Phylogeny, reef fish conservation biology, and the Live Reef Fish Trade

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SUMMARY: Coral reefs and associated systems support highly diverse assemblages of fishes that demonstrate remarkable variation in patterns of geographic distribution, ecology, behavior and life history. Unfortunately, our understanding of these patterns is relatively limited. Meanwhile, many species for which little information exists are under direct or indirect threat from destructive fishing, over-fishing, and habitat loss associated with fish harvests and from the effects of coral bleaching. The necessity to obtain good data is in conflict with the urgency to define species-specific levels of sustainability, if any, and to develop and implement effective conservation and management plans. Phylogenetic methods may be utilized to analyze life history traits, and well as patterns of ecology and behavior. These methods have been applied in intra- and intergeneric comparisons or in comparisons between different families of fishes. The results have predictive value for related species for which little or no data exist. This point is illustrated in comparisons within two families of reef fishes, the groupers (Serranidae: Epinephelinae), which are harvested for food, and the hawkfishes (Cirrhitidae), which are harvested largely for the aquarium trade.

KEY WORDS: groupers, hawkfish, live reef fish, phylogeny, reef fisheries

INTRODUCTION

Coral reef fishes are under increasingly serious threats from over-fishing and habitat destruction world-wide. This is especially true in developing nations that, because of relatively high levels of poverty, are compelled to practice extensive subsistence and commercial export fisheries. The Live Reef Fish Trade (LRFT) has developed recently into a major export fishery worth an average US$ 600 million to US$1 billion annually in Southeast Asia alone. In the Indo-Pacific region, this trade has extended beyond the confines of Southeast Asia and now ranges from the Red Sea east to Hawaii. Similar activities occur or are emerging in the eastern Pacific and the Atlantic, regions already affected from the over-harvest of species by other means. The LRFT has two major components: food fishes, which are shipped largely to Hong Kong and south China and aquarium or ornamental fishes, which are shipped primarily to North America, Europe, Japan and Australia. Regrettably, target species taken in the LRFT are harvested often by destructive means, such as the use of cyanide or other poisons, and by the physical destruction of habitat. Further, fishes are also harvested with hook and line or traps to an extent that, with added pressure from subsistence, hookah and scuba spearfishing, netting, and local commercial harvests, over-fishing occurs. The problem is further exacerbated by the effects of habitat destruction by other human activities or by natural events, i.e. coral bleaching, crown-of-thorns starfish outbreaks, etc. Extermination or extinction of species with limited ranges, large-bodied long-lived species with low levels of reproduction and recruitment, or species with highly-specialized habitat or microhabitat requirements, i.e. obligate coral-dwelling fishes, are highly probable.

The development and implementation of conservation and management plans that promote the protection and sustainability of species under harvest, and the habitats they occur in, is an urgent requirement. Unfortunately, sustainability, from a biological standpoint, rather than a fisheries standpoint, remains to be defined for most species or communities of species. Data are largely absent or few, and more detailed studies of population and community processes are required. This requirement may not or cannot be met sufficiently in many cases, however because of the nature of fisheries operating in tropical environments, because of logistical and temporal difficulties related to geography, because only a few agencies have the expertise and resources to accomplish this task, or because existing methods, such as the aggregation of
species in the management of fisheries, are inappropriate to the point of disaster\textsuperscript{15,16,17,18}.

**PHYLOGENETIC METHODS**

Recently, phylogenetic methods have been employed to make predictions on how species, for which relatively little data are available, will react to exploitation or other impacts\textsuperscript{19}. These methods utilize existing life history, behavioral and ecology data\textsuperscript{20,21,22}. Phylogenetic methods (i.e. historical ecology\textsuperscript{20,23}) have demonstrated considerable utility in studies of freshwater species\textsuperscript{22,23,24}, but only recently have they been applied to tropical reef species\textsuperscript{18,25}. In this brief overview, two examples, with additional details, are described.

**RESULTS & DISCUSSION**

The groupers (Serranidae: Epinephelinae), consist of at least 163 species distributed mainly upon reefs and deep flats in tropical and subtropical waters world-wide\textsuperscript{26}. A number are protogynous hermaphrodites and spawn either in spawning aggregations\textsuperscript{27,28} or in harem mating systems\textsuperscript{29}. Groupers are a major target of commercial and subsistence fisheries\textsuperscript{18,30} and are a significant component of the LRFT for food fishes\textsuperscript{31}. Coral trouts (genus *Plectropomus*) are the species most often taken for the trade\textsuperscript{3} and are thus subject to intense over-fishing, often by destructive means\textsuperscript{3,30}. Larger groupers of the genera *Epinephelus*, *Cromileptes*, *Cephalopholis*, *Variola*, *Anyperodon*, *Aethaloperca* and *Triso* are also targeted heavily\textsuperscript{6}. Groupers common to the LFRT tend to be caught easily by a variety of methods that include hook and line, traps and cyanide. This is especially true when fishers target groupers that form spawning aggregations during certain times of the year. The impact of harvests upon local populations and communities, which must also sustain subsistence and non-export commercial fisheries, is often considerable, with extirpations a frequent possibility\textsuperscript{18}. Estimates of fishing mortality are not known locally for many species and so it is difficult to partition the effects of fishing mortality and life history in the responses of these fishes to exploitation\textsuperscript{18}. Jennings et al.\textsuperscript{18} examined this problem and found that with some knowledge of phylogenetic relationships and life history patterns, trends in the abundance of some fish species could be predicted without

![Fig. 1 Life history classes of groupers mapped upon a preliminary phylogeny based upon morphological characters.](image-url)
and that levels of vulnerability to exploitation could be predicted as well. Although a robust phylogeny of groupers remains to be completed, six species from four genera of groupers taken by fishers at Kadavu Island, Fiji were studied, in addition to 17 species of parrotfishes (Scaridae) and 10 species of snappers (Lutjanidae). The species of grouper that decreased in abundance more than its nearest phylogenetic relative had greater maximum size. Thus, the abundance of *Epinephelus polyphekadion*, a relatively large species of grouper, declined more than its smaller congener, *E. merra*. Similarly, the abundance of the larger *Cephalopholis argus* declined before that of *C. urodeta*. Groupers have two life history classes, small (dwarf) and large (giant), the distribution of each being influenced by habitat. Five genera of groupers may be classified as small, five as large, and four with mixed strategies (Fig. 1). Based upon the work of Jennings et al., one would predict that those genera consisting of large-sized groupers would be more vulnerable to exploitation than genera with smaller-sized groupers. Further, within genera that have mixed life history size classes, large species would be more vulnerable to exploitation than smaller congeners.

The relationship between life history size class, habitat, and mating system, all important factors for assessing stocks and developing effective management plans, is currently being investigated in a phylogenetic context. Mating system characters mapped upon a preliminary phylogeny of grouper genera (Fig. 2) indicates that five genera mate in spawning aggregations, one genus has a harem mating system, and one genus has a mixed strategy. That the mating systems of eight genera are unknown is indicative of the necessity to conduct further studies on grouper reproduction.

In a similar vein, ornamental fishes taken by the aquarium trade are a major component of the LRFT. The exploitation of many species, but in particular those with harem mating systems, proceeds with little or no regulation, and often by destructive means. Many protogynous (e.g., hawkfishes, Cirrhitidae; pygmy angelfishes, Pomacanthidae) and polyandrous (e.g., anenomefishes, Pomacentridae) species have relatively small-sized mating groups with patchy distributions that are often limited by the availability of suitable microhabitat (e.g., corals or host anenomes). If habitat and microhabitat destruction occurs, perhaps as a consequence of coral bleaching or some other factor, local population abundances will be negatively affected. If unregulated exploitation also occurs, extirpation may result because population mortality will exceed replacement rate.

Mating system structure, and hence reproductive potential, can be predicted from knowledge of habitat and microhabitat

![Fig. 2. Mating system characters mapped upon a preliminary phylogeny of the groupers. SPAG denotes spawning aggregation.](attachment:phylogeny.png)
demonstrated for hawkfishes. Hawkfishes (Cirrhitidae) number about 33-35 species in 12 genera; their taxonomy and systematics are under revision. These fishes are distributed on tropical and warm-temperate coral or rocky reefs worldwide. Hawkfishes have four principal microhabitat associations: obligate coral-dwelling, facultative coral-dwelling, non-coral substratum-dwelling, or water column-dwelling. All may be protogynous hermaphrodites with either haremic or facultatively monogamous mating systems. A number of species, but especially two obligate coral-dwelling species that practice facultative monogamy, Neocirrhites armatus and Oxycirrhites typus, are harvested for the aquarium trade. Donaldson employed phylogenetic methods to predict hawkfish mating system patterns based upon microhabitat utilization. Benthic-dwelling and facultative coral-dwelling species were predicted to have a haremic mating system. Obligate coral-dwelling species were predicted to have facultative monogamy because microhabitat size limited mating group size. The loss of microhabitat for obligate coral-dwelling hawkfishes would have severe consequences. The destruction of preferred coral species by natural or anthropogenic means (ie destructive fishing or sedimentation) would be followed by sharp declines in hawkfish population size. These hawkfishes would be forced to utilize less suitable corals or no corals at all and be lost to predation. Or, hawkfishes would attempt to gain entry into remaining corals already occupied by a mating group but the success of obtaining entry would be limited by both the size of the coral and by the sex of the entrant; a resident male would expel or attempt to expel other males while a resident female would attempt to expel new females. Thus, with a decrease in population size there would be a corresponding decrease in reproductive potential as well as recruitment potential (local or remote source) because fewer offspring would be produced and because there would be less suitable microhabitat for offspring to recruit to. Similar effects would be predicted, perhaps with lesser impact, for facultative coral-dwelling species at localities where coral-dwelling is well pronounced, because microhabitat loss could have a destabilizing influence upon haremb structure. The implication for conservation is obvious. Unregulated fishing pressure, in the form of harvest for the ornamental trade, upon populations of coral-dwelling species could lead to local extirpation of those species.

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