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, Yasubikotakia 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 Sundac fauna (Sundaland: the south of the Malay Peninsula and the Great Sunda Islands (Sumatra, Java and Borneo). The proportion of Sundac fauna included within the total fauna decreases northwards. Several species and genera of that Sundac fauna are also known from Southeastern Thailand (Chanthaburi and Trat provinces) and coastal areas of Cambodia (for example, Barbucca, Vaillantiella, 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...
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, *Laboe 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
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
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.

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

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of fish species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extinct</td>
<td>1</td>
</tr>
<tr>
<td>Extinct in the Wild</td>
<td>0</td>
</tr>
<tr>
<td>Critically Endangered</td>
<td>21</td>
</tr>
<tr>
<td>Endangered</td>
<td>39</td>
</tr>
<tr>
<td>Vulnerable</td>
<td>52</td>
</tr>
<tr>
<td>Near Threatened</td>
<td>33</td>
</tr>
<tr>
<td>Least Concern</td>
<td>518</td>
</tr>
<tr>
<td>Data Deficient</td>
<td>514</td>
</tr>
<tr>
<td>Total</td>
<td>1,178</td>
</tr>
</tbody>
</table>

% Threatened (excluding DD and EX spp.) 16.9

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
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).

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.

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.

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.

<table>
<thead>
<tr>
<th>Omitted species</th>
<th>(Duncker, 1904)</th>
<th>Malay Peninsula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brevibora dorsiocellata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Badis juergenschmidtii</td>
<td>Schindler &amp; Linke, 2010</td>
<td>Sittaung</td>
</tr>
<tr>
<td>Lepidocephalichthys kranos</td>
<td>Havird &amp; Page, 2010</td>
<td>Middle Mekong</td>
</tr>
<tr>
<td>Lepidocephalichthys zeppelini</td>
<td>Havird &amp; Tangjitjaroen, 2010</td>
<td>Middle Mekong</td>
</tr>
<tr>
<td>Macrophagus dorsiocellatus</td>
<td>Britz, 2010</td>
<td>Sittaung, Salween</td>
</tr>
<tr>
<td>Kryptopterus hesperius</td>
<td>Ng, 2002</td>
<td>Mae Khlong</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recently described species</th>
<th>Kottelat, 2012</th>
<th>Tenasserim, Mae Khlong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthocobitis pictilis</td>
<td>Conway &amp; Kottelat, 2011</td>
<td>Malay Peninsula</td>
</tr>
<tr>
<td>Boraras naevus</td>
<td>Ng, Dang &amp; Nguyen, 2011</td>
<td>Phu Quoc Island</td>
</tr>
<tr>
<td>Clarias gracilens</td>
<td>Ou, Montaña, Winemiller &amp; Conway, 2011</td>
<td>Lower Mekong</td>
</tr>
<tr>
<td>Scleropages inscriptus</td>
<td>Roberts, 2012</td>
<td>Tenasserim</td>
</tr>
<tr>
<td>Erythistoides luteola</td>
<td>Ng, Ferraris &amp; Neely, 2012</td>
<td>Sittaung</td>
</tr>
<tr>
<td>Pseudentropius indigenus</td>
<td>Ng &amp; Vidthayanon, 2011</td>
<td>Malay Peninsula</td>
</tr>
</tbody>
</table>

Figure 3.1 Numbers of freshwater fish species in each IUCN Red List Category 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.
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.
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

*Platypus 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 nasifils; 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 vulnerability to impacts from threats such as, in the case of this species, hydropower development.

*Yasuhikotakia sidhimunki* (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...
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...
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).

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
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
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
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 trade.

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 Vidhathanon
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 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 Vidhayanon 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 clarid 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.
‘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 valued and receive significant attention (see, for example, Baird, 2009, 2011). Some funding agencies now pay attention to aquatic species directly dependent upon terrestrial species, and their habitats, are often attempted, little attention is paid to aquatic species directly dependent upon 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 valued and receive significant attention (see, for example, Baird, 2009, 2011). Some funding agencies now pay attention to aquatic species directly dependent upon terrestrial species, and their habitats, are often attempted, little attention is paid to aquatic species directly dependent upon

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 siliation, 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?

EAs 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 effort. 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 deepwater 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
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 its 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 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.

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.

3.6 References


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).

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 in 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 was ~3,000 m, and the climate was becoming markedly drier. By the late 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 Phraya 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 brunnea* (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 grayeyi* (NT), *Silurus burmanensis* (DD), *Channa harcourtbutleri* (NT), *Macrogathus caudicellatus* (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](image-url)
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 least 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
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