# Species Extinction in the Marine Environment: Tasmania as a Regional Example of Overlooked Losses in Biodiversity

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**Abstract:** *We used Tasmania as a case example to question the consensus that few marine species have recently become extinct or are approaching extinction. Threats to marine and estuarine species—primarily in the form of climate change, invasive species, fishing, and catchment discharges—are accelerating, fully encompass species ranges, and are of sufficient magnitude to cause extinction. Our ignorance of declining biodiversity in the marine environment largely results from an almost complete lack of systematic broad-scale sampling and an overreliance on physicochemical data to monitor environmental trends. Population declines for marine species approaching extinction will generally go unnoticed because of the hidden nature of their environment and lack of quantitative data.*

**Key Words:** climate change, effects of fishing, global warming, introduced species, marine protected area, marine reserve, siltation, threatened species

Extinción de Especies en el Medio Marino: Tasmania como Ejemplo Regional de Pérdidas de Biodiversidad Ignoradas

**Resumen:** *Usamos a Tasmania como ejemplo para cuestionar el consenso de que pocas especies marinas se han extinguido o están cerca de la extinción recientemente. Las amenazas a especies marinas y estuarinas—principalmente el cambio climático, las especies invasoras, la pesca y las descargas en cuencas—están acelerando, abarcan completamente el área de distribución de especies y tienen la suficiente magnitud para causar extinción. Nuestra ignorancia de la declinación de la biodiversidad en el ambiente marino resulta en gran medida de una carencia casi total de muestreos sistemáticos a gran escala y una confianza excesiva en datos fisicoquímicos para monitorear tendencias ambientales. Las declinaciones poblacionales de especies marinas cercanas a la extinción generalmente pasarán inadvertidas por la naturaleza oculta de su ambiente y por la ausencia de datos cuantitativos.*

**Palabras Clave:** área marina protegida, calentamiento global, cambio climático, efectos de la pesca, especies amenazadas, especies introducidas, reserva marina, sedimentación

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## Introduction

Conservation scientists and managers generally agree that extinction is a minor issue for marine plants and animals compared with terrestrial species. Few would disagree that many marine populations are depressed by fishing, pollution, and other anthropogenic threats, and that local extinction is possible; however, marine species are also considered to typically possess large ranges and good dispersal capabilities that insulate them against extinction (Roberts & Hawkins 1999).

This consensus is supported by available statistics. On the World Conservation Union (IUCN) Red List of Endangered Species, for example, only 2.5% of threatened

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**Table 1. The total number of terrestrial species and marine species (in parentheses) listed under the World Conservation Union (IUCN) Red List[a] and Tasmanian Threatened Species Protection Act[b] on 23 January 2004.**

| *Taxon* | *Extinct* | *Critically endangered* | *Endangered* | *Vulnerable* | *Rare* | *Total* |
|---|---|---|---|---|---|---|
| IUCN Red List | | | | | | |
| plants | 106 (1) | 1275 (0) | 1633 (0) | 3862 (0) | | 6876 (1) |
| animals | 820 (21) | 2249 (48) | 2999 (74) | 7011 (199) | | 13079 (342) |
| Tasmanian Threatened Species Protection Act | | | | | | |
| plants | 23 (0) | | 103 (0) | 67 (0) | 282 (1) | 475 (1) |
| mammals | 1 (0) | | 0 (5) | 0 (1) | 1 (1) | 2 (7) |
| birds | 4 (0) | | 10 (8) | 1 (7) | 1 (4) | 16 (19) |
| reptiles | 0 (0) | | 3 (1) | 1 (3) | 1 (0) | 5 (4) |
| fishes | 0 (0) | | 5 (2) | 2 (2) | 4 (0) | 11 (4) |
| invertebrates | 4 (0) | | 13 (2) | 15 (0) | 88 (1) | 120 (3) |

[a] *Source: http://www.redlist.org.*

[b] *Source: http://www.dpiwe.tas.gov.au/inter.nsf/WebPages/SJON-58E2VD?open.*

animal species are marine (Table 1), and only a single marine plant is listed (0.01% of total). No obligate marine fish, one marine plant, and only four marine invertebrate species (all gastropods) are listed as extinct (IUCN 2001).

Regardless, given our rudimentary knowledge of the distribution and abundance of most marine species and recognition that endangered species listings are biased by paucity of information, we need to critically assess the possibility that our consensus largely reflects ignorance (Roberts & Hawkins 1999). We reviewed available information on threats to marine biodiversity for one region—Tasmania—and the ways managers and scientists assess those threats. The Tasmanian region should not be considered unusual, other than perhaps its recent European colonization (1803) and low human population density (450,000 people inhabiting 67,000 $km^2$), which make it less affected by human activity than most temperate coasts.

The Tasmanian marine environment is publicly perceived to be in reasonable condition, aside from contamination by heavy metals and sewage discharge that affects some estuaries, localized infestations of invasive species, and high rates of sediment and nutrient runoff (DPIWE 1997). For Australia in general, water quality and habitat loss are considered the two major marine environmental issues (Australian State of the Environment Committee 2001). The Australian State of the Marine Environment Report considered that the nation's ecosystems were generally "fair" to "excellent," with the exception of estuaries, seagrass beds, and open sandy beaches in developed areas, which were reported as "poor" to "fair" (Zann 1995).

## Endangered Species Listings

Few marine species are listed under the Tasmanian Threatened Species Protection Act as "extinct," "endangered," "vulnerable," or "rare"—the four official categories of threat (Table 1). Inspection of listed species nevertheless reveals a clear taxonomic trend. Among the higher vertebrates, the number of marine species listed exceeds the number of terrestrial species, whereas negligible numbers of marine invertebrates and plants are included. Thus, numerous air-breathing marine species (whales, sea lions, albatross, petrels, and turtles) are recognized as threatened, whereas only eight fully aquatic species are listed (21% of total).

Several hypotheses explain this trend: (1) higher vertebrates produce few offspring per year, making them disproportionately vulnerable to episodic impacts because of slow population recovery; (2) higher vertebrates possess relatively large body mass, making them preferred hunting targets for humans; (3) species with both terrestrial and marine habitat requirements are disproportionately vulnerable to threats because they must cope with hazards in both realms; (4) the charismatic nature of higher vertebrates enhances public and scientific interest, increasing the likelihood that a researcher will investigate a species and generate data suitable for successful threatened species listing; or (5) air-breathing taxa are monitored relatively easily at the sea surface or on land, providing some long-term data on population trends. These hypotheses are not mutually exclusive; all are likely to be true in some cases. Nevertheless, on their own, hypotheses 1, 2, and 3 do not fully account for observed patterns. For example, the majority of shark species produce fewer offspring annually than sea turtles. Many fish and kelp species grow to a larger mass than seabirds. Numerous cetacean species are listed despite lacking terrestrial connections.

In reality, the almost complete absence of baseline population data for marine species other than those commercially exploited or visible at the sea surface makes it virtually impossible to successfully propose marine species for listing under the Tasmanian Threatened Species Protection Act. Consequently, for example, only one mollusk species (*Gazameda gunnii*) has been listed as threatened, despite the majority of the $>1000$ Tasmanian mollusk species (May & Macpherson 1958) not having been sighted or collected alive during the past two decades.

Moreover, regardless of magnitude of threat, few marine invertebrates and plant species are likely to be listed in the foreseeable future because of the near absence of specialist researchers. The majority of biologists (≈50) and biologically trained managers (≈30) dealing with marine subjects in Tasmanian government institutions and universities are concerned with fisheries issues. No macroalgal botanist is currently employed in Tasmania, and only five ecologists (no taxonomists) predominantly study unexploited marine invertebrates.

## Available Evidence on Population Declines

Although no population data are available for most Tasmanian marine species, limited inferences on interdecadal trends can be made for some groups by using (1) catch statistics for commercially exploited fishes and invertebrates, (2) historical aerial photographs for canopy-forming marine plants, and (3) dated sediment cores for mollusk assemblages. All data sets indicate major population declines for the majority of species, supporting results from studies elsewhere (Pauly et al. 2000; Jackson 2001; Jackson et al. 2001) that show widespread historical changes to inshore ecosystems. These declines generally have gone unnoticed with changes between human generations—the so-called "sliding baseline syndrome" (Dayton et al. 1998).

Catch statistics indicate that populations of most major fisheries species (most notably native oysters, commercial scallops, southern rock lobster [*Jasus edwardsii*], orange roughy [*Hoplostethus atlanticus*], eastern gemfish [*Rexea solandri*], barracouta [*Thyrsites atun*], southern bluefin tuna [*Thunnus maccoyii*], jack mackerel [*Trachurus declivis*], school shark [*Galeorhinus galeus*], and trumpeter [*Latridopsis forsteri*]) have declined by >50% over three generations—the IUCN criterion for endangered status—and many have declined by >80% (IUCN critically endangered; Harries & Croome 1989; Kailoa et al. 1993; Edgar & Samson 2004). Aerial photographs indicate that giant *Macrocystis pyrifera* (L). C. Ag. kelp beds, once sufficiently large to be commercially harvested, have declined by approximately half along the Tasmanian east coast since 1944 (Edyvane 2003). According to one estimate ( Rees 1993), seagrass beds have declined in area by approximately 25% since the 1950s. Inshore mollusk biodiversity has decreased from an average of 21 species per 5-cm slice for sediment cores dated at the start of the twentieth century to 7 species per slice in 1990 (Edgar & Samson 2004). No kelp, seagrass, or commercially exploited fish species is listed under the Tasmanian Threatened Species Protection Act.

## Scale of Threats

Catastrophic population declines, as many Tasmanian marine species have experienced over the past century, may or may not progress to extinction. If threatening processes act within a subset of the range of a species, then local extinction is possible, whereas total extinction is unlikely. Conversely, a wide species distribution provides little insurance against extinction if the scale of a threatening process fully encompasses that range.

Most marine species possess a widely dispersing life-cycle phase—generally planktonic larvae—and are distributed over thousands of kilometers of coast. Others develop directly from demersal eggs or by live birth (e.g., all amphipods and isopods, some fishes, mollusks, echinoderms, and polychaetes) and can be highly localized in distribution (e.g., the live-bearing seastar *Patiriella vivipara*, which is restricted to $<1$ km$^2$ of intertidal shore near Hobart, Tasmania; Prestedge 1998). Regardless of mode of dispersal, few species possess refuges from the major threats to inshore biodiversity: climate change, introduced species; fishing; and siltation, nitrification, and other catchment effects. These threats also interact, often in unpredictable ways.

### Climate Change

Mean surface sea temperature off the Tasmanian east coast has increased by >1° C since the 1940s (Crawford et al. 2000). This change has been accompanied by local transformation of habitat types, both in terms of population gain for warm-temperate biota such as the "barrens"-forming sea urchin (*Centrostephanus rodgersii*) and population loss for cool-temperate species such as the giant kelp.

If global warming contributes another 1–2° C rise over the next century, an average change predicted by current models (Houghton et al. 2001), suites of cool-temperate organisms are likely to disappear, including a number of endemic species restricted to southeastern Tasmania (Dartnall 1974). As with oceanic islands, Tasmanian ecosystems are particularly susceptible to temperature rise because the southward range extension of species is prevented by a deepwater barrier. By contrast, species with ranges currently centered on mainland Australia are potentially able to migrate south to maintain residence in preferred temperature bands and avoid competition with species better adapted to warmer conditions. Sea temperature rise is an accelerating global threat that extends beyond the range of Tasmanian species.

### Introduced Species

The threat of introduced species is similarly global, largely uncontrolled, and accelerating. Introduced species threaten native species and the functioning of ecosystems through habitat modification, competition, predation, disease, and poisoning (e.g., Carlton 1989; Carlton & Geller 1993).

Species at all trophic levels were introduced during the past century into Tasmanian coastal waters and are now proliferating rapidly. Among the most notable and functionally important introductions are habitat-forming ricegrass (*Spartina anglica* Hubbard); kelp (*Undaria pinnatifida* Harvey); a toxic dinoflagellate (*Gymnodinium catenatum* Graham); planktivorous invertebrates (*Maoricolpus roseus, Crassostrea gigas, Petrolisthes elongatus, Sabella spallanzani*, and *Ascidiella aspersa*); deposit-feeding bivalves (*Corbula gibba, Raeta pulchella, Venerupis largillierti*, and *Theora lubrica*); benthic-grazing invertebrates (*Amaurochiton glaucus* and *Patiriella regularis*); predatory crabs (*Carcinus maenas* and *Cancer novaezelandiae*); a predatory sea star (*Asterias amurensis*); and fish (*Forsterygium varium, Salmo salar, Salmo trutta*, and *Oncorhynchus mykiss*).

Impacts of introduced flora and fauna on native taxa largely remain unknown and unstudied. Nevertheless, the magnitude of their impact is indicated by the results from a recent study of changes over the past century in mollusk shell fragments in dated sediment cores collected off southeastern Tasmania (Edgar & Samson 2004). For all 13 sites across the 100-km regional span of study, the mean number of shell fragments belonging to introduced species increased from <2% of total shells in 1900 to 50% in 1990 (Fig. 1). Comparable data for live mollusks collected during more extensive surveys across southeastern Tasmania (279 core or grab samples obtained from 93 sites in 1997–1999; G.J.E., unpublished data) indicated that 39% of total mollusk numbers and 83% of total mollusk biomass belonged to introduced taxa.

During the past century, the abundance of some native mollusks has declined in synchrony with rises in abundance of introduced taxa. For example, across all sites the native semelid bivalve *Theora fragilis* declined from a mean of 1.6 shells per 5-cm slice in sediments deposited prior to 1950 to 0 in 1990 (Fig. 2). By contrast, the congener *Theora lubrica*, a species introduced from southeast Asia, increased greatly in abundance from 1950 (Fig. 2). Although no causality can be attributed to this negative association, the population decline of *T. fragilis*, and an absence of specimens collected alive in Tasmania during the past two decades, clearly signal trouble.

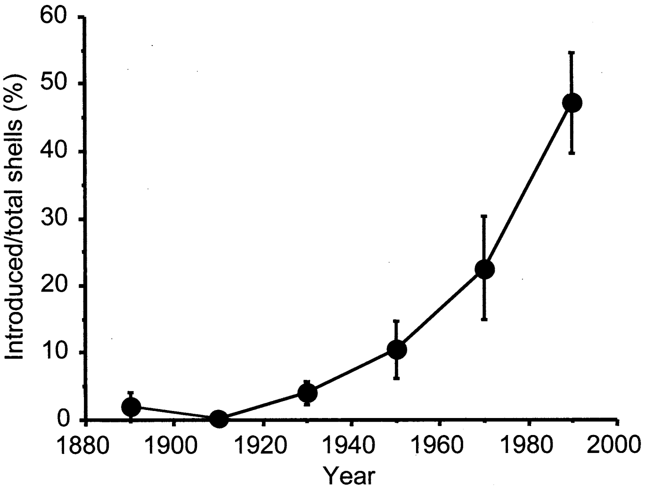

*Figure 1. Ratio of introduced species to total species for mollusk shell fragments in 5-cm-thick sediment slices for 13 dated sediment cores collected from shallow depths (4–14 m) across the southeastern Tasmanian region (C.R.S. & G.J.E., unpublished data; for methodology see Edgar & Samson [2004]).*

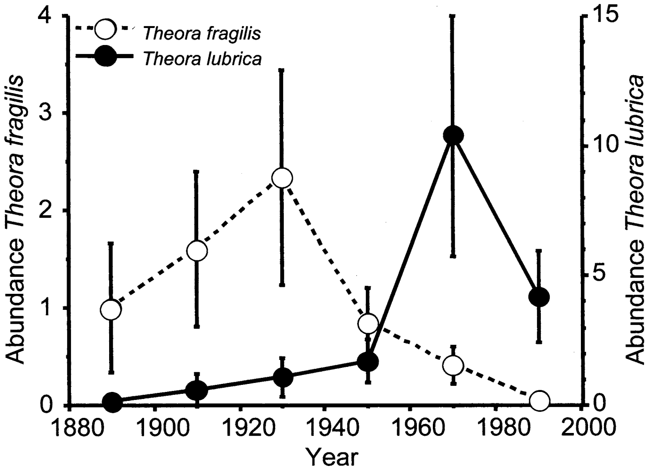

*Figure 2. Mean number (± SE) of shell fragments belonging to the native bivalve* Theora fragilis *and the introduced bivalve* Theora lubrica *in 5-cm thick sediment slices for 13 dated sediment cores collected from shallow depths across the southeastern Tasmanian region (C.R.S. & G.J.E., unpublished data; for methodology see Edgar & Samson [2004]).*

## Fishing

Targeted fish catches will rarely cause extinction of a species because the cost of capture of overharvested populations will eventually exceed economic returns (i.e., "commercial extinction") and effort will transfer to other species. Indirect effects of fishing, however—habitat damage, bycatch, and trophic cascades—are not closely linked to economics and can potentially lead to extinction.

Fishing has probably caused extinction of species in the Tasmanian region through trawling of deepwater seamounts that rise 300–600 m from the continental slope in water depths of 1000–2000 m. Large schools of orange roughy were discovered aggregating on the approximately 70 seamounts off southern Tasmania in 1989, and a trawl fishery blossomed over the subsequent 5-year period until more stringent management controls were enacted. During the initial "gold rush" period, all shallow (<1000 m depth) seamounts were extensively trawled with heavy bottom gear, some more than 3000 times (Koslow & Gowlett-Holmes 1998; Koslow et al. 2001). The typical basal diameter of seamounts is 2 km.

Seamounts just below maximum trawling depths (1300 m) were found to be consistently covered by a living coral matrix (Koslow & Gowlett-Holmes 1998; Koslow et al. 2001). By contrast, this habitat type was lacking on seamounts peaking in depths of <1000 m, despite existing before the trawl fishery commenced (based on remnant basal coral fragments and tons of coral brought onboard early commercial trawls). Assuming that some coral-associated species formerly present in habitats of <1000 m depth did not range into deeper water and that a subset was endemic, then species extinction caused by coral habitat loss is probable. Approximately 48% of the invertebrate fauna found during the 1997 research survey was considered restricted to the region (Koslow et al. 2001).

Negligible information is available on fishing gear damage for other Tasmanian marine habitats, although oyster beds were lost as a habitat type statewide around 1890 following extensive dredging, and inshore scallop beds were depleted during the twentieth century (Edgar & Samson 2004). The fate of species associated with these habitat types is unknown.

The importance of bycatch as a threat to biodiversity is indicated by changes within the New South Wales continental slope trawl fishery (500 km north of Tasmania) since 1977 (Graham et al. 1997; Graham et al. 2001). Over the first 20 years of the fishery, total fish catch per unit effort (CPUE) declined from 681 to 216 kg/hour (68%), whereas CPUE for slow-growing dogshark (*Centrophorus* spp.) declined from 139 to 0.6 kg/hour (99.6%). Although clearly threatened, *Centrophorus* populations presumably continue to decline because sufficient target fish stocks exist for the trawl fishery to persist. Shark species appear particularly vulnerable to bycatch threats because of slow growth, late onset of sexual maturity, direct reproduction, low fecundity, and low natural mortality. Southeastern Australian *Centrophorus* species produce only one or two young following a gestation period of between 1 and 2 years (Graham et al. 2001).

Indirect ecosystem effects of fishing remain virtually unknown in Tasmania. Nevertheless, given that many large predators and herbivores have been functionally lost from the Tasmanian coastal zone (Edgar & Barrett 1999) and that loss of such species can profoundly affect marine ecosystems (Barkai & Branch 1988; Duran & Castilla 1989; Menge 1995), broad-scale habitat changes associated with chronic fishing should be considered likely (Dayton et al. 2000; Jackson et al. 2001).

Indirect effects of fishing can be partly gauged by analysis of long-term biological trends in marine protected areas (MPAs; Walters & Holling 1990). In Tasmania annual surveys of plants and animals in four MPAs since their establishment in 1991 have revealed direct effects such as order of magnitude increases in biomass of rock lobsters and trumpeter, and indirect effects such as declines in population numbers of abalone (*Haliotis* spp.; Edgar & Barrett 1999). Declines in populations of large grazing invertebrates—including sea urchins, which have decreased by 70% in the largest MPA over 12 years (N.S.B. & G.J.E, unpublished data)—have not yet translated to detectable changes in algal cover. In the New Zealand Leigh marine reserve, however, the only temperate MPA worldwide that has been studied for more than 20 years, increasing rock lobster and fish predation on grazers ultimately transformed sea urchin barren habitats to macroalgal forests after 15 years (Shears & Babcock 2002, 2003).

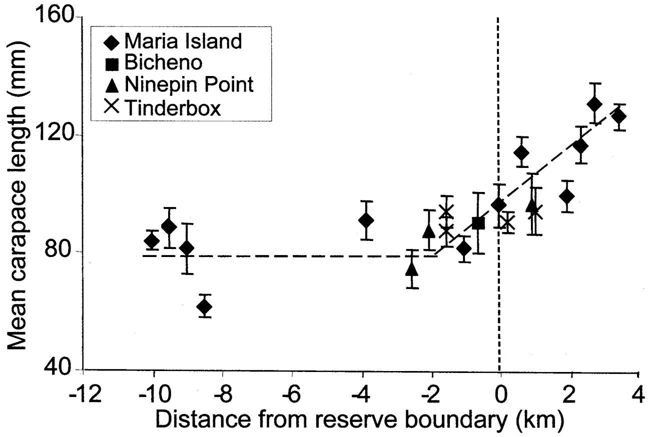

*Figure 3. Mean carapace length of rock lobsters (±SE) plotted against distance of survey sites from the marine protected area (MPA) boundary for sites in different Tasmanian MPAs surveyed 10 years after declaration. Positive distances indicate sites located within the MPA and negative distances indicate external reference sites (N.S.B. and G.J.E, unpublished data; for methodology see Edgar& Barrett [1999]).*

Tasmanian MPAs do not appear to be sufficiently large to generate the full trophic cascades associated with large predators. This is indicated by a lack of an asymptote in the relationship between mean carapace length of rock lobsters and distance from reserve boundary at sites in the four Tasmanian MPAs when surveyed 10 years after MPA declaration (Fig. 3). A sigmoidal curve is expected for this relationship, with asymptotes outside the MPA from the distance where "spillover" effects become negligible and inside the MPA at distances greater than those affected by emigration from the protected area. The observed curve shows increasing rock lobster size at greatest distance inside the MPA boundary (3.5 km), implying that full protection of rock lobsters requires an MPA spanning more than 7 km—the longest protected coastal strip in Tasmania. Fishing poses a globally ubiquitous threat to marine species, albeit one that is subject to local control.

## Siltation, Nutrification, and Other Catchment Effects

A statewide survey of benthos in Tasmanian estuaries indicates a clear faunal dichotomy between estuaries with human population densities of $<1/\text{km}^2$ within catchments and estuaries with population densities of more than

10/km$^2$ (Edgar & Barrett 2000). Estuaries isolated from human activity possess sandy sediments and a predominance of epifaunal species, whereas estuaries with populated catchments possess muddy sediments and a majority of infaunal animals. Downstream runoff from catchments, primarily in the form of increased sediment loads associated with land clearance, is probably responsible for this broad-scale habitat transformation. Other potentially important catchment impacts that affect estuarine biota include freshwater diversion and increased nutrient loadings that can lead to die-off of seagrass beds.

Although Tasmania is unusual in a global sense in that it possesses numerous estuaries with uninhabited catchments that are reserved as national parks, such estuaries are largely confined to the western and southern coasts and have remained uninhabited because of poor soils, which in turn generates low aquatic productivity and depauperate estuarine biota (Edgar et al. 1999). Almost all estuaries on the northern and eastern coasts, where the majority of Tasmanian estuarine species are located (Edgar et al. 1999), have been badly degraded by catchment activity (Edgar et al. 2000).

### Pollution, Shore Reconstruction, and Other Local Threats

Oil spills, fish farms, land reclamation, foreshore development, sewage effluent, heavy metal discharge, and chemical outfalls frequently generate intense impacts on the marine environment, including complete loss of flora and fauna in extreme cases; however, such effects are generally highly localized (Crawford et al. 2000). Thus, in contrast to public perceptions that pollution poses the greatest hazard to marine life (L. Dropkin, www.compassonline.org/activities/summary.html), pollution is unlikely to cause species extinction, other perhaps than for taxa with extremely restricted intertidal or shallow subtidal ranges.

## Assessment of Threats to Marine Biodiversity

Trends in the health of Tasmanian marine ecosystems are monitored using a defined set of environmental indicators that are reported every 5 years in the Tasmanian and Australian State of the Environment Reports (DPIWE 1997; Australian State of the Environment Committee 2001). Despite this coverage, little information is available on the changing biological state of the marine environment. Virtually all State of the Environment (SOE) indicators relate to human "pressure" or management "response," or are physicochemical rather than biological metrics. Thus, for example, considerable information is available on changing levels of total phosphate input into estuaries, but negligible information is available on the biological response of ecosystems to changing loadings. Whether greater reductions in phosphates are required to have a significant ecosystem effect or whether phosphates are unimportant despite considerable expense in remedial management actions remains unknown.

Rather than ecological efficacy, SOE indicators were selected primarily for reasons of low perceived cost (i.e., able to be statistically compiled without significant additional cost for data gathering). Biological "condition" indicators are reliant on ad hoc rather than systematically directed research and are thereby confounded by changing effort, debasing their long-term value. "Extent and condition of aquatic habitats" is widely used as a condition indicator (Ward et al. 1998); however, marine habitat classes are primarily physical (e.g., hard sand, low-profile reef) and remotely sensed and thus unlikely to change greatly over time (seagrass beds are an exception). Although aerial and satellite habitat mapping is extremely effective for monitoring large-scale changes in terrestrial vegetation types, it is much less useful in the marine environment.

Overall, changes in existing SOE indicators should be recognized as providing little insight into the current state or trends in marine ecosystems. Complete transformation of communities could occur with, for example, the arrival of invasive species or climate change, and no indicator would detect this trend. To be effective, the systematic collection of biological data is unavoidable. No long-term surveys of marine communities are currently being undertaken in Tasmania, other than an MPA monitoring program that relies on ad hoc funding.

## Conclusion

Our main goal is to question the widespread assumption that an absence of unequivocal proof implies that extinction is an extreme rarity in the marine environment. Proof of extinction is unattainable, and the hidden nature of the marine environment and lack of baseline data means that population declines for almost all species approaching extinction will go unnoticed. Rather than assuming population persistence, a key question is, How do rare species manage to find mates and survive in the face of multiple interacting and ubiquitous threats and increasing population fragmentation?

Adequate comprehension of change in the marine environment requires reversal of the "burden of proof" (Gerrodette et al. 2002) and the systematic collection of broad-scale data sets. As scientists, we continually bemoan difficulties in assessing human impacts in the environment in the absence of baseline data, yet rarely undertake quantitative sampling over large spatial scales to provide useful comparative information for the future. Until current funding to conserve marine biodiversity is partially applied to a systematic quantitative global survey, we will continue to grope blindly with unrealistic models when assessing and addressing threats.

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