# Threats to marine biodiversity

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## Threats to marine ecosystems:

In broad terms, the living inhabitants of the marine realm face five major threats:

- *climate change*: changes to oceanic temperatures, acidity and patterns of water movement (including currents, eddies and fronts), largely caused by *increasing atmospheric carbon dioxide*, as well as impacts from damage to the ozone layer;
- *overfishing* with attendant bycatch problems, both from commercial fishing, recreational fishing, illegal unregulated or unreported fishing (IUU), and ghost fishing[1];
- *habitat damage* largely caused by fishing gear, especially bottom trawling, but also including the effects of coastal development: destruction of coral reefs, mangroves, natural freshwater flows (and passage), coastal foreshores, coastal wetlands and sometimes entire estuaries – which all support coastal marine ecosystems;
- *pollution* (in-sea and land-based, diffuse and point source) including nutrients, sediments, plastic litter, noise, hazardous and radioactive substances; discarded fishing gear, microbial pollution, and trace chemicals such as carcinogens, endocrine-disruptors, and info-disruptors; and
- ecosystem alterations caused by the introduction of *alien organisms*, especially those transported by vessel ballast water and hull fouling.

*Amongst these five major threats to marine biodiversity, fishing has, until the present time, been the most damaging on a global scale. The destructive impacts of fishing stem chiefly from overharvesting, habitat destruction, and bycatch. Over the coming century the threats posed by increasing atmospheric greenhouse gases pose huge dangers to the marine environment (Veron 2008, Koslow 2007, Turley et al. 2006). At smaller scales, other threats (particularly pollution and habitat damage) are dominant at different localities. Coral reef, mangrove, estuarine, seagrass, mud-flat, and sponge-field habitats have been (and are being) extensively damaged. River passage, essential for anadromous and diadromous species, has been impaired or destroyed around the globe.*

Overharvesting is probably as old as human civilization. There is evidence that ancient humans hunted many terrestrial animals to extinction (eg: Alroy 2001). Historically, fishing has rarely been sustainable (Pauly et al. 2002). On the global scene, modern fishing activities constitute the most important threat to marine biodiversity (Hiddink et al. 2008, Helfman 2007:8; MEA Millennium Ecosystem Assessment 2005a:67, 2005b:8, 2005c:12; Crowder & Norse 2005:183; Kappel 2005:275; Myers & Worm 2003; Pauly et al. 2002; Renolds et al. 2002; Jackson et al. 2001; Leidy & Moyle 1998 - noting contrary views from Gray 1997). Of all recently documented marine extinctions, the most common cause has been excessive harvesting activities (Malakoff 1997, Carlton et al. 1999, VanBlaricom et al. 2000).

Fisheries in the deep sea have "undoubtedly had the greatest ecological impact to date" of all known threats (Thiel & Koslow 2001:9). Fishing was identified as the main threat to marine ecosystems in the northwest Atlantic over the period 1963-2000 (Link et al. 2002). The fisheries of the Bering Sea have long been recognised as among the world's best managed (Aron et al. 1993); however Greenwald (2006) in a study of the region's vertebrates, identified commercial fishing as the most important threat, followed by climate change, habitat degradation, ecological effects and pollution.

Historically, the impacts of fishing activities, even when regulated by governments, have in many cases caused major, often irretrievable damage to marine ecosystems (Jackson et al. 2001, Ludwig et al. 1993). The benthic ecosystems of large areas of the ocean seabed have

been destroyed or damaged (Watling 2005). The genetic effects of fishing may be substantial, yet are commonly ignored (Law & Stokes 2005). The failure of managers to learn from past mistakes appears to be a notable feature of the history of fisheries management (Mullon et al. 2005) in what Agardy (2000) has called the "global, serial mismanagement of commercial fisheries".

"In many sea areas, the weight of fish available to be harvested is calculated to be less than one tenth or even one one-hundredth of what it was before the introduction of industrial fishing." ( MEA 2005c:16)

On the Australian scene, fishing activities appear to be the primary threat to fishes (Pogonoski et al. 2002) and the second most important threat to marine invertebrates (Ponder et al. 2002) after habitat degradation.

Overfishing is defined in this discussion as *a level of fishing which puts at risk values endorsed either by the fishery management agency, by the nation in whose waters fishing takes place, or within widely accepted international agreements*. A point of critical importance in this regard is that a level of fishing intensity which successfully meets traditional stock sustainability criteria (for example fishing a stock at maximum sustainable yield) may well be considerably higher than a level of fishing intensity which meets criteria designed to protect marine biodiversity (Jennings 2007). The wide endorsement of the *Convention on Biological Diversity 1992* implies that the latter level is the critical level by which overfishing should be measured.

Amongst fishery scientists (and to lesser extent fishery managers) it is widely believed that “governance, and not science, remains the weakest link in the [fisheries] management chain” (Browman & Stergiou 2004:270). To a large extent fisheries managers, like bankers, do not learn the lessons of the past, they simply repeat them.

The core impacts of **climate change** are caused by:

- an increase in the temperature of ocean waters - causing, for example, coral bleaching (Veron 2008);
- the increase in the acidity of ocean waters, causing a rising aragonite saturation horizon, particularly in the North Pacific and Southern Ocean - with resulting impacts on organisms using calcium carbonate body structures (Turley et al. 2006), and
- a reduction in ocean overturning circulation, risking, for example, impacts on deep ocean oxygen content (Koslow 2007).

Important reviews of **pollution** in the marine environment are provided by:

- nutrients – a general review: Rabalais (2005), Carpenter et a. (1998); – in the Caribbean: Siung-Chang (1997); – on shallow coral reefs: Koop et al. (2001); – on the Great Barrier Reef: Alongi & McKinnon (2005); – on the Gulf of Mexico: Rabalais et al. (2002)
- plastic litter – Derraik (2002); Goldberg (1997); Koslow (2007); Gregory (1991)
- noise – Cummings (2007); Firestone & Jarvis (2007); NRC (2005); Koslow (2007)
- radioactive waste – Koslow (2007)
- armaments – Koslow (2007)
- heavy metals – Islam & Tanaka (2004); Hutchings & Haynes (2005)
- discarded fishing gear – Matsuoka et al. (2005); Brown & Macfadyen (2007)
- microbial pollution – Islam & Tanaka (2004)
- endocrine disruptors – Lintelmann et al. (2003); Porte et al. (2006)
- info-disruptors – Lurling & Scheffer (2007)
- other hazardous materials – Islam & Tanaka (2004); Koslow (2007).

Important papers on marine and estuarine **habitat damage** include:

- estuaries and rivers – Ray (1996, 2004, 2005), Jackson et al. (2001), Blaber et a. (2000), Lotze et al. (2006), Collett & Hutchings (1978), Kappel (2005); Drinkwater & Frank (1994);
- impacts of bottom trawling – Koslow (2007), Gray et al. (2006), Jones (1992), NRC (2002), Gianni (2004);
- coral ecosystems – Aronson & Precht (2006), Pandolfi et al. (2003), Gardiner et al. (2003), Hughes et al. (2003), McClanahan (2002), Jackson et al. (2001), McManus (1997);
- mangroves – Duke et al. (2007), Alongi (2002), Ellison & Farnsworth (1996);
- seagrasses – Orth et al. (2006), Duarte (2002);
- kelp – Steneck et al. (2002), Dayton et al. (1998).

For a general introduction to the problem of **alien species**, see Mooney & Hobbs (2000), McNeely (2001), and Mack et al. (2000). General references on marine issues include Hewitt & Campbell (2007), Streftaris & Zenetos (2006), Carlton & Rutz (2005), Bax et al. (2003), and Rutz et al. (1997).

## Threats and controls:

Over the last thirty years, broad controls have been proposed or developed related to the five major threats. Controls can be categorised with threats (Table 1 below). Many nations have commendable statutes and policies; however implementation failures are widespread.

**Table 1. Threats and controls:** overview of general strategies:

| *Threats* | *Controls* |
|---|---|
| Overfishing and bycatch | Restricted entry to fishery, catch quotas, limits or requirements on gear, limits on fishing seasons, limits on fishing areas, no-take areas, prohibitions on dumping or discarding gear.<br>Attempts to reduce or eliminate government subsidies contributing to fishing over-capacity.<br>Control by flag States of high seas fishing particularly in regard to compliance with international and regional fishing agreements.<br>Market-based fishery accreditation systems such as that of the Marine Stewardship Council.<br>Government control programs based on minimising ecosystem effects<br>Surveillance and compliance programs including VMS[2]. |
| Habitat damage | Limits on gear, limits on fishing areas, no-take areas.<br>Fixed mooring systems in sensitive (eg coral) environments. Surveillance and compliance programs.<br>Land-based zoning schemes combined with project assessment and approval provisions aimed at minimising the loss of coastal habitat resulting from land-based developments. Special protection for high conservation value estuaries. Zoning of key migration rivers to exclude dams, weirs and other impediments to fish passage. Protection of the catchment of high conservation value estuaries and rivers to maintain natural water flows and water quality. |

| *Threats* | *Controls* |
|---|---|
| Climate change | International agreements, such as those focussed on greenhouse gasses or chlorofluorocarbons or (eg: the Kyoto Protocol, Montreal Protocol) - and the implementation programs which follow, including incentives, prohibitions and market-based schemes aimed at reducing GG emissions. |
| Pollution | Controls focussed on fixed point sources, mobile point sources and diffuse terrestrial sources – including dumping and emissions to air and water . Controls on marine noise.<br>Controls focused on specific pollutants, such as plastics or highly toxic or radio-active substances.<br>Integrated coastal and river basin planning, including objectives to limit the passage of nutrients and other pollutants to the marine environment.<br>Surveillance and compliance programs. |
| Alien organisms | Controls on ballast water and hull fouling based on risk minimisation rather than prevention. Import prohibitions relating to aquaculture stocks. Infestation monitoring and removal programs.<br>Surveillance and compliance programs. |

Good general references covering threats and management options are Koslow (2007) and Norse & Crowder (2005).

## Three core concepts of modern marine management

Any overview of threat control programs would be incomplete without mentioning the evolution of three core concepts which underpin most national marine conservation policy frameworks, and many practical control programs:

- *ecosystem-based fishery management* (EBM);
- the *precautionary principle* (PP) and the closely-related precautionary approach (PA); and
- the *strategic development of networks of marine protected areas* (MPAs).

Several fishery experts made comments during the eighteenth century to the effect that the resources of the ocean were so vast as to defy any possible damage from human activities. These views, although proved incorrect more than a century ago, still linger on, particularly in fisher cultures. Within government fishery agencies and academic circles, the need to take into account the effects of fishing for particular species on marine ecosystems has been accepted for several decades. Promotion of ecosystem-based management was a core feature of the FAO *Code of Conduct for Responsible Fisheries* 1995. Although the concept is now embedded in international and national law, fishery agencies have generally been slow to incorporate EBM in fishery controls, usually citing the need for more research as the primary reason for the delay.

The precautionary principle, and its 'softer' version the precautionary approach, appeared in international discussions some decades ago[3], and have been accepted, like EBM, into international and national law. Article 174 of the Treaty establishing the European Community requires, inter-alia, that Community policy on the environment be based on the precautionary principle. The principle was one of the core environmental principles contained in the Rio Declaration 1992 (UN Conference on Environment and Development) as well as the earlier World Charter for Nature 1982. One of countless similar definitions of the principle states it as follows:

Where the possibility exists of serious or irreversible harm, lack of scientific certainty should not preclude cautious action by decision-makers to prevent such harm. Decision-makers needs to anticipate the possibility of ecological damage, rather than react to it as it occurs.

Like EBM, use of the precautionary principle in practical control strategies has lagged behind its adoption in policy, not only in the EU but around the world. This remains the case, in spite of the prominence given to the principle on the FAO Code of Conduct.

Marine protected areas were un-known in an era when it was generally considered that the oceans needed no protection. However, as the damage to the marine environment became more widely understood, marine protected area programs have featured in international agreements as well as national conservation programs. The FAO Code of Conduct stresses the need to protect critical habitat in aquatic environments, for example.

One of the most widely quoted international statements calling for the acceleration of marine protected area programs around the world is that from the World Summit on Sustainable Development (WSSD Johannesburg 2002). The marine section of the WSSD Key Outcomes Statement provides basic benchmarks for the development of marine protected areas as well as other key issues:

> Encourage the application by 2010 of the ecosystem approach for the sustainable development of the oceans.
>
> On an urgent basis and where possible by 2015, maintain or restore depleted fish stocks to levels that can produce the maximum sustainable yield.
>
> Put into effect the FAO international plans of action by the agreed dates:
> - for the management of fishing capacity by 2005; and
> - to prevent, deter and eliminate illegal, unreported and unregulated fishing by 2004.
>
> Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012.
>
> Establish by 2004 a regular process under the United Nations for global reporting and assessment of the state of the marine environment.
>
> Eliminate subsidies that contribute to illegal, unreported and unregulated fishing and to over-capacity.

The same statement also contains a commitment: “Achieve by 2010 a significant reduction in the current rate of loss of biological diversity.”

## Protection of representative marine ecosystems:

Attention needs to be given to the use of the word “representative” in the WSSD text above. Requirements to provide adequate and comprehensive protection for representative examples of all major types of ecosystems date back many years. Clear requirements for action are contained in:

- the 1992 United Nations international Convention on Biological Diversity;
- the 1982 World Charter for Nature (a resolution of the UN General Assembly); and
- the 1972 Stockholm Declaration of the United Nations Conference on the Human Environment.

The 1982 World Charter for Nature states: “Principle 3: All areas of the earth, both land and sea, shall be subject to these principles of conservation; special protection shall be given to unique areas, to representative samples of all the different types of ecosystems, and to the habitat of rare or endangered species.”

Principle 2 of the Stockholm Declaration 1972 states: “The natural resources of the earth, including the air, water, land, flora and fauna and especially representative samples of natural ecosystems, must be safeguarded for the benefit of present and future generations through careful planning or management, as appropriate.”

An examination of the wording of both the Charter and the Declaration reveals that they place wide obligations, not only on governments, but on all agencies of governments as well as individuals. These instruments are however soft law, and as such carry no explicit reporting requirements or sanctions for non-compliance.

## Summary

The oceans of the world are being severely damaged. Five major threats continue to undermine biodiversity values across the marine realm. According to a United Nations advisory committee (GESAMP 2001):

The state of the world’s seas and oceans is deteriorating. Most of the problems identified decades ago have not been resolved, and many are worsening. New threats keep emerging. The traditional uses of the seas and coasts – and the benefits that humanity gets from them – have been widely undermined.

It is generally believed that the major failings of national programs to protect marine biodiversity rest on failures of governance rather than failures of science. The three core governance concepts discussed above are crucial to all serious attempts to address marine conservation issues in a strategic way. However, in general, attempts to apply them have often been poorly resourced, badly planned and ineffectually implemented.

The primary ingredient missing from national programs across the globe is political commitment to address the issues in the face of short-sighted resistance from vested interests, such as polluters, fishers and coastal developers. This failure in turn rests on widespread ignorance of the severity of the issues amongst the general community in all nations, rich and poor alike.

In many cases, the degradation which is occurring now cannot be reversed within the timescale of a human life. Decisive and intelligent action by politicians and community leaders is urgent. Such action must be underpinned by programs aimed at developing an increased awareness of the issues amongst the general population.

## References:


Alongi, DM & McKinnon, AD (2005) 'The cycling and fate of terrestrially-derived sediments and nutrients in the coastal zone of the Great Barrier Reef shelf', *Marine Pollution Bulletin*, vol. 51, no. 1-4, pp. 239-52.

Alongi, DM (2002) 'Present state and future of the world's mangrove forests', *Environmental Conservation*, vol. 29, pp. 331-49.

Alroy, J (2001) 'A multispecies overkill simulation of the end-Pleistocene megafaunal mass extinction', *Science*, vol. 292, pp. 1893-6.

Aron, W, Fluharty, D, McCaughran, D & Roos, JF (1993) 'Fisheries management', *Science*, vol. 261, pp. 813-4.

Aronson, RB & Precht, WF (2006) 'Conservation, precaution, and Caribbean reefs', *Coral Reefs*, vol. 25, pp. 441-50.

Bax, N, Williamson, A, Aguero, M, Gonzalez, E & Geeves, W (2003) 'Marine invasive alien species: a threat to global biodiversity', *Marine Policy*, vol. 27, pp. 313-23.

Blaber, SJM, Cyrus, DP, Albaret, J-J, Day, J, Elliot, M, Fonseca, MS, Hoss, DE, Orensanz, JML, Potter, IC & Silvert, W (2000) 'Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems', *ICES Journal of Marine Sciences*, vol. 57, pp. 590-602.

Browman, HI & Stergiou, KI (2004) 'Introduction to the theme section: Perspectives on ecosystem-based approaches to the management of marine resources', *Marine Ecology Progress Series*, vol. 274, pp. 269-303.

Brown, J & Macfadyen, G (2007) 'Ghost fishing in European waters: Impacts and management responses', *Marine Policy*, vol. 31, no. 4, pp. 488-504.

Carlton, JT & Rutz, GM (2005) 'The magnitude and consequences of bioinvasions in marine ecosystems: implications for conservation', in EA Norse & LB Crowder (eds), *Marine conservation biology*, Island Press, Washington.

Carlton, JT, Geller, JB, Reaka-Kudla, ML & Norse, EA (1999) 'Historical extinction in the sea', *Annual Review of Ecology and Systematics*, vol. 30, pp. 515-38.

Carpenter, S, Caraco, NF, Correll, DL, Howarth, RW, Sharpley, AN & Smith, VH (1998) 'Nonpoint Pollution of Surface waters with Phosphorus and Nitrogen', *Ecological Applications*, vol. 8, no. 3, pp. 559-68.

Collett, LC & Hutchings, PA (1978) *Guidelines for the protection and management of estuaries and estuarine wetlands.*, Australian Marine Sciences Association, Cronulla.

Crowder, LB & Norse, EA (2005) 'The greatest threat: fisheries', in EA Norse & LB Crowder (eds), *Marine conservation biology*, Island Press, Washington DC.

Cummings, J (2007) 'Regulating Ocean Noise: Entering Uncharted Waters', *Journal of International Wildlife Law & Policy*, vol. 10, no. 2, pp. 101-7.

Dayton, PK, Tegner, MJ, Edwards, PE & Riser, L (1998) 'Sliding baselines, ghosts, and reduced expectations in kelp forest communities', *Ecological Applications*, vol. 8, no. 2, pp. 309-22.

Derraik, JGB (2002) 'The pollution of the marine environment by plastic debris: a review', *Marine Pollution Bulletin*, vol. 44, no. 9, pp. 842-52.

Drinkwater, KF & Frank, KT (1994) 'Effects of river regulation and diversion on marine fish and invertebrates ', *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 4, no. 2, pp. 135-51.

Duarte, CM (2002) 'The future of seagrass meadows', *Environmental Conservation*, vol. 29, pp. 192-206.

Duke, NC, Meynecke, J-O, Dittmann, S, Ellison, AM, Anger, K, Berger, U, Cannicci, S, Diele, K, Ewel, KC, Field, CD, Koedam, N, Lee, SY, Marchand, C, Nordhaus, I & Dahdouh-Guebas, F (2007) 'A world without mangroves?' *Science*, 317 (6) 41-2.

Ellison, AM & Farnsworth, EJ (2006) 'Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends and future predictions', *Biotropica*, vol. 28, pp. 549-65.

Firestone, J & Jarvis, C (2007) 'Response and Responsibility: Regulating Noise Pollution in the Marine Environment', *Journal of International Wildlife Law & Policy*, vol. 10, no. 2, pp. 109-52.

Gardiner, TA, Cote, IM, Gill, JA, Grant, A & Watkinson, AR (2003) 'Long-term region-wide declines in Caribbean corals', *Science*, vol. 301, pp. 958-60.

GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (2001), *A sea of troubles*, UN Advisory Committee on Protection of the Sea (ACOPS), London.

Gianni, M (2004) *High seas bottom trawl fisheries and their impacts on the biodiversity of vulnerable deep-sea ecosystems: options for international action*, IUCN, Gland Switzerland.

Goldberg, ED (1997) 'Plasticizing the seafloor: An overview', *Environmental Technology*, vol. 18, no. 2, pp. 195-201.

Gray, JS (1997) 'Marine biodiversity: patterns, threats and conservation needs', *Biodiversity and Conservation*, vol. 6, no. 1, pp. 153-75.

Gray, JS, Dayton, PK, Thrush, SF & Kaiser, MJ (2006) 'On effects of trawling, benthos and sampling design', *Marine Pollution Bulletin*, vol. 52, pp. 840-3.

Greenwald, N (2006) *The Bering Sea: a biodiversity assessment of vertebrate species*, Center for Biological Diversity, Tucson Arizona.

Gregory, MR (1999) 'Plastics and South Pacific Island shores: environmental implications', *Ocean & Coastal Management*, vol. 42, no. 6-7, pp. 603-15.

Helfman, GS (2007) *Fish conservation: a guide to understanding and restoring global aquatic biodiversity and fishery resources*, Island Press, Washington DC.

Hewitt, CL & Campbell, ML (2007) 'Mechanisms for the prevention of marine bioinvasions for better biosecurity', *Marine Pollution Bulletin*, vol. 55, no. 7-9, pp. 395-401.

Hiddink, JG, MacKenzie, BR, Rijnsdorp, A, Dulvy, NK, Nielsen, EE, Bekkevold, D, Heino, M, Lorance, P & Ojaveer, H (2008) 'Importance of fish biodiversity for the management of fisheries and ecosystems', *Fisheries Research*, vol. 90, pp. 6-8.

Hughes, TP, Baird, AH, Bellwood, DR, Card, M, Connolly, SR, Folke, C, Grosberg, R, Hoegh-Guldberg, O, Jackson, JBC, Kleypas, J, Lough, JM, Marshall, P, Nystrom, M, Palumbi, SR, Pandolfi, JM, Rosen, B & Roughgarden, J (2003) 'Climate change, human impacts, and the resilence of coral reefs.' *Science*, vol. 301, pp. 929-33.

Hutchings, P & Haynes, D (2005) 'Editorial: marine pollution bulletin special edition', *Marine Pollution Bulletin*, vol. 51, pp. 1-2.

Islam, MS & Tanaka, M (2004) 'Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis', *Marine Pollution Bulletin*, vol. 48, pp. 624-49.

Jackson, JBC, Kirby, MX, Berger, WH, Bjorndal, KA, Botsford, LW, Bourque, BJ, Bradbury, RH, Cooke, RG, Erlandson, J, Estes, JA, Hughes, TP, Kidwell, S, Lange, CB, Lenihan, HS, Pandolfi, JM, Peterson, CH, Steneck, RS, Tegner, MJ & Warner, RR (2001) 'Historical overfishing and the recent collapse of coastal ecosystems.' *Science*, vol. 293, pp. 629-38.

Jennings, S (2007) 'Reporting and advising on the effects of fishing', *Fish and Fisheries*, vol. 8, no. 3, pp. 269-76.

Jones, JB (1992) 'Environmental impact of trawling on the seabed: a review', *New Zealand Journal of Marine and Freshwater Research*, vol. 26, pp. 59-67.

Kappel, CV (2005) 'Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species', *Frontiers in Ecology and the Environment*, vol. 3, no. 5, pp. 275-82.

Koop, K, Booth, D, Broadbent, A, Brodie, J, Bucher, D, Capone, D, Coll, J, Dennison, W, Erdmann, M, Harrison, P, Hoegh-Guldberg, O, Hutchings, P, Jones, GB, Larkum, AWD, O'Neil, J, Steven, A, Tentori, E, Ward, S, Williamson, J & Yellowlees, D (2001) 'ENCORE: The Effect of Nutrient Enrichment on Coral Reefs. Synthesis of Results and Conclusions', *Marine Pollution Bulletin*, vol. 42, pp. 91-120.

Koslow, A (2007) *The silent deep: the discovery, ecology and conservation of the deep sea*, University of New South Wales Press, Sydney.

Law, R & Stokes, K (2005) 'Evolutionary impacts of fishing on target populations', in EA Norse & LB Crowder (eds), *Marine conservation biology*, Island Press, Washington.

Leidy, RA & Moyle, PB (1998) 'Conservation status of the world's fish fauna', in PL Fiedler & PM Kareiva (eds), *Conservation biology for the coming decade*, Chapman & Hall, London, pp. 187-227.

Link, J, Brodziak, JKT, Edwards, SF, Overholtz, WJ, Mountain, D, Jossi, JW, Smith, TD & Fogarty, MJ (2002) 'Marine ecosystem assessment in a fisheries management context', *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 59, no. 9, pp. 1429-40.

Lintelmann, J, Katayama, A, Kurihara, N, Shore, L & Wenzel, A (2003) 'Endocrine disruptors in the environment', *Pure and Applied Chemistry*, vol. 75, pp. 631-81.

Lotze, HK, Lenihan, HS, Bourque, BJ, Bradbury, RH, Cooke, RG, Kay, MC, Kidwell, S, Kirby, MX, Peterson, CH & Jackson, JBC (2006) 'Depletion, degradation and recovery potential of estuaries and coastal seas', *Science*, vol. 312, pp. 1806-9.

Ludwig, D, Hilborn, R & Walters, C (1993) 'Uncertainty, resource exploitation and conservation: lessons from history.' *Science*, vol. 260, no. 2, p. 17.

Lürling, M & Scheffer, M (2007) 'Info-disruption: pollution and the transfer of chemical information between organisms', *Trends in Ecology & Evolution*, vol. 22, no. 7, pp. 374-9.

Mace, PM (2004) 'In defense of fisheries scientists, single-species models and other scapegoats: confronting the real problems', *Marine Ecology Progress Series*, vol. 274, pp. 285-91.

Mack, RN, Simberloff, D, Lonsdale, WM, Evans, H, Clout, M & Bazzaz, FA (2000) 'Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control ', *Ecological Applications*, vol. 10, no. 3, pp. 689-710.

Malakoff, D (1997) 'Extinction on the high seas.' *Science*, vol. 227, pp. 486-8

Matsuoka, T, Nakashima, T & Nagasawa, N (2005) 'A review of ghost fishing: scientific approaches to evaluation and solutions', *Fisheries Science*, vol. 71, no. 4, pp. 691-702.

McClanahan, TR (2002) 'The near future of coral reefs', *Environmental Conservation*, vol. 29, pp. 460-83.

McManus, JW (1997) 'Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia', *Coral Reefs*, vol. 16, no. 5, pp. S121-S7.

McNeely, JA (ed.) (2001) *Global strategy for addressing the problem of invasive alien species*, Global Invasive Species Programme (GISP) IUCN, Gland Switzerland.

MEA Millennium Ecosystem Assessment (2005a) *Ecosystems and human well-being: synthesis*, World Resources Institute, Washington DC.

MEA Millennium Ecosystem Assessment (2005b) *Ecosystems and human well-being: biodiversity synthesis*, World Resources Institute, Washington DC.

MEA Millennium Ecosystem Assessment (2005c) *Living beyond our means; natural assets and human wellbeing: statement by the Board*, Island Press, Washington DC.

Mooney, HA & Hobbs, RJ (eds) (2000) *Invasive species in a changing world*, Island Press, Washington DC.

Mullon, C, Freon, P & Cury, P (2005) 'The dynamics of collapse in world fisheries', *Fish and Fisheries*, vol. 6, pp. 111-20.

Myers, RA & Worm, B (2003) 'Rapid worldwide depletion of predatory fish communities', *Nature*, vol. 423, pp. 280-3.

Norse, EA & Crowder, LB (eds) (2005) *Marine conservation biology: the science of maintaining the sea's biodiversity*, Island Press, Washington DC.

NRC National Research Council (2002) *Effects of trawling and dredging on seafloor habitat*, National Academies Press, Washington DC.

Orth, RJ, Carruthers, TJB, Dennison, B, Duarte, CM, Fourqurean, JW, James, W, Heck, HK, Hughes, AR, Kendrick, GA & Kenworthy, WJ (2006) 'A global crisis for seagrass ecosystems', *BioScience*, vol. 56, pp. 987-96.

Pandolfi, JM, Bradbury, RH, Sala, E, Hughes, TP, Bjorndal, KA, Cooke, RG, McArdle, D, McClenachan, L, Newman, M, Paredes, G, Warner, RR & Jackson, JBC (2003) 'Global trajectories of the long-term decline of coral reef ecosystems.' *Science*, vol. 301, pp. 955-8.

Pauly, D, Christensen, V, Guenette, S, Pitcher, TJ, Sumaila, UR, Walters, CJ, Watson, R & Zellar, D (2002) 'Towards sustainability in world fisheries', *Nature*, vol. 418, pp. 689-95.

Pogonoski, JJ, Pollard, DA & Paxton, JR (2002) *Conservation overview and action plan for Australian threatened and potentially threatened marine and estuarine fishes*, Australian Museum, Sydney.

Ponder, W, Hutchings, P & Chapman, R (2002) *Overview of the conservation of Australian marine invertebrates: a report for Environment Australia*, Australian Museum, Sydney.

Porte, C, Janer, G, Lorusso, LC, Ortiz-Zarragoitia, M, Cajaraville, MP, Fossi, MC & Canesi, L (2006) 'Endocrine disruptors in marine organisms: Approaches and perspectives', *Comparative Biochemistry and Physiology Part C*, vol. 143, pp. 303-15.

Rabalais, NN (2005) 'The potential for nutrient over-enrichment to diminish marine biodiversity', in EA Norse & LB Crowder (eds), *Marine conservation biology*, Island Press, Washington.

Rabalais, NN, Turner, ER & Scavia, D (2002) 'Nutrient policy development for the Mississippi River watershed reflects the accumulated scientific evidence that the increase in nitrogen loading is the primary factor in the worsening of hypoxia in the northern Gulf of Mexico', *BioScience*, vol. 52, no. 2, pp. 129-42.

Ray, GC & McCormick-Ray, J (2004) *Coastal-marine conservation: science and policy*, Blackwell Science, Oxford UK.

Ray, GC (1996) 'Coastal-marine discontinuities and synergisms: implications for biodiversity conservation', *Biodiversity and Conservation*, vol. 5, pp. 1095-108.

Ray, GC (2005) 'Connectivities of estuarine fishes to the coastal realm', *Estuarine, Coastal and Shelf Science*, vol. 64, pp. 18-32.

Reynolds, JD, Dulvy, NK & Roberts, CM (2002) 'Exploitation and other threats to fish conservation', in PJB Hart & CS Reynolds (eds), *Handbook of fish biology and fisheries*, Blackwell, Malden MA

Rutz, GM, Carlton, JT, Grosholz, ED & Hines, AH (1997) 'Global Invasions of Marine and Estuarine Habitats by Non-Indigenous Species: Mechanisms, Extent, and Consequences', *American Zoology*, vol. 37, pp. 621-32.

Siung-Chang, A (1997) 'A review of marine pollution issues in the Caribbean', *Environmental Geochemistry and Health*, vol. 19, no. 2, pp. 45-55.

Steneck, RS, Graham, MH, Bourque, BJ, Corbett, D, Erlandson, J, Estes, JA & Tegner, MJ (2002) 'Kelp forest ecosystems: biodiversity, stability, resilience and future', *Environmental Conservation*, vol. 29, no. 4, pp. 436-59.

Streftaris, N & Zenetos, A (2006) 'Alien Marine Species in the Mediterranean - the 100 'Worst Invasives' and their Impact', *Mediterranean Marine Science*, vol. 7, no. 1, pp. 87-118.

Thiel, H & Koslow, A (2001), *Managing risks to biodiversity and the environment on the high seas, including tools such as marine protected areas - scientific requirements and legal aspects*, German Federal Agency for Nature Conservation, Vilm Germany.

Turley, C, Blackford, J, Widdicombe, S, Lowe, D & Nightingale, P (2006) Reviewing the impact of increased atmospheric carbon dioxide on oceanic pH and the marine ecosystem, Plymouth Marine Laboratory, Plymouth UK.

VanBlaricom, GR, Gerber, LR & Brownell, RL (2000) 'Extinctions of marine mammals', in SA Levin (ed.), *Encyclopedia of biodiversity*, Academic Press, San Diego, pp. 37-69.

Watling, L (2005) 'The global destruction of bottom habitats by mobile fishing gear', in EA Norse & LB Crowder (eds), *Marine conservation biology*, Island Press, Washington.

## Endnotes:

1. Ghost fishing refers to the continued effects of lost and abandoned fishing gear.

2. VMS refers to Vessel Monitoring Systems – compulsory fitting of satellite tracking and reporting devices.

3. The precautionary principle appears in one of its many variations in the *World Charter For Nature 1982*, a resolution of the UN General Assembly, and was more formally endorsed in the Rio Declaration 1992 (United Nations Conference on Environment and Development).