149. Cervera R et al (2010) Effects of different oocyte activation procedures on development and gene expression of porcine preimplantation embryos. Reprod Domest Anim 45(5):e12–e20
150. Schurmann A, Wells DN, Oback B (2006) Early zygotes are suitable recipients for bovine somatic nuclear transfer and result in cloned offspring. Reproduction 132(6):839–848
151. Kishikawa H, Wakayama T, Yanagimachi R (1999) Comparison of oocyte-activating agents for mouse cloning. Cloning 1(3):153–159
152. Ross PJ et al (2008) Parthenogenetic activation of bovine oocytes using bovine and murine phospholipase C zeta. Bmc Develop Biol 8:16
153. Ross PJ et al (2009) Activation of bovine somatic cell nuclear transfer embryos by PLCZ cRNA injection. Reproduction 137(3):427–437
154. Sparman ML, Tachibana M, Mitalipov SM (2010) Cloning of non-human primates: the road “less traveled by”. Int J Dev Biol 54(11–12):1671–1678
155. Vajta G et al (2010) Embryo culture: can we perform better than nature? Reprod Biomed Online 20(4):453–469
156. Zhou Q, Dai XP, Hao J (2009) A modified culture method significantly improves the development of mouse somatic cell nuclear transfer embryos. Reproduction 138(2):301–308
157. Hill JR, Chavatte-Palmer P (2002) Pregnancy and neonatal care of cloned animals. In: Cibelli J, Lanza R, Campbell K, West M (eds) Principles of cloning. Academic, New York, pp 247–266
158. Meirelles FV et al (2010) Delivery of cloned offspring: experience in Zebu cattle (*Bos indicus*). Reprod Fertil Dev 22(1):88–97
159. Enright BP et al (2003) Epigenetic characteristics and development of embryos cloned from donor cells treated by trichostatin A or 5-aza-2′-deoxycytidine. Biol Reprod 69(3):896–901
160. Maalouf WE et al (2009) Trichostatin A treatment of cloned mouse embryos improves constitutive heterochromatin remodeling as well as developmental potential to term. BMC Dev Biol 9:11
161. Loi P et al (2008) Nuclear reprogramming: what has been done. Bioessays 30(1):66–74
162. Tsuji Y, Kato Y, Tsunoda Y (2009) The developmental potential of mouse somatic cell nuclear-transferred oocytes treated with trichostatin A and 5-aza-2′-deoxycytidine. Zygote 17(2):109–115
163. Kiziltepe T et al (2007) 5-Azacytidine, a DNA methyltransferase inhibitor, induces ATR-mediated DNA double-strand break responses, apoptosis, and synergistic cytotoxicity with doxorubicin and bortezomib against multiple myeloma cells. Mol Cancer Ther 6(6):1718–1727
164. Ding X et al (2008) Increased pre-implantation development of cloned bovine embryos treated with 5-aza-2′-deoxycytidine and trichostatin A. Theriogenology 70(4):622–630
165. Rathbone AJ et al (2010) Reprogramming of ovine somatic cells with *Xenopus laevis* oocyte extract prior to SCNT improves live birth rate. Cell Reprogram 12(5):609–616
166. Loi P et al (2002) Nuclei of nonviable ovine somatic cells develop into lambs after nuclear transplantation. Biol Reprod 67(1):126–132
167. Gurdon JB (1988) A community effect in animal development. Nature 336(6201):772–774
168. Boiani M et al (2003) Pluripotency deficit in clones overcome by clone-clone aggregation: epigenetic complementation? EMBO J 22(19):5304–5312
169. Balbach ST et al (2010) Governing cell lineage formation in cloned mouse embryos. Dev Biol 343(1–2):71–83
170. Zhou WL et al (2008) Aggregation of bovine cloned embryos at the four-cell stage stimulated gene expression and in vitro embryo development. Mol Reprod Dev 75(8):1281–1289
171. Matoba S et al (2011) RNAi-mediated knockdown of Xist can rescue the impaired postimplantation development of cloned mouse embryos. Proc Natl Acad Sci
172. Okamoto I et al (2011) Eutherian mammals use diverse strategies to initiate X-chromosome inactivation during development. Nature 472(7343):370–U141
173. Inoue K et al (2010) Impeding Xist expression from the active X chromosome improves mouse somatic cell nuclear transfer. Science 330(6003):496–499

Living Ocean, An Evolving Oxymoron

A. Alonso Aguirre[1,2], E. Scott Weber III[3]
[1]Department of Environmental Science and Policy, George Mason University, Fairfax, VA, USA
[2]Smithsonian-Mason School of Conservation, C/O Smithsonian Conservation Biology Institute, Front Royal, VA, USA
[3]Medicine and Epidemiology: Vet Med Center for Aquatic Biology and Aquaculture, University of California, Davis, Davis, CA, USA

Article Outline

Glossary

By-catch In fisheries, species that are caught by accident and are discarded dead or alive but injured back into the ocean, a major threat to marine biodiversity.

Conservation medicine The emerging discipline of ecological health in practice.

Global toxification Global toxification can be referred as the deposition of thousands of environmental contaminants in the biosphere that are poorly degraded and can move through water, wind or other transport medium to other countries, regions or continents with catastrophic effects in individuals and populations.

Harmful algal bloom A rapid increase or accumulation in the population of toxic or otherwise harmful phytoplankton in an aquatic system. These events also are known as red tides due to the coloration of the bloom that varies from brown to red. Some examples of harmful toxins include brevetoxin, ciguatera, domoic acid, okadaic acid.

Hypoxia Deprived of adequate oxygen supply.

Invasive species "An invasive species is a nonnative species – including seeds, eggs, spores, or other propagules – whose introduction causes or is likely to cause economic harm, environmental harm, or harm to human health. The term *invasive;* is used for the most aggressive species. These species grow and reproduce rapidly, causing major disturbance to the areas in which they are present." (http://www.invasive.org/101/index.cfm).

Ornamental fisheries Ornamental fisheries is often used as a generic term to describe aquatic animals kept in the aquarium hobby, including fishes, invertebrates such as corals, crustaceans (e.g., crabs, hermit crabs, shrimps), mollusks (e.g., snails, clams, scallops), and also live rock.

Sentinel species Due to their size, movements and behavior, marine mammals, sea birds and sea turtles have been classified as sentinel species because they can provide essential early warning information of damage to the environment and consequently raise concerns for public health. These animal groups can serve as sentinels of marine ecosystem health in relatively pristine habitats or highly degraded or overfished ecosystems.

Taurine An essential sulfonic acid for muscle development in animal species.

Transdisciplinarity (TD) TD thinking employs perspectives and methods that transcend traditional disciplinary boundaries and engage students in addressing real-world problems. TD requires the team members to share roles and systematically cross discipline boundaries. The primary purpose of this approach is to pool and integrate the team expertise so that more efficient and comprehensive assessment and intervention may be provided in a determined field. The communication style in TD involves continuous give-and-take among all members on a regular, planned basis. Assessment, intervention, and evaluation are carried out jointly. TD brings together students, and outside the classroom, the future academic experts, field practitioners, community members, research scientists, political leaders, and business owners among others, to solve some of the pressing problems facing the world, from the local to the global and the natural and social sciences, to address the ecology and health of species and ecosystems.

Definition of the Subject

The ocean, in which life on earth began, is increasingly threatened by human activities. Ecological stresses – including overfishing, transformed coastlines, pollution, sediment loss, introduced species, emerging infectious diseases, altered agricultural runoff, sewage discharges, red tides, increased ultraviolet radiation, and an apparently changing climate with acidification and increased hypoxia – are together impacting oceans and the health of humans, marine life and ecosystems. The health of the marine environment is at risk. Methods to assess marine ecosystem health are grossly lacking. A system to monitor and assess marine health threats linked to conservation and management policies is needed. This chapter summarizes the state of the oceans, human impacts including fisheries, climate change, globalization, trade, and coastal development, and provides solutions including an integrated health assessment initiative for marine ecosystems, the use of early warning indicator species, and day-to-day green activities that you as a citizen can contribute for a healthier planet.

Introduction

The global loss of biological diversity affects the well being of both animals and people. Human impact on ecosystems and ecological processes is well documented. Habitat destruction and species loss have led to ecosystem disruptions that include, among other impacts, the alteration of disease transmission patterns (i.e., emerging diseases), the accumulation of toxic pollutants, and the invasion of alien species and pathogens [1–3].

Beyond more visible terrestrial systems, growing evidence indicates that the ecological integrity of marine ecosystems is also under increasing threat. Oceanographers have been documenting changes in sea surface and deep core ocean temperatures, ocean acidification and increased hypoxia caused by human activities and global environmental change. The world coastal zones face enormous human developmental and urbanization pressures as most people on the planet live along the coast. Some ecological health symptoms of collective human impacts on the marine environment include increased frequency and intensity of harmful algal blooms (HABs) killing marine organisms. For example, brevetoxicosis in manatees, dolphins, and sea turtles; domoic acid poisoning in sea lions, cetaceans, and brown pelicans; ciguatera in Hawaiian monk seals and sea lions; and brown tide poisoning in humans; are being linked to increased environmental stress on species at higher trophic levels as a result of overfishing, loss of breeding/nursery habitats, and the spread of persistent chemical pollutants such as dioxins and PCBs that bio-accumulate in the food chain [2, 4–7]. Many populations of marine mammals, marine birds, and sea turtles are exposed to pollutants from agricultural runoff, human sewage, and pathogens with a terrestrial origin. Intensive agricultural practices resulting in increased nutrient loading and decreased water quality give rise to concerns of *Cryptosporidium* contaminations and potentially harmful algal blooms [8]. However, methodologies to assess marine ecosystem health are very poorly developed and the scale of monitoring required is well beyond present surveillance capacity. The health consequences of these events require innovative monitoring strategies in order to promote disease prevention, health management, and conservation. Society is ill-equipped to deal with these health impacts at present, lacking professionals with the transdisciplinary skills to link ecosystem, animal, human health issues, and inadequate large scale marine health surveillance capacity [9–11]. But these skills are necessary to change policy and management for improved health. For the past 30 years, human impacts on the health of the planet can be classified within four areas of environmental concern [12]:

1. Increasing biological impoverishment, including loss of biodiversity, habitat destruction and degradation, and modification of ecological processes.
2. Increasing global “toxification” including the spread of hazardous wastes and toxic substances and the impact of low level pollutants such as the pervasive endocrine disruptors.
3. Global environmental change.
4. Global transport of species, including but not limited to pathogens and parasites, into novel environments.

These discrete and cumulative human-induced global impacts have not only diminished the environmental capital of the planet but have also yielded an array of health concerns including the growing physiological impacts on species’ reproductive health, developmental biology, and immune systems [13–15].

The Living Ocean

The ocean is the basic source for the hydrologic cycle that makes life on Earth possible, a global thermostat that regulates entire climates, absorbs carbon dioxide and generates oxygen, a superhighway that carries most globalized trade; and, the playground for millions of people. The ocean comprises approximately 71% of the planet's surface with an area of about 361 million square kilometers (139,400,000 square miles). More than 50% of this area is over 3,000 m (9,800 ft) deep and a total volume of about 1,347,000,000 km^3 (322,280,000 cubic miles). Each cubic mile of seawater weighs 4.7 billion tons and holds 166 million tons of dissolved solids. One of the most unique aspects of ocean water is its salinity, or dissolved salt content. The measurement of salinity is essentially the determination of the amount of dissolved salts in 1 kg of water and is expressed in parts per thousand (‰). Ocean salinities commonly range from 33‰ to 38‰, with an average of 35‰. Six elements (chlorine, sodium, magnesium, sulfur, calcium, and potassium) constitute over 90% of the total salts dissolved in the ocean. The pressure in the ocean increases with depth due to the weight of the overlying water at the rate of 1 atm (=15 lb per square inch), for every 10 m (33 ft). The average temperature of the ocean is 3.9°C (39°F).

Over 230,000 marine species are known to science to date; however, the total could be up to 100–1,000 times that number. However, the extinction threat of marine species is increasing dramatically due to overexploitation and habitat loss. Climate change is becoming an important factor; due to shifting temperatures species ranges are expanding to the poles and into deeper, cooler waters. Shifts in currents and temperatures will affect the food supply of animals. To date, many species have suffered commercial and regional extinction. Entire coral reefs are getting lost within a single generation [16].

Recent studies demonstrate that viruses, despite their small size, are the most abundant biological entity in the ocean (see http://oceanworld.tamu.edu/resources/oceanography-book/microbialweb.htm). Scientists have identified less than 1% of the viruses on the planet; however, there can be three million viruses in 1 ml of water and each one contains 0.2 fg of carbon. That number is larger than the number of stars in the observable universe. Viruses consume the carbon equivalent to 200 million belugas (*Delphinapterus leucas*) if it is estimated that there are approximately 4×10^{30} viruses in the oceans worldwide [17, 18]. Using a molecular technique denominated "shotgun sequencing," Venter et al. (2004) reported 1,800 genomic species based on sequence relatedness, including 148 previously unknown bacterial phylotypes in water samples from the Sargasso Sea [19]. In total, over 1.2 million previously unknown genes were represented amongst these phylotypes and the vast majority of these unknowns have not yet been grown and studied.

Fish Diversity

Fish are the most species-rich class of vertebrates, numbering greater than 56,000 described species and subspecies, of which over 1,100 new species have been added since 2008, with these vertebrates adapted to a diverse range of aquatic habitats from desert to glacial mountain lakes and from deep sea vents to intertidal marshes [20]. Due to their relative abundance, fish and other aquatic animals have played a prominent role in human civilization by:

- Providing an important protein and omega-3 fatty acid source from both fisheries and aquaculture.
- Rapidly becoming one of the most common laboratory animal models for a variety of toxicological, infectious disease, immunologic, and genetic research facilities.
- Remaining the most numerous companion animals, as pets in bowls, aquariums, and ponds.
- Representing the fastest growing vertebrate taxa used for education in public displays at aquaria and zoos.
- Serving as vital sentinel species for marine and freshwater ecosystem evaluation, habitat assessment, conservation medicine, and ecological health.
- Being propagated for stocking natural fisheries for sport and natural enhancement.

Thus, an understanding of fish health and disease is crucial to incorporate a proactive approach when addressing current and future needs in conservation medicine and ecological health. Invertebrate animals will be discussed in brief in this chapter, but have an equally significant role in conservation medicine. Historic and current examples will be used to better illustrate these conservation medicine dilemmas and challenges.

Fisheries, Habitat Destruction and Extinction

Over 30 years ago, it was assumed that the future of humanity was going to be in the ocean due to its magnificent biodiversity and huge biomass, but within three decades humankind has been able to cause severe impacts to a degree that the ocean is in trouble due to ocean acidification, climate change, and overfishing. The ocean provides a primary source (16%) of animal protein (fish) and more than 3.5 billion people depend directly of fish resources. Approximately 110 million tons of fish are removed every year – an amount way above carrying capacity of the ocean – with a value of $50 billion dollars. For example, along the Gulf of Mexico, 5 kg (12 lb) of sea life mostly juvenile fish may be killed for 0.5 kg (1.1 lb) of shrimp. Basically, more than 75% of world fish stocks assessed for several years are over-exploited or depleted from which 60–70% require urgent action (i.e., allow recovery by closing a fisheries). Marine food webs are literally being fished down causing a cascade of trophic effects unknown to human and ecosystem health [21]. These fisheries core problems can be summarized as follows: there are too many fishing fleets with massive government subsidies for fishermen and cooperatives, with millions of tons of unwanted bycatch picturing an unsustainable future for fisheries. Entire fish stocks can be depleted within a single fishing season. Commercial fishing operations target unregulated deep waters where large migratory fish predatory species are exploited with their bycatch consequences. Of course unreliable statistics (i.e., how many fish of a species swim in the ocean and how many can be caught without causing a decline) and habitat destruction including nurseries, coral reefs, and sea floors are major contributing factors.

Recent numbers estimate that less than 1% of marine habitats are protected. Although more than 50,000 species are estimated to live in a coral reef, only the extinction of four snails, five seabirds, and four marine mammals is known in the history of humankind. These numbers provide a sense of how little is known about the ocean [22].

Aquaculture

Although aquatic organisms have been cultivated for centuries, aquaculture production is a relatively new branch of agriculture. US aquaculture in 2008 has decreased slightly from previous peaks in tonnage (2004) and in value (2006), while world aquaculture production for inland and marine animal species has nearly doubled in both tonnage and value from 1998 to 2007 [23]. With an increase in aquaculture production, there are also increased pressures on wild fisheries to help provide broodstock, seedstock, and a nutritional source of protein and fish oils in commercial aquaculture feeds for raising many aquatic species of economic importance. A frequently cited example that well illustrates realized and theoretical pressures on these fisheries is that the ecologic input purported to raise caged salmon in Norway roughly equates to 5 metric tons of food fish to produce each metric ton of farmed salmon [24]. Despite these numbers being calculated over two decades ago, opponents to commercial salmon aquaculture most frequently cite them. Even when dietary inputs for commercial salmon feeds are not double counted for fish meal and for fish oil components, and when increased feed efficiency is noted, the best true feed conversion rates of dry weight to wet weight (1.6–1.8) still require fishery inputs for salmon aquaculture [25]. In 2000, it was recognized that despite dependence on wild fisheries for fishmeal in aquaculture, aquaculture production actually increased world fish supplies, but this earlier publication does not account for a doubling of production since 2000 [26]. Based on increases in feed conversion efficiency for a variety of aquaculture species and scientific improvements in nutrition, some researchers are convinced that aquaculture use of wild fisheries for fish meal and fish oil in aquaculture feeds will continue to decrease [27]; despite an encouraging decrease in use of wild fisheries to all farmed aquaculture of 0.63 and fisheries harvest for fishmeal in aquaculture feeds are well-regulated, others debate that greater economic and regulatory efforts are still needed to protect wild fisheries [28]. One of the greatest limiting factors when rearing marine piscivorous species for food consumption is the need for taurine in the diets for these animals [29]. Taurine is commonly found in fishmeal but often is lacking in soy and poultry replacements. In the US, the Food and Drug Administration (FDA) restricts supplementing taurine to commercial aquaculture diets, which prevents more sustainable dietary formulations for some of the most popularly raised and consumed fish species and provides a significant hurdle for US offshore aquaculture development.

One of the greatest areas of growth in aquaculture has been the shrimp industry in Central and South America and Southeast Asia. FAO reports show industry growth from 5 million metric tons in 1995, to 40 million tons by 2007 [23], which suggests the reason shrimp are considered "white gold" *oro blanco* in countries such as Ecuador. Problems with such rapid expansion and increasing global demands include habitat use, species protection, and infectious disease. As early as the 1970s in Thailand, shrimp was becoming the fastest growing aquaculture industry, and environmental impacts realized by 1995 were mangrove/wetland destruction, saltwater intrusion, land subsidence, water quality degradation, sediment disposal, abandoned shrimp farms, and displacement of traditional livelihoods [30]. Similar environmental issues including fishery depletion were associated with the shrimp industry in Honduras over a similar time period [31]. Infectious disease problems resulted in major production declines in Taiwan (1988), for China (1993), in Thailand (1996–1997), for Indonesia and the Philippines (1999), and in Ecuador (1999) [32, 33].

The effects of aquaculture on fisheries are multifactorial, including: habitat modification, using wild seed for stocking, impacts on food web interactions, introduction of non-indigenous organisms, and effluent discharge [26]. Understanding the basics for aquaculture health management, biosecurity, and biodiversity are vital to addressing needs of ecological health for aquatic organisms. Aquaculture's effects on biodiversity are seldom recognized as a positive benefit. Instead, aquaculture is viewed as negatively impacting biodiversity through land use, fossil fuel reliance, environmental pollution, antibiotic runoff, exotic species introductions, reliance on fish meal from wild fisheries, broodstock or seed allocation, and water use. However, maintaining biodiversity is essential for current and future aquaculture development [34, 35]. Some realized and potential positive impacts of aquaculture on biodiversity include decreasing exploitation on wild seafood products with cultured livestock, using certain species to enhance wild stocks, and increasing natural production and species diversity [35].

With any type of live organism captive management, there is naturally a direct relationship with disease and production level. As the intensity of production increases, the prevalence of disease also tends to increase. Intensification generally refers to increasing the number of animals raised in confined or restricted areas. For example, the greatest limitations to sustaining development of Asian aquaculture – which accounts for 89% of world aquaculture production [23] – are aquatic animal health concerns, and, without appropriate aquatic animal health management, major disease outbreaks and newly emerging pathogens will continue to dominate costs and socioeconomic development of aquaculture throughout Asia [36].

With optimal aquatic organism health management, advances in technology can be better applied for disease prevention, diagnosis, and amelioration. Increased sophistication of fish health research, advances in molecular diagnostics, and improvements in fish health management will minimize infectious disease in aquaculture (e.g., vaccines and biosecurity) similar to trends noted in production of some terrestrial animals. For example, infectious disease has appeared to have declined in the Atlantic salmon aquaculture industry in British Columbia today than it was 15–20 years ago (Dr. Gary Marty, personal communication).

Aquaculture poses great potential to help feed world populations, improve human health through nutrition, and advance agricultural practices through more practical environmental solutions [37]. As aquatic health practitioners, incorporating a strong foundational aquatic animal health program is essential to the management and future success of aquaculture and the maintenance or restoration of our aquatic ecosystems (including wild fisheries).

Fisheries Interactions

Rapid alterations to the ocean are creating a medium for new disease patterns and health manifestations. For example, new variants of *Vibrio cholerae* have been identified within red tide algal blooms. These toxic blooms are occurring in greater frequency and size throughout the temperate coastal zones of the world.

Intensive aquaculture is a relatively new agricultural practice, and there are several interactions between aquaculture reared animals and wild fisheries. Intensive aquaculture is marked by decreasing needs for natural inputs for husbandry in order to raise greater biomass (number of fish) in less space, while extensive aquaculture relies on enhancing natural food resources and has a greater dependence on livestock density. In the context of conservation, some prominent concerns are fisheries interactions resulting in disease outbreaks, farm-source antibiotic/chemical resistant pathogens, and environmental contamination caused by effluent. Although aquaculture may contribute to these fisheries interactions, other industries and environmental utilization also make substantial changes to the environment posing a threat to aquaculture and native fish populations. Because of the vast expanse of oceans identifying and quantifying the impact of infectious disease on wild fisheries is compounded by fish mortalities going undetected through natural attrition by predation, sinking to the bottom, or occurrences in remote locations. Understanding infectious diseases in wild fish requires effectively led transdisciplinary teams with expertise in fisheries biology, medicine, pathology, mathematical modeling, and ecology. By including participation of concerned citizens and multiple specialists, fish health professionals will be ultimately equipped to diagnose, treat, and/or mitigate emerging infectious disease outbreaks in fisheries and aquaculture [38].

Emerging Infectious Diseases

Emerging infectious diseases are commonly defined as those that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range or appear in new hosts (i.e., canine distemper a disease of dogs has killed tens of thousands of common seals in the North Sea [10]). This rapid trend has been observed in many human populations from AIDS to SARS and from West Nile virus infection to highly pathogenic H5N1 avian influenza. Although current diagnostic methodologies allow the detection of novel pathogens, unprecedented number of emerging and reemerging diseases in marine ecosystems such as brucellosis in dolphins, aspergillosis in coral reefs, fibropapillomatosis in sea turtles, toxoplasmosis in sea otters, and morbillivirus infections linked to large-scale marine mammal die-offs have been documented in recent times [39]. The trends of diseases in the oceans are increasing since 1970 for many taxa including turtles, corals, urchins, and mollusks [40]. The human impacts on the world's oceans have devastated populations, species, and ecosystems at a rapid scale. Some of the emerging pathogens recently documented in the oceans are listed in Table 1. Ancient diseases like mycobacteriosis (tuberculosis) offers some of the greatest health management challenges for managed collections or groups of fish, and have been identified recently in hundreds of freshwater and marine ornamentals, laboratory animals, and also from aquaculture reared striped bass (*Morone saxatilis*) from California [41]. In the last decade mycobacteria infections have been isolated from clinically infected wild striped bass and in juvenile Atlantic menhaden (*Brevoortia tyrannus*) disease prevalence ranged from 2% to 57% in tributaries of the Chesapeake Bay [42] and multiple *Mycobacteria* spp. can colonize numerous species of native fish in this region [43].

Aquatic Invasive Species

Invasive species have a great socioeconomic impact when they negatively impact native species [44]. These alterations can be associated with directly changing the environment such as by eating prey species of fish or invertebrates, eating or disrupting the vegetation and/or phytoplankton, eliminating other important native controls for insects or pests, and changing water flow and water chemistry [45]. Many of these examples can be found on the website for the aquatic nuisance species task force [46]. Some of these examples include (invasive species – probable source):

- Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*), and Water hyacinth (*Eichhornia crassipes*) in Lake Victoria, Africa – developmental projects [47].
- Asian carp in Mississippi Delta and Great Lakes, United States – aquaculture/research.
- *Hydrilla verticillata* in southeast US and *Caulerpa taxifolia* in the Mediterranean – aquarium and water garden trade.
- Zebra mussels (*Dreissena polymorpha*) in watersheds around the world affecting native shellfish populations, water quality, and larval fish – ballast water [48].
- Sea lamprey (*Petromyzon marinus*) parasitism and disease in Great Lakes fishery – possibly Erie and Welland canal projects.

Living Ocean, An Evolving Oxymoron. Table 1 Some emerging and reemerging disease agents recently reported in the marine environment

Disease	Species	Etiologic agent
Adenovirus infection	Walrus	Walrus adenovirus W77R
Arboviral encephalitis	Orca, gray whales, harbor seal [130]	EEE, SLE viruses
Aspergillosis	Marine organisms	*Aspergillus fumigatus*
Black band /white band disease	Corals	Unknown
Bonamiasis	*Ostreaedulis*	*Bonamia ostrea*
Brucellosis in marine mammals	Marine mammals	*Brucella ceti, B. pinnipedialis*
Calicivirus infections	Marine mammals	Caliciviruses (39 serotypes)
Candidiasis	Marine mammals	*Candida albicans*
Canine distemper	Phocids	Canine distemper virus
Chlamydiosis	Sea turtles, Pinnipeds	*Chamydophila psittaci*
Cutaneous viral papilloma	Orca, manatees	Papillomavirus
Disseminated neoplasia/Germinomas	Bivalves	Unknown
Dolphin morbillivirus	*Stenella*	Dolphin morbillivirus
Enterovirus infection	Walrus	Walrus enterovirus 7–19
Erysipelas	Delphinids, little blue penguins [131]	*Erisipelotrix rusiopathiae*
Fibropapillomatosis	Marine turtles	Unknown: Herpesvirus, Retrovirus, possibly Papillomavirus
Hepadnaviral hepatitis	Delphinids	Hepadnavirus
Herpesvirus infection	Phocids; northern fur seals; salmonids, ictalurids, *Cyprinus carpio* [132], *Sardinops sagax*, other fish species	Phocine herpesvirus 1 and 2; Marine herpesvirus 206 CyHV1,2,3; HPV1,2; CCV; Pilchard herpes virus
Immunoblastic malignant lymphoma	*Stenella/Tursiops*	Unknown
Ichthyophoniasis	*Oncorhynchus* spp. [133]	*Ichthyophonus* sp.
Leptospirosis	Pinnipeds	*Leptospira* spp.
Keloidalblastomycosis/ Lobomycosis/Lobo's disease	Delphinids	*Lacazia loboi*
Melioidosis	Delphinids (SE Asia, Australia)	*Burkholderia pseudomallei (Pseudomonas pseudomallei)*
Megalocytisvirus	Numerous fish species [134]	BCIV, ISKNV, RSIV, TRBIV
Metastatic oral squamous cell carcinoma	Delphinids	Possibly papillomavirus
Morbillivirus infection	Mediterranean monk seals	Monk seal morbillivirus

Living Ocean, An Evolving Oxymoron. Table 1 (Continued)

Disease	Species	Etiologic agent
Mycobacteriosis	striped bass; ornamental and tropical marine and freshwater fish species	*Mycobacterium* spp.
Native parasitic sea lice	Salmonid species of genus *Onchorynchus* [135, 136]	*Lepeophtheirus salmonis*
Nocardiosis	Marine mammals	*Nocardia* spp.
Phaeohyphomycosis	Temperate marine teleosts	*Exophiala* spp.
Phocine distemper	Phocids	Phocine distemper virus
Polyps and hyperplasms	Corals	Unknown
Porpoise morbillivirus infection	Porpoises	Porpoise morbillivirus
Pseudomoniasis	Marine mammals	*Pseudomonas* spp
Ranavirus	Amphibians, fish, and chelonian species	FRV-3, numerous others
Rotavirus infection	California sea lion	California sea lion rotavirus A111R
Retrovirus infection	Walrus	Walrus retrovirus T2/19
Salmon fluke	*Salmonid* spp.	*Gyrodactylus salaris Malmberg, 1957*
Salmonellosis	Ornamental freshwater fish and dwarf African frogs	*Salmonella paratyphimyrium* and *S. typhimyrium*
Sea lion transitional cell carcinoma	California sea lions	Herpesvirus??
Seal influenza	Phocids	Influenza virus type A
Seal pox	Pinnipeds	Pox virus
Stress-related necrosis	Corals	High water temperatures
Toxoplasmosis	Pinnipeds, Delphinids	*Toxoplasma gondii*
Vibriosis	Marine mammals, fish, and shellfish [103]	*Campylobacter* spp., *Vibrio* spp., *Photbacterium* ssp.
Viral hemorrhagic septicemia	Marine and freshwater teleosts in northern hemisphere [137]	Viral hemorrhagic Septicemia virus (VHSV)
Whirling disease	Salmonid spp.	*Myxobolus cerebralis*

Invasive species are also detrimental because they *change* predator/prey ecology for ecosystems. These include species that are both predators and prey. Invasive predatory species have an obvious detrimental effect by preying on species that may not have had natural predators in certain habitats. Invasive prey species can have direct or more cryptic effects by consuming resources for native prey species, or through replacing a more nutritious food resource for predators. Some examples are:

Predatory Species

- Pacific Batfish (*Platax orbicularus*) in Molasses Reef in the Florida Keys 2000.
- Lionfish (*Pterois volitans, Pterois miles*) in Northwestern Atlantic and Caribbean, 1992 aquarium escape after hurricane Andrew Biscayne bay [49].
- Snakehead (*Channa argus*), in 2002, this species was discovered in a pond in Crofton, Maryland individual release from aquarium or live food industry.

- Butterfly (*Cichla ocellaris*) and speckled peacock bass (*Cichla temensis*) in Florida by intentional release as game fish 1984.
- Northern Pike (*Esox lucius*) in Davis Lake, California by individual introduction 1994 Prey Species.
- Alewife/Shad (*Alosa pseudoharengus*) 1931 in Great Lakes via Wellend canal.

A greater issue is caused by the release of animals from other geographical locations. Some of these animals may be closely related to native animals separated only by ecological barriers. These species can readily survive in the new location, but given the circumstance for release could pose a greater risk to native relatives. Some examples of this include the release of Maryland diamondback terrapins (*Malaclemys terrapin*) in New York waters from Asian food markets (personal communication with Russell Burke). These terrapins have been exposed to a variety of chelonian species from around the world in poor husbandry conditions that are often unregulated and unhygienic. These animals have potential to become asymptomatic or symptomatic carriers for new diseases that could pose a threat to native threatened and endangered populations. Some examples of sources for these invasives include:

- Aquaculture.
- Live Food Markets.
- Laboratories.
- Collectors.
- Water Gardens/Landscape designers.
- Unwanted Pets – Habitatitude$^{\text{TM}}$: (http://www.habitattitude.net/).
- Restoration/Repopulation projects.

New diseases and health problems in native populations can arise from invasives from all the descriptions above. Alterations in the environment can create poor water quality conditions for native species. Well-documented diseases associated with introductions of nonnatives have occurred in fish, invertebrates, reptiles, and amphibians:

- Chytridiomycosis by *Batrachochytrium dendrobatidis* – amphibians globally [50].
- Thiamin deficiency and thiaminase – salmonids Great lakes, alligators Lake Griffin, Florida [51, 52].
- Viral Hemorrhagic Septicemia VHSV – FW and possibly Marine from Great Lakes [53].
- *Hydrilla verticillata*/blue green algae – Avian Vacuolar Myelinopathy Southeastern US [54]
- *Myxobolus cerebralis* causing Whirling Disease Western US [55].
- *Gyrodactylus salaris* from Baltic to North Sea 1974 [56].
- Malpeque and MSX: links between disease and non-indigenous species in *Atla*ntic Canada [57].
- *Trypanosoma acerinae* from Caspian to Lake Superior in Ballast Water 1992 fish pathogen [58]. *Bonamia ostrea* from California to France, Maine, Washington State, and British Columbia [59–62].

As veterinarians and aquatic animal professionals, our role with aquatic invasives is to recognize new and emerging disease threats, including those that might be caused by human actions [63]. This role includes using our skills in education, nutrition, infectious diseases, and public health to help investigate problems associated with the current epidemic of aquatic invasive species. Some of these diseases may have been overlooked because of poor associations or because current husbandry complicate diagnosing new pathogens. Some brief examples of potential threats include:

- *Exophiala* sp. in cold marine and temperate water fishes [64].
- Megalocytisvirus in ornamental freshwater and marine fishes [65].
- *Salmonella* sp. in freshwater fish, amphibians, and turtles [66].
- *Enterococcus* sp. in sea turtles (Innis, Sims, and Weber unpublished data).

Ornamental Fisheries

Marine and freshwater ornamental fisheries are a growing area, and they involve largely unregulated movement of livestock with global implications for potential disease outbreaks [67, 68]. The ornamental aquarium industry includes captive (>90%) and wild freshwater fish with over 632 million animals produced in Malaysia alone as recorded by the Malaysian ornamental fish industry (2010), coupled with a far greater variety of marine ornamental species that are traded with estimates of close to 8,000 different species of marine animals with only ∼25 species captive bred [69–71]. FAO estimates in 2009 suggest 59% of all production of ornamental aquaculture related products were produced in Asian countries. Aquatic animals include fish, reptiles, amphibians, invertebrates (including corals), and live rock (dead coral that becomes encrusted with marine macro- and microorganisms in the wild). Farms in Florida (USA) and Southeast Asia raise many freshwater ornamental varieties with additional inputs from other countries, hobbyists, and wild-caught fisheries. Hobby specialty groups actively trade some of the animals highly prized for appearance, such as African and South American cichlids. The freshwater temperate ornamental industry consists primarily of koi (*Cyprinus carpio*) and goldfish (*Carassius auratus auratus*) with major production in Israel, Arkansas (USA), Japan, and China. There is little marine ornamental production of farm raised stock, and the majority of marine fish for the hobbyist trade come from captured wild stocks in the Caribbean Ocean, Red Sea, and Indo-Pacific Ocean. Methods used for collection in the Philippines for many marine species in the past have included dynamite stunning and potassium cyanide poisoning causing irreparable damage to stock collected as well as the environment and animals caught as bycatch [72]. Zoos and aquariums contribute to these pressures on aquatic animals; they are net consumers of wildlife and are and must maintain high standards of animal care. The increased fishing pressures on these animals have made some species extremely vulnerable. In just the last decade Banggai cardinal fish (*Pterapogon kauderni*) have become one of the first marine ornamentals to be listed on the International Union for Conservation of Nature (IUCN) red list for threatened species [73, 74], and institutions like the Shedd Aquarium in Chicago have sponsored conservation efforts such as *Project Seahorse* to help with education and research of dwindling numbers of sygnathid species. Although restoration projects are proposed to support conservation for many of these species [75], such endeavors can cause catastrophic effects on native populations, and will need to include aquatic animal veterinarians and fish health professionals to develop responsible protocols to help ensure the health status of captive breeding animals and their offspring prior to release with native populations. Restoration efforts should also involve conducting health surveys on wild populations to screen for presence of common and emerging pathogens known to threaten these native organisms [70].

The primary cause of mortality for many ornamental species is from stress associated with transport, resulting in death either immediately from environmental quality issues or later from disease. Mortality for wild caught ornamentals approaches 100% of some shipments. Shipments bring animals together from different geographical locations into holding systems with shared filtration. Geographical strains of common parasites can be deadly for naïve animals using a shared recirculating water source. Emerging infectious disease agents are largely undetected and seldom appear in the peer-reviewed scientific literature despite the existence of a large industry. This lack of knowledge is mostly the result of mortalities in the aquarium and ornamental trade being discarded without any obligation or regulation for movement of these animals, and often, no gross pathology and/or histopathology is performed on fish mortalities.

Threats to Coral Reefs

Destruction of coral reefs and coral diseases are fast outpacing new reef formation [76]. Coral reefs have tremendous species diversity and there are many new resources on conserving coral reefs. Expertise in understanding coral reef destruction through scientific research has uncovered numerous new pathogens and disease syndromes identified in corals, linking environmental quality and climate change to many problems faced by these invertebrates [77]. Corals are being threatened by anthropogenic (human-induced) and environmental variables such as bleaching, infectious disease, climate change, predator plagues, and invasive species [78]. Recently sunscreen was implicated in contributing to causing coral bleaching and promoting viral infections in heavily touristy areas [79].

Global Toxification

Pollution is a common thread for many of these environmental variables and several examples will be highlighted to illustrate the complicated nature of these interactions. Natural populations of fish in Europe are contaminated with PCBs. Fish from the Rhone River downstream from an incineration plant had high levels of contamination, and that the consequence of this exposure was significant increase in cytochrome P-450 dependent monooxygenase activities [80]. Pollutants can have direct environmental consequences such as the accumulation of halogenated contaminants in farmed salmon, trout, tilapia, pangasius, and shrimp as compared with wild caught marine fisheries, showing salmon as having a greater contaminant level than all other species investigated and Polychlorinated biphenyls (PCBs) being found in the highest concentration [81]. Subsequent studies investigating salmon from Europe and North America in 2004 and 2005 suggested that PCB levels were also significantly higher than levels found in wild Alaskan Chinook salmon but that farms from Eastern Canada had decreased PCB detection in the second year [82–84]. Comparing over 2 metric tons of farmed and wild salmon from around the world for organochlorine contaminants, farmed salmon had significantly higher contaminant levels than wild salmon with Europe having higher levels than both North and South America [85]. However, more recent research showed that much of these differences were a result of lower lipid content in wild Pacific salmon than in farmed Atlantic salmon [86]. Pollutant levels in wild populations of salmonids from the Great Lakes may be improving based on human studies illustrating a decrease of PCBs and DDT among all populations in the Great Lakes region including sport fishers over a 10 year period from 1995 to 2005 [87].

Pollution is also evident from manmade causes and disasters from mines, factories, inadequate wastewater treatment, and oil spills. Fish exposed chronically to petroleum hydrocarbons at the site of the Exxon Valdez oil spill in Alaska had a significant difference in the prevalence and intensity of trichodina parasitism between sculpin originating from an oil-free and an oil-contaminated site, with the oil-contaminated having the greater infection; although extensive environmental differences in both sites were not sufficiently described, as this parasite can also increase rapidly in water temperatures differing by only a couple of degrees C°, especially in eutrophic conditions [88]. After exposure to a variety of pollutants, heavy metals, acid rain, and xenobiotics were shown to cause gross and microscopic lesions of the gill epithelium that were directly linked to osmoregulatory, acid–base, or hemodynamic malfunction, suggesting that toxins may be processed in the gills of fish similar to human pathways found in the kidney, intestine, and liver [89, 90]. Other investigators looking for biomarkers of toxicity caused by crude oil have demonstrated that even at very low exposure the metabolic enzymes citrate synthase and lactate dehydrogenase measured in the gills of Atlantic salmon appeared to be good biomarkers of exposure to the WAF of Bass Strait crude oil, and to chemically dispersed crude oil [90]. Among the many toxins in the aquatic environment, heavy metal toxins are of historical significance. Minamata disease is a disease in humans marked by severe congenital birth deformities that result from eating fish contaminated with methyl mercury waste first characterized in Minamata bay, Japan. Lakes in the Western US such as the Great Salt Lake are reported to have heavy concentrations of mercury and selenium affecting migrating waterfowl [91]. Trends in mercury concentrations in the US Great Lakes from 1969 to 2005 had the greatest downward trends in fish samples from 1969 to 1987, correlating to decreased mercury in sediment and peat cores over that period [92], marking positive news for mitigation of the bioaccumulation of this toxin in this region. Emerging chemicals of concern (ECC) are constantly being investigated such as the effect of endocrine disruptors on fish species [93]. In UK Rivers, a high prevalence of intersexuality and sexual disruption in the roach *Rutilus rutilus* was concomitant with environmental detectable levels of pollutant endocrine disruptors, documenting an initial change in vertebrate behavior related to such compounds [94]. Similar research is investigating fish endocrine disruption in rivers of Virginia and West Virginia.

Veterinarians and the medical profession have the ability to directly mitigate a growing pollutant problem of this century, antibiotics found in the aquatic environment and their possible link to antibiotic resistance of some pathogenic bacteria. Researchers are only beginning to understand the ramifications of antibiotic waste for various ecosystems generated from human and agricultural uses. With improved analytical techniques, antibiotics can easily be identified in waste water and post treatment effluent, and studies suggest that of six antibiotics (ciprofloxacin, trimethoprim/sulphamethoxazole, tetracycline, ampicillin, trimethoprim, and erythromycin) tested pre- and post-wastewater treatment, some bacteria were resistant to all six antibiotics pretreatment, and posttreatment bacteria were still resistant to two of this antibiotics [95]. In broader surveys conducted on samples from 16 sites in the southern North-Rhine Westphalia of Germany, antibiotics were detected in all watersheds. Both large (Rhine River) and small creeks had some substances (erythromycin and sulfamethoxazole) identified in nearly all samples, and concentrations of these pharmaceutical products ranged from detectable to the limit quantization [96]. Early surveys in Germany also detected antibiotics in groundwater and wastewater, but groundwater in heavy livestock areas was free from antibiotic residues, suggesting that most environmental contamination in Germany is from human medical practices [97]. Although much of this environmental contamination is from human waste or terrestrial agricultural effluent, aquaculture may also contribute the problem of antimicrobial resistance. In a more comprehensive review of the literature, many veterinary treatments are found in the aquatic environment including insecticides, antihelmenthics, and antibiotics [98, 99]. Four Danish freshwater trout farms were investigated comparing inlet and outlet water samples, and assessing levels of antibiotic resistance from bacterial sampling of fish, water, and sediment. Two major fish pathogens (88 *Flavobacterium psychrophilum* isolates and 134 *Yersinia ruckeri* isolates) and 313 motile *Aeromonas* isolates had increased antibiotic-resistant among the culturable microflora that was statistically significant among the motile aeromonads; the study used five MICs from antibiotics commonly used in Danish aquaculture (oxolinic acid (OXA) and sulfadiazine-trimethoprim (S-T), amoxicillin (AMX), oxytetracycline (OTC), and florfenicol (FLO) [100]. In another study, Oxytetracycline-resistant (OTr) mesophilic aeromonads from untreated hospital effluent and from fish farm hatchery tanks in Cumbria shared tetracycline resistance-encoding plasmids identical to a similar plasmid found in *E. coli* even though coming from distinct locations [101]. The long-term consequences of antibiotic resistance in the environment are not fully understood, although some of the work by Costanzo showed certain antibiotics negatively affected bio-nitrification [95]. There are large research gaps for understanding all the implications of antibiotic pollution for ecosystem health and sources of these therapeutants, but this lack of research should not prevent further assessment and proactive approaches to addressing environmental accumulation with these drugs.

Microbes also cause environmental concerns for cultivated and harvested fisheries. Many of these pathogens not only cause disease in aquatic animals, but also pose a health risk for people. Some of the more recent findings include epidemiologic investigations of *Salmonella* outbreaks in Australia. One outbreak was the first to link gastroenteritis outbreaks in humans with identical isolates from home aquaria for multidrug-resistant *S. paratyphi* B dT+ (ApCmSmSpSuTc phenotype) (ampicillin, chloramphenicol, streptomycin, spectinomycin, sulfonamides, tetracycline) containing SGI1 [66]. Subsequent investigations correlated human outbreaks of gastroenteritis with a second multidrug-resistant *S.paratyphi* B biovar Java (*S. Java*) with strains that were resistant to ApCmSmSpSuTc, and this isolate was directly linked with home aquaria maintenance [102]. Aquaculture products can also become incidental vehicles to transmit pathogens as illustrated by a 1991 outbreak of cholera in Guayaquil, Ecuador of multiple antimicrobial resistant *V. cholerae* O1 recovered from a pooled sample of a bivalve mollusk and from 68% of stool samples from case patients [103].

Global Environmental Change

Climate change whether induced by humans or natural, has potential to greatly alter the aquatic landscape in ways poorly appreciated or understood by researchers at present. Climate change may be intimately linked to many issues presented in this chapter from providing sustainable aquaculture to harvesting ornamental fish, from the success or failure of invasive species [104] to natural changes in range for many animals, and from coral reef survival to the ecology of infectious disease organisms [78, 105]. Fish populations at risk to climate change in Northern European countries include disease threats from disease agents occurring in warmer climates such as *Lactococcus garvieae* in farmed trout in the UK [106] and proliferative kidney disease (PKD) in wild Swiss grayling (*Thymallus thymallus*) [107]. Aquatic biologists and veterinarians must begin to keep records and develop methods of monitoring disease outbreaks in wild fisheries and in managed species globally.

Tracking Marine Disturbance and Disease in Marine Ecosystems

A new model of bridging the growing gap between conservation science and conservation advocacy that now faces the environmental movement is needed. Environmental problems are being defined as more complex interactions. The scale and complexity of issues require novel solution-oriented approaches that are based upon meaningful collaborations among disciplines and institutions. Obviously, the scale of the Ocean makes it difficult to get a handle on the entire health status of this marine environment. And certainly any focal subset of the Pacific Ocean for example the Bering Sea or the Hawaiian Islands does not diminish issues of scale. The ocean is huge by any measure.

An integrated assessment that links together data from ecological, climatic and economic sources was proposed in the late 1990s [108]. This project had the objective of identifying major marine ecological disturbances (MMEDs) through this assessment process. MMEDs can be mapped, using a geographic information system (GIS), to find spatial "hotspots" and temporal clusters of events (e.g., during El Niño years). Data for this effort is derived from peer-reviewed scientific articles, a network of government and academic researchers, existing data sets and, for more current events, mass media sources.

This ocean health framework is similar to traditional epidemiological (population health) models. The model tracks potentially harmful algae, marine pathogens, and other species that respond rapidly to environmental change. Diseases arise from a combination of pathogenicity (degree of disease causing capability), host vulnerability, and a conducive environment. Marine morbidity and mortality (disease) events may be symptomatic of compounding and chronic ecosystem abuse.

A comprehensive survey of instances of marine ecological disturbance, and a methodology for future major marine ecological disturbance (MMED) investigation, is desired by international, federal and state agencies in their efforts to better understand the changes occurring in the world's oceans. The HEED approach drew together the expertise of over 15 separate disciplines, organized historic data in one standard format, assessed the integrity and coverage of data, and provided a method for future standardized data collection and analysis. Events within this morbidity and mortality database served as (eco) indicators of ecologically and economically significant disturbances. The overall framework enabled the assessment of marine ecosystem health.

The six data sets integrated into the HEED (http://heedmd.org/) model include:

- MMED Database: Morbidity/mortality and adverse occurrences among coral, seagrasses, invertebrates, fish, sea turtles, sea birds, marine mammals, and humans, including HABs data.
- Climate Databases: Sea-surface temperature anomalies, precipitation anomalies, unusual weather events, movement of the Gulf Stream, and indices of climatological anomalies, including the NAO and ENSO phenomena.
- Biophysical Databases: Dissolved inorganic and organic nutrients, river flux, metal concentrations, water column stratification, oxygen, salinity, solar radiation, presence/absence and abundance of sentinel species.
- Baseline Ecosystem Datasets: Chlorophyll biomass, plankton abundance and diversity, dynamics and life history for benthic and pelagic species, and their organization in trophodynamic guilds for particular places over time.
- Economic Database: National Marine Fisheries Service fisheries statistics, Federal Emergency Management Agency and Small Business Administration requests for assistance, and other economic and social costs of morbidity and mortality events.
- Mass Media Database: Article searches of MMED-related stories and economic costs, to ensure complete coverage of data too recent to appear in published literature. Case studies include global marine mammal reports.

In HEED study areas which included the Western North Atlantic, Caribbean Sea, and the Gulf of Mexico, major marine ecological disturbances have increased during the last 50 years. Initial findings in the Atlantic Ocean show a rise in marine-related diseases along the USA Atlantic coast, Gulf of Mexico and Caribbean.

This suggests that coastal conditions conducive to illness are widespread. Other findings of note include:

- New diseases are emerging and old diseases are reappearing across a wide range of marine life.
- Humans face increasing health risks associated with seafood consumption and recreation.
- Of deepest concern, infections appear to be spreading among seagrass meadows and coral reefs, the habitat upon which other species depend.
- Disease outbreaks can lead to significant economic losses for seafood industries, fishing communities, trade, travel and tourism.
- Monitoring and supporting communication networks for harmful algal blooms, and combining disease and environmental surveillance, can generate health early warning systems.
- A continuation of the trends described could significantly alter the structure and function of coastal marine ecosystems.

Results from the original HEED effort for the Atlantic Ocean [109] depict a geographic expansion and overall increase in marine ecological disturbances over the last several decades – including unprecedented events, and disturbances of increasing severity. These have had, in some cases, significant human health and economic impacts. Increased understanding of marine ecological disturbances through the use of the tracking methodology provides a justification and basis for a rapid response to public health risks and threats to ecosystems. NOAA's Office of Global Programs and NASA provided support for the Atlantic Ocean monitoring effort (http://www.heedmd.org/).

Hawaiian Monk Seals as Sentinels of Ocean Health

Possibly the best indicator of ecological integrity of Hawaii's regional marine ecosystem, including the Northwestern Hawaiian Islands (NWHI), is the health of marine vertebrates known to be sensitive to system-wide human impacts including fishing. Sea turtles, sea birds, and marine mammals recently have been described as "sentinels" of marine ecosystem health [110, 111]. Hawaiian monk seals (*Monachus schauinslandi*) fall into this category. The Hawaiian monk seal is one of the most endangered marine mammals in the world and the most endangered pinniped in USA waters. Of three species globally, the Caribbean monk seal (*M. tropicallis*) is believed extinct since the late 1950s and the Mediterranean monk (*M. monachus*) seal nearly so with only a few hundred animals remaining. The decline of both species mirrored the development in their respective regions, including increasingly intensive fishing and degradation of coral reef ecosystems [112].

Populations of Hawaiian monk seals have shown a severe decline in recent years and have placed the species in threat of extinction comprising 1,300 individuals in the wild. Although little is known of the pattern of historic decline of the species, precipitous decline in juvenile survival of Hawaiian monk seals since 1990 followed a climate-induced shift in ecosystem carrying capacity together with overharvesting of lobsters, a known prey of juvenile seals. Monk seal-fishing interactions have been documented in all NWHI fisheries. It is highly likely that the cumulative effects of commercial fishing activity negatively impact the monk seal population through both direct and indirect (ecosystem level) mechanisms. It is unlikely this can be determined definitively unless observed by allowing commercial fishing to continue in or adjacent to monk seal habitat [112].

Understanding the potential role of disease and toxins in this recent decline is a high priority. Several natural sources of mortality have been identified or suggested (e.g., ciguatera poisoning, starvation, shark predation, trauma/mobbing and parasites), but the relative significance of these factors and their effect on population trends are poorly understood. Efforts to enhance the recovery of the Hawaiian monk seal will require a better understanding of the health and disease status of the wild population. Thus, health and disease impacts on the population merit a cohesive, well-supported effort to mitigate potential effects [113].

As demonstrated by intensive serologic surveys on a wide number of marine mammal species, it is evident that many diseases known to affect terrestrial species for decades or centuries are now recently being identified in marine ecosystems. Species and disease interactions are resulting in the appearance of mass mortalities and new reservoir hosts in new geographic areas. Examples of these diseases in marine ecosystems include several strains of morbillivirus, *Brucella* spp.

and leptospirosis. NMFS Marine Mammal Research Program has actively investigated Hawaiian monk seal health and disease for more than 30 years. This investigation has included surveillance and analysis, primarily in the Northwestern Hawaiian Islands (NWHI). Veterinarians, marine biologists and other scientists conduct studies including gross necropsy and histopathology, parasitology, hematology, serology, morphometrics, microbiology, epidemiology, scat and spew analysis, population abundance/survival assessment, and reproductive rates. Recent research [114] shows the serologic presence of several infectious agents. The three infectious diseases endemic to the MHI considered to have the highest risk for the Hawaiian monk seal population are morbilliviruses (i.e., canine distemper, seal distemper), *Brucella* spp. and *Leptospira* spp. Fortunately, canine distemper in Hawaii is rarely diagnosed in domestic pets. Leptospirosis is endemic and widespread but public awareness and state monitoring are helpful. Also, Hawaiian monk seals are mostly solitary, reducing the potential for the spread of this deadly disease from seal to seal. The potential for *Brucella* to affect the survival of Hawaiian monk seals is unclear but a cause for concern. *Brucella* is believed to cause reproductive failure in other species and techniques for diagnosis in monk seals are being developed and may be available in the near future.

Data collected regarding morbillivirus, *Leptospira* spp. and *Brucella* spp. need to be analyzed to provide for example: epidemiological trends, morbidity/mortality curves, geographic distribution and prevalence/incidence information. In addition, herpesvirus epidemics and morbillivirus serologic evidence are being reported affecting pinnipeds in the Pacific coast of the USA (http://www.pifsc.noaa.gov/psd/mmrp/health.php). A cooperative initiative has been proposed to systematically address these disease concerns in one of the richest ecosystems of the world.

Sea Turtles as Sentinels of Ocean Health

Habitat destruction, ingestion of plastics, fisheries bycatch, boat collisions, and emerging diseases are among the documented threats to sea turtles in all oceans. Because sea turtles are large and long-lived air-breathing animals that regularly visit the same sites near the coast, they are excellent indicators or sentinels of the health of an ecosystem.

Sea turtles have been threatened by an epidemic of fibropapillomatosis (FP – tumors of skin involving epidermis, dermis and other epithelial tissues) since the mid 1980s. These debilitating tumors are suspected of having a viral etiology. Populations of turtles exposed to agricultural runoff, pollution, HABs or warm water temperatures have been shown to have an increased risk of infection.

FP is a disease characterized by multiple cutaneous masses ranging from 0.1 to more than 30 cm in diameter that has primarily affected green turtles (*Chelonia mydas*), although the condition has been observed in other species including loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*), Kemp's ridley (*L. kempii*) and flatback (*Natator depressus*) turtles. The disease has a worldwide circumtropical distribution and has been observed in all major oceans. Where present, prevalence of the disease varies among locations, ranging from as low as 1% to as high as 90%. Although several viruses have been identified associated with the tumors, including several herpesviruses, a retrovirus and a papillomavirus, the primary etiological agent remains to be isolated and identified.

The green turtle nesting population, found at French Frigate Shoals, NWHI, has increased since its protection 18 years ago. No population impacts caused by FP have been observed in the number of nesting females, with the highest season ever being recorded in 1997 (ca. 500 nests); however, less than 100 nests were recorded for 1998. A photograph taken in Kaneohe Bay in 1958 documented the first case of FP for the Hawaiian Islands. This turtle was released to the wild. Between 1989 and 1997, 581 green turtles were captured alive at this Bay. Mild to severe FP was reported in 44% of the turtles handled, of which 17% presented oral tumors. The annual prevalence of the disease has ranged from 42% to 65% with no consistent trend observed. Growth rates for turtles with severe FP were significantly slower than turtles free of FP (1.0 vs. 2.2 cm/year carapace length). To date, FP has not been shown as causing a big impact on the overall population. However, further research is necessary to elucidate the long-term impacts. FP in green turtles has served as an indicator of ocean health at several levels. Although reported since the late 1930s in Florida, it was not until the late 1980s that it reached epizootic proportions in several sea turtle populations. Long-term studies have shown that pelagic turtles recruiting to near shore environments are free of the disease. After exposure to these benthic ecosystems, FP manifests itself with primary growths in the corner of the eyes spreading to other epithelial tissues. Field observations support that the prevalence of the disease is associated with heavily polluted coastal areas, areas of high human density, agricultural runoff, and/or biotoxin-producing algae. Marine turtles can serve as excellent sentinels of ecosystem health in these benthic environments. FP can possibly be used as an indicator but correlations with physical and chemical characteristics of water and other factors need to be made [115]. Further research in identifying the etiologic agent and its association with other environmental variables can provide sufficient parameters to measure the health of coastal marine ecosystems, which serve not only as ecotourism spots but also as primary feeding areas for sea turtles.

One Ocean, One Health

The idea of the combined health of people, wildlife, and ecosystems – one health – is emerging from this increasingly apparent but still largely overlooked web of linkages. Symptoms of marine ecosystem distress due to nutrient loading with potential contributions of anthropogenic global climate change are associated with the frequency and intensity of HABs and associated toxicity for marine mammals and humans. Many populations of marine animals, marine birds, and sea turtles are exposed to pollutants from agricultural runoff, human sewage, and pathogens of terrestrial origin best described as pathogen pollution [116]. The following example involving a penguin, a pilchard, and a herpesvirus depicts how the terrestrial and aquatic environments are so delicately interconnected.

The Australian pilchard (*Sardinops sagax*) is a schooling fish related to herring that navigates temperate waters in Australia and New Zealand. Australia is also the range for the smallest and more primitive species of penguin referred to as the little blue or fairy penguin (*Eudyptula minor*) which inhabits the beaches of Western Victoria, Australia, Tasmania, and New Zealand. Although they can swim for long distances, *E. minor* do not exhibit the long migrations of Antarctic species. These penguins main food source is the pilchard. A great mass mortality of pilchard with epithelial lesions of the gills that greatly compromised respiratory and osmotic regulation was documented during 1995 off Western Australia. The spread of disease mortality for these animals was 30 km day^{-1} and after a thorough diagnostic investigation, one consistent finding was the presence of novel herpesvirus inclusions in the gills of infected pilchard [117]. The initial introduction of this herpesvirus is currently unknown. Shortly after, little blue penguins on Phillip and St. Kilda islands began experiencing great mortality of adult (86%) and first year birds (14%) with starvation and intestinal parasitism as the only consistent necropsy finding among 1,926 animals [118]. During the subsequent breeding season 1995–1996 these same birds delayed nesting season by 2 weeks and had a decreased chick fledged rate of 0.3 as compared with the mean of 1.0, and researchers concluded increased mortality and subsequent decreased reproduction were associated with the pilchard mortality [118]. Although the origin of the herpes virus is unknown, this example may very well exhibit the devastating consequences of novel pathogens and/or disease-translocation across geographic boundaries can have on multiple trophic levels [119].

Your Everyday Green Choices

Estimates show that marine litter is now 60–80% plastic, and that amount can reach 90% in certain areas. Plastic degrades slowly. Estimates for plastic bag degradation range from 500 to 1,000 years or even longer. Plastic pieces outnumber sea life 6:1 and there are expansive "garbage patches" of broken up plastics in both the Pacific and Atlantic Oceans (see http://marinedebris.noaa.gov/info/patch.html).

- Do your bit to minimize your impact on ocean pollution. Always remember the 3 Rs: Reduce, Reuse and Recycle. *Know what you are buying and how to recycle!!*
- Be a wise consumer. Support companies that are environmentally conscious. Buy products that minimize use of plastic or use degradable materials.
- Consumers choosing to buy sustainably sourced seafood and avoiding threatened species, i.e., Sea Food Watch App for smart phones.

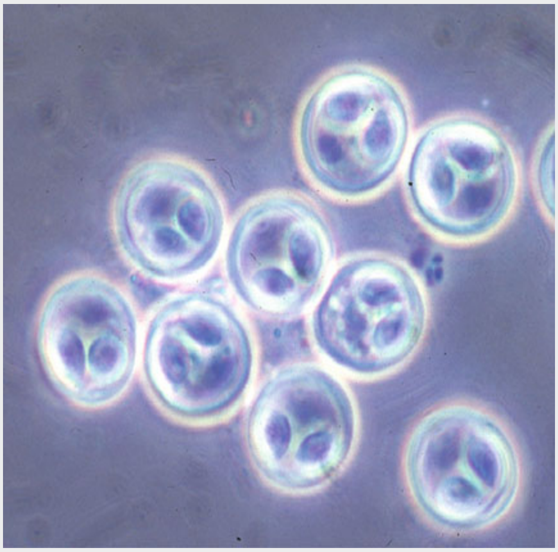
- Follow the National seafood and sushi watch cards or consumer choice cards.
- Put pressure on governments and regulatory bodies to limit fishing subsidies and tighten regulations on industrial, agricultural and domestic pollution.
- Support research projects aimed at understanding pollution better and finding ways to reduce the amount of pollution in our oceans.
- Help support the establishment and expansion of Marine Protection Areas (MPAs). Presently, 1% of the oceans are MPAs.
- Websites for green options and choices: Blueocean.org; Fold-pak.com; Livingoceans.org; Montereybayaquarium.org; Oceanconservancy.org; Ocenaleadership.org; Seakeepers.org; Seathos.org; Sustainablesushi.net

Future Directions

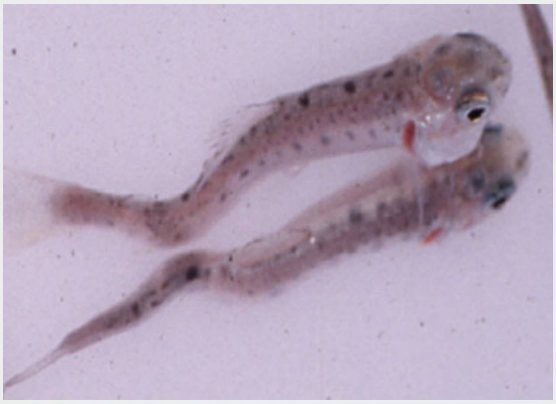
Not all changes in fisheries can be simply ascribed to overfishing or environmental destruction; for example, the non-recovery of Pacific herring populations in Alaska has recently been attributed to natural mortality events caused by several infectious pathogens and subsequent disease, which has been illustrated using an age-structured assessment (ASA) model of disease and population abundance [120]. Box 1 illustrates how research advances when mitigating invasive and emerging pathogens such as *Myxobolus cerebralis* that causes whirling disease in many native species of salmonid fish. With the advent and increasing use of molecular diagnostics, infectious disease modeling, increasing globalization, and changing environmental conditions, marine health scientists will have to rely more heavily on epidemiology irrespective of specialty for the benefit of their clients as well as their patients. This chapter is far from comprehensive, but hopefully it serves to encourage readers, and especially our young readers, to think outside of routine way of life and to become involved with issues that demand a rapid response from consumption to recycling, from advocacy to policy change. Given the vast number of species and current exploitation of our aquatic resources many conservation issues have not been included but are equally relevant to conservation of the ocean, such as the exploitation of sharks and rays in finning fisheries,

Box 1. Whirling Disease: Problems and Solutions

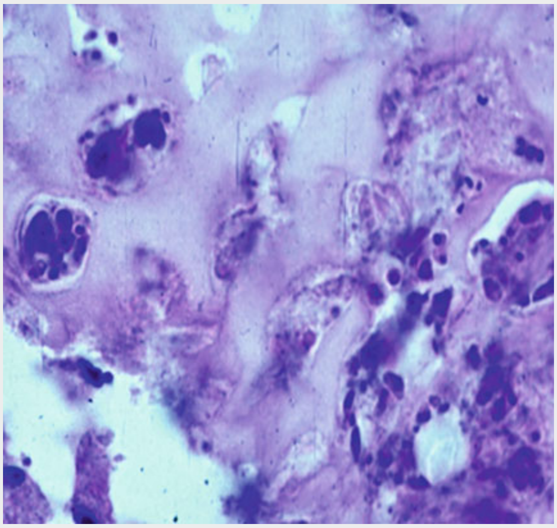
Though speculative, the myxozoan parasite *Myxobolus cerebralis*, likely reached North America in the 1950s with frozen rainbow trout or imported brown trout from Europe [55, 121]. The first recorded epizootic in North America was among brook trout at a hatchery in Pennsylvania, USA. Subsequent episodes were reported in numerous other eastern state trout hatcheries, frequently among rainbow trout, one of the more susceptible species of salmonids [55]. Under conditions of high infectivity, whirling disease may induce severe cranial and spinal deformations and death as parasite stages feed upon and destroy skeletal cartilage prior to bone formation in young fish [122]. The myxospore stages of *M. cerebralis* in the skeletal elements of chronically infected trout may not result in the blackened tail and erratic swimming characteristic of acute disease. If the spores are not detected, the parasite will spread to new geographic regions with the transport of hatchery fish for stocking in rivers and streams for the sport fishery. This mode of parasite movement has facilitated the spread of the parasite to over 25 states in the USA, including most profoundly wild trout in the intermountain west (e.g., Colorado, Montana) where large scale population declines, particularly among rainbow trout have destroyed once highly prized sport fisheries [123, 124]. The two-host life cycle of *M. cerebralis*, which also includes the oligochaete *Tubifex tubifex*, has added to the complexity associated with the control and management of whirling disease. However, a combination of improved diagnostic procedures for parasite detection, in both fish and oligochaetes, and new management procedures in aquaculture are improving the ability to control whirling disease. The advent and now widespread application of PCR can detect the pathogen among fish with no clinical signs of disease, thus preventing the inadvertent movement of infected fish [125]. Improved sanitation in trout hatcheries using both treatments of the water supply with ultraviolet irradiation and several common disinfectants for ponds and equipment including transport vehicles has further reduced the spread of the parasite [126, 127]. Finally, the discovery and exploitation of rainbow trout strains resistant to whirling disease has provided a powerful management approach to significantly reducing and perhaps eliminating whirling disease from certain hatchery environments and ideally from selected wild trout sport fisheries [128, 129]. The most broadly exploited whirling disease resistant rainbow trout strain is the product of 120 years of selection in a commercial hatchery in Europe. This strain is now being reared in state and commercial fish hatcheries in the USA. It is also being bred with wild trout with the aim to restore selected wild populations of rainbow trout in Colorado.



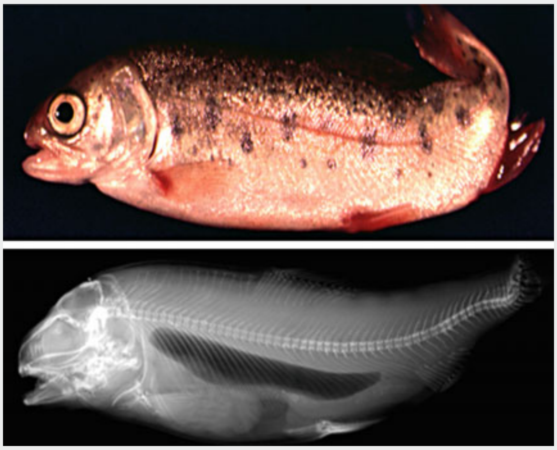
Terminal stage of *Myxobulus cerebralis* found in salmonid fish



Rainbow trout 2.5 mo post infection showing darker and deformed tail, deformed gill covers and cranium – inability to swim and eat lead to death.



Histopathology section stained with H & E showing trophozoites actively destroying cartilage in the young trout skeleton.



A rainbow trout with chronic deformities caused by whirling disease with a corresponding right lateral radiograph illustrating spinal and skull deformities.

invertebrate aquaculture production, and coral reef conservation.

The conservation of biodiversity in the ocean is becoming increasingly complex because of the intimate role that water has with conserving our terrestrial environs. The vastness of the aquatic world should not be looked at with trepidation, but rather with excitement for the vast wealth of knowledge it has yet to bestow on us. Although the challenges presented are great, the ocean has been forgiving to anthropogenic transgressions and there is a need to continue striving to leave a smaller wake and help others follow by example.

Acknowledgments

E.P. Weber III wants to thank Dr. Bryon Jacoby for all his patience during the drafting, rewriting, and editing of this chapter and he thanks Dr. Ronald Hedrick for assistance with the whirling disease section and providing images. Dr Hedrick has led Fish Health at the University of California School of Veterinary Medicine in Davis over the last 30 years and has contributed to nearly 300 publications related to Aquatic Animal Health. Ron is a great friend, colleague, and mentor. We are most grateful to H.M. Smith, S. Sgroi and M. DeRario for their thoughtful input and comments for lightening it our scientific jargon up to an enjoyable reading for our K-12 public.

Bibliography

1. Colborn T, Dumanoski D, Meyers JP (1996) Our stolen future. Dutton, New York
2. Epstein PR (1993) Algal blooms in the spread and persistence of cholera. Biosystems 31:209–221
3. McMichael AJ, Bolin B, Costanza R, Daily GC, Folke C, Lindahl-Kiessling K, Lindgren B, Niklasson E (1999) Globalization and the sustainability of human health: an ecological perspective. Bioscience 49:205–210
4. Estes JA, Duggins DO (1995) Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm. Ecol Monogr 65:75–100
5. Epstein PR (1999) Climate and health. Science 285: 347–348
6. Bejarano AC, Van Dolah FM, Gulland FMD, Rowles TK, Schwacke LH (2008) Production and toxicity of the marine biotoxin domoic acid and its effects on wildlife: a review. Human Ecol Risk Assess 14:544–567
7. Weber ES (2012) Emerging infectious diseases in fisheries and aquaculture. In: Aguirre AA, Ostfeld RS, Daszak P (eds) New directions in conservation medicine: applied cases of ecological health. Oxford University Press, New York
8. Burkholder JM, Glasgow HB Jr (1995) Interactions of a toxic estuarine dinoflaglellate with microbial predators and prey. Arch Protistenk 145:177–188
9. Meffe G (1999) Conservation medicine. Conserv Biol 13:953–954
10. Aguirre AA, Ostfeld RS, Tabor GM, House CA, Pearl MC (eds) (2002) Conservation medicine: ecological health in practice. Oxford University Press, New York, 407 pp
11. Aguirre AA, Ostfeld RS, Daszak P (eds) (2012) New directions in conservation medicine: applied cases of ecological health. Oxford University Press, New York
12. Tabor GM, Ostfeld RS, Poss M, Dobson AP, Aguirre AA (2001) Conservation biology and the health sciences: defining the research priorities of conservation medicine. In: Soulé ME, Orians GH (eds) Research priorities in conservation biology, 2nd edn. Island Press, Washington, DC, pp 165–173
13. Jones KE, Patel N, Levy M, Storeygard A, Balk D, Gittleman JL, Daszak P (2008) Global trends in emerging infectious diseases. Nature 451:990–994
14. Milligan SR, Holt WV, Lloyd R (2009) Impacts of climate change and environmental factors on reproduction and development in wildlife. Phil Trans R Soc 364:3313–3319
15. Gore A (2010) Disrupting chemicals from basic research to clinical practice. Humana Press, Totowa, 349 pp
16. Rogers AD, Laffoley Dd'A (2011) International earth system expert workshop on ocean stresses and impacts. Summary report. IPSO, Oxford, 18 pp
17. Suttle CA (2005) Viruses in the sea. Nature 437:356–361
18. Weinbauer MG (2004) Ecology of prokaryotic viruses. FEMS Microbiol Rev 28:127–181
19. Venter JC, Remington K et al (2004) Environmental genome shotgun sequencing of the Sargasso sea. Science 304(5667):66–74
20. Eschmeyer WN (ed) Catalog of fishes electronic version (25 Oct 2010). http://research.calacademy.org/ichthyology/catalog/fishcatmain.asp. Accessed 12 Nov 2010
21. Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F (1998) Fishing down marine food webs. Science 279:860–863
22. Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. Nature 423:280–283
23. Food and Agricultural Organization Aquaculture Production Statistics 1998–2007 (Food and Agricultural Organization, Rome, 2008). http://www.fao.org/fishery/statistics/programme/3,2,1/en. Accessed 15 June 2010
24. Folke C (1988) Energy economy of salmon aquaculture in the Baltic Sea. J Environ Manage 12:525–537
25. Tacon AGJ (2005) Salmon aquaculture dialogue: status of information on salmon aquaculture feed and the environment. Int Aquafeed 8:22–37
26. Naylor RL, Goldberg RJ, Primavera JH et al (2000) Effects of aquaculture on World food supplies. Nature 405:1017–1024
27. Tacon AGJ, Metian M (2009) Fishing for aquaculture: nonfood use of small pelagic forage fish, a global perspective. Rev Fish Sci 17:305–317
28. Naylor RL et al (2009) Feeding aquaculture in an era of finite resources. Proc Natl Acad Sci USA 106:15103–15110
29. Takagi S, Murata H, Goto T, Ichiki T, Munasinghe DMS, Endo M, Matsumoto T, Sakurai A, Hatate H, Yoshida T, Sakai T,

Yamashita H, Ukawa M, Kuramoto T (2005) The green liver syndrome is caused by taurine deficiency in yellowtail, *Seriolaquinque radiata* fed diets without fishmeal. Aquac Sci 53:279–290

30. Dierberg FE, Kiattisimkul W (1995) Issues, impacts, and implications of shrimp aquaculture in Thailand. J Environ Manage 20(5):649–666
31. Dewalt BR, Vergne P, Hardin M (1996) Shrimp aquaculture development and the environment: people, mangroves and fisheries on the Gulf of Fonseca, Honduras. World Development 24(7):1193–1208
32. Kautsky N, Ronnback P, Tedengren M, Troell M (2000) Ecosystem perspectives on management of disease in shrimp pond farming. Aquaculture 191(1–3):145–161
33. Primavera JH (1997) Socioeconomic impacts of shrimp culture. Aquac Res 28:815–827
34. Beveridge MCM, Ross LG, Kelly LA (1994) Aquaculture and biodiversity. Ambio 23:497–502
35. Diana JS (2009) Aquaculture production and biodiversity conservation. Bioscience 59:27–38
36. Bondad-Reantaso MG, Subasinghe RP, Arthur JR, Ogawa K, Chinabut S, Adlard R, Tan Z, Shariff M (2005) Disease and health management in Asian aquaculture. Vet Parasitol 132:249–272
37. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327:812–818
38. Georgiadis MP, Gardner IA, Hedrick RP (2001) The role of epidemiology in the prevention, diagnosis, and control of infectious diseases of fish. Prev Vet Med 48:287–302
39. Gulland FMD, Hall A (2007) Is marine mammal health deteriorating? Trends in the global reporting of marine mammal disease. Ecohealth 4:135–150
40. Ward JC, Lafferty KD (2004) The elusive baseline of marine disease: are diseases in ocean ecosystems increasing? PLoS Biol 2:542–547
41. Hedrick RP, McDowell T, Groff J (1987) Mycobacteriosis in cultured striped bass from California. J Wildl Dis 23(3):391–395
42. Kane A, Stine CB, Hungerford L et al (2007) Mycobacteria as environmental portent in Chesapeake Bay fish species. Emerg Infect Dis 13(2):329–331, www.cdc.gov/eid
43. Stine CB, Jacobs JM, Rhodes MR et al (2009) Expanded range and new host species of *Mycobacterium shottsii* and *M. pseudoshottsii*. J Aquat Anim Health 21:179–183
44. Lovell SJ, Stone SF, Fernandez L (2006) The economic impacts of aquatic invasive species: a review of the literature. Agric Resour Econ Rev 35(1):195–208
45. McNeely JA, Schutyser F (2003) Invasive species: a global concern bubbling to the surface. In: International conference on the impact of global environmental problems on continental and coastal marine waters. Geneva, Switzerland, 16–18 July 2003, pp 1–14
46. Aquatic Nuisance Species (ANS) task force. http://www.anstaskforce.gov/default.php Accessed 30 March2010. Northeast Aquatic Nuisance Species (NEANS) Panel. http://www.northeastans.org Accessed 15 Dec 2010
47. Njiru M, Nzungi P, Getabu A, Wakwabi E, Othina A, Jembe T, Wekesa S (2007) Are fisheries management, measures in Lake Victoria successful? The case of Nile perch and Nile tilapia fishery. African J Ecol 45:315–323
48. Johnson LE, Padilla DK (1996) Geographic spread of exotic species: ecological lessons and opportunities from the invasion of the zebra mussel Dreissena polymorpha. Biol Conserv 78:23–33
49. Morris JA Jr, Akins JL, Barse A et al (2008) Biology and ecology of the invasive lionfishes, *Pterois miles* and *Pterois volitants*. In: Proceedings of the 61st Gulf and Caribbean Fisheries Institute. Gosier, Goudeloupe, French West Indies, 10–14 Nov 2008, pp 1–6
50. Fisher MC, Garner TWJ (2007) The relationship between the emergence of *Batrachochytrium dendrobatidis*, the international trade in amphibians and introduced amphibian species. Fungal Biol Rev 21:2–9
51. Tillitt DE, Zajicek JL, Brown SB et al (2005) Thiamine and thiaminase status in forage fish of salmonines from Lake Michigan. J Aquat Anim Health 17:13–25
52. Schoeb TR, Heaton-Jones TG, Clemmons RM et al (2002) Clinical and necropsy findings associated with increased mortality among American alligators of Lake Griffin, Florida. J Wildl Dis 38(2):320–337
53. Lumsden JS, Morrison B, Yason C, Russell S, Young K, Yazdanpanah A, Huber P, Al-Hussinee L, Stone D, Way K (2007) Mortality event in freshwater drum *Aplodinotus grunniens* from Lake Ontario, Canada, associated with viral haemorrhagic septicemia virus, Type IV. Dis Aquat Organ 76:99–111
54. Wilde SB, Murphy TM, Hope CP et al (2005) Avian vacuolar myelinopathy linked to exotic aquatic plants and a novel cyanobacterial species. Environ Toxicol 20(3):348–353
55. Hoffman GL (1990) *Myxobolus cerebralis*, a worldwide cause of salmonid whirling disease. J Aquat Anim Health 2:30–37
56. Malmberg G (1957) *Om förekomsten av Gyrodactylus påsvenska fiskar. – Skr. söd. Sver. Fisk För. Årsskr.*1956: 19–76. (In Norwegian, English summary)
57. Needler AWH, Logie RR (1947) Serious mortalities in Prince Edward Island oysters caused by a contagious disease. Transcr R Soc Canada, Ser III 41(V):73–89
58. Pronin NM, Selgeby JH, Litvinov SV, Pronina SV (1998) Comparative ecology and parasite fauna of exotic invaders in the great lakes of the world: amur sleeper (*Percottus glehni*) in Lake Baikal and ruffe (*Gymnocephalus cernuus*) in Lake Superior. Siberian J Ecol 5(5):397–406 (In Russian)
59. Elston RA, Farley CA, Kent ML (1986) Occurrence and signicance of bonamiasis in European flat oysters *Ostrea edulis* in North America. Dis Aquat Organ 2:49–54
60. Friedman CS, McDowell T, Groff JM, Hollibaugh JT, Manzer D, Hedrick RP (1989) Presence of *Bonamia ostreae* among populations of the European flat oyster, *Ostrea edulis* Linne, in California, USA. J Shellfish Res 8:133–137

61. Friedman CS, Perkins FO (1994) Range extension of *Bonamia ostreae* to Maine, USA. J Invertebr Pathol 64:179–181
62. Marty GD, Bower SM, Clarke KR, Meyer G, Lowe G, Osborn AL, Chow EP, Hannah H, Byrne S, Sojonky K, Robinson JH (2006) Histopathology and a real-time PCR assay for detectionof *Bonamia ostreae* in *Ostrea edulis* cultured in western Canada. Aquaculture 261:33–42
63. Crowl TA, Crist TO, Parmenter RR et al (2008) The spread of invasive species and infectious disease as drivers of ecosystem change. Front Ecol Environ 6(5):238–246
64. Nyaoke A, Weber ES, Innis C et al (2009) Disseminated phaeohyphomycosis in weedy seadragons (*Phyllopteryxtae niolatus*) and leafy seadragons (*Phycodurus eques*) caused by species of Exophiala, including a novel species. J Vet Diagn Investig 21(1):69–79
65. Whittington RJ, Chong R (2007) Global trade in ornamental fish from an Australian perspective: the case for revised import risk analysis and management strategies. Prev Vet Med 81:92–116
66. Levings RS, Lightfoot D, Hall RM, Djordjevic SP (2006) Aquariums as reservoirs for multidrug-resistant *Salmonella paratyphi* B. Emerg Infect Dis 12(3):507–510 www.cdc.gov/eid. (Accessed on 21 May 2010)
67. Dentler JL (1993) Noah's farce: the regulation and control of exotic fish and wildlife. University of Puget Sound Law Review 17:192–242
68. Andrews C (1990) The ornamental fish trade and fish conservation. J Fish Biol 37:53–59
69. Helfman GS (2007) Fish conservation: a guide to understanding and restoring global aquatic biodiversity and fishery resources. Island Press, Chicago
70. Smith KF, Behrens MD, Schloegel LM, Marano N, Burgiel S, Daszak P (2009) Reducing the risks of the wildlife trade. Science 324:594–595
71. Food and Agricultural Organization Aquaculture Production Statistics 2010 (Food and Agricultural Organization, Rome, 2010). State of World Fisheries and Aquaculture 2010. http://www.fao.org/docrep/013/i1820e/i1820e.pdf. Accessed 15 June 2011
72. Galvez R, Therese GH, Bautista C, Tungpalan MT (1989) Sociocultural dynamics of blast fishing and sodium cyanide fishing in two fishing villages in the Lingayen Gulf area. 43–62. In: Silvester G, Miclat E, Chua TE (eds) Towards sustainable development of the resources of Lingayen Gulf, Philippines. ICLARM conference proceeding number 17, 200 pp
73. Vagelli AA (2004) Significant increase in survival of captive-bred juvenile Banggai cardinalfish, *Pterapogon kauderni*, with an essential fatty acid enriched diet. J World Aquac Soc 35(1):61–69
74. Lunn KE, Moreau MA (2004) Unmonitored trade in marine ornamental fishes: the case of Indonesia's Banggai cardinalfish (*Pterapogon kauderni*). Coral Reefs 23:344–351
75. Ziemann DA (2001) The potential for the restoration of marine ornamental fish populations through hatchery releases. Aquar Sci Conserv 3:107–111
76. Wilkinson C (2004) Status of coral reefs of the world volumes 1 & 2. Global reef monitoring network. Australian Insititute of Science. http://www.gcrmn.org/status2004.aspx. Accessed 1 May 2011
77. Hoegh-Guldberg O et al (2007) Coral reefs under rapid climate change and ocean acidification. Science 318:1737–1742
78. Goldberg J, Wilkinson C (2004) Global threats to coral reefs: coral bleaching, global climate change, disease, predator plagues, and invasive species. In: Wilkinson C (ed) Status of coral reefs of the world: 2004, vol 1. Australian Institute of Marine Science, Townsville, 301 pp reportscr2004v1-01, pp 68–92
79. Danovaro R, Bongiorni L, Corninaldesi C, Giovannelli D, Damiani E, Astolfi P, Greci L, Pusceddu A (2008) Sunscreens cause coral bleaching by promoting viral infections. Environ Health Perspect 116:441–447
80. Monod G, Devaux A, Riviere JL (1988) Effects of chemical pollution on the activities of hepatic xenobiotic metabolizing enzymes in fish from the Rhone River. Sci Total Environ 73:189–201
81. VanLeeuwen SPJ, van Velzen MJM, Swart CP et al (2009) Halogenated contaminants in farmed salmon, trout, tilapia, pangasius, and shrimp. Environ Sci Technol 43:4009–4015
82. Shaw SD, Brenner D, Bourakovsky A et al (2005) PCBs, dioxin-like PCBs and organochlorine pesticides in farmed salmon (*Salmosalar*) from Maine and eastern Canada. Organohalogen Compounds 67:1571–1576
83. Shaw SD, Brenner D, Berger ML et al (2006) PCBs, PCDD/Fs, and organochlorine pesticides in farmed Atlantic salmon from Maine, eastern Canada, and Norway, and wild salmon from Alaska. Environ Sci Technol 40:5347–5354
84. Shaw SD, Brenner D, Berger ML et al (2007) PCBs, PCDD/Fs, and organochlorine pesticides in farmed Atlantic salmon from Maine, eastern Canada, and Norway, and wild salmon from Alaska (comment/correction). Environ Sci Technol 41:4180
85. Hites RA, Foran JA, Carpenter DO et al (2004) Global assessment of organic contaminants in farmed salmon. Science 303:226–229
86. Ikonomou MG et al (2007) Flesh quality of market-size farmed and wild British Columbia salmon. Environ Sci Technol 41:437–443
87. Knobeloch L, Turyk M, Imm P, Schrank C, Anderson H (2008) Temporal changes in PCB and DDE levels among a cohort of frequent and infrequent consumers of Great Lakes sportfish. Environ Res 109:66–72
88. Khan RA (1990) Parasitism in marine fish after chronic exposure to petroleum hydrocarbons in the laboratory and to the Exxon Valdez Oil Spill. Bull Environ Contam Toxicol 44:759–763
89. Evans DH (1987) The fish gill: site of action and model for toxic effects of environmental pollutants. Environ Health Perspect 71:47–58
90. Gagnon MM, Holdway DA (1999) Metabolic enzyme activities in fish gills as biomarkers of exposure to petroleum hydrocarbons. Ecotoxicol Environ Saf 44:92–99

91. Conover MR, Vest JL (2009) Concentrations of selenium and mercury in eared grebes (*Podiceps nigricollis*) from Utah's Great Salt Lake, USA. Environ Toxicol Chem 28(6):1319–1323
92. Chalmers AT, Argue DM, Gay DA et al (2010). Mercury trends in fish from rivers and lakes in the United States, 1969–2005. Environmental Monitoring and Assessment; published online 10 June 2010. Accessed 05 July 2010
93. Mills LJ, Chichester C (2005) Review of evidence: are endocrine-disrupting chemicals in the aquatic environment impacting fish populations? Sci Total Environ 343:1–34
94. Jobling S, Nolan M, Tyler CR et al (1998) Widespread sexual disruption in wild fish. Environ Sci Technol 32:2498–2506
95. Costanzo SD, Murby J, Bates J (2005) Ecosystem response to antibiotics entering the aquatic environment. Mar Pollut Bull 51:218–223
96. Christian T, Schneider RJ, Farber HA (2003) Determination of antibiotic residues in manure, soil, and surface waters. Acta Hydrochimicaethydrobiologica 31(1):36–44
97. Hirsch R, Ternes T, Haberer K, Kratz KL (1999) Occurrence of antibiotics in the aquatic environment. Sci Total Environ 225(1–2):109–118
98. Boxall ABA, Fogg LA, Blackwell PA et al (2004) Veterinary medicines in the environment. Rev Environ Contam Toxicol 180:1–91
99. Kemper N (2008) Veterinary antibiotics in the aquatic and terrestrial environment. Ecol Indic 8:1–13
100. Schmidt A, Bruun MS, Dalsgaard I et al (2000) Occurrence of antimicrobial resistance in fish-pathogenic and environmental bacteria associated with four Danish rainbow trout farms. Appl Environ Microbiol 66(11):4908–4915
101. Rhodes G, Huys G, Swings J et al (2000) Distribution of oxytetracycline resistance plasmids between aeromonads in hospital and aquaculture environments: implications of TN1 721 in dissemination of the tetracycline resistance determinant Tet A. Appl Environ Microbiol 66(9):3883–3890
102. Musto J, Kirk M, Lightfoot D et al (2006) Multi-drug resistant *Salmonella java* infections acquired from tropical fish aquariums, Australia, 2003–04. Commun Dis Intell 30:222–227
103. Weber JT, Mintz ED, Cañizareset R (1994) Epidemic cholera in Ecuador: multi-drug resistance and transmission by water and seafood. Epidemiol Infect 112:1–11
104. Rahel FJ, Olden JD (2008) Assessing the effects of climate change on aquatic invasive species. Conserv Biol 22(3):521–533
105. Riley SC, Munkittrick KR, Evans AN, Krueger CC (2008) Understanding the ecology of disease in Great Lakes fish populations. Aquat Ecosystem Health and Management 11(3):321–334
106. Bark S, McGregor D (2001) The first occurrence of lactococcosis in farmed trout in England. Trout News 31:9–11
107. Wahli T, Knuesel R, Bernet D, Segner H, Pugnovkin D, Burkhardt-Holm P, Escher M, Schmidt-Posthaus H (2002) Proliferative kidney disease in Switzerland: current state of knowledge. J Fish Dis 25:491–500
108. Sherman BH, Epstein PR (2001) Past anomalies as a diagnostic tool for evaluating multiple marine ecological disturbance. Human Ecol Risk Assess 7:1493–1517
109. Sherman BH (2000) Marine disturbance, a survey of morbidity, mortality and disease events. Mar Pollut Bull 41:232–254
110. Aguirre AA, Tabor GM (2004) Marine vertebrates as sentinels of marine ecosystem health. Ecohealth 1:236–238
111. Tabor GM, Aguirre AA (2004) Ecosystem health and sentinel species: adding an ecological element to the proverbial "canary in the mineshaft". Ecohealth 1:226–228
112. Kittinger JN, Duin KN, Wilcox BA (2009) Commercial fishing, conservation and compatibility in the Northwestern Hawaiian Islands. Mar Policy. doi:10.1016/j.marpol.2009.06.007
113. Aguirre AA, Reif JS, Antonelis GA (1999) Hawaiian monk seal epidemiology plan: health assessment and disease status studies. U.S. Department of Commerce, NOAA Technical report NMFS NWFSC-280, 63 pp
114. Aguirre AA, Keefe TJ, Reif JS, Kashinsky L, Yochem P, Saliki JT, Stott JL, Goldstein T, Dubey JP, Braun R, Antonelis G (2007) Infectious disease monitoring of the endangered Hawaiian monk seal. J Wildl Dis 43:229–241
115. Aguirre AA, Lutz P (2004) Sea turtles as sentinels of marine ecosystem health: is fibropapillomatosis an indicator? Ecohealth 1:275–283
116. Daszak P, Cunningham AA, Hyatt AD (2000) Emerging infectious diseases of wildlife – threats to biodiversity and human health. Science 287:443–449
117. Whittington RJ, Jones JB, Hine PM, Hyatt AD (1997) Epizootic mortality in the pilchard *Sardinops sagax neopilchardus* in Australia and New Zealand in 1995. 1. Pathology and epizootiology. Dis Aquat Organ 28:1–16
118. Dann P, Norman FI, Cullen JM et al (2000) Mortality and breeding failure of little penguins, *Eudyptula minor*, in Victoria, 1995–6, following a widespread mortality of pilchard *Sardinops sagax*. Mar Freshw Res 51:355–362
119. Gaughan DJ (2002) Disease-translocation across geographic boundaries must be recognized as a risk even in the absence of disease identification: the case with Australian Sardinops. Rev Fish Biol Fisheries 11:113–123
120. Marty GD, Hulson P-JF, Miller SE, Quinn TJ II, Moffitt SD, Merizon RA (2010) Failure of population recovery in relation to disease in Pacific herring. Dis Aquat Organ 90:1–14
121. Bartholomew JL, Reno PW (2002) The history and dissemination of whirling disease, pp 3–24. In: Bartholomew JL, Wilson JC (eds) Whirling disease: reviews and current topics. American Fisheries Society, Symposium 29, Bethesda, Maryland
122. Halliday MM (1973) Studies of *Myxosoma cerebralis*, a parasite of salmonids. II. The development and pathology of *Myxosoma cerebralis* in experimentally infected rainbow trout (*Salmon gairdneri*) fry reared at different water temperatures. Nord Vet Med 25:349–358
123. Nehring RB, Walker PG (1996) Whirling disease in the wild: the new reality in the Intermountain West. Fisheries 21:28–30
124. Vincent ER (1996) Whirling disease and wild trout: the Montana experience. Fisheries 21:32–34

125. Andree K, Hedrick RP, MacConnell E (2002) A review of approaches to detect *Myxobolus cerebralis*, the cause of salmonid whirling disease, pp 197–212. In: Bartholomew JL, Wilson JC (eds) Whirling disease: reviews and current topics. American Fisheries Society, Symposium 29, Bethesda, Maryland
126. Hedrick RP, Petri B, McDowell TS, Mukkatira K, Sealey LJ (2007) Evaluation of a range of doses of ultraviolet irradiation to inactivate the waterborne actinospore stages of *Myxobolus cerebralis*. Dis Aquat Organ 74:113–118
127. Hedrick RP, McDowell TS, Mukkatira K, MacConnell E, Petri B (2008) Effects of freezing, drying, ultraviolet irradiation, chlorine and quaternary ammonium treatments on the infectivity of myxospores of *Myxobolus cerebralis* or *Tubifex tubifex*. J Aquat Anim Health 20:116–125
128. Hedrick RP, McDowell TS, Marty GD, Fosgate GT, Mukkatira K, Myklebust K, El-Matbouli M (2003) Susceptibility of two strains of rainbow trout (one with a suspected resistance to whirling disease) to *Myxobolus cerebralis* infection. Dis Aquat Organ 55:37–44
129. Schisler GS, Myklebust KA, Hedrick RP (2006) Inheritance of resistance to *Myxobolus cerebralis* among F1 generation crosses of whirling disease resistant and susceptible strains of rainbow trout. J Aquat Anim Health 18:109–115
130. McBride MP, Sims MA, Cooper RW, Nyaoke AC, Cullion C, Kiupel M, FrascaJr S, Forrester N, Weaver SC, Weber ES (2008) Eastern equine encephalitis in a captive harbor seal (*Phoca vitulina*). J Zoo Wildl Med 39(4):631–637
131. Boerner L, Necvis KR, Hinckley LS et al (2004) *Erysipelthrix*-septicemia in a little blue penguin (*Eudyptula minor*). J Vet Diagn Investig 16:145
132. Hedrick RP, Marty G, Nordhausen RW, Kebus M, Bercovier H, Eldar A (1999) A herpesvirus associated with mass mortality of juvenile and adult koi *Cyprinus carpio*. Fish Health Newsletter, Fish Health Section, American Fisheries Society 27:7
133. Kocan R, Hershberger P, Winton J (2004) Ichthyophoniasis: an emerging disease of Chinook salmon in the Yukon River. J Aquat Anim Health 16:58–72
134. Chinchar VG, Essbauer S, He JG et al (2005) Iridoviridae. In: Fauguet CM, Mayo MA, Maniloff J (eds) Virus taxonomy: 8th report of the international committee on the taxonomy of viruses. Elsevier, London, pp 163–175
135. McVicar AH (1997) Disease and parasite implications of the coexistence of wild and cultured Atlantic salmon populations. ICES J Mar Sci 54:1093–1103
136. Marty GD, Saksida SM, Quinn II TJ (2010) Relationship of farm salmon, sea lice, and wild salmon populations. Proceedings of the National Academy of Sciences of the United States of America for P Natl Acad Sci USA. doi: 10.1073/pnas.1009573108 PNAS December 28, 2010 107(52):22599–22604
137. Hedrick RP, Batts WN, Yun S et al (2003) Host and geographic range extensions of the North American strain of viral hemorrhagic septicemia virus. Dis Aquat Organ 55:211–220

Lodging Resistance in Cereals

PETE M. BERRY
Sustainable Crop Management, ADAS UK Ltd, Malton, North Yorkshire, UK

Article Outline

Glossary

Anchorage failure moment Anchorage failure at the point of failure. Also described as anchorage strength.

Base bending moment Wind-induced force acting on the base of the shoot or the anchorage system. Also described as leverage force.

Brackling Lodging resulting from buckling of the upper half of the stems.

Crop management Agronomic methods of growing crops.

Failure wind speed Wind speed at which a plant will lodge.

Hagberg falling number (HFN) Measure of bread making quality.

Lodging Permanent displacement of cereal stems from their vertical position.

Lodging-proof ideotype Plant dimensions required to achieve a lodging-return period of 25 years.

Necking Lodging resulting from buckling of the stem just below the ear.

Plant growth regulators – (PGRs) Chemical growth regulators that reduce the rate of stem extensions.

Root lodging Lodging resulting from failure of the anchorage system.

Stem failure moment Stem strength at the point of failure. Also described as stem strength.

Stem lodging Lodging resulting from buckling of the lower stems.