ISAC
INVASIVE SPECIES ADVISORY COMMITTEE

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Marine Bioinvasions and Climate Change

Approved by ISAC on June 24, 2010

ISSUE

No ocean area is unaffected by human impact (Halpern et al. 2008). Marine bioinvasions are one of the greatest threats from human activity on this environment (Carlton 1996). However, our knowledge of the impacts of invasions is severely lacking for many key regions of the country and the world, and very little is known of the impacts from invasive species in relation to climate change (Sorte et al. 2010). Environmental consequences may include loss of marine biodiversity as oceans freshen, warm, and sea level rises. Additional impacts to native communities may occur as a result of ocean acidification and/or changing current and wind patterns.

An overall warming between 2.0 and 4.5° C is predicted in the next century as a result of global climate change (Solomon et al. 2007). This shift in temperature will affect marine ecosystems by raising water temperatures, decreasing oceanic pH, altering stream flow patterns, increasing storm events, and contributing to sea level rise. These changes are expected to have a substantial impact on the abundance and distribution of marine species as well ecosystem functioning and food webs. The Intergovernmental Panel on Climate Change (IPCC) has confirmed that range shifts among marine flora and fauna have already begun to occur in response to warming trends and include poleward and elevational shifts (Solomon et al. 2007).

Non-native species are those that evolved elsewhere and have been transported by natural processes or human activities, either intentionally or accidentally, into a new region. Invasive species are the subset of introduced species that persist, reproduce, and spread rapidly into new locations, causing economic or ecosystem harm or harm to human health (Williams and Smith 2007).

Invasive species share traits that may allow them to capitalize on the impacts of global climate change including fast growth, rapid reproduction, and the ability to survive in a wide range of environmental conditions.

Further, spcies that have long been “in motion,” but were failed invasions as a result of too-cold waters, will now likely invade these once "off limits" thermal regimes (Solomon et al. 2007). Consequently, a decline in cold-affinity or even "typical" resident species and an increase in warm-affinity residents can be expected, which will change species proportions as well as community structure and dynamics.

An estimated 10,000 marine species are transported around the world in ballast water *every day* (Carlton 1999). Biological invasions will be further aided by global climate change through increased dispersal of non-native species via ballast and hull fouling resulting from changes in maritime or recreational routes. Other consequences of global climate change may include increased diseases (Lawrence 2008), increased loss of calcified species from ocean acidification, opening of new habitat via inundation with increased disturbance to existing habitat from increased pollution and terrestrial runoff (Doney et al. 2009). Synergies among all of these processes are most likely. These outcomes will result in the decline of native species, create open space, and deliver new invasive competitors to habitats once held off limits by natural processes.

BACKGROUND

Invasive species are second only to habitat destruction as the greatest cause of species endangerment and global biodiversity loss. Invasive species can cause severe and permanent damage to the ecosystems they invade. Consequences of invasion include competition with or predation upon native species, hybridization, carrying or supporting harmful pathogens and parasites that may affect wildlife and human health, disturbing ecosystem function through alteration of food webs and nutrient recycling rates, acting as ecosystem engineers and altering habitat structure, and degradation of the aesthetic quality of our natural resources. In many cases we may not fully know the native animals and plants in an area. For example, *Aureophycus aleuticus,* a large kelp was just described with similar discoveries of new taxa in many other latitudes. Invasive species have the potential to permanently change ecosystems before we fully understand the native communities.

Recent studies suggest that invasive species share similar traits that allow for easier establishment in habitats that become disrupted by climate change. The examples below highlight some of the ongoing and expected changes to marine ecosystems that may occur as a result of the interactions between global climate change and biological invasion.

Sea Level Rise

Sea level rise has been estimated at 3.1 ± 0.7 mm yr-1 as a result of thermal expansion of water and the melting of continental ice sheets (Williams and Smith 2007). A rise in sea level of less than 1 m would submerge an estimated 10,000 square miles of land (Titus 1989). Existing wetland and salt marshes will be flooded and die, calling into question the types of communities that will replace these lost ecosystems.

Inundation could also disrupt groundwater flow from aquifers to ocean by altering the water table level relative to the sea level, potentially diminishing the delivery of essential nutrients to at least, tropical reef communities and disrupting coastal wetlands (Titus 1989). Native marine species will likely be subjected to increased turbidity and pollution resulting from runoff from the land. Although some native species will be able to adapt to the newly created habitats, the high level of disturbance caused by sea level rise will render marine communities particularly vulnerable to the introduction of opportunistic invasive species.

Increased Ocean Temperatures

Since 1961, ocean temperatures have risen 0.10° C from the surface to a depth of 700 m (Williams and Smith 2007). Warmer water conditions may facilitate the successful establishment of invasive species adapted to warmer environments. Such species may prey on or compete for food resources with native species, possibly leading to extinction unless the native species are able to find refuge at higher latitudes. Many regions have already experienced the impacts of warming coastal waters, demonstrating an alteration in species ranges. This alteration includes an expansion of organisms tolerant to warm waters, thus migrating poleward, and a reduction in ranges of cold water species, thus shrinking poleward (Solomon et al. 2007). For example, tropical algae have already successfully invaded now-warmer temperate locations and it is expected that tropical-to-temperate algal invasions may become more common. Some temperate invasive algae have been noted to become less seasonal and are now reproducing all year round whereas in their native ranges they have retained much stronger seasonality.

Increased ocean temperatures may result in the extinction of several species, which may lead to a complete alteration of ecosystems. For example, a shift in ocean temperatures by as little as 1° C above the maximum monthly mean results in coral bleaching, which negatively impacts the entire coral reef ecosystem. Animals, plants, and seagrasses that rely on the low-lying habitat provided by coral reefs are likely to be significantly affected, although these potential impacts are just beginning to be explored. Loss of coral will likely create open spaces, rendering the ecosystem vulnerable to invasion. Some invasive seaweeds are not as thermally sensitive as corals (Smith et al. 2004), thus warmer ocean temperatures may set a stage for these "weedy" species to thrive.

Changes to Salinity

Salinity trends are characterized by decreased salinity in oceans within subpolar latitudes whereas shallower waters of the tropical and subtropical oceans have shown increased salinity levels. Freshening is pronounced in the Pacific Ocean while increased salinity is found in the Atlantic and Indian Oceans. These trends are consistent with changes in precipitation that are a possible consequence of global climate change (Williams and Smith 2007).

Major shifts in the abiotic environment will result in a change in the existing species composition as there will be some organisms that will be unable to adapt to their new environment; therefore these species will be forced to disperse to adjacent habitats or become extinct. This loss of biodiversity may facilitate the establishment of new weedy / invasive species that are able to thrive in the changing environment.

Successful invasion may also be assisted by a change in the vectors responsible for introduction. For example, ballast water has been a major transport carrier for invasive species since the late 20th century as a result of the increased scale of global trade. This increase has encouraged the need for larger ships, traveling at faster speeds. As open water exchange is the most common ballast management practice used today, increased salinity in coastal waters may enhance the probability of survival of propagules in ballast water. Higher survival rates will increase the probable number of individuals released at a given place at a given time as well as the number of transported organisms that are capable of survival and reproduction following release.

Ocean Acidification

Uptake of atmospheric carbon dioxide by the oceans has already lowered the pH of coastal waters in urbanized regions and is expected to substantially lower oceanic pH over the next decades. The increase in total inorganic carbon causes a decrease in the depth at which calcium carbonate dissolves, causing a decrease in surface ocean pH (Williams and Smith 2007).

In tropical regions, entire (non-living) calcareous reef structures are at risk (Doney et al. 2009). In terms of the food web for these ecosystems, all organisms that photosynthesize, phytoplankton and seaweeds, will be impacted via changed concentrations and species of carbon for photosynthesis. Further, acidification directly harms the ocean's plants and animals that build shells composed of calcium carbonate. Calcifying species include corals, mollusks, crustaceans, and coralline algae that provide critical habitat and food sources for other organisms. Declining number and/or abundances of these species may promote the success of existing invaders or the colonization of new invaders—namely fleshy/ non-calcified algae. The introduction of competitive non-native species into an ecosystem may have a substantial, and often irreversible, influence on biodiversity, habitat quality, and ecosystem functioning.

Change in Ocean Circulation and Currents

Decreased upwelling due to warmer waters will result in fewer nutrients being transported from deep in the water column to the water surface (Williams and Smith 2007). The productivity of marine ecosystems will be reduced as these areas depend on the delivery of nutrients from upwelling areas and ocean currents. Species that depend on ocean currents for reproduction and migration will also be affected. For example, many coral and fish species rely on dispersal of their larvae by currents; therefore, changes in circulation will result in lower recruitment into new areas, reducing species dispersal as well as overall habitat diversity. The disruption of recruitment could facilitate the establishment of invasive species as newly opened areas will be vulnerable to the introduction of these opportunistic species.

Evidence that Change has Already Occurred

There is evidence that some marine species have already responded to climate change. For example, in 1999 the marine diatom, *Neodenticula seminae*, was found in the Atlantic Ocean during routine plankton surveys (Reid et al. 2007). This diatom migrated from the North Pacific to the Atlantic Ocean as a result of the diminishing ice cover in the Arctic which opened up a temporary passageway between the Arctic and Pacific Oceans. The presence of the diatom in the North Atlantic, establishing itself in areas where it was last found during the Pleistocene, indicates a change in the circulation between the North Pacific and North Atlantic oceans as a response to the major climatic and oceanographic changes that have taken place in the Arctic in recent years (Reid et al. 2007). As sea ice diminishes, we will continue to see changes in the distribution, composition and abundance of algal species. Algae are the foundation of most of Arctic trophodynamics, and thus these changes will produce a cascading effect through the food web.

Range shifts are defined as changes in the distribution of native species that are not directly human mediated. As a result of global climate change, many species will migrate to maintain the temperature conditions needed for reproduction, growth, and feeding. There is a growing concern that these shifting species will begin to function as invasive species, disrupting the structure and function of their new community. Over 100 marine range shifts have already been documented; these cases are likely only a fraction of the marine species that have moved or are in the process of moving (Solomon et al. 2007). This trend, illustrated in the examples below, has been seen in a broad range of taxa including algae, bryozoans, cnidarians, crustaceans, and mollusks:

- *Caulerpa taxifolia*, the "killer algae," is a tropical seaweed that has already been able to invade temperate regions. This algal species has rapidly colonized the Mediterranean, where it covers the bottom and fills the water column with hundreds of tons of plant biomass per hectare. Infestations in California took 6 years and over $7M to eradicate. With warming seas around many temperate coastlines, *Caulerpa* invasions may become more common.
- The Pacific Lionfish *(Pterois volitans)* was first detected in Florida in 1990s and is now common off the Carolinas. As of 2009, the tropical fish was found as far north as Cape Cod during the summer months. Warming conditions probably will permanently expand the range of this fish along much of the eastern coast of the United States. The broad diet of the lionfish suggests that this invasive species may become a real threat to many native reef fish populations through direct predation as well as competition for food resources with native piscivores. Further, its voracious feeding behavior may impact the abundance of ecologically important species such as herbivorous fishes that keep seaweeds and macroalgae from overgrowing corals.
- "Caribbean Creep" is defined by the invasion of Georgia, the Carolinas, and Chesapeake Bay by tropical and subtropical species. Species that have successfully invaded these temperate areas include the Brazilian green porcelain crab (*Petrolisthes armatus),* Florida rocksnail *(Stramonita haemastoma*), the Indian caprellid crustacean (*Caprella scaura*)*,* and the Asian-Pacific Titan acorn barnacle (*Megabalanus coccopoma*). These are not one-off occurrences of individuals of southern species; these examples represent permanently established populations of species that previously found the South Atlantic Bight and Chesapeake Bay too cold to live in.
- The New Zealand pillbug, *Sphaeroma quoianum*, invaded Oregon in the 1990's. This isopod crustacean creates burrows within banks composed of mud, clay, or peat. The system of interconnected burrows within the banks has led to an increase in erosion rates by as much as 250% in many estuarine environments. The burrows also damage docks, wooden structures, levees and dikes. The invasion into substances such as Styrofoam can disperse microscopic polystyrene particles into local waterways; 100,000 isopods in a Styrofoam float release more than 20,000,000 styrene particles per day into the ocean.

RECOMMENDATIONS

Changes in the Earth's climate will likely continue, or even accelerate, over the next century. The economic, energy, social, and environmental impacts of invasions mediated by climate change may be profound. Our understanding of climate-driven species movements is only the tip of the iceberg: a great many more species are in motion. Predictions of how species and their habitats will respond to climate change will assist in making conservation decisions and managing our natural resources. Invasive species management will need to develop tools that include both invasion biology and climate change impacts. The following are recommendations to assist the development of such tools:

Fund Research Programs

Dedicated research programs across a diversity of regions (e.g. high, mid and low latitude sites) must be developed and adequately funded to detect species movements and likely interspecies interactions, in order to predict, and possibly prevent, the impact of invasion resulting from global climate change. These goals will best be accomplished via focused, mechanistic studies of invasive species to inform and predict how global climate change factors may impact native species, invasive species and interact with local stressors to affect invasion success.

Increased Coordination

Build partnerships among federal agencies and academic institutions to enhance capacity for detecting, responding to, and managing invasive species.

Develop Rapid Response Plans

Risk assessments are needed to prioritize species that deserve rapid responses. Strategies need to be developed for rapid response to these species. Further, an emergency fund for such efforts should also be established.

Vector Management

These scenarios of the "ghost of Christmas future" support the need to strikingly enhance vector management policies to prevent future invasions.

Expand Educational and Outreach Programs

It is imperative for the public to understand the implications of their actions, with or without the climate change message. Increased efforts should be initiated to translate the combined risks from climate change and biological invasion to the public through real-world examples.

National Strategy for Monitoring

Global climate change will result in the loss of species; yet without adequate monitoring the extent of this loss may not be known. For example, some species are endemic to Alaska; however, as a result of the large size and remoteness of the state, many species still are unknown. Extensive monitoring across environments is needed to document the distribution of native species, identify range shifts, and detect invasions.

ACKNOWLEDGEMENTS

This paper was drafted by James T. Carlton, Williams College; Sandra C. Lindstrom, University of British Columbia; Celia M. Smith, University of Hawai'i; Jennifer E. Smith, Scripps Institution of Oceanography and reviewed by a range of stakeholders with expertise in marine invasive species issues.

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