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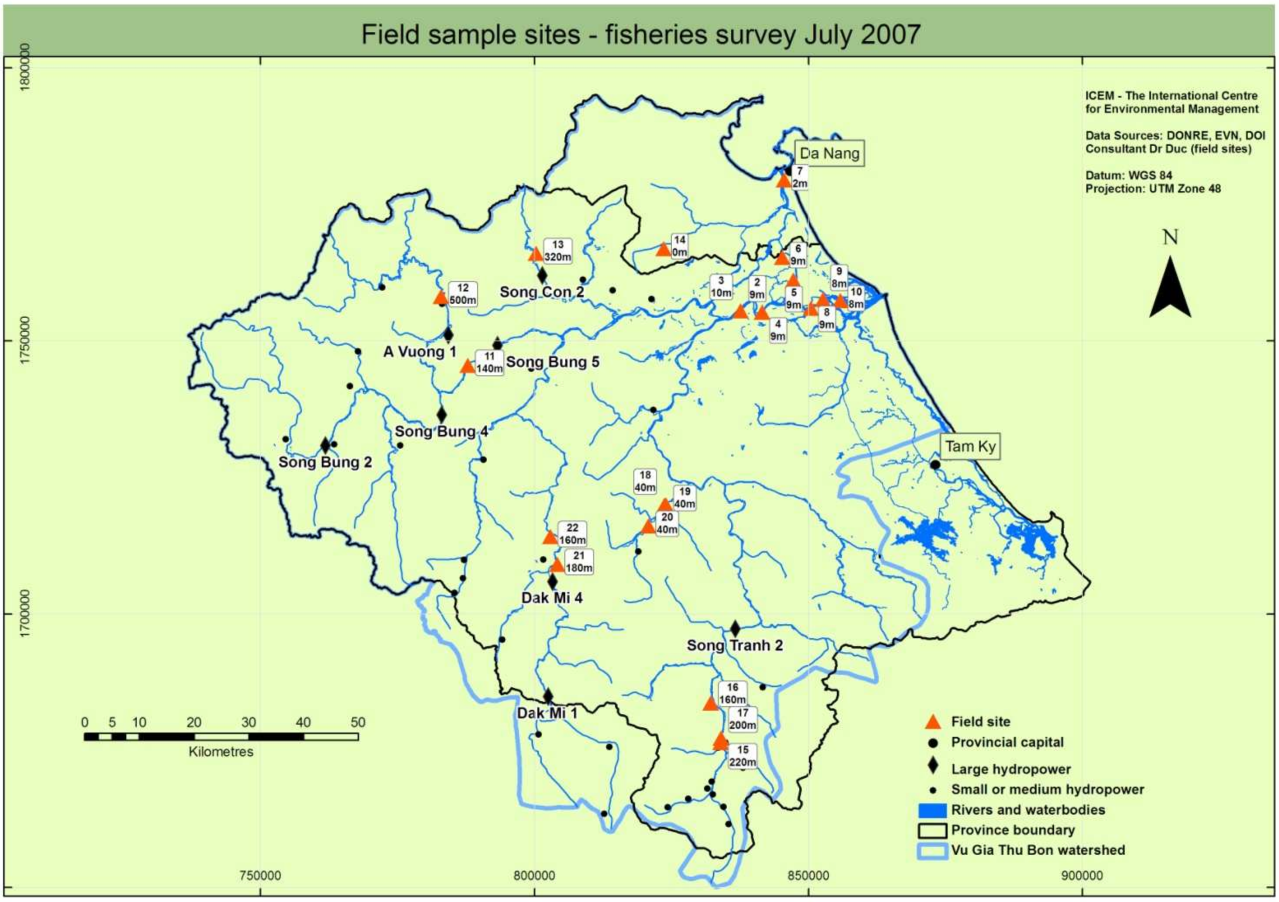
A PRELIMINARY EVALUATION OF THE ECOLOGICAL ATTRIBUTES OF THE FISH FAUNA OF THE VU GIA – THU BON RIVER SYSTEM AND ITS VULNERABILITY TO IMPACTS FROM CLUSTERED HYDROPOWER DEVELOPMENTS



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Content

SUMMARY

Rapid economic development has seen Vietnam's energy demand grow at a rate of 13-15% per annum over the last decade, leading to chronic and severe power shortages, and plans for extensive hydropower development. The Vu Gia – Thu Bon River Basin in central Vietnam will be one of the first areas to see increased hydropower development with 8 major and at least 34 minor hydro installations planned for completion over the next 10 years. This intense clustering of hydro developments on the Vu Gia – Thu Bon system has the potential for extensive impacts on aquatic fauna and ecosystems and is likely to negatively impact livelihoods through changes to fisheries outputs. Despite the potential danger to the integrity of aquatic systems there is little information on which to base any assessment of potential impacts. We sampled fresh and estuarine fish across the Vu Gia – Thu Bon basin to evaluation of the current status of the fish fauna, determining the extent of zonal (eg. altitudinal) and habitat specialisation, determine the prevalence of migration as a component of life-history strategies, evaluate the likely magnitude of impacts of hydropower development, and highlight the areas where more extensive study is most urgently required. Given current high levels of exploitation, the fish fauna appeared surprisingly intact; freshwater fish are diverse and apparently still abundant, and in estuaries all trophic groups, including large predators, were captured in substantial numbers. However, a number of attributes of the fauna makes it particularly vulnerable to the impacts of hydropower development. The prevalence of migration as a life-history tactic makes that large component of the fauna particularly vulnerable to the impacts of barriers created by hydropower development. Additionally, extensive areas of habitat within dams and in areas of water diversion will be highly modified leading to the loss of habitat specialists from these areas. The focus of hydropower development at high altitudes means habitat modification will be most extensive in fast flowing reaches inhabited by the rheophilic habitat specialists, which are important components of Vietnam's unique freshwater fish assemblages. Without extensive mitigation, the combinations of habitat alteration in dam and diversion areas and the imposition of a proliferation of barriers to migrations will lead to severe population fragmentation, increasing the potential for local extinction, and severely compromise opportunities for recolonisation. This work highlights the need for extensive well targeted study of the aquatic ecology of the Vu Gia – Thu Bon system, both prior to extensive hydropower development and as the hydropower plan is implemented over the next decade. Such a study would provide a detailed baseline understanding of the nature of the fish fauna, and provide a time series of information detailing the full extent of impacts. Both types of understanding are crucial if the ecological effects of hydropower development on aquatic fauna are to be minimised in future large scale hydro developments in Vietnam.

1. INTRODUCTION

Rapid economic development has seen Vietnam's energy demand grow at a rate of 13-15% per annum over the last decade, leading to chronic and severe power shortages (IHA 2007). This has seen a rapid and continuing increase in generating capacity, with a capacity of almost 11,000 MW in 2004 expected to more than double to over 22,000 MW by 2010. A large part of this expansion is expected to come from hydropower development on the many rapidly flowing rivers descending the precipitous eastern slopes of the Giai Truong Son mountain range that forms the boundary between Laos and Vietnam.

Vietnam contains a broad diversity of freshwater and coastal marine habitats that harbour an extremely rich fish fauna, with over 450 species found in freshwater alone (Kottelat & Whitten 1996). Rates of regional endemism are high with new species still being identified (Hao & Duc 2000). However, there is little knowledge of many species beyond taxonomic studies (Kottelat & Whitten 1996), with no detailed information on distribution, habitats, migration, feeding, reproduction or population dynamics available, and no ecosystem level understanding.

Hydropower development has the potential to impact this unique and diverse fauna in a diversity of ways, through increased pollution and sediment load during construction, flow alteration and diversion, habitat loss, and impeded migration (Kottelat & Whitten 1996). The most obvious impacts stem from barriers to migration from the imposition of dams and the diversion of rivers between dams and power stations that can severely depress flows during dry periods. These barriers can effectively prevent aquatic fauna undertaking normal migrations (Borges Barthem et al. 1991, Cooke & Leach 2004, Katano et al. 2006, Sheer & Steel 2006). This is a serious issue for Vietnam where a large proportion of river and estuarine fish are migratory(Jensen 2001, Poulsen et al. 2002). A second major issue is the habitat loss and alteration caused by changes in flow volume and pattern, and the conversion of stream ecosystems to lake-like reservoir ecosystems. These can lead to substantial changes in the structure (Jensen 2001, Poulsen et al. 2002, Erny et al. 2003, Fujita et al. 2005, Anderson et al. 2006), distribution (Dauble et al. 2003), availability and use of habitats (Brenden et al. 2006), resulting in extensively modified species compositions (Anderson et al. 2006). Additionally, nutrient trapping in reservoirs (Rausch & Schreiber 1981) is likely to greatly reduce nutrient delivery to areas downstream (Childers et al. 2006).

Impacts of barriers and altered flows can cascade downstream to produce effects that extend throughout the whole river system. The life-cycles of many lowland and estuarine species that rely on free migrations through freshwater for reproduction (Connor & Pflug 2004, Walsh et al. 2005), feeding (Borges Barthem et al. 1991, McCormick et al. 1998, Cooke & Leach 2004), dry season refuge (Poulsen et al. 2002) or nursery ground access are likely to be compromised. Altered freshwater flow volume or timing is also likely to impact estuaries, because seasonal flows are crucial to support productivity (Bate & Adams 2000), for the recruitment of larvae (Strydom et al. 2002, Islam & Tanaka 2006), for nursery ground provision (North et al. 2002, Strydom et al. 2002, Whitfield 2005), and in determining the location (Uncles et al. 2006) and nature of the Estuarine Turbidity Maximum zone, which is as an area of concentration of small juvenile and larval fish (North et al. 2002, 2005, Shoji & Tanaka 2006) and their prey (Chicharo et al. 2001).

The Vu Gia – Thu Bon River Basin in central Vietnam will be one of the first areas to see increased hydropower development with 8 major (60 – 225 MW) and at least 34 minor (<60 MW) hydro installations planned for completion over the next 10 years (Anon 2006), with a total potential of about 1,300 MW (NHP) (Fig. 1). Of the 8 major developments the A Vuong 1 and Song Tranh 2 projects are already under construction, with the further six projects, Song Bung 2, Song Bung 4, Song Bung 5, Dac Mi 1, Dac Mi 4, and Song Con 2 identified for implementation over the next 5 years. At present the Vu Gia – Thu Bon River System is a continuous water body without barriers to fish migration (Berge et al. 2006), and comprising a diversity of aquatic habitats. Although there have been no detailed studies of the ecology of fish assemblages of the Vu Gia – Thu Bon Basin, a number of recent hydropower-related EIAs (eg. Berge et al. 2006) have indicated that Vietnam's high aquatic biodiversity is reflected there. Consequently, the intense clustering of hydro developments on the Vu Gia – Thu Bon system has the potential for extensive impacts on aquatic fauna and ecosystems and is likely to negatively impact livelihoods through changes to fisheries outputs.

Detailed understanding of the ecology of potentially impacted aquatic fauna and ecosystems is pivotal to the development of hydropower plans that minimise impacts on aquatic systems. The lack of even the most basic knowledge of the aquatic ecology of the Vu Gia – Thu Bon river system was highlighted during the recent International Centre for Environmental Management (ICEM) Strategic Environmental Assessment (SEA) of hydropower development in the Vu Gia – Thu Bon basin. This prompted the current broad scale study of the distribution and abundance of its fish fauna initiated under the guidance of ICEM.

The study was aimed at taking an initial step towards developing an understanding fish fauna of the Vu Gia – Thu Bon River Basin. Specifically the aims were to: (a) produce broad scale evaluation of the current status of the fish fauna, by evaluating species richness and the relative abundance of various trophic groups, (b) evaluate the nature of the fauna by determining the extent of zonal (eg. altitudinal) and habitat specialisation, (c) determine the prevalence of migration as a component of life-history strategies, (d) evaluate the likely magnitude of impacts of hydropower development, and (e) highlight the areas where more extensive study is most urgently required.

2. METHODS

SITE DESCRIPTION

The Vu Gia – Thu Bon River Basin in central Vietnam lies between the Truong Son Mountain Range and the Gulf of Tonkin. Its two major river systems, the Song Vu Gia and Song Thu Bon, have a total catchment of about 11,510 km^2 and are cross linked about 36km upstream from the coast (Fig. 1). Their major outflow is via the Thu Bon estuary at the ancient port city of Hoi An, but a complex of channels links the lower reaches of the Vu Gia and Thu Bon to the Han estuary in the city of Da Nang. The basin is some 100km wide and 120km long, and has a narrow, flood-prone coastal plain backed by the steep Truong Son Mountain Range that rises to 2600m. The combined flows of the Vu Gia – Thu Bon system range from a mean of 104 m^{3}s^{-1} in the dry season (January to August) to 1,356 m^{3}s^{-1} in the wet season (September to December). The tidal range in the estuary is small 0.9 (MG 2007) but the intense seasonality means that the physical limits of estuarine intrusion varies greatly throughout the year in response to river flow patterns.

Large human populations, the impact of defoliants (Thu & Populus 2007), and extensive bank-side development for aquaculture (Benthem et al. 1997) and housing, have led to extensive habitat degradation in downstream freshwater and estuarine reaches (Benthem et al. 1997, Jensen 2001, Thu & Populus 2007). Most natural lowland riparian vegetation has been replaced by farms, grasses and bamboo stands. Most of the estuary banks are occupied by aquaculture, urban areas or sand dredging operations, with only small areas of mangrove (principally *Nipa fruticans*) remaining. Many wetlands have been in-filled and converted to farm land. Upstream freshwater reaches of the Vu Gia – Thu Bon system are oligotrophic (Berge et al. 2006), a typical situation for similar systems around the world (eg. Leira & Sabater 2005, Alexander & Smith 2006, Domenech et al. 2006, Roelke et al. 2006) indicating a situation where productivity and population sizes are limited by nutrient supply.

Major hydropower developments range in power output from 60 -225 MW with dam heights from 37 - 110m (Table 1). No specific information is available for the 34 minor projects.

SAMPLING

Fish were sampled at 21 sites in the Da Nang/Quang Nam area between 17 and 26 July 2007 (Table 2, Fig. 1), the late dry season in central Vietnam (H-MSV 2008). Sampling was conducted in both the Vu Gia and Thu Bon Rivers and their tributaries, as well as in the connected Han River system (Fig. 1). Two habitats were sampled at each of two of the sites making a total of 23 sampling units. Sampling sites were selected to provide replicate representative sites in altitudinal zones identified from GIS data (Fig. 1); estuarine and lowland 0-10m, mid altitude 10-100m, high altitude 100-250m, very high altitude >250m. Estuarine sites were differentiated from lowland sites during analysis based on their characteristic fish species compositions.

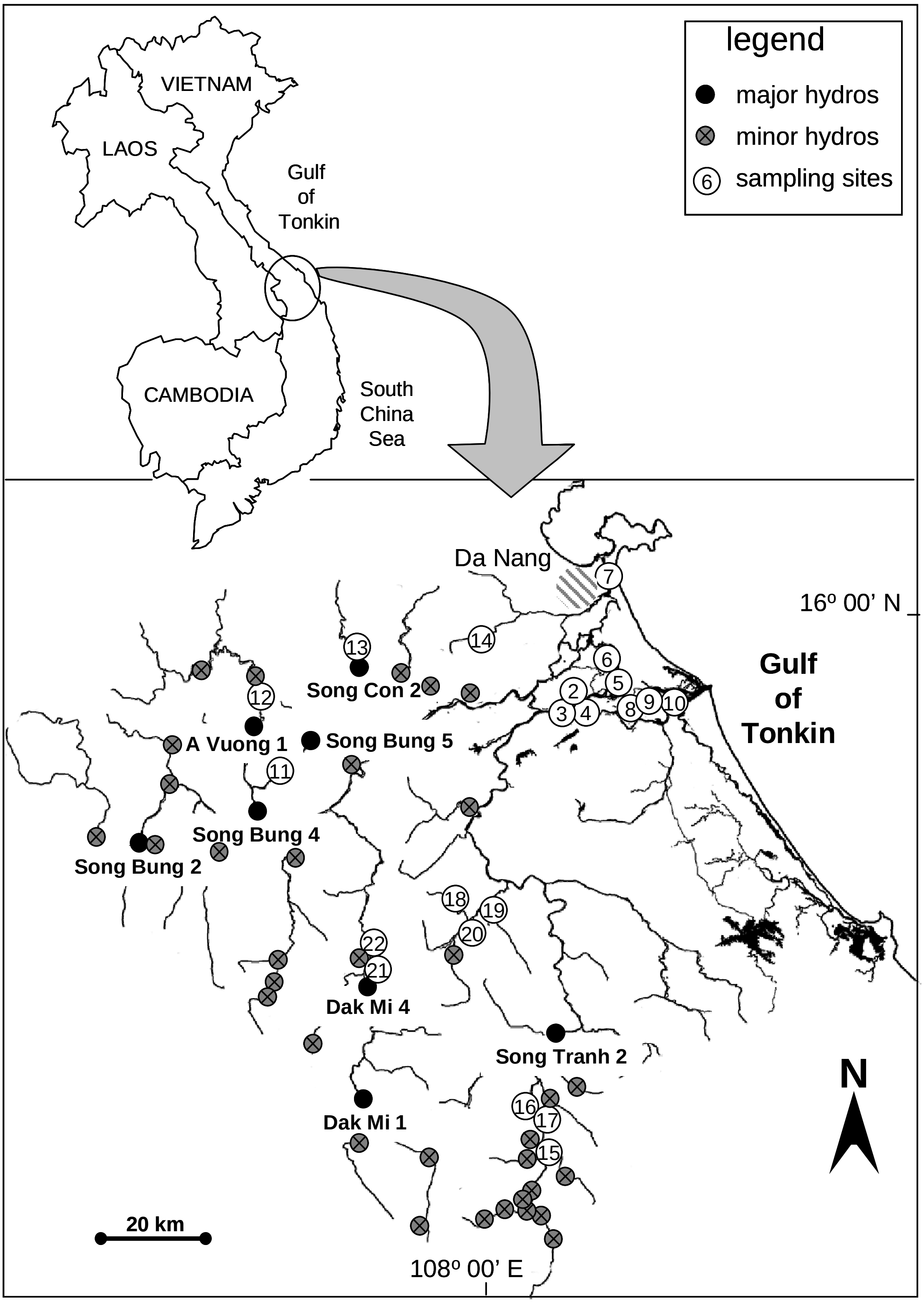

FIGURE 1: **LOCATION MAP SHOWING SITES OF MAJOR AND MINOR HYDROPOWER DEVELOPMENTS AND SAMPLING SITES.**

GPS coordinates were recorded for each location, together with water temperature and secchi depth. Salinity could not be measured because no salinometer was available. Sampling was conducted using a single gear type, 18mm mesh, 8m diameter multifilament cast nets, to produce samples that were comparative over the full range of habitats and salinities encountered. Four cast net throws were made in each location-habitat combination. Cast netting was conducted by local fishermen experienced in cast net fishing. Fish that could not be reliably identified to species in the field were retained for laboratory identification.

Table 1: Summary of capacity and dimensions of large hydropower schemes planned for the Vu Gia – Thu Bon basin.

	Peak Power MW	Reservoir volume Mm^3	Reservoir Area Km^2	Dam height m
Song Bung 2	100	102	2.9	97
Song Bung 4	156	494	15.8	110
Song Bung 5	60	20	2.1	37
Dak Mi 1	225	223	4.5	103
Dak Mi 4	180	279	10.5	105
Song Con 2	60	211	unknown	57
A Vuong	210	344	9.1	99
Song Tranh 2	135	462	21.5	92

Habitat types identified included urbanised areas at estuary mouths (mouth), channels along banks vegetated with trees and bamboo (veg banks), rushes (rush banks), channels alongside farms (farm banks), shallow sandy areas (sand), shallow areas with cobble bottom (cobble), areas with consolidated rock bottom (bedrock), riffles, and rapids.

DATA ANALYSIS

Fish were identified with reference to region-specific sources (Huong 1991, 1992, 1993b, a, Duc & Yen 1994, Duc 1997, Duc & Hao 1997, Freyhof & Dmitri 2000, 2001, Hao & Van 2001, Kottelat 2001b, Kottelat 2001a, Chen & Kottelat 2003, Hao 2005, Hao & Van 2005) and FishBase (Froese & Pauly 2007). As the most comprehensive database relating to fish biology, FishBase was interrogated for information on trophic role, salinity and habitat preferences, reproductive strategies, and migratory requirements. Although the migratory strategies of a majority of species are poorly known, enough information was available from FishBase to provide general information on the migratory strategies of a substantial proportion of species. Information on habitat associations from the current study was compared to that summarised in FishBase. Sufficient information was available from FishBase to define the trophic identities of most species captured at estuarine sites, or where sufficient information was not available diets of related species were specific enough to allow reasonable extrapolation. In contrast, for species from freshwater sites there was insufficient dietary information, or diets were too varied, to allow reasonable trophic categorisation of most species. Insufficient specific ecological and biological detail was available on FishBase, or from other sources, to define reproductive strategies or salinity preferences of the majority of species, preventing informative comparisons across the study sites.

Table 2: Summary of sampling sites in the Da Nang/ Quang Nam area

Site	River	zone	habitat
site 4	Thu Bon	estuarine	channel/rush bank
site 5	Vinh Dien	estuarine	channel/farm
site 6	Vinh Dien	estuarine	channel/farm
site 7	Han	estuarine	channel/farm
site 8	Thu Bon	estuarine	channel/veg bank
site 9	Thu Bon	estuarine	channel/veg bank
site 10	Thu Bon	estuarine	estuary mouth
site 2	Vu Gia	lowland	channel/veg bank
site 2	Vu Gia	lowland	sand
site 3	Thu Bon	lowland	channel/veg bank
site 18	Thu Bon	mid altitude	riffle
site 19	Thu Bon	mid altitude	sand
site 20	Thu Bon	mid altitude	sand
site 11	A Vuong	high altitude	rapid
site 14	Phu	high altitude	rapid
site 15	Thu Bon	high altitude	riffle
site 16	Thu Bon	high altitude	rapid
site 17	Thu Bon	high altitude	cobble
site 21	Dak Mi	high altitude	rapid
site 22	Vu Gia	high altitude	riffle
site 12	Kazung	very high altitude	riffle
site 12	Kazung	very high altitude	shallow pool
site 13	Con	very high altitude	shallow pool

Data were analysed as both presence-absence data and row standardised abundances (standardised by sample totals). Row standardisation converted the abundances to proportions at a site allowing an interpretation that two samples would be considered to have similar compositions if they had species in similar proportions. Both approaches produced outcomes that were identical in their essential patterns for all analyses so only analyses based on the more robust presence-absence data are presented.

To determine the major structure in the fish assemblage, all species that occurred in two or more samples were analysed using a multivariate classification and regression tree (mCART) (De'ath 2002), with site, habitat type, altitude, temperature and turbidity as explanatory variables. mCARTs recursively partition data into increasingly homogeneous subsets. Splits close to the root of the tree are typically more important (yield greater improvement in the fit of the model) than those that are closer to the bottom of the tree. Split selection was based on minimising within-group sum-of-squared residual deviation of the resultant groups. Selection of the final tree models was conducted using 10-fold cross validation, with the 1-SE tree (the smallest tree with cross validation error within 1 SE of that of the tree with the minimum cross validation error) selected as the final tree model. This procedure is generally considered to produce valid, biologically interpretable trees (Breiman et al. 1984, De'ath & Fabricius 2000, De'ath 2002, Urban 2002). The pattern of grouping of sites per zone (estuarine, lowland fresh, mid altitude, high altitude, very high altitude), the important factor in the tree analysis, was illustrated using nonmetric multidimensional scaling (nMDS) conducted on the Primer 6 software using Sorensen distance.

3. RESULTS

1173 fishes from 119 species comprising 38 families were captured during the study, including 7 species listed as vulnerable in Vietnam's Red Book (MONRE 2000) (Table 3). Of the 119 species 88 species (74%) were captured only from a single zone, while 33 were captured from multiple zones (Table 3).

Table 3: Species captured from 5 zones of the Vu Gia – Thu Bon basin and their migratory habits. Codes indicate the habitats species were collected from: Estuarine = est, Lowland = low, Mid altitude = mid, High altitude = hi, Very high altitude = vhi; if they are recorded as vulnerable in Vietnam's Red Book = VU; and their known migratory status: am = amphidromous, a = anadromous, c = catadromous, p = potamodromous, pl = potamodromous with lateral migration into bankside habitats during floods.

	estuarine	lowland	mid	high	very high		Vietnam Red Book Species	migratory
Acanthopagrus berda	est							
Acanthopagrus latus	est							
Ambassis buruensis	est							am
Ambassis kopsii	est							am
Boesemania microlepis	est							p
Butis butis	est							am
Chelonodon patoca	est							a
Clupanodon thrissa	est						**VU**	a
Cynoglossus bilineatus	est							
Takifugu sp.	est							
Gerres filamentosus	est							am
Gerres limbatus	est							am
Hyporhamphus sinensis	est							p
Konosirus punctatus	est						**VU**	
Lates calcarifer	est							c
Leiognathus equulus	est							am
Leiognathus lineolatus	est							
Liza carinata	est							
Liza melinoptera	est							am
Lutijanus argentimaculatus	est							
Monodactylus argenteus	est							
Mugil cephalus	est							c
Parapocryptes serperaster	est							am
Platycephalus indicus	est							
Pomadasys argenteus	est							
Pomadasys hasta	est							
Pseudorhombus cinnamoneus	est							
Pseudorhombus quinquocellatus	est							
Metzia lineata	est							
Scatophagus argus	est							am
Secutor indicus	est							
Siganus fuscescens	est							
Siganus guttatus	est							

Solea elongata	est							
Stenogobius genivittatus	est							a
Brachirus orientalis	est							a
Terapon jarbua	est							c
Triacanthus biaculeatus	est							
Valamugil cunnesius	est							am
Anabas testudineus	est	low						pl
Arius sinensis	est	low						
Cyprinus centralus	est	low						
Glossogobius giuris	est	low						am
Mystus gulio	est	low						a
Rhabdosargus sarba	est	low						
Carassioides acuminatus	est	low	mid					
Megalobrama terminalis	est	low	mid					
Ancherythroculter daovantieni		low						
Atherinomorus lacunosus		low						
Parambassis siamensis		low						
Osteochilus microcephalus		low						pl
Oxyeleotris urophthalmus		low						
Rhodeus ocellatus		low						
Cranoglanis bouderius		low	mid				**VU**	
Hemiculter leucisculus		low	mid					
Paraspinibarbus macracanthus		low	mid	hi				
Mastacembelus armatus		low	mid	hi	vhi			pl
Opsariichthys bidens		low	mid	hi	vhi			
Oreochromis mossambicus		low	mid	hi	vhi			
Cirrhina molitorella		low		hi				pl
Oreochromis niloticus		low		hi				
Awaous ocellaris			mid					
Sinohomaloptera kwangsiensis			mid					
Cryptocentrus sp.			mid					
Gobiobotia kolleri			mid					
Hemibarbus labeo			mid					
Hemibarbus lehoai			mid					
Osteochilus brachynotopteroides			mid					
Pelteobagrus fulvidraco			mid					
Pseudogobio guilinensis			mid					
Rasbora myersi			mid					
Rhinogobius giurinus			mid					am
Rhinogobius lineatus			mid					
Rhinogobius sp			mid					
Rhinogobius vermiculatus			mid					
Schistura tizardi			mid					
Squalidus atromaculatus			mid					
Squaliobarbus curriculus			mid					
Puntius brevis			mid					
Onychostoma laticeps			mid				**VU**	
Garra orientalis			mid	hi				
Microphysogobio labeoides			mid	hi				
Osteochilus salsburyi			mid	hi				
Pseudohemiculter pacboensis			mid	hi				
Rhinogobius leavelli			mid	hi				

Saurogobio dabryi			mid	hi				
Spinibarbus denticulatus			mid	hi				
Hemibagrus guttatus			mid	hi	vhi			
Sewellia lineolata			mid	hi	vhi			
Spinibarbus hollandi			mid	hi	vhi		**VU**	
Onychostoma gerlachi			mid	hi	vhi			
Annamia thuathienensis			mid		vhi			
Puntius semifasciolata			mid		vhi			
Barbonymus altus				hi				pl
Chanda sinensis				hi				
Channa striata				hi				p
Cyclocheilichthys enoplus				hi				p
Garra fuliginosa				hi				
Hypsibarbus wetmorei				hi				
Microphysogobio kachekensis				hi				
Poropuntius kontumensis				hi				
Pseudohemiculter dispar				hi				
Schistura dalatensis				hi				
Schistura kontumensis				hi				
Sinibrama affinis				hi				
Bangana lemassoni				hi			**VU**	
Spinibarbus brevicephalus				hi				
Puntius binotatus				hi				
Neolissochilus stracheyi				hi				
Tor tambroides				hi			**VU**	
Papuligobius uniporus				hi	vhi			
Sewellia analis				hi	vhi			
Sewellia medius				hi	vhi			
Parasewellia monoloba				hi	vhi			
Carassius auratus					vhi			
Oryzias latipes					vhi			am
Schistura pellegrini					vhi			
Schistura carbonaria					vhi			
Trichogaster trichopterus					vhi			pl

LARGE-SCALE SPATIAL STRUCTURE

The only variable that was important in mCART analysis (Fig. 2) was site, with the 4 most downstream sites in the Thu Bon River and those in the Vinh Dien and Han Rivers separated from those further upstream. Fish assemblages at these downstream sites were characterised by marine and brackish water species, most of which did not occur at sites further upstream (Table 3), so these sites were designated as estuarine for subsequent analyses. As well as showing the clear split between estuarine and freshwater sites, nMDS (Stress = 0.14) indicates general faunal change from estuarine, through lowland sites to higher altitude sites that show a much greater range of faunal compositions than estuarine sites (Fig. 3).

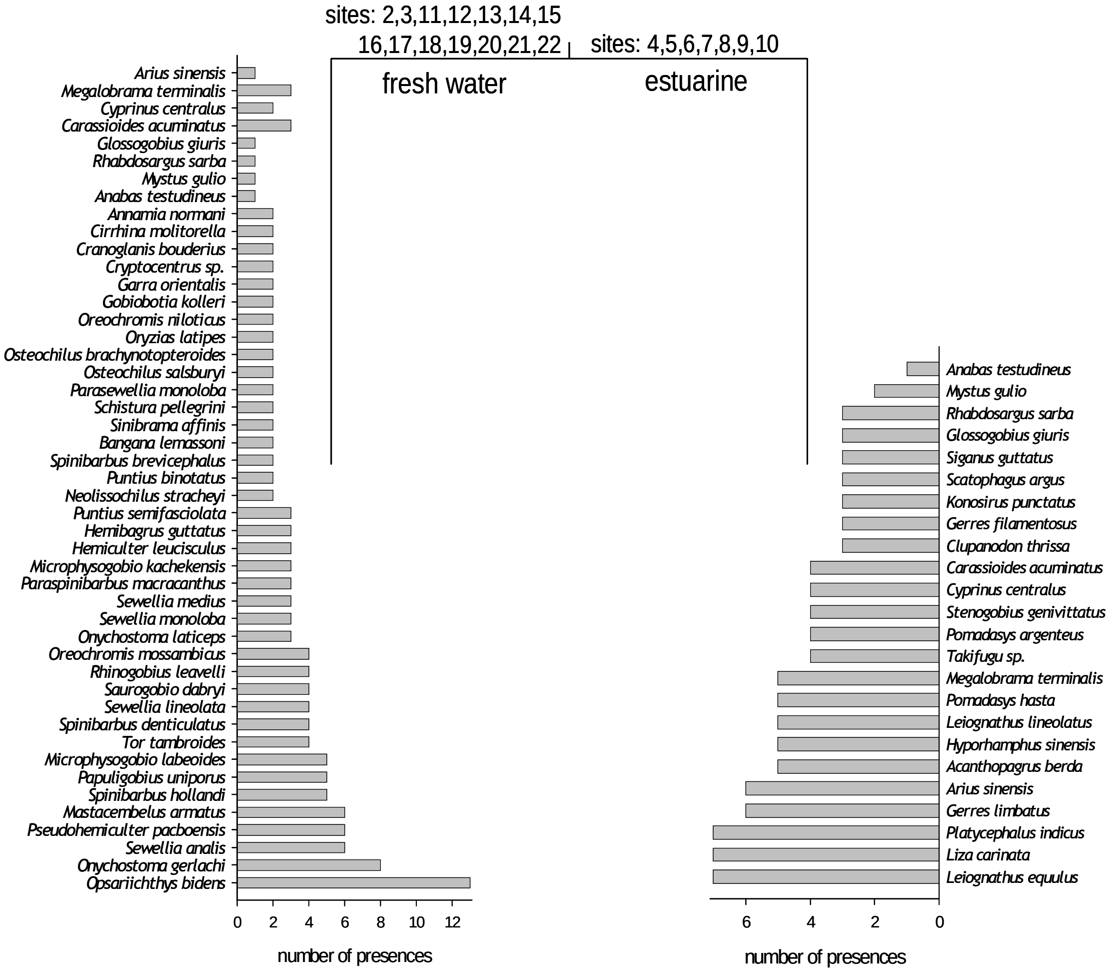

FIGURE 2: **MULTIVARIATE CART FOR THE PRESENCE OF SPECIES THAT OCCURRED IN 2 OR MORE SAMPLES. PREDICTOR VARIABLES ARE HABITAT, RIVER, ALTITUDE, TEMPERATURE, TURBIDITY.**

The large number of species found only in one zone (Table 3) suggests more extensive sampling may have led to their collection in other zones. However, 31 of the 119 species (26%) were collected in at least b of samples from at least one zone (Table 4), indicating sampling was intense enough to represent common species well, that these species were characteristic of the zones in which they were collected, and that their presence or absence indicated real differences among zones.

Estuarine sites contained the most specialist species (species occurring only in the estuary zone but occurring in at least b of samples) comprising a group of species common across most of the tropical Indo-Pacific region (Table 4). Although there were distinct mid altitude and high altitude specialists a number of these showed occurrences in adjacent zones. As well as the specialists, a number of species occurred generally across lowland habitats, both estuarine and fresh, and a further group occurred generally throughout freshwater habitats.

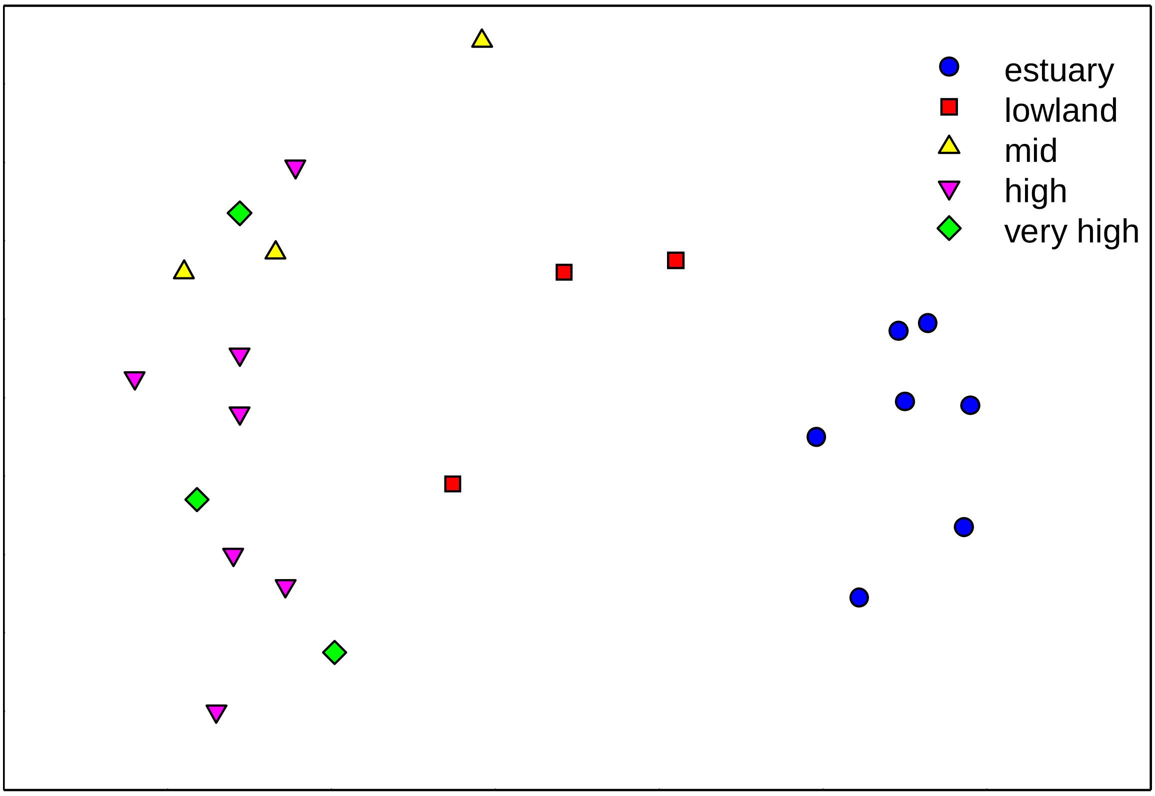

FIGURE 3: **NONMETRIC MULTIDIMENSIONAL SCALING FOR THE PRESENCE OF SPECIES WITH 2OR MORE OCCURRENCES; STRESS = 0.14.**

MIGRATORY SPECIES

Despite a paucity of detailed information on migratory patterns, interrogation of FishBase indicated 31 species (26%) are known to be migratory; 5 anadromous (breed in fresh), 3 catadromous (breed in sea), 13 amphidromous (migrate between fresh and salt for reasons besides breeding), and 10 potamodromous (migration confined within freshwater) of which 6 are recorded as migrating into forests and other bankside habitats during flooding (Table 3). Although most of the species captured from estuarine zone were not captured in freshwater sites, a substantial proportion (47%) are recognised as undertaking migrations to fresh water areas. These include important fisheries species like *Clupanodon thrissa* that migrates from the sea to upstream freshwater areas for spawning (Riede 2004).

Table 4: Zone specialists and generalists. Includes all species occurring in more than 2/3 of samples from any zone. Numbers indicate the percentage of samples from a zone a species occurred in. x indicates occurrence in less than 2/3 of samples in a zone, - indicates absence from the zone.

	estuarine	lowland	mid	high	very high	
Acanthopagrus berda	71	-	-	-	-	estuarine specialists
Gerres limbatus	86	-	-	-	-	
Hyporhamphus sinensis	71	-	-	-	-	
Leiognathus equulus	100	-	-	-	-	
Leiognathus lineolatus	71	-	-	-	-	
Liza carinata	100	-	-	-	-	

Platycephalus indicus	100	-	-	-	-	
Pomadasys hasta	71	-	-	-	-	
Arius sinensis	86	x	-	-	-	low altitude generalists
Cyprinus centralus	x	67	-	-	-	
Carassioides acuminatus	x	67	x	-	-	
Megalobrama terminalis	71	67	x	-	-	
Cryptocentrus sp.	-	-	67	-	-	mid altitude specialists
Gobiobotia kolleri	-	-	67	-	-	
Hemiculter leucisculus	-	x	67	-	-	
Microphysogobio labeoides	-	-	67	x	-	
Onychostoma laticeps	-	-	100	-	-	
Osteochilus brachynotopteroides	-	-	67	-	-	
Pseudohemiculter pacboensis	-	-	67	71	-	
Saurogobio dabryi	-	-	67	x	-	
Squalidus atromaculatus	-	-	67	-	-	
Oryzias latipes	-	-	-	-	67	high altitude specialists
Papuligobius uniporus	-	-	-	x	67	
Parasewellia monoloba	-	-	-	x	100	
Schistura pellegrini	-	-	-	-	67	
Sewellia analis	-	-	-	x	67	
Mastacembelus armatus	-	67	67	x	x	freshwater generalists
Onychostoma gerlachi	-	-	67	-	67	
Opsariichthys bidens	-	67	67	86	100	
Puntius semifasciolata	-	-	x	-	67	
Sewellia lineolata	-	-	67	x	x	

HABITAT ASSOCIATIONS

Habitats were largely segregated by zone (Table 2) with various vegetated banks dominating estuarine and lowland sites and rapids and riffles common in upstream areas. There were similar percentages of species found in only one habitat type in both estuarine sites (61%) (Table 5) and freshwater sites (57%) (Table 6). The current study provided little new information on the habitat preferences of estuarine species because most of the species captured in estuaries have been reported from a much wider range of habitats than those sampled in the Vu Gia – Thu Bon system (Table 5). In contrast, samples from freshwaters greatly extended on the published information on habitat relationships (Table 6). The ranges of habitats from which fish were sampled in this study agreed with information summarised in FishBase for 29 species, and extended on the known habitats used for 17 others. However, for 34 of the species no habitat specific information had previously been reported in FishBase or other known sources, or habitat information had only been reported at a much more general level.

Table 5: Habitat associations of species from ***estuarine*** sites. **a.** species found in a single habitat type, **b.** species found in multiple habitats. **Trophic identities**: inverts = benthic invertebrate feeders, plank/invert = feeders on plankton and small invertebrates, fish crust = predators on fish and mobile

crustaceans, phytodetrit = feeders on plants and detritus, omnivorous = plant and animals, ? = no specific records and related species diets to varied to extrapolate.

a.	mouth	veg bank	rush bank	farm bank		trophic identity
Acanthopagrus latus	mouth					inverts
Ambassis buruensis	mouth					plank/invert
Ambassis kopsii	mouth					plank/invert
Boesemania microlepis	mouth					fish crust
Brachirus orientalis	mouth					inverts
Chelonodon patoca	mouth					inverts
Cynoglossus bilineatus	mouth					inverts
Liza melinoptera	mouth					phytodetrit
Lutijanus argentimaculatus	mouth					fish crust
Mugil cephalus	mouth					phytodetrit
Parapocryptes serperaster	mouth					?
Pseudorhombus cinnamoneus	mouth					inverts
Pseudorhombus quinquocellatus	mouth					inverts
Siganus fuscescens	mouth					herb
Solea elongata	mouth					inverts
Terapon jarbua	mouth					inverts
Triacanthus biaculeatus	mouth					inverts
Butis butis		veg				fish crust
Lates calcarifer		veg				fish crust
Monodactylus argenteus		veg				plank/invert
Secutor indicus		veg				plank/invert
Valamugil cunnesius		veg				phytodetrit
Anabas testudineus			rush			omnivorous
Metzia lineata			rush			?
Konosirus punctatus				farm		?
b.						
Gerres filamentosus	mouth	veg				inverts
Scatophagus argus	mouth			farm		phytodetrit
Siganus guttatus	mouth			farm		herb
Mystus gulio		veg	rush			inverts
Carassioides acuminatus		veg		farm		?
Glossogobius giuris		veg		farm		inverts
Pomadasys hasta		veg		farm		inverts
Rhabdosargus sarba		veg		farm		inverts
Takifugu sp.		veg		farm		inverts
Stenogobius genivittatus	mouth	veg	rush			?
Acanthopagrus berda	mouth	veg		farm		inverts
Gerres limbatus	mouth	veg		farm		inverts
Leiognathus lineolatus	mouth	veg		farm		inverts
Pomadasys argenteus	mouth	veg		farm		inverts
Arius sinensis		veg	rush	farm		inverts
Clupanodon thrissa		veg	rush	farm		?
Cyprinus centralus		veg	rush	farm		?
Hyporhamphus sinensis		veg	rush	farm		insects
Megalobrama terminalis		veg	rush	farm		?
Leiognathus equulus	mouth	veg	rush	farm		inverts
Liza carinata	mouth	veg	rush	farm		phytodetrit

Platycephalus indicus	mouth	veg	rush	farm		fish crust

TROPHIC IDENTITIES

From a trophic standpoint, estuarine sites seemed to harbour a faunal mix typical of tropical estuaries, with a variety of benthic invertebrate feeders, plankton and small invertebrate feeders, and phytodetritivores present. There were also a number of predators on fish and mobile crustaceans including the large predators *Boesemania microlepis*, *Lates calcarifer* and *Lutjanus argentimaculatus*. The only trophic group that may have been underrepresented was specialist planktivores, although a number of abundant species, such as *Clupanodon thrissa* and *Konosirus punctatus*, for which trophic identities could not be defined, may have fulfilled that role. A lack of sufficient information with the necessary detail prevented similar evaluation for freshwater sites.

Table 6: Habitat associations of species in ***fresh water*** sites. a. species found in a single habitat type, b. species found in multiple habitats. Final column indicates the relationship of the habitat information to information summarised in FishBase; N = new information, x = extends on reported habitat understanding, a = agrees with current understanding.

a.	sand	cobble	riffle	rapid	bedrock	veg bank		FishBase
Anabas testudineus	sand							N
Atherinomorus lacunosus	sand							N
Hemibarbus labeo	sand							N
Hemiculter leucisculus	sand							a
Hemibarbus lehoai	sand							N
Oxyeleotris urophthalmus	sand							N
Parambassis siamensis	sand							a
Pelteobagrus fulvidraco	sand							x
Rasbora myersi	sand							x
Rhinogobius vermiculatus	sand							x
Rhodeus ocellatus	sand							N
Squalidus atromaculatus	sand							a
Chanda sinensis		cobble						N
Schistura dalatensis		cobble						a
Schistura kontumensis		cobble						N
Awaous ocellaris			riffle					a
Channa striata			riffle					x
Pseudogobio guilinensis			riffle					N
Osteochilus salsburyi			riffle					N
Rhinogobius giurinus			riffle					a
Rhinogobius lineatus			riffle					a
Rhinogobius sp			riffle					N
Schistura tizardi			riffle					x
Puntius brevis			riffle					*a*
Sinohomaloptera kwangsiensis			riffle					N
Squaliobarbus curriculus			riffle					N
Bangana lemassoni				rapid				N
Barbonymus altus				rapid				x

Cyclocheilichthys enoplus				rapid				x
Garra fuliginosa				rapid				a
Hypsibarbus wetmorei				rapid				x
Neolissochilus stracheyi				rapid				a
Poropuntius kontumensis				rapid				a
Pseudohemiculter dispar				rapid				N
Carassius auratus					rock			a
Oryzias latipes					rock			x
Schistura carbonaria					rock			x
Trichogaster trichopterus					rock			x
Ancherythroculter daovantieni						veg		N
Arius sinensis						veg		N
Cyprinus centralus						veg		N
Glossogobius giuris						veg		a
Mystus gulio						veg		a
Osteochilus microcephalus						veg		a
Rhabdosargus sarba						veg		a
b.								
Cryptocentrus sp.	sand		riffle					N
Gobiobotia kolleri	sand		riffle					N
Onychostoma laticeps	sand		riffle					N
Osteochilus brachynotopteroides	sand		riffle					x
Spinibarbus brevicephalus		cobble	riffle					N
Puntius binotatus		cobble		rapid				a
Oreochromis niloticus		cobble				veg		a
Garra orientalis			riffle	rapid				a
Hemibagrus guttatus			riffle	rapid				x
Microphysogobio kachekensis			riffle	rapid				N
Sinibrama affinis			riffle	rapid				N
Annamia thuathienensis			riffle		rock			a
Schistura pellegrini			riffle		rock			a
Carassioides acuminatus			riffle			veg		x
Cranoglanis bouderius			riffle			veg		x
Megalobrama terminalis			riffle			veg		N
Sewellia medius				rapid	rock			N
Cirrhina molitorella				rapid		veg		a
Saurogobio dabryi	sand	cobble	riffle					x
Microphysogobio labeoides	sand		riffle	rapid				a
Pseudohemiculter pacboensis	sand		riffle	rapid				N
Spinibarbus hollandi	sand		riffle	rapid				a
Puntius semifasciolata	sand		riffle		rock			N
Sewellia lineolata	sand			rapid	rock			a
Rhinogobius leavelli		cobble	riffle	rapid				N
Spinibarbus denticulatus		cobble	riffle	rapid				x
Tor tambroides		cobble	riffle	rapid				a
Parasewellia monoloba			riffle	rapid	rock			N
Paraspinibarbus macracanthus			riffle	rapid		veg		N
Onychostoma gerlachi	sand		riffle	rapid	rock			a
Mastacembelus armatus	sand		riffle		rock	veg		a
Oreochromis mossambicus	sand		riffle		rock	veg		N
Papuligobius uniporus		cobble	riffle	rapid	rock			a
Sewellia analis		cobble	riffle	rapid	rock			N

Opsariichthys bidens	sand	cobble	riffle	rapid	rock	veg		N

4. DISCUSSION

THE CURRENT STATUS OF FISH FAUNA OF THE VU GIA – THU BON

The fish fauna of the Vu Gia – Thu Bon system featured two distinct components, a diverse freshwater fauna, reflecting the highly species richness expected for Vietnam's freshwater systems (Kottelat & Whitten 1996), and an estuary fauna similar to that in other areas of the tropical Indo-Pacific (Sheaves 2006).

Despite extensive habitat modification (Thanh et al. 1996), and the high levels of exploitation (Thao 2004, Stobutzki et al. 2006) and use of destructive fish practices reported throughout the region (Thao 2004), the fish fauna of the Vu Gia – Thu Bon basin appeared surprisingly intact. The freshwater fauna is diverse and apparently still abundant, although the limited spatio-temporal extent of the study and an absence of suitable comparative data make definitive evaluation difficult. Estuarine sites produced a substantial number of species, considering the extent of sampling, including widespread tropical species and species with regionally restricted ranges. All the expected trophic groups were represented in reasonable numbers, including the large predators, *Boesemania microlepis*, *Lates calcarifer* and *Lutjanus argentimaculatus*, which are the functional group most heavily impacted by anthropogenic modification (Pauly & Watson 2003, Worm et al. 2003, Myers et al. 2007). However, in spite of the appearance of intactness, the broad scale nature of the study means that the information on the fish fauna is not definitive.

A notable feature of the fish fauna of the Vu Gia – Thu Bon system is the large number of species that migrate between freshwater and estuarine habitats or within freshwater. The highly migratory nature of the fauna has been noted previously (Jensen 2001), and contrasts with the situation in northern Australia, the one well studied region in the tropics, where only a small proportion (5%) of estuarine species migrate into freshwater (Sheaves 2006). The migratory fauna of the Vu Gia – Thu Bon includes many anadromous and catadromous species that undertake spawning related migrations between fresh and marine waters, amphidromous species that migrate for purposes such as nursery ground access and utilisation of dry season refuges, and potamodromous species, many of which migrate laterally during wet season floods to enter flooded littoral areas for feeding and reproduction. Although such migrations are recorded as important for a substantial proportion of the fauna (26%) this is unlikely to be the full extent of species for which migration is important, because there is little ecological information available for many of the freshwater species.

Overall, the fish fauna of the Vu Gia – Thu Bon system features two distinct faunal elements (a) a substantial number of species that occur broadly across habitat types, and altitudinal and salinity gradients, and (b) a large number of species that specialise in occupying specific habitat types. These two groups represent contrasting population structures. Species comprising the first group are likely to comprise continuous populations (Gehrke et al. 2002), with a continuity of suitable habitats and conditions providing little potential for the development of distinct local population structure. In contrast, the second group are likely to demonstrate strong spatial structuring, with metapopulations occurring in isolated areas of suitable habitat with the potential for recolonisation from other metapopulations if local extinction occurs (Hanski 1998, Freckleton & Watkinson 2002). In the context of these two faunal elements, the highly migratory nature of the fish fauna maintains the continuous distributions of the widespread species and serves to replenish and maintain local metapopulations of the habitat specialists.

IMPACTS OF HYDROPOWER DEVELOPMENT

Imposing 8 major and 34 minor hydropower developments on a single river system appears certain to devastate the fish fauna. It will prevent crucial migrations, directly degrade or alter aquatic habitats, disrupt metapopulation dynamics of habitat specialists, fragment populations of widespread species, and alter nutrient flows and dynamics.

With dam wall heights of between 37 and 110 m, and no provision for fish passage, the 8 major dams will cut off the upper reaches of most major branches of the Vu Gia – Thu Bon system from downstream parts, effectively preventing fish migration, an outcome that has been seen repeated around the world in countries as far apart as Poland (Borzecka 1998, Swierzowski & Godlewska 2001), Brazil (Agostinho et al. 2004b), Taiwan (Chang et al. 1999), USA (Martinez et al. 1994, Miller 1997, Dauble et al. 2003), Slovakia (Holcik 2003), Australia (Gehrke et al. 2002), Puerto Rico (Holmquist et al. 1998), Canada (Locke et al. 2003), and Japan (Morita et al. 2000, Morita & Yamamoto 2002, Katano et al. 2006). Although many of the smaller developments are likely to be run-of-the river schemes, which may provide less impediment to migration (Acolas et al. 2006), even small dams (1.5-4m) can seriously impede migration (Katano et al. 2006). Moreover, their very number and positioning on most major upstream tributaries means that migration routes to other upstream tributaries are also likely to be heavily impacted. At present there are apparently no plans to provide fish passage on any of these, although their small sizes would appear to make the provision of fish passages physically, if not financially, feasible on a number of the minor developments. Without provision of appropriate fish passage devises, these minor hydro dams are likely to represent impediments to migration just as substantial as presented by the major dams. Considered as a group, the proliferation of barriers represented by the 42 major and minor hydro developments represents a major obstacle to connectivity within the Vu Gia – Thu Bon system that seems certain to severely compromise the viability of species requiring migration to upstream areas, and the integrity of the ecosystems of which they are components. In addition, changes in flow regimes that are likely to stem from flow-regulation have the potential to alter patterns of downstream flooding, impacting on the ability of fish to migrate laterally into littoral and floodplain habitats (Agostinho et al. 2004a, Sheaves 2005).

In addition to the barriers represented by dams, the diversion of water between reservoirs and power stations will leave considerable lengths of rivers (approx. 38km (J. Anderson pers com)) with little or no water flow, at least during dry periods (Dauble et al. 2003). As well as providing additional barriers to migration, these areas will undergo extensive habitat modification with altered flow regimes and seasonal dynamics rendering them inhospitable to many species. Additionally, extensive areas of fast-flowing mountain streams will be converted into lacustrine habitats within the impoundments formed by the major dams (Gehrke et al. 2002). Even though these present large areas of new habitat it is likely that few of the species inhabiting the fast flowing high altitude streams where the dams are situated will be able to adapt to the still water conditions (Martinez et al. 1994).

The combinations of habitat alteration in dam and diversion areas and the imposition of a proliferation of barriers to migrations must produce severe population fragmentation (Morita & Yamamoto 2002), leading to increased potential for local extinction, and severely compromise opportunities for recolonisation. For species with continuous populations this fragmentation and loss of potential for recolonisation is likely to see substantial range reductions (Martinez et al. 1994, Gehrke et al. 2002). The situation is particularly bleak for habitat specialists and species with life history patterns that require migration to or from upstream areas. Barriers to migration will compromise the metapopulation dynamics of habitat specialist by impeding recolonisation, prevent life-history migrations (eg. access to spawning or nursery grounds) (Dauble et al. 2003, Burdick & Hightower 2006), and reduce the potential for gene flow (Neraas & Spruell 2001, Cook et al. 2007). Additonally, the concentration of habitat modification at high altitudes will severely reduce the area of habitat suitable for rheophilic species, such as rapid or riffle specialists that are important components of Vietnam's unique freshwater assemblage (Kottelat & Whitten 1996, Kottelat 2001b).

More indirectly, altered flow regimes (Bate et al. 2002) and the trapping of nutrients in reservoirs (Rausch & Schreiber 1981, Avnimelech & Wodka 1988) are likely to alter nutrient supply, nutrient dynamics and productivity in habitats downstream of dams because nutrient dynamics can be profoundly altered by changes in flow regimes (Jassby 2005). The specific details of the Vu Gia – Thu Bon hydro development and of current patterns of nutrient flows that are needed to determine the full extent of this problem are not available. However, experience from around the world (Adams et al. 1992, Adams et al. 2002, Childers et al. 2006) shows the potential for far reaching consequences, with the potential for significant impacts downstream as far as estuaries and coastal waters (Bate & Adams 2000).

STUDY NEEDS

Although taking a broad scale view and representing a narrow temporal window, this study constitutes a considerable increase in understanding of the ecology of the diverse fish fauna of Vietnam's river systems. However, the fact that a study of this extent has produced such a great increase in knowledge highlights that much more needs to be done. Regardless of the appearance of intactness there is an urgent need for specific high resolution evaluation of the fish fauna of the Vu Gia – Thu Bon and similar river systems in Vietnam. There are no base-line data against which to evaluate the specific status of the fauna, what habitats have been lost or the quality of the habitats that remain. Comprehensive surveys of the fish fauna are urgently required but these should no simply take the form of species lists. Instead, studies should be instituted that are capable of detailing habitat-specific distributions, recruitment success, population structure, and reproductive and nursery ground strategies, as well as studies concentrating on the nature of habitats, what habitats may have been lost, and opportunities for habitat rejuvenation and enhancement.

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