CLIMATE CHANGE AND BIODIVERSITY IN MELANESIA

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CLIMATE CHANGE AND BIODIVERSITY IN MELANESIA: IMPLICATIONS FOR AND IMPACTS UPON REEF FISHES

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Synopsis

Climate change poses a significant set of problems for reef fishes associated with coral reef systems, mainly from the negative effects of habitat loss from coral bleaching, ocean acidification, and subsequent physical degradation. The effects are direct (i.e., loss of obligate or facultative microhabitat, food supply or breeding sites) or indirect (i.e., effects of community phase shifts from coral to algal domination, effects on non-obligate coral reef species from loss of prey associated with corals, etc.). In addition, cumulative negative effects upon reef fish diversity and abundance from other sources. Exploitation and over-exploitation are expected to continue regardless of local and regional declines in the diversity and abundance of target species that may be affected directly or indirectly by climate change processes. Changes in the assemblage structure of reef fishes, and corresponding changes in ecological communities, because of climate change effects, will have profound effects upon human users of reef resources. Simple rules of thumb on how to proceed to conserve species in a relatively short time span are needed, as is the application of existing and new methodologies towards understanding how species will respond to habitat loss and what can be done to reduce extinction threats on local, regional and global scales.

Introduction

Globally, extinction risks in marine and terrestrial systems are increasing annually (Hughes *et al.*, 1997; Roberts and Hawkins, 1999; Chapin *et al.*, 2000). Major threat processes include habitat loss or degradation, direct losses from exploitation, intrinsic factors, and indirect losses (Hilton-Taylor, 2000). Greater than 87% of the Earth's surface has been impacted by anthropogenic activities (Sanderson *et al.*, 2002). These impacts are coupled with non-anthropogenic effects that can lead to local and global extinctions. In marine systems, threats are greatest from exploitation and habitat loss (Hilton-Taylor, 2000; Reynolds *et al.*, 2002; Dulvy et al 2003) and fishes are particularly vulnerable (Reynolds *et al.*, 2002; Myers and Worm, 2003; Hutchings and Reynolds, 2004). As a consequence of these impacts, increased extinction rates range in magnitude and may have mass proportions (May and Tregonning, 1998) at local or global scales (Carlton *et al.*, 1999; Pitcher, 2001; Dulvy *et al.* 2003). Thus, the sum of local extinctions across the range of species is a proportion of global extinction.

Both wide-ranging and narrow-ranging marine fish species are vulnerable to extinction because of environmental disturbances, over-fishing or indirect effects of both. Many reef fishes are harvested for food at subsistence, artisanal and commercial levels (Russ, 1991; McManus, 1997; Jennings *et al.* 1999). Non-food fishes are harvested generally for the aquarium trade (Wood, 2001a; 2001b; Sadovy and Vincent, 2002; Vincent 2006), traditional medicine (Vincent, 2006), as by-catch (Kaiser and Jennings, 2001), or for other uses. Life history correlates of harvested species often pre-dispose them to extinction susceptibility, as well (Jennings *et al.*, 1999; Dulvy *et al.*, 2003; Hudson, 2003; Reynolds, 2003; Donaldson *et al.*, unpublished manuscript). These include large body size, late maturity, long generation time, and long life span. Population traits include low maximum growth rates, low or rare abundance, small range sizes, and reproductive bottlenecks. Extrinsic factors include: habitat loss and over-exploitation (Hudson, 2003). Many non-food fish species share similar correlates (Donaldson *et al.*, unpublished manuscript). For example, anenomefishes (*Amphiprion* spp., Pomacentridae) are relatively long-lived, experience reproductive bottlenecks, i.e., socially-mediated protandrous sex-change, and are strongly site-attached to a living microhabitat that in itself is vulnerable (Moyer, 1976; Moyer and Nakazono, 1978).

Coral reef fishes comprise a highly significant component of reef systems, with high rates of species diversity, endemism, ecological specialization, and for a number of taxa, abundance. They exercise considerable influence upon the biological and physical dynamics of coral reefs and associated habitats (Bellwood *et al.*, 2003), and are of special interest because of the effects of climate change upon tropical and subtropical reefs globally and, with respect to Melanesia, regionally. The fish fauna of many Melanesian localities is highly diverse (Randall, 2005) and characterized by having species with both wide and narrow geographic ranges. Both rarity and commonality exist with respect to the local and regional abundance of many species (Jones *et al.*, 2002), regardless of range size, and rarity amongst some species may occur globally. Coral reef fishes have been demonstrated to be highly vulnerable to exploitation (Wilkinson, 2006), even at the level of subsistence fishing (Jennings *et al.*, 1999; Dulvy *et al.*, 2003), and from habitat loss (Dulvy *et al.*, 2003), because of negative effects primarily upon shelter (Munday, 2004) and food (Kokita and Nakazono, 2004). Other factors, such as pollution and stochastic events, also promote vulnerability to extinction, mainly at local levels. Changes in habitat structure, complexity, and availability, as a consequence of climate change, are expected to have profound negative effects upon many reef fishes. Here, I examine briefly the implications of climate change and its potential impacts upon reef fishes with emphasis upon Melanesia.

Responses of the fishes and fish assemblages to projected environmental changes

The principal sources of habitat loss for reef fishes as a result of climate change are coral bleaching and ocean acidification (Sheppard, 2006; Hoegh-Guldburg *et al.*, 2007), and physical disturbance locally as a result of increased storm activity (Knowlton, 2006). All are linked to the presence of increased carbon dioxide in the atmosphere. Bleaching and increased storm activity are linked to increases in water temperature as a result of increased levels of atmospheric carbon dioxide (Hoegh-Guldberg, 1999; Hughes *et al.*, 2003; Sheppard, 2006; Knowlton, 2006), while ocean acidification is caused by the reaction of increased pCO2 with seawater (Hoegh-Guldberg *et al.*, 2007). The mechanisms of habitat loss include the reduction of architectural complexity and integrity of reefs, habitat phase shifts towards monolithic species composition or algal-dominant rather than coral-dominant community structures, and eventual degradation to rubble and sand (Sheppard, 2006). Reef fishes are predicted to make corresponding changes in assemblage structure with a reduction in species diversity, abundance, or trophic complexity (Knowlton, 2006; Sheppard, 2006). These changes are expected to proceed via two types of responses to habitat loss: direct and indirect.

Direct responses will be mainly in a decline in the species diversity and abundance of species that utilize corals for microhabitat (e.g., shelter), breeding sites, or food. Thus, for example, obligate and facultative coral-dwelling species, such as gobies of the genera *Gobiodon* and *Paragobiodon* (Gobiidae), hawkfishes (Cirrhitidae;) and coral-crouchers (Caracanthidae), are expected to decline in both species diversity and abundance locally with the loss of critical coral microhabitats (mainly *Acropora* and *Pocillopora* spp. corals) (Donaldson 1989; unpublished manuscript; Dulvy *et al.*, 2003; Munday, 2004; Wong *et al.*, 2005; Thompson *et al.*, 2007). An ontogenetic effect is expected for species whose post-settlement larvae and juveniles utilize corals for shelter, even if they do not use corals as adults. Species that utilize corals as substrates for nesting, e.g., algal patches created on corals by the filefish *Oxymonacanthus longirostris* (Monacanthidae) (Barlow, 1987), and damselfishes of the genus *Plectroglyphididon* spp. (Pomacentridae) (see Myers, 1999), are predicted to decline as well with the physical loss of coral skeletons from degradation. Obligate coral-feeding species, i.e., the filefish *O. longirostris* (Kokita and Nakazono, 2001), butterflyfishes (Chaetodontidae; Myers, 1999), the parrotfish *Bolbometopon muricatum* (Bellwood *et al.*, 2003; Donaldson and Dulvy, 2004; Dulvy and Polunin, 2004), or those species that farm algae in living coral patches (i.e., the damselfishes *Stegastes lividus, S. nigricans*, and *Hemiglyphididon plagiometopon*; see Myers, 1999), are all expected to decline either from the direct loss of food (coral polyps) or structure used to "grow" food (algae). Direct responses to ocean acidification may include the interruption of ontogenetic development in larval fishes.

Indirect responses will include a cascade effect upon predators of species that utilize corals for shelter either obligatively, facultatively, or opportunistically. Adult reef fishes of many species may not necessarily be affected by loss of corals but rather will be affected negatively by loss of prey that are associated with corals. Indirect responses will also include effects upon omnivores and herbivores that feed upon specific prey or forage associated usually with living corals. As corals decline, so will the prey or forage associated with these corals.

Aside from direct and indirect effects of climate change upon reef fish biodiversity, one must consider also the cumulative negative effects upon reef fish diversity and abundance from other sources. Exploitation and over-exploitation are likely to continue regardless of local and regional declines in the diversity and abundance of target species that may be affected directly or indirectly by climate change processes. Additionally, the effects of intrinsic factors (described above) and extrinsic factors, such as pollution, poor land-use practices leading to sedimentation, and anthropomorphic or non-anthropomorphic physical destruction (i.e., coral mining, dredging, storm effects) upon habitat, and hence upon reef fishes that utilize that habitat, must also be accounted for. Climate change effects will not operate in a vacuum. So, any consideration of the effects of climate change upon reef fish diversity and abundance must also include a summation of estimated proportional impacts from other intrinsic and extrinsic factors. The interaction of these factors will influence extinction susceptibility, vulnerability and risk (Hudson, 2003; Purvis *et al.*, 2005, Donaldson *et al.*, unpublished manuscripts). Localized extinctions (Dulvy *et al.* 2000) are predicted to proceed at a pace matching the loss of coral reef habitat coupled with increased pressure from exploitation and other factors.

Consequences of impact on the species group or ecological community for ecosystem services to humans

Changes in the assemblage structure of reef fishes, and corresponding changes in ecological communities, because of climate change effects, will have profound effects upon human users of reef resources. Fishers are often dependant upon reef resources associated directly or indirectly with corals. The loss of corals is predicted to lead to a decline in reef resources and especially reef fishes. Those species dependent upon corals will likely decline in abundance and diversity first, with those species dependent in part upon coral-dependent species following suit over time and especially in the face of other extrinsic and intrinsic factors. The potential loss of larval fishes to ocean acidification during ontogenetic development will have an even greater impact upon fish assemblage structure and abundances on reefs and related systems. Thus, reef fish resources will be lost to human users and reef ecosystem function will deteriorate as well.

Research needs

Côté and Reynolds (2002) and Côté *et al.* (2006) suggest that “Things are getting worse” and advocate the use of simple rules of thumb on how to proceed to conserve species in a relatively short time span. While their concern is not strictly about the effects of climate change upon biodiversity, their insistence that we utilize methods that allow us to assess impacts but also address them while confronted by a paucity of data, has validity and should be heeded. A number of tools or methodologies may be brought to bear. It is necessary, however, to employ their use in a framework that allows for the integration of previous research results, however limited, and new research that will allow us to improve our abilities to predict the results of negative impacts but also to design and implement strategies that are effective for conserving threatened and endangered species.

First, it is always nice to know what you are working with. For reef fishes, knowledge of life history correlates of many species need to be estimated (Reynolds *et al.*, 2001; Reynolds, 2003). For many taxa, especially in a data-poor environment, it is necessary to infer what these might be by use of phylogenetic methods (Jennings *et al.*, 1999; Reynolds, 2003; Purvis *et al.*, 2005). These methods can allow researchers and management biologists to determine which intrinsic factors are relevant to impacts from climate change.

Second, knowledge of these intrinsic factors, coupled with knowledge of extrinsic factors (mechanisms of habitat loss and exploitation, plus acidification) and their interaction can be used to assess the extinction susceptibility, and hence risk, of species or groups of species (genera or families). Thus, direct and indirect responses by impacted taxa may be predicted. The responses of reef larvae to changing conditions, especially decreases in pH locally, should be included because ocean acidification may have profound negative effects upon developing fish larvae. Extinction susceptibility calculations (Purvis *et al.*, 2005) and matrix constructions (Hudson, 2003; Donaldson *et al.*, unpublished manuscript; Donaldson, unpublished manuscript) may be relatively easy to perform, are valid (Donaldson *et al.*, unpublished manuscript), are modifiable with newly acquired data, and are useful for prioritizing conservation effort (Hudson, 2003; Purvis *et al.*, 2005).

Third, direct observation and measurement of direct and indirect responses for species not yet documented should be made wherever possible. Observations should include the collection of water temperature and pH data along depth profiles where possible, and species interactions in altered habitats (i.e., phase-shifted reefs). These observations should be reported to an accessible data base and made available for extinction susceptibility assessments (Hudson, 2003; Purvis *et al.*, 2005), IUCN Red List assessments (Hilton-Taylor, 2000), or other analyses (i.e. meta-analysis) (Côté *et al.*, 2006).

Fourth, Dulvy *et al.* (2004) provide methods for assessing extinction risk in marine fishes. These should be tailored specifically for the effects of habitat loss from climate change but should also account for losses from other sources (anthropomorphic and non-anthropomorphic) in a cumulative fashion.

Fifth, methods for estimating the probabilities of recovery should be developed and, or implemented (Kerr and Deguise, 2004). In terrestrial systems, habitat loss explains most of the variation in declines of terrestrial flora and fauna that lead ultimately to species extinction. The same outcomes should be expected for marine organisms and especially coral reef fishes. The ability to estimate the probability of recovery for a taxon, or better, a suite of taxa, from the effects of habitat loss on reefs will depend upon knowledge of life histories, but also upon knowledge of protections afforded by reef habitats at less risk of loss. For example, habitat at depths below the transition zone between patches of the reef vulnerable to bleaching versus not vulnerable to bleaching (Sheppard, 2006), as well as in reefs that afford protection from anthropogenic impacts, especially fishing (i.e., Roberts *et al.*, 2006), should be identified.

Sixth, and perhaps from a somewhat different perspective, although linked both to tracking changes and estimating probabilities of recovery, it might prove quite useful to think of large-scale declines in reef fish populations and assemblages from climate change-induced habitat loss in the context of severe over-exploitation (see Reynolds *et al.*, 2001). Predictions using models modified from those created for exploitation effects, with modification equating massive habitat loss effects with those of exploitation rate, might be possible. Simply put, one would treat the effects of habitat loss as the “result” of exploitation but on a grander scale. Models exploring selective exploitation might be used to consider species-specific direct responses to a massive loss of habitat or food. Non-selective exploitation (i.e., by-catch) models might be equivalent to indirect responses to massive loss of habitat or food.

Seventh, geospatial models need to be developed and used to predict the geography of extinction from habitat loss as a consequence climate change. These should incorporate localized extinction events sequentially as a means of estimating the percentage of regional (e.g., Melanesia) and global extinction of a given species. These models should incorporate also shifts in local assemblage and community structure sequentially. The use of appropriate statistics to analyze spatial structure must be employed in order to avoid various pitfalls associated with spatial data (Perry *et al.*, 2002).

Eighth, the worst case scenario model should provide a summation of effects from climate change with those from other intrinsic and extrinsic factors. Predicted losses from climate change should include, in step-wise fashion, predicted losses from exploitation, plus losses from other forms of habitat change, such as pollution or trawling effects (Jennings *et al.* 2001), sedimentation, palm cultivation and other forms of coastal land misuse, as well as dredging and coral mining, subsistence mining of corals for betel nut, etc., non-anthropogenic, i.e., typhoons, tsunamis, volcanic eruptions, etc. Estimates of effects may be derived from previous studies and examined in a meta-analysis framework (Côté *et al.*, 2006) in order to predict overall effects upon reef fish species. Then, these should be considered along with losses attributed to their interaction with intrinsic factors in order to estimate extinction susceptibility and risk (i.e. Hudson, 2003; Purvis *et al.*, 2005).

Specific implications for the Melanesia region

Subsistence and artisanal fisheries will be impacted negatively because of direct and indirect effects of habitat loss. Localized extinctions are likely to follow and will be accelerated because of increased fishing effort on remaining species, with abundances of larger species being reduced first (Jennings *et al.* 1999; Graham *et al.*, 2005). The Live Reef Food Fish Trade will likely increase fishing effort upon declining stocks of target species, as well. This fishery exploits threatened and rare species with no consideration of economic extinction because the value of target species increases with increasing rarity (Sadovy and Vincent, 2002; Sadovy *et al.*, 2003). While local peoples may realize gains in short-term income by participating in this fishery, the long-term consequences of exploiting declining stocks will likely have negative effects upon subsistence and commercial fisheries.

Coral reefs are attractive for tourism (Jobbins, 2006). Tourism, specifically dive tourism, will likely be impacted negatively because of both the loss of attractive habitats (e.g., coral reefs), and the loss of attractive fishes (both large species and small, showy species) because of direct and indirect effects. As desirable reef habitat and its inhabitants decline, so shall dive tourism and the direct (dive operations) and indirect (lodging, restaurants, boat services, etc.) industries and the employees that support it.

The loss of the intrinsic value of biodiversity, which can be translated functionally to include also the reef system's capacity for stability but also its potential for phase shift between two dominant structural components (i.e., McManus *et al.*, 2000), is of prime importance. Stable and diverse reef systems have been shown to be intrinsically productive within physical and chemical limits. The potential for alternatively stable systems to develop via a phase shift, systems that are based upon lower species diversity and abundance, is considerable (Knowlton, 2006). An example may be a system driven formerly by corals but now dominated by benthic algae. Corresponding changes in the assemblage structure of reef fishes as a consequence of the maintenance of this alternative stability would likely see drastic declines or localized extinctions of coral-associated species and their predators, and their replacement by herbivorous fishes and their predators. Such a change would affect both human utilization of resources but also the physical structure and maintenance of reefs in Melanesia and elsewhere (Bellwood *et al.*, 2003; Sheppard, 2006).

Implications for natural resource management

Researchers, management biologists, managers, policy makers, and user groups will all have to recognize the necessity of treating declines in reef fish populations and reductions or shifts in assemblage structure from climate change effects as being equivalent to a massive exploitation event. There will be attempts to continue business as usual, i.e., the continuation of current or increasing fishery exploitation rates, and the application of relatively similar rates of anthropogenic habitat destruction, as reef fish populations decline and assemblage structures change. These attempts should be resisted and done so simply but intelligently. Research is needed that produces models that allow for the development of management strategies that partition the relative roles of both intrinsic and extrinsic factors, and their cumulative effects, in addition to those direct and indirect effects from climate change-induced habitat loss.

It will be necessary also to know what you have, what it needs to survive, and what to look for as it begins to disappear. Many extinctions, be they local or global, often go unnoticed for a considerable time (Dulvy *et al.*, 2003). Local knowledge can be a powerful tool in understanding how reef fishes respond to habitat loss in the face of other impacts. Often, local knowledge can be transferred regionally if the same or similar species are being considered. The importance of such transfers of information within Melanesia, and the use of this information towards regional conservation of reef fishes, cannot be over emphasized.

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