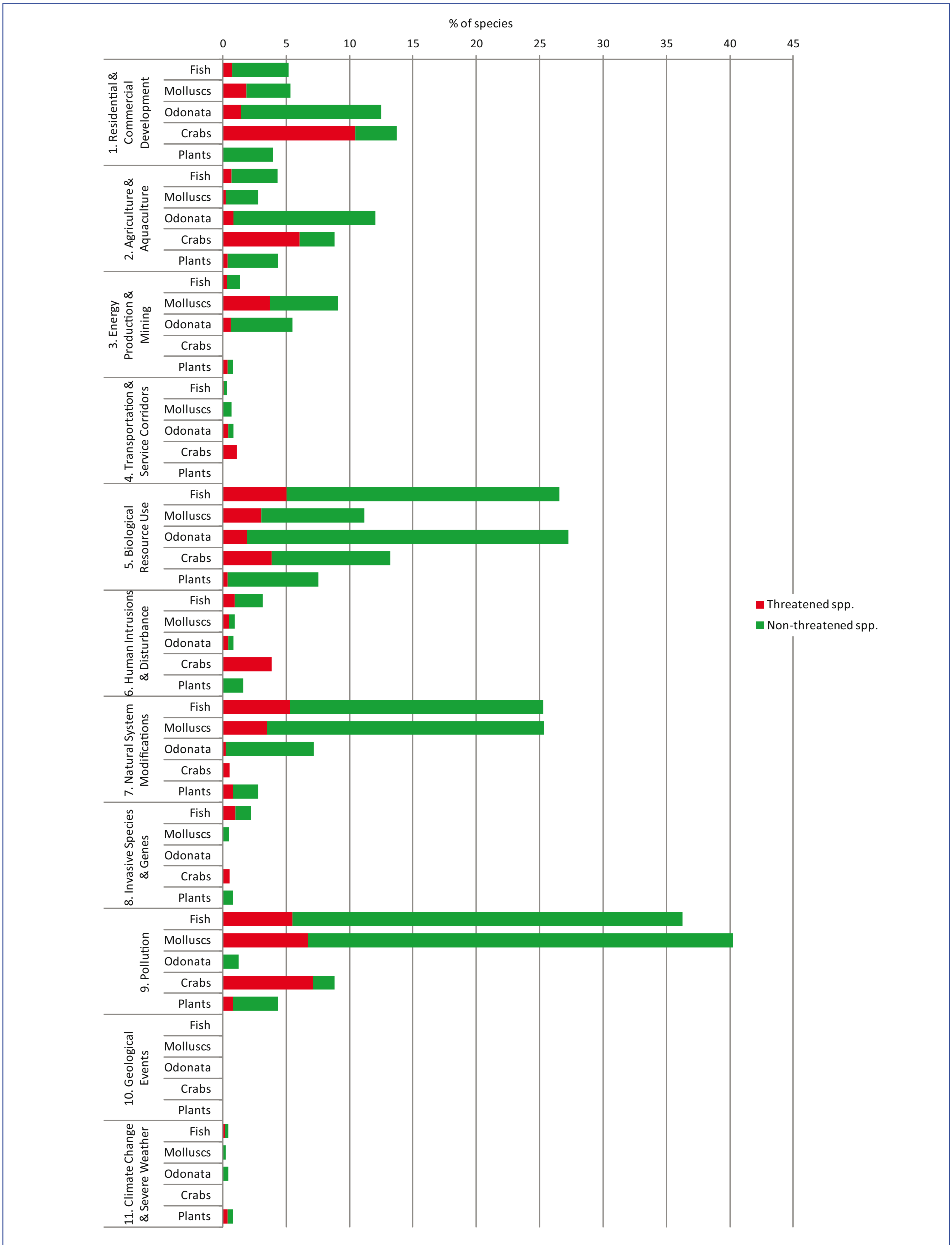


Figure 8.8 The proportion of freshwater species impacted by each category of threat (ongoing) in Indo-Burma, showing the proportion of total species impacted that are also threatened. Only the upper level threats within the IUCN Red List threats classification scheme are shown. The total bar length represents the % of species from that taxonomic group impacted by the threat, the green coloured section representing non-threatened species (NT, LC, DD), and the red coloured section threatened species (CR, EN, VU).

the key outcomes from this analysis for the Indo Burma region is the predicted impact of future dam construction on freshwater biodiversity. An additional 15% of mollusc species and 9% of fish species are predicted to be negatively impacted by dams in the future, whereas for the other taxonomic groups the predicted impact is minimal (Figure 8.9).

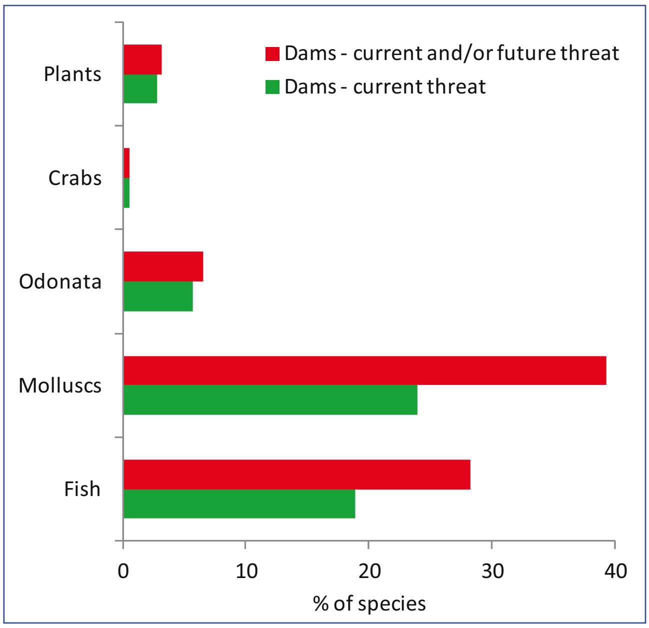
More detail on the threats to freshwater biodiversity and how they impact each particular taxonomic group is provided in the sections on *Major threats* within each of the taxonomic chapters (Chapters 3 to 7).

8.4 Freshwater Key Biodiversity Areas

8.4.1 Key Biodiversity Areas methodology

Site selection criteria developed by IUCN for the identification of freshwater Key Biodiversity Areas (Holland *et al.* 2012) were applied to datasets for the Indo-Burma fishes, crabs, molluscs and odonates. Plants were excluded from the analysis as most species were only mapped to presence within countries and, in addition, Plantlife International have developed an alternative

Figure 8.9 Comparison of the proportion of freshwater species identified as being currently impacted by dams (current threat) and predicted to be impacted by dams now and in the future (current and/or future threats).



A dam in Cua Dat Than Hoa province in Vietnam. Dams are a significant current and future threat to freshwater species in the region © Le Hung Anh

Table 8.3. The number of freshwater species impacted by each category of threat (ongoing) in Indo-Burma. Only the top and second level threats of the IUCN Red List threat classification scheme are shown here.

IUCN Threat classification scheme	FISH (n=1178)		MOLLUSCS (n=430)		ODONATA (n=473)		CRABS (n=182)		PLANTS (n=252)	
	All spp.	Thr. spp.	All spp.	Thr. spp.	All spp.	Thr. spp.	All spp.	Thr. spp.	All spp.	Thr. spp.
1. Residential & Commercial Development	**61**	**9**	**23**	**8**	**59**	**7**	**25**	**19**	**10**	**0**
1.1 Housing & Urban Areas	46	6	22	8	34	1	17	12	8	0
1.2 Commercial & Industrial Areas	29	0	12	4	29	1	14	9	1	0
1.3 Tourism & Recreation Areas	12	4	5	3	25	6	8	7	5	0
2. Agriculture & Aquaculture	**51**	**8**	**12**	**1**	**57**	**4**	**16**	**11**	**11**	**1**
2.1 Annual & Perennial Non-Timber Crops	39	7	4	0	25	2	16	11	6	1
2.2 Wood & Pulp Plantations	10	1	1	0	40	2	0	0	5	1
2.3 Livestock Farming & Ranching	2	0	2	0	2	0	1	1	3	0
2.4 Marine & Freshwater Aquaculture	4	0	9	1	0	0	0	0	1	0
3. Energy Production & Mining	**16**	**4**	**39**	**16**	**26**	**3**	**0**	**0**	**2**	**1**
3.1 Oil & Gas Drilling	0	0	0	0	0	0	0	0	0	0
3.2 Mining & Quarrying	16	4	39	16	4	3	0	0	2	1
3.3 Renewable Energy	0	0	0	0	22	0	0	0	0	0
4. Transportation & Service Corridors	**4**	**1**	**3**	**0**	**4**	**2**	**2**	**2**	**0**	**0**
4.1 Roads & Railroads	4	1	0	0	4	2	2	2	0	0
4.2 Utility & Service Lines	0	0	1	0	0	0	0	0	0	0
4.3 Shipping Lanes	0	0	2	0	0	0	0	0	0	0
5. Biological Resource Use	**313**	**59**	**48**	**13**	**129**	**9**	**24**	**7**	**19**	**1**
5.1 Hunting & Collecting Terrestrial Animals	0	0	0	0	0	0	0	0	1	0
5.2 Gathering Terrestrial Plants	0	0	0	0	0	0	1	1	5	1
5.3 Logging & Wood Harvesting	76	12	20	11	129	9	5	5	14	0
5.4 Fishing & Harvesting Aquatic Resources	264	55	37	9	0	0	20	3	1	0
6. Human Intrusions & Disturbance	**37**	**11**	**4**	**2**	**4**	**2**	7	7	**4**	**0**
6.1 Recreational Activities	13	7	4	2	2	2	7	7	3	0
6.3 Work & Other Activities	25	4	0	0	2	0	0	0	2	0
7. Natural System Modifications	**298**	**62**	**109**	**15**	**34**	**1**	**1**	**1**	7	**2**
7.1 Fire & Fire Suppression	3	3	0	0	4	0	0	0	0	0
7.2 Dams & Water Management/Use	222	59	103	14	27	1	1	1	7	2
7.3 Other Ecosystem Modifications	105	7	11	2	3	0	0	0	0	0
8. Invasive & Other Problematic Species & Genes	**26**	**1**	**2**	**0**	**0**	**0**	**1**	**1**	**2**	**0**
8.1 Invasive Non-Native/Alien Species	19	9	1	0	0	0	1	0	2	0
8.2 Problematic Native Species	5	5	1	0	0	0	0	0	0	0
8.3 Introduced Genetic Material	6	1	0	0	0	0	0	0	0	0
9. Pollution	**427**	**65**	**173**	**29**	**6**	**0**	**16**	**13**	**11**	**2**
9.1 Domestic & Urban Waste Water	120	26	4	8	0	0	12	11	3	1
9.2 Industrial & Military Effluents	84	18	75	12	0	0	5	4	2	1
9.3 Agricultural & Forestry Effluents	402	63	142	23	6	0	8	5	7	1
9.4 Garbage & Solid Waste	9	1	5	2	0	0	0	0	0	0
10. Geological Events	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
11. Climate Change & Severe Weather	**5**	**2**	**1**	**0**	**2**	**0**	**0**	**0**	**2**	**1**
11.1 Habitat Shifting & Alteration	0	0	0	0	0	0	0	0	1	0
11.2 Droughts	3	2	1	0	2	0	0	0	0	0
11.3 Temperature Extremes	1	0	0	0	1	0	0	0	0	0
11.4 Storms & Flooding	2	0	0	0	1	0	0	0	1	1

set of criteria, specific to plants, to identify Important Plant Areas (see Anderson 2002, Plantlife International 2010). Key Biodiversity Areas, or KBAs, are defined as sites containing species of global conservation significance, identified by applying criteria relating to vulnerability and irreplaceability where vulnerability is defined as the likelihood that a species will be lost over time, and irreplaceability refers to the spatial options for conservation of the species. Langhammer *et al.* (2007) provide a detailed discussion and examples of the application of KBA methodologies for various taxonomic groups.

For the purposes of this study three criteria were applied to identify sites that qualify as potential freshwater KBAs.

Criterion 1. A site is known or thought to hold a significant number of one or more globally threatened species or other species of conservation concern. Here the presence of species assessed as Vulnerable, Endangered or Critically Endangered triggered qualification of the sub-catchment.

Criterion 2. A site is known or thought to hold non-trivial numbers of one or more species (or infraspecific taxa as appropriate) of restricted range. Threshold values of 20,000 km^2 were applied to fish, crabs and molluscs and 50,000 km^2 to odonates for the species to qualify as restricted range.

Criterion 3. A site is known or thought to hold a significant component of the group of species that are confined to an appropriate biogeographic unit or units. Here the WWF freshwater ecoregions of the world (Abell *et al.* 2008) were used as the biogeographic unit, and qualification was triggered where at least 25% of the species within any sub-catchment were restricted to the ecoregion.

The aim of the freshwater KBA methodology is to identify all sites that meet the site selection criteria, these are termed 'potential KBAs'. This exercise represents only the first step in the formal identification, recognition, and designation of KBAs. This is, as such, a preliminary exercise designed to provide an initial output that might then be taken forwards through a series of stakeholder workshops to determine the suitability of each potential site for designation as a formal KBA. Final designation of sites as formal KBAs should consider each site within the context of other pre-existing and overlapping managed sites and with consideration of all other relevant administrative, economic and social issues. The resulting KBA may include the entire sub-catchment or sites within that catchment depending upon the nature of the species within it and the type of management required. In the current study we present maps showing the number of times each sub-catchment qualifies as a KBA (in terms of the number of species or species assemblages within it that meet any of the three the KBA criteria), however, no effort is made to prioritise amongst sites. The prioritisation of potential KBAs, through such approaches as Systematic Conservation Planning, represents a priority for future work.

8.4.2 Potential freshwater Key Biodiversity Areas

Following application of the KBA selection criteria, 1,008 sub-catchments (out of a total of 1,081 sub-catchments in the Indo-Burma assessment region) qualify as potential KBAs – meaning that each of these sub-catchments contains at least one species, or assemblage of species, meeting at least one of the three selection criteria listed above. Table 8.4 summarises the results, and shows that fish trigger the greatest number of sub-catchments, followed by crabs and molluscs and then odonates. For the fishes, Criterion 1 (threatened species) triggers the greatest number of sub-catchments (829). However, for molluscs, crabs and odonates Criterion 2 (restricted range species) triggers the greatest number of sub-catchments per taxon-group.

Figures 8.10 to 8.13 show the locations of potential KBA sub-catchments triggered by fish, crab, mollusc and odonata species, respectively. For fishes (Figure 8.10) the middle and upper Red River in northern Viet Nam and the main channel of the middle and lower Mekong River contain the sub-catchments with the greatest numbers of KBA trigger species (those species meeting any of the three KBA site selection criteria) (27 to 38 species). Many of the tributaries to the middle Mekong, the Mekong Delta in Viet Nam to the Tonlé Sap in Cambodia, the middle and lower Chao Phraya, Inlé Lake and its catchment in eastern Myanmar and parts of the upper Red River also contain sub-catchments with high numbers of KBA trigger species (19 to 26 species). For molluscs (Figure 8.11) the greatest numbers of KBA trigger species (37 to 65 species) are found around the Khone Falls area of the Mekong River at the southern tip of Lao PDR. Other sub-catchments also containing high numbers of mollusc trigger species (21 to 36 species) are those directly connected to and in close proximity to the Khone Falls. For odonates (Figure 8.12), the sub-catchments with the highest numbers of trigger species (11 to 13 species) are found in the middle Red River in northern Viet Nam. Seven to ten trigger species are found in sub-

Table 8.4 Numbers of sub-catchments containing species that meet each of the freshwater Key Biodiversity Area criteria for each taxonomic group in the Indo-Burma assessment region.

	Fish	Molluscs	Odonates	Crabs	All taxa
Criterion 1	**829**	**247**	**58**	**87**	**888**
Criterion 2	**492**	**296**	**257**	**329**	**781**
Criterion 3	**24**	**0**	**0**	**277**	**291**
Total	**966**	**420**	**266**	**420**	**1,008**

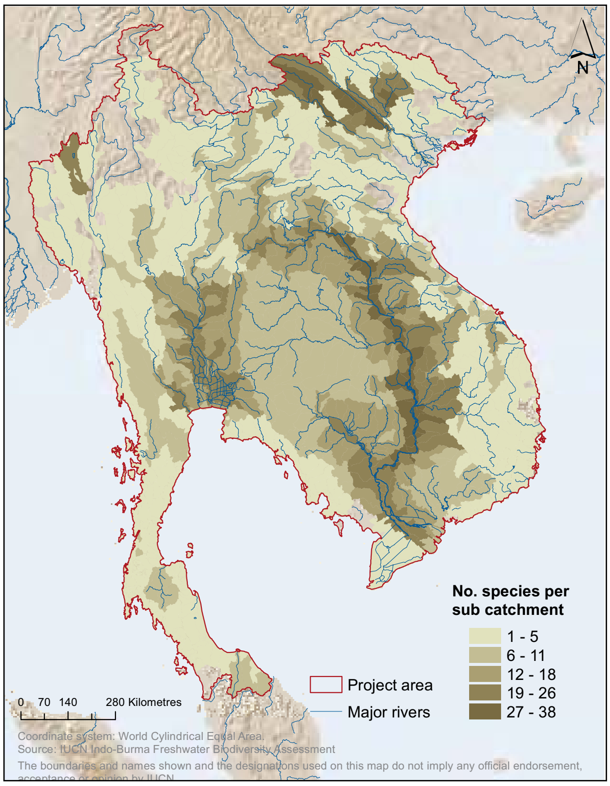


Figure 8.10 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for fishes. Sub-catchments in darker green indicate presence of higher numbers of species meeting the KBA criteria.

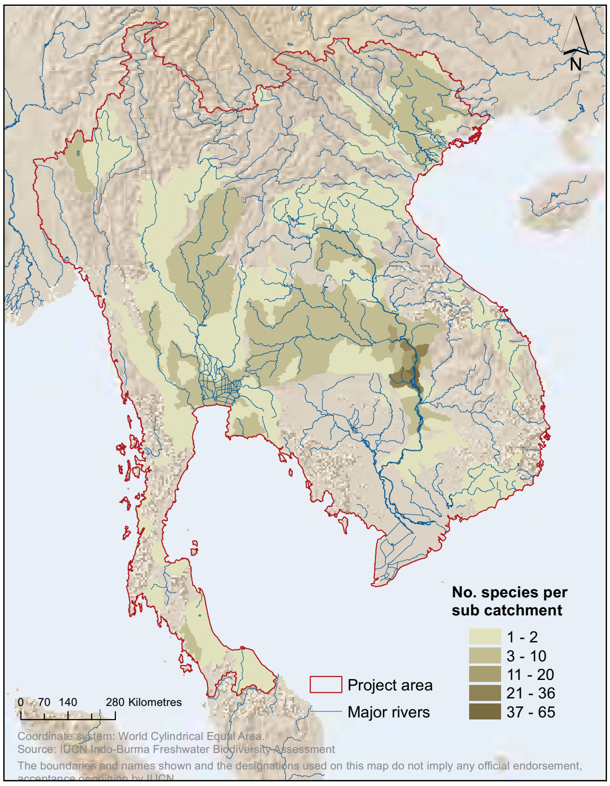


Figure 8.11 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for molluscs. Sub-catchments in darker green indicate presence of higher numbers of species meeting the KBA criteria.

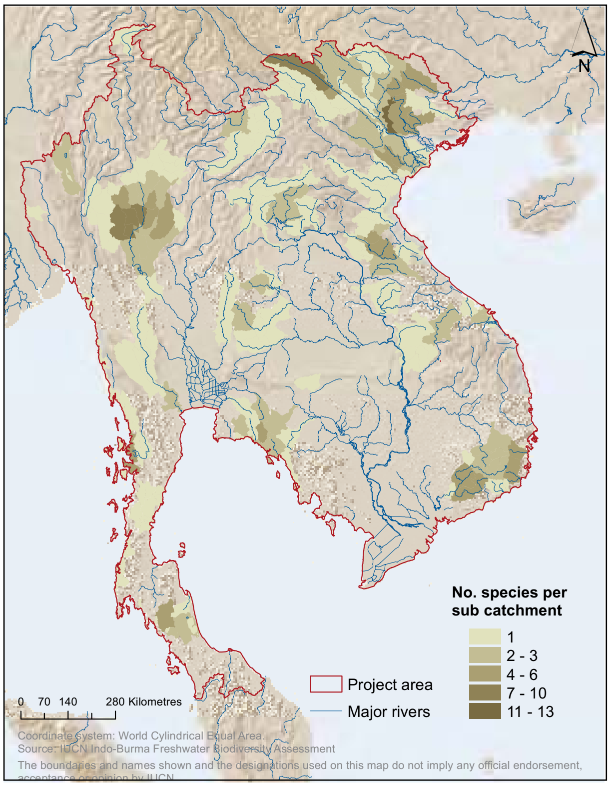


Figure 8.12 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for odonates. Sub-catchments in darker green indicate presence of higher numbers of species meeting the KBA criteria.

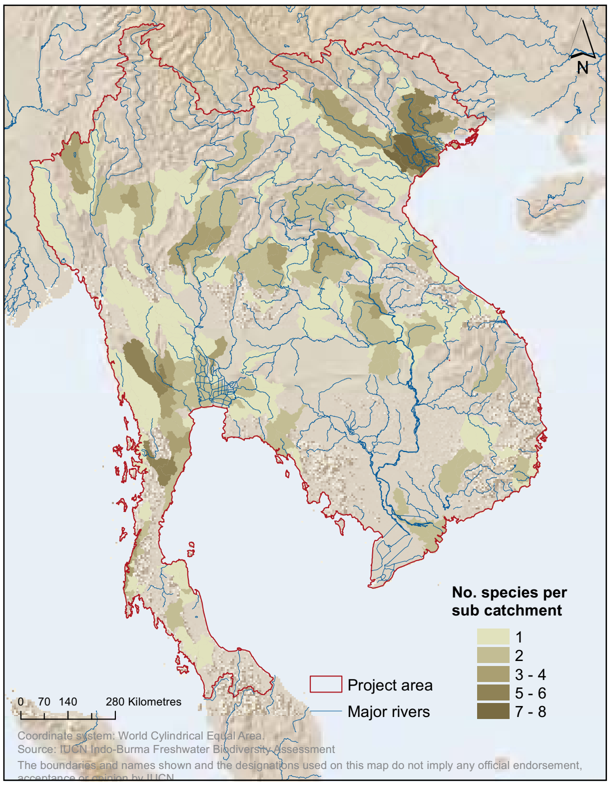


Figure 8.13 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for crabs. Sub-catchments in darker green indicate presence of higher numbers of species meeting the KBA criteria.

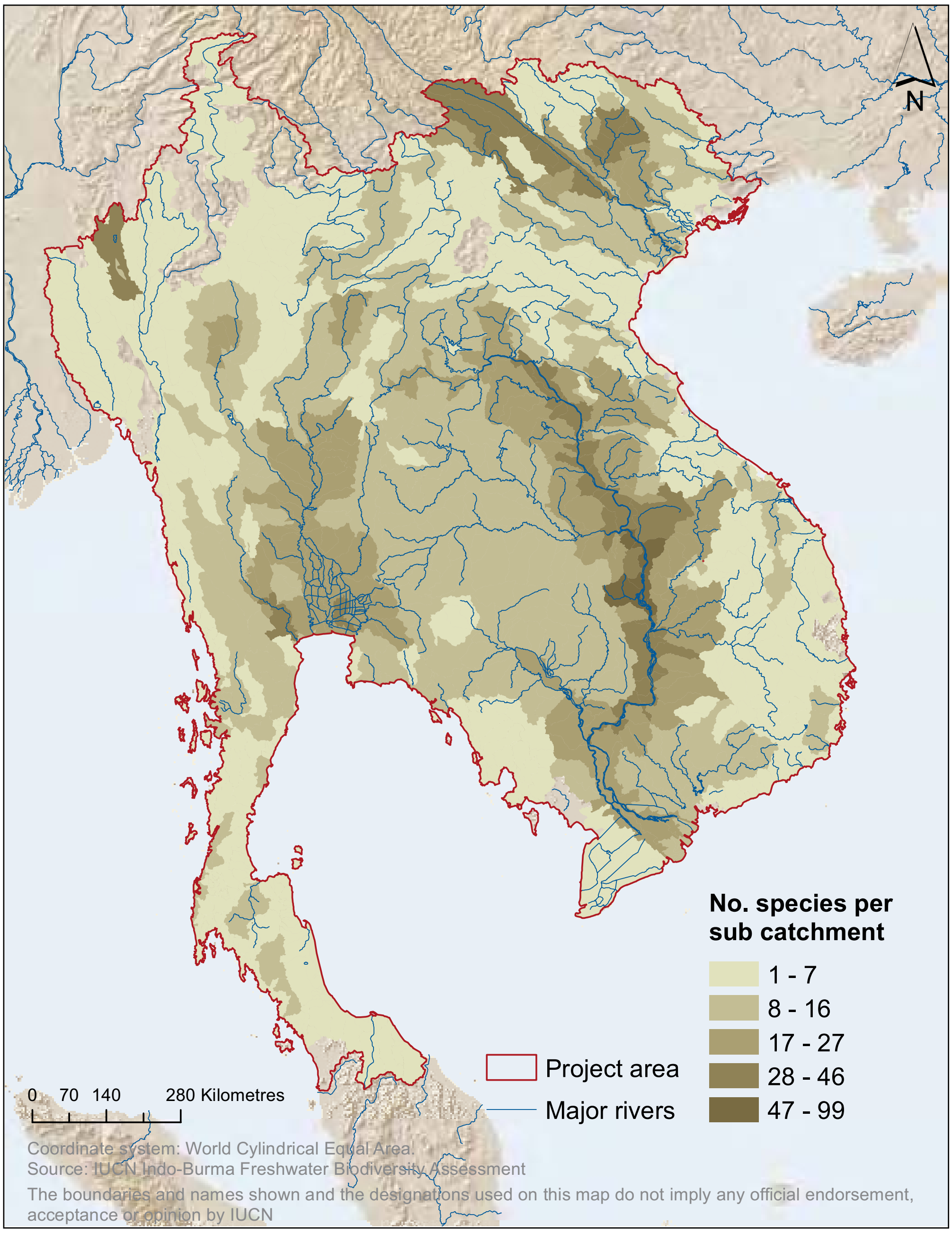
catchments in the upper reaches of the Chao Phraya in north western Thailand, and the upper Red River. The highest numbers of crab species (7 to 8 species) that trigger KBA criteria are within a few sub-catchments in the lower Red River, northern Viet Nam (Figure 8.13). An eastern tributary of the Mae Khlong, western Thailand, and the southern tributaries of the Great Tenassarim River, southern Myanmar also contain high numbers of trigger species (5 to 6 species).

When the potential freshwater KBA sub-catchments for all taxonomic groups are combined within a single map (Figure 8.14), the sub-catchments with the highest number of trigger species (47 to 99 species) are found in southern Lao PDR around Khone Falls on the main Mekong River. The second highest numbers of KBA trigger species (28 to 46 species) are found in the main stem of the middle and lower Mekong, the middle and upper Red River in Viet Nam, Inlé Lake and its catchment in eastern Myanmar, and the lower Chao Phraya and Mae Khlong in Thailand. While these areas are undoubtedly important for freshwater species, they also reflect the areas of most intense survey effort (in particular Khone Falls and lower and middle Mekong river). Sub-catchments showing lower numbers of species triggering KBAs, may require additional field survey in order to be sure that no additional KBA trigger species are present.

8.4.3 Next steps: Formal designation of KBAs and gap analysis

As mentioned above (Section 8.4.1), application of the KBA criteria to identify potential KBAs represents only the first step in the process for formal designation of freshwater KBAs. Following this initial analysis expert knowledge and conservation planning tools (see Margules and Pressey 2000, Turak and Linke 2011) can be used to identify a network of priority sub-catchments given

Figure 8.14 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for any of the freshwater species (fishes, molluscs, odonates and crabs). Sub-catchments in darker green indicate presence of higher numbers of species meeting the KBA criteria.



that it is unlikely to be practical to develop specific management plans for all those sites meeting the basic criteria. Systematic Conservation Planning approaches might be used to design such a network of priority sites.

Systematic Conservation Planning principles are often referred to as CARE as they: i) aim to prevent bias by including the full range of species, processes and ecosystems (Comprehensiveness); ii) ensure that the design of the conservation network is suitable for their persistence (Adequacy); iii) ensure that the network of sites captures all aspects of biodiversity (Representativeness) and; iv) aim to minimise the costs and impacts on stakeholders (Efficiency) (Linke *et al.* 2011). Recent years have seen the development of a range of software tools to guide this process. However, engagement with stakeholders on the ground is clearly key to this process (Barmuta *et al.* 2011) as to be effective the final network of sites must take into consideration not only biodiversity targets but the full range of social, economic and political factors.

Once these processes have been undertaken the prioritized network can be proposed to the relevant national and international bodies for formal recognition. These additional steps in the process for the formal identification of freshwater KBAs are yet to be undertaken for the Indo-Burma region.

8.4.4 Overlap with existing Key Biodiversity Areas

By overlaying the existing terrestrial Key Biodiversity Areas in the Indo-Burma region, as defined by CEPF, the Bird Conservation Society of Thailand, Kadoorie Farm and Botanic Gardens, and WWF Cambodia Programme for globally threatened flora and fauna (mammals, birds, reptiles, fish and amphibians), with those sub-catchments identified above as

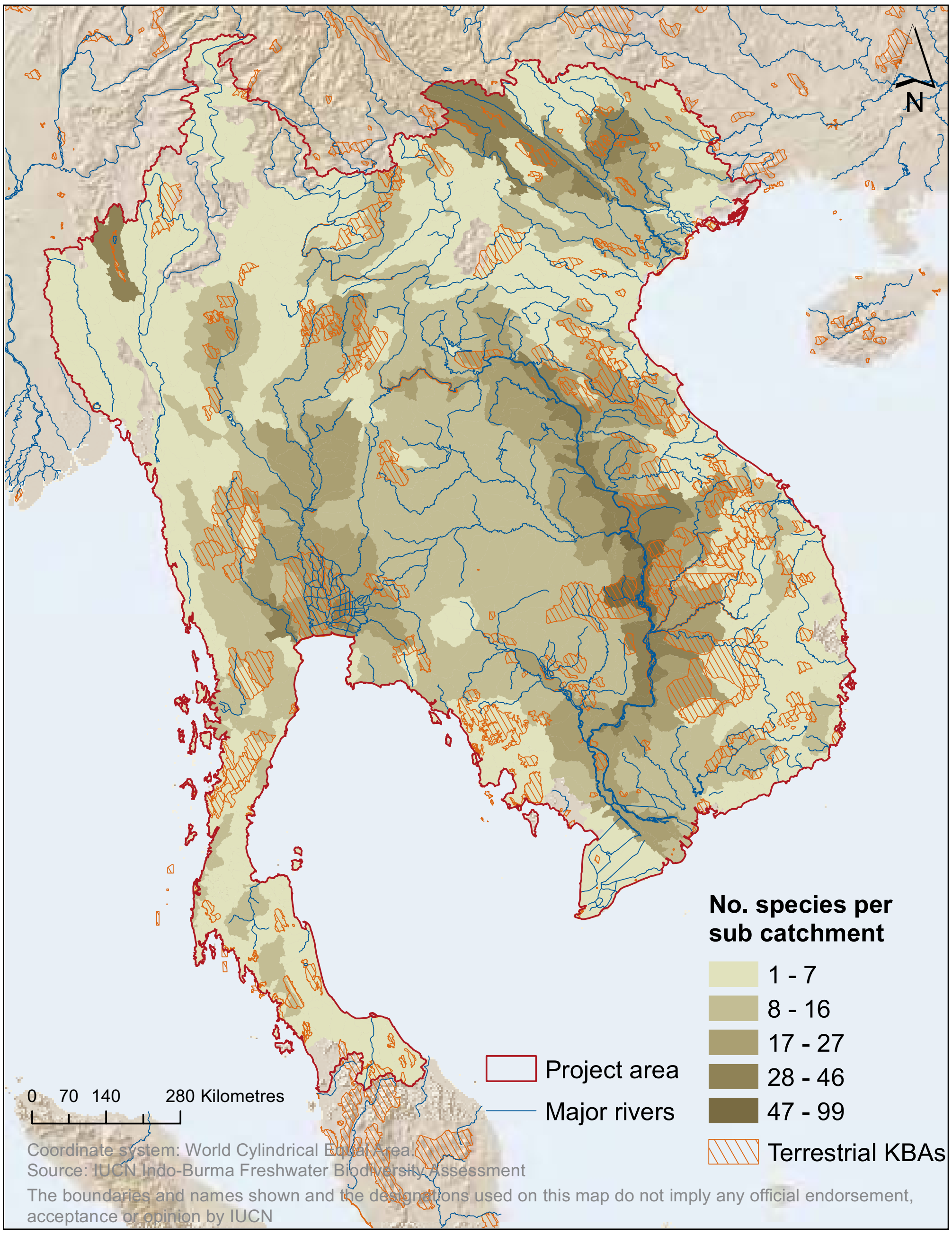


Figure 8.15 Sub-catchments qualifying as potential freshwater Key Biodiversity Areas for all groups (fishes, molluscs, odonates and crabs) overlaid with terrestrial KBAs. Sub-catchments in darker green indicate presence of higher numbers of species meeting the freshwater KBA criteria. Terrestrial KBA data were provided by BirdLife *et al.* (2011).

meeting the criteria for potential freshwater KBAs, areas of spatial overlap can be identified (Figure 8.15). The wider Khone Falls area in southern Lao PDR (with 47 to 99 species triggering freshwater KBA criteria) is partially included within a number of existing terrestrial KBAs including Siphandon, the Mekong Channel from Phou Xiang Thong to Siphandon, Chhep, Dong Khanthung, Dong Hua Soa, Xe Pian.

8.5 Provisioning ecosystem services from freshwater biodiversity in Indo-Burma

In Indo-Burma, millions of people rely on products from aquatic ecosystems to sustain their livelihoods, for example the Lower Mekong Basin is the world's largest freshwater capture fishery which may reach 2.5 million tons, worth an estimated US$2.2–3.9 (Hortle 2009, MRCS 2011). Information collated through the freshwater species assessments reported here allows us to identify those species that directly contribute to provisioning ecosystem services (for example, food, medicine, fodder etc.). Where harvesting of a species for a particular purpose is thought to be a possible threat to the species, this has been recorded. These preliminary findings are not, however, based on any quantitative analysis of sustainable harvest levels (which would be a recommendation), and do not therefore imply that the species should be assessed as being threatened, by overexploitation, according to the IUCN Red List Categories and Criteria. The odonates are not included in this analysis as no species was recorded as being directly utilised.

The key provisioning services directly contributed to by freshwater biodiversity are *human food*, *pets/display animals and horticulture*, and *medicine* (Figure 8.16). All freshwater biodiversity indirectly contributes to many other ecosystem services, for example bivalves contribute to the provisioning service of water filtration, but these indirect services are not recorded here.

Aquatic plants have by far the most diverse set of uses for livelihoods but are predominantly used as medicines, with 34% of plants species recorded as being harvested from the wild for medicinal purposes, food for humans (21% of species), and for display and in horticulture (15% of species) (Figure 8.16). Only the harvesting of species for display and horticulture in the national and international trade is identified as a potential threat to species survival to one species of plant (Figure 8.17). This species is the Water Onion (*Crinum thaianum*), an Endangered plant that is popular with aquarists, and is also used to make skin cream. It grows in clear running fresh water on the coastal plain of southern Thailand, but is now confined to isolated patches in only a few rivers and streams in Phang Nga and Ranong Provinces due to dredging of rivers for construction material, river diversion for agriculture, sedimentation and overharvesting.

Freshwater fishes, while providing a variety of direct services are predominantly harvested for food for people (63% of species), mostly for subsistence use, and are collected for the ornamental pet trade (29% of species) (Figure 8.16). Twenty seven percent of species assessed as threatened are possibly threatened by overharvesting for food (mostly at a subsistence scale) and 15.2%

Bagnet fishery in Cambodia. The Lower Mekong Basin is the world's largest freshwater capture fishery which may reach 2.5 million tons, worth an estimated US$2.2–3.9 © William Darwall

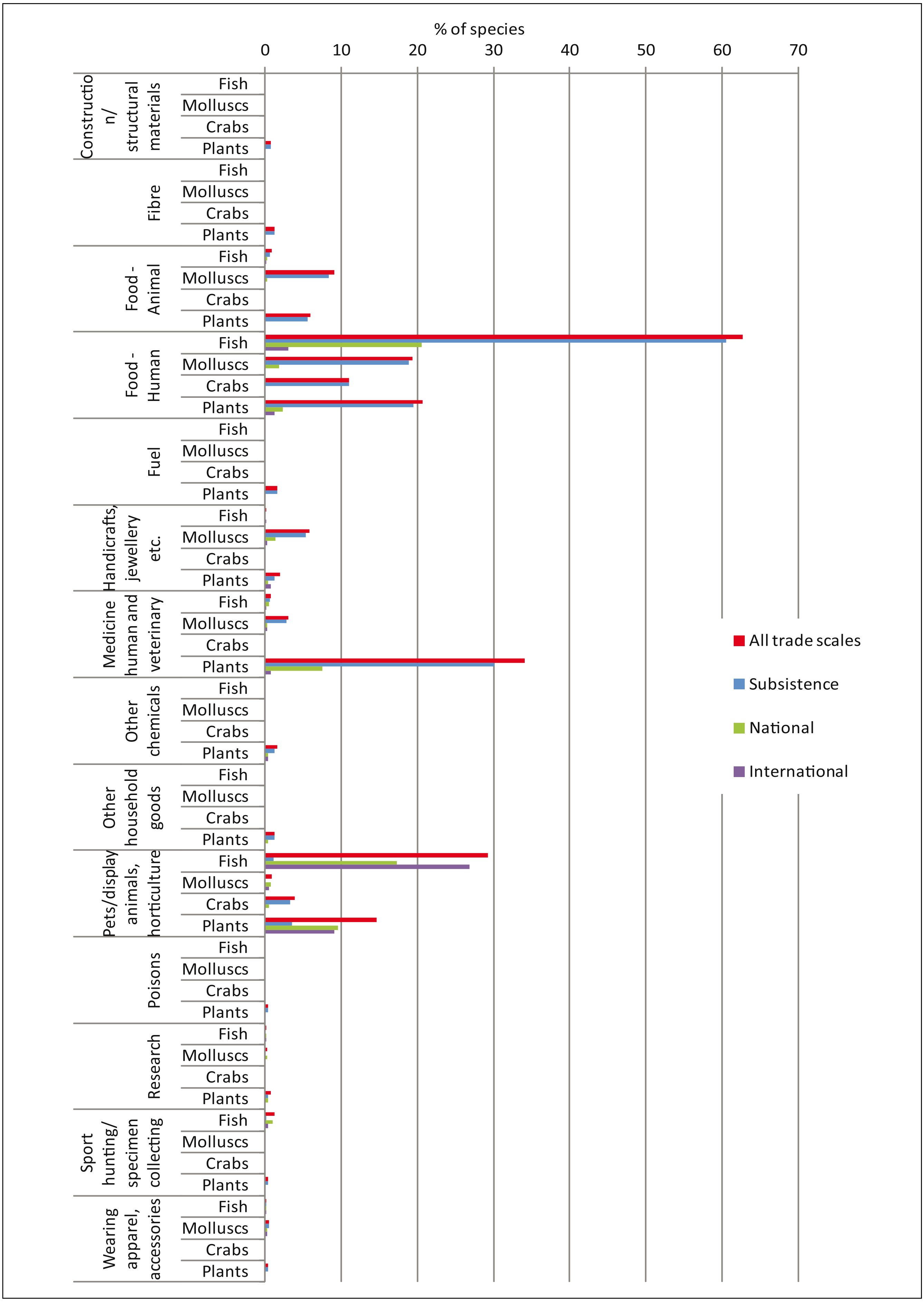


Figure 8.16 The proportion of freshwater species being harvested from the wild for a variety of purposes.

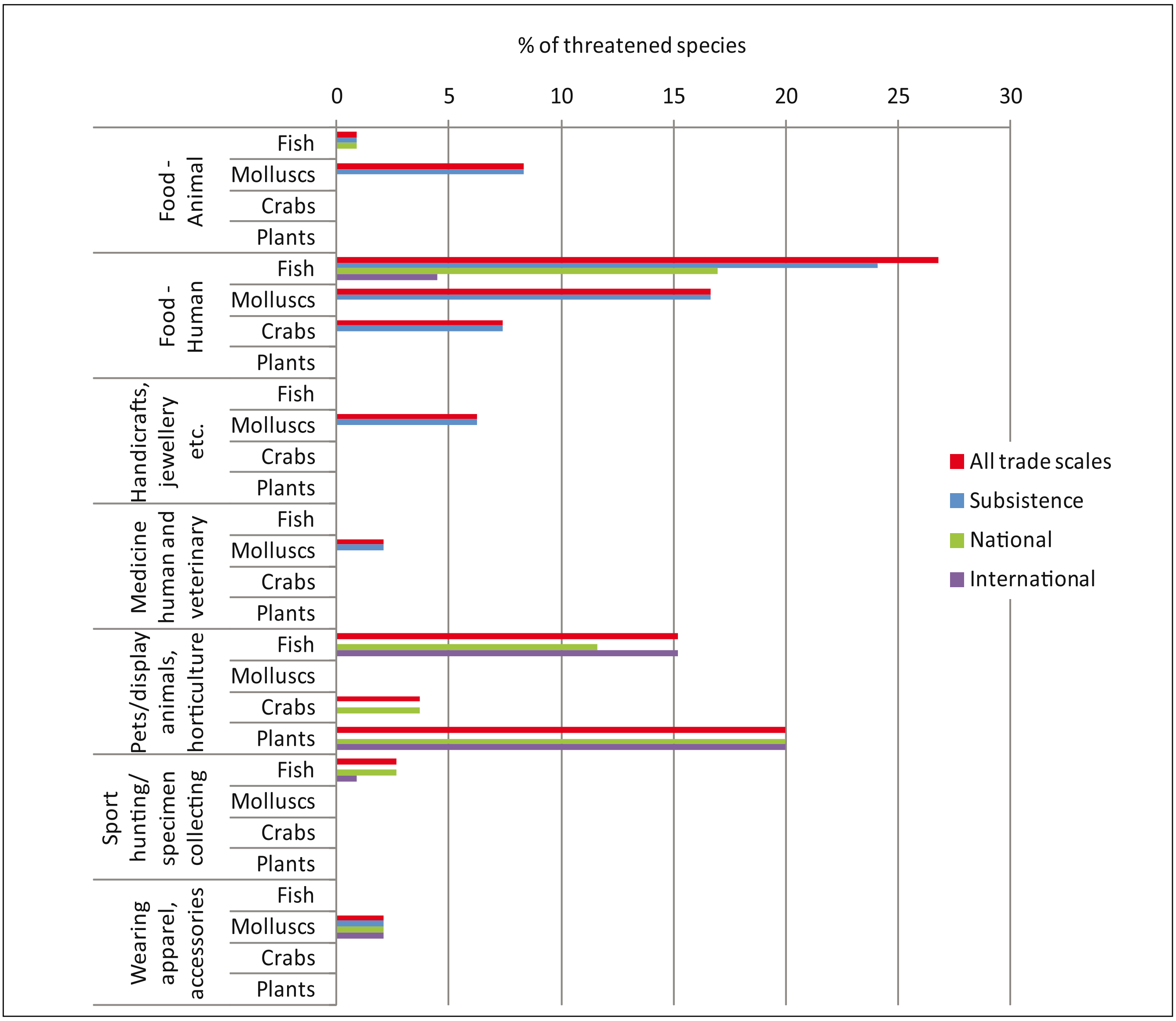


Figure 8.17. The proportion of threatened freshwater species where the harvesting from the wild for a range of purposes is considered to be a possible threat.

of threatened species are potentially threatened by over collection for the ornamental pet trade (for both international and national trade) (Figure 8.17).

As with the other groups, the greatest threat to molluscs (in terms of species numbers) is through harvesting for food for people, with 19% of species being harvested from the wild for this purpose (Figure 8.16). Nine percent of mollusc species are also harvested as food for animals (livestock), and six percent are harvested for making handicrafts and jewellery. All the harvesting of molluscs in the region is primarily for subsistence use. Collection of molluscs for human consumption, as animal food, for handicrafts and jewellery is also a listed as a possible threat to 17%, eight percent and six percent of threatened species, respectively (Figure 8.17).

Crabs, are less commonly utilised than the other groups (in terms of species numbers), with 11% of species being harvested for food (primarily for subsistence use by people) and 4% for the ornamental pets trade. Seven percent of threatened species of crabs are possibly threatened by over harvesting for food (Figure 8.17).

Botia sp. are taken for the ornamental trade as a by-catch of the Bagnet fishery © William Darwall

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Box 8.1 Wetland birds in the Indo-Burma region

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The Indo-Burma project area contains around 220 species of freshwater dependant and coastal wetland birds, a total that is likely to increase taking taxonomic review and new observations from field surveys into account. The conservation status of all birds is regularly assessed (see BirdLife International and the IUCN Red List), and of the 220 species, four (1.8%) are currently considered Critically Endangered, nine (4.1%) as Endangered, 13 (5.9%) as Vulnerable, 19 (8.6%) as Near Threatened, and the remainder as Least Concern. Just over 5% of the wetland birds in the region are therefore currently considered threatened, somewhat below the global level of threatened birds at present. However, ongoing (April 2012) re-assessments of species indicate that the situation in SE Asia is deteriorating: of the seven species listed as CR, two (White-eyed River Martin, *Eurochelidon sirintarae*, and Pink-headed Duck, *Rhodonessa caryophyllacea*) have not been recorded for almost 40 and 60 years, respectively, and are almost certainly Extinct. Two more species listed as EN may be shortly reassessed as CR (Baer's Pochard, *Aythya baeri* and Nordmann's Greenshank, *Tringa guttifer*). This would raise the list of wetland birds in the CR category to six species.

Several water birds are endemic to the region (c.10%), such as the Giant Ibis (*Thaumatibis gigantea*) and White-shouldered Ibis (*Pseudibis davisoni*) both CR, demanding special attention and conservation focus. The region also hosts significant numbers of common and non-threatened wetland birds, such as large wintering concentrations of Bar-headed Geese (*Anser indicus*) and concentrations of over 50,000 wintering waders in the Gulf of Martaban.

The hotspot contains a number of vital and unique wetland ecosystems. Coastal wetlands and estuaries (for example, the Ayeyarwady, Mekong and Red River deltas and Myanmar's Arakan coast) are especially important for several globally threatened migratory waterbirds, such as the Black-faced Spoonbill (*Platalea minor*) and the rapidly declining Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*). The hotspot's lowland rivers support a unique assemblage of birds which nest on seasonally-exposed sandbars. Higher dry season flows, as well as impacts from human disturbance and livestock grazing, could cause the loss of nesting sites and the extirpation of this entire assemblage. Wet grasslands associated with seasonally flooded river plains and lake margins, such as those around the Tonlé Sap Lake in Cambodia provide vital habitat for a range of resident and migratory species.

The list of threats to wetland birds is extensive and ranges from habitat loss, river damming for irrigation and power generation, pollution, hunting and trapping, and disturbance. In addition, many wetland birds, including some of the threatened species, are migratory and encounter multiple threats along their flyway route, making it difficult to locate and identify the main cause of decline. Some migrations cover several thousand kilometres stretching from breeding grounds to wintering areas in SE Asia, such as for the Spoon-billed Sandpiper (CR, migration distance c.8,000 km), Nordmann's Greenshank (*Tringa guttifer*) (EN, migration distance c.6,000 km), and the Swan Goose (*Anser cygnoides*) (VU, migration distance c.6,000 km).

Hunting has been identified as a major threat throughout all major habitat types but conservation activities involving local communities in coastal Myanmar and inland Cambodia have made huge and encouraging progress towards addressing the issue. However, habitat loss, often combined with pollution from unsustainable agricultural and industrial development, remain major threats to water birds, especially on fragile coastal habitats, but also in inland wetlands. Undisturbed river systems are increasingly subjected to damming and mining with potentially devastating consequences for the ecosystems, and are highly threatened in all countries but particularly in Myanmar. Most threatened are birds breeding on river sandbanks, and species such as the Indian Skimmer (*Rynchops albicollis*), Black-bellied Tern (*Sterna acuticauda*), Little Pratincole (*Glareola lacteal*), River Lapwing (*Vanellus duvaucelii*) and Eurasian Thick-knee (*Burhinus oedicnemus*) may soon join the White-eyed River Martin and disappear forever if the pressure on the remaining river systems continues to increase. Growing water demand and an increase in agrochemical use in some regions will also threaten inland lake systems and their fragile bird communities. Protection of lake sites is incomplete and often also inadequate if management of the catchment area is not taken into account. Deforestation and land use changes in the Inlé Lake system in Myanmar illustrate the complexity of site protection for the most prominent lakes in the region.

The Critically Endangered Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*) Zöckler *et al.* (2010), over-winters in several countries within the region, using tidal mudflats in river deltas and on offshore islands. Photographed here in the Minjiang River estuary, Fujian Province in southeast China, the species has declined as a result of exploitation and habitat loss. © Gao Chuan

Safeguarding the future of Indo-Burma's water birds will be very challenging. In addition to the designation of freshwater systems as protected areas it is important to include a resource management perspective to ensure the safeguarding of both pristine river systems that hold rare and threatened river biodiversity and the highly impacted fragile coastal wetland systems of estuaries and intertidal mudflats. Hunting and trapping seems to have halted in some key areas but such improvements need to be extended to many other areas in the region with supervision and monitoring at key sites. The main challenge, however, is to promote more strongly sustainable economic development to boost both local communities and wetland bird conservation through, for example, eco-tourism and other soft development approaches, and small-scale farming and fishing practices.

Further reading and resources

BirdLife International Datazone. www.birdlife.org/datazone. Information on species, Important Bird Areas, and country profiles for the region.

IUNC Red List of Threatened Species. www.iucnredlist.org. Conservation assessments of all birds from the region.

Box 8.2 Freshwater turtles in Indo-Burma: conservation trends

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The Indo-Burma region as defined in this project is inhabited by 39 species of freshwater turtles. The number has varied over the years – new taxonomic insights have led to a general increase in recognized species, field surveys have documented occurrences in the region that we were previously unaware of, and a few taxa have been eliminated from consideration after they shown to be hybrids.

An Indochinese box turtle *Cuora galbinifrons* (CR) in a captive breeding group. Found in hill forest areas of northern Viet Nam and southern China including Hainan, its populations have dramatically declined as a result of targeted exploitation for the food, medicinal and pet trades. © Peter Paul van Dijk

The freshwater turtles of Indo-Burma were last comprehensively assessed for the IUCN Red List in 2000. Based on current taxonomy, of the 39 species, seven (18%) were assessed as Critically Endangered, 12 (31%) as Endangered, seven (18%) as Vulnerable, two (5%) as Near Threatened, one (3%) each as Least Concern and Data Deficient, and nine (23%) were not recognized as valid species at that time and thus were Not Evaluated. It is remarkable to see that of the 29 assessed species (excluding DD) 26 species, or nearly 90%, were assessed as threatened (CR, EN, or VU).

A re-assessment of all tortoises and freshwater turtles of Asia is in progress and, while the assessments have not been finalized for all species, the current (March 2012) drafts indicate that the situation remains serious: of the 39 species, 18 (46%) are on track for being assessed as Critically Endangered, 7 to 9 (18 to 23%) as Endangered, 5 or 6 (13 to 15%) as Vulnerable, 3 (8%) as Near Threatened, one (3%) remains Least Concern, and 4 (10%) as Data Deficient. That amounts to 31 threatened species, or 89% of evaluated species when excluding the Data Deficient species, with more than half of all threatened species being Critically Endangered.

A number of factors contribute to creating these worryingly high levels of threat to freshwater turtles. The life history characteristics of turtles, with high juvenile losses balanced by great longevity and very high annual survival rates of adult turtles, mean that Red List assessments based on a three-generation time period reflect population trends over several decades. These life history characteristics make turtle populations relatively tolerant to harvesting of eggs and juveniles but highly vulnerable to the removal of adults. Despite this vulnerability the removal of adults has been extensive over the past few decades as the growing economic prosperity in southern China from the late 1980s has created a market demand for turtles for direct consumption, medicinal purposes, and the pet trade. The countries of Indo-Burma and beyond have been willing to collect and sell their turtles to meet this demand. While much of the demand, and therefore the turtle trade, is not specific in the types of species that are traded and consumed, two groups of turtles have been hit particularly hard. The Asian Box Turtles of the genus *Cuora* are specifically sought after as one of the species, the Three-striped Box Turtle or Golden Coin Turtle (*Cuora trifasciata*) is claimed to be a remedy for cancer, and the other *Cuora* species are in high demand by association, also being box turtles. As a result, all *Cuora* species are Critically Endangered, with the exception of the widespread *Cuora amboinensis* which remains Vulnerable. The other freshwater turtles under great pressure are the large river turtles of the genus *Batagur*. Traditionally exploited for their eggs and intensively collected from traditional nesting beaches at very predictable times and places, these turtles suffered long-term gradual declines and local extinctions during the 20th century. The more recent additional demand for live turtles for international trade has led to nesting females and accompanying males being captured at nesting areas, such that entire populations have been decimated and extirpated in recent years. In the best of circumstances, following a complete cessation of collection for the last remaining animals and their eggs, these river turtle populations will need decades to recover to their former levels. In an environment also impacted by intensifying human settlement of riparian areas, hydrological effects of dams and reservoirs, sand mining and dredging from river beds and banks, and erosion and pollution resulting from agricultural expansion and urbanization, the survival prospects for these species are particularly slim. The most severe case is that of the Red River Giant Softshell Turtle (*Rafetus swinhoei*), for which its entire global population is now limited to just four individuals – two animals surviving in two separate wetlands in northern Viet Nam, and a non-reproducing pair of adults held in a Chinese zoo.

Safeguarding the future of Indo-Burma's freshwater turtles will be very challenging. Key populations and sites must be protected in appropriately managed protected areas. Local exploitation and, in particular, international trade of wild-caught turtles needs to be better regulated, monitored, and significantly decreased. For several species, including all the large river turtles, intensive recovery programs must be implemented which would likely include captive breeding. Increased community awareness of the value and vulnerability of turtle populations is needed, preferably associated with presentation of alternative livelihood options.

Further reading

Turtles in Trouble: The World's 25+ Most Endangered Tortoises and Freshwater Turtles—2011. Turtle Conservation Coalition (IUCN/SSC Tortoise and Freshwater Turtle Specialist Group, Turtle Conservation Fund, Turtle Survival Alliance, Turtle Conservancy, Chelonian Research Foundation, Conservation International, Wildlife Conservation Society, and San Diego Zoo). www.iucn-tftsg.org/trouble/

The Burmese Roofed Turtle (*Batagur trivittata*) is currently assessed as Endangered, although a recent reassessment has upgraded the species to Critically Endangered. Previously known from throughout the Ayeyarwaddy, Sittaung and lower Salween drainages in Myanmar, it is now thought to be restricted to a handful of individuals in the upper Chindwin and a tributary of the Ayeyarwaddy. It has been impacted by the chronic collection of the turtle and its eggs for subsistence consumption, habitat degradation, and hydropower development. Fortunately a remnant nesting population remains, estimated at no more than ten females, and a program to protect the few known nesting beaches has successfully hatched over 500 offspring, all of which are being safely cared for at two facilities in Myanmar. © Rick Hudson / Fort Worth Zoo

Cantor's giant softshell turtle (*Pelochelys cantorii*) (EN) has a widespread but localized distribution in the great rivers of southeast Asia and southern China. Key threats include exploitation and habitat destruction, and several populations have been extirpated. © Peter Paul van Dijk

Box 8.3 Amphibians: conservation trends and issues

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Globally, approximately one-third of all amphibian species are threatened with extinction and almost half are experiencing population declines. The amphibians of Indo-Burma appear superficially less threatened than in other regions, with only 11.6% of the 234 amphibian species presently listed as threatened. However, the amphibian fauna of Indo-Burma is so poorly known that an accurate assessment of conservation status is not currently possible for a large proportion of species, with almost one-third of Indo-Burmese amphibians currently listed as Data Deficient, and an additional 15% have only recently been described and are yet to be assessed. Even basic information on amphibian diversity, distribution and conservation status is limited for most areas, particularly in Myanmar, Lao PDR, and Cambodia. A significant proportion of amphibian diversity in Indo-Burma remains undiscovered.

Our limited understanding of the nature and scale of threats facing amphibians in the region also hampers amphibian conservation efforts in the region. It is often difficult or impossible to obtain reliable information on the threats they face, and the information that does exist is often anecdotal or is based on highly limited geographic areas. Despite our deficit in knowledge, the amphibians of Southeast Asia, including Indo-Burma, appear to be facing an extinction crisis (Rowley *et al*. 2010).

The single greatest threat to amphibian species in Indo-Burma is habitat loss. The majority of species appear to require specific forested habitats and water regimes, and are only found in relatively intact, natural forests. Secondary forests and plantation forests may constitute viable habitats primarily for widespread, generalist amphibian species, and highly disturbed habitats tend to be dominated by a subset of these species. Habitat loss is likely to pose the most significant threat to restricted-range forest-dwelling species, and the identification of such species is a high priority.

Overharvesting is also a significant threat, with many species being harvested from the wild for human consumption, animal feed, traditional medicine, and the pet trade. The collection of amphibians for human consumption is common throughout Indo-Burma, with many people, particularly in rural areas, supplementing their protein intake or generating additional income through frog collection. Most frogs consumed by humans are caught in the wild, and the species harvested tend to be associated with lowland agricultural land.

Habitat loss is of the major threat to amphibians in the Indo-Burma region, especially the clearance and degradation of forests. Here, clearance of forest for agriculture in Quang Nam Province, Viet Nam, disconnects habitat and causes downstream sedimentation in streams. © Jodi J.L. Rowley

Forest-dependent (mostly upland) frog species are generally collected for local consumption rather than sale. The few figures available for the regional, national and international trade in frogs for human consumption indicate that huge volumes are being harvested and traded. Whilst the impact of harvesting for human consumption is largely unknown, anecdotal reports indicate that it is significantly impacting at least some species. The most significantly impacted species appears to be the lowland fossorial *Glyphoglossus molossus*. Anecdotal reports also suggest declines in frog abundance for other harvested species in Cambodia and Lao PDR.

A number of amphibian species are sold for use in traditional medicine, and attractive or otherwise charismatic species such as salamanders and tree frogs are harvested throughout Indo-Burma for the international pet trade. Many amphibians targeted for the pet trade are rare and/or range restricted, making them more vulnerable to over-harvesting (Rowley *et al*. 2010).

Disease may pose an additional threat to the amphibians of Indo-Burma. The pathogen *Batrachochytrium dendrobatidis*, causally linked to amphibian population declines and extirpations globally, has recently been detected on amphibians in Cambodia, Lao PDR and Viet Nam but no associated mortality, morbidity or population declines have been reported so far. The impacts of *B. dendrobatidis* on amphibian populations in Indo-Burma remain unclear.

The magnitude of other threats such as pollution and climate change are very poorly understood. While amphibians are widely accepted as being highly sensitive to a range of environmental contaminants, there are no published studies examining the effects of environmental pollutants on Indo-Burmese amphibians. Similarly, the nature and magnitude of the impact of climate change are difficult to predict, largely due to our poor understanding of amphibian distribution and biology.

Urgent conservation actions are required for the long-term conservation of Indo-Burmese amphibians (Rowley *et al*. 2010). The most critical conservation action required is the strict protection of areas of habitat that are deemed most important for amphibians (ie. areas of high amphibian diversity or endemism). Amphibian survey efforts should be increased in the region, and include long-term population monitoring programmes. Other conservation actions required include the collection of basic biological and ecological information, continued taxonomic research, and an evaluation of the impact of commercial food, medicine and pet trades. Strengthening of legislation and law enforcement aimed at protecting amphibians is essential, particularly for rare or restricted range species targeted by the pet trade. Efforts should also be made to determine the current and potential threats of infectious diseases, climate change and environmental contaminants. Increased public awareness and local scientific capacity is essential to accomplish these actions.

Further reading:

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The Indo-Burma region contains a remarkable number of recently described amphibian species, such as the Vampire Flying Frog (*Rhacophorus vampyrus*) from Bidoup-Nui National Park, Lam Dong Province, Viet Nam. © Jodi J.L. Rowley

IUCN Red List of Threatened Species™ – Regional Assessment Projects

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