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An Introduction To Marine Invasive Species

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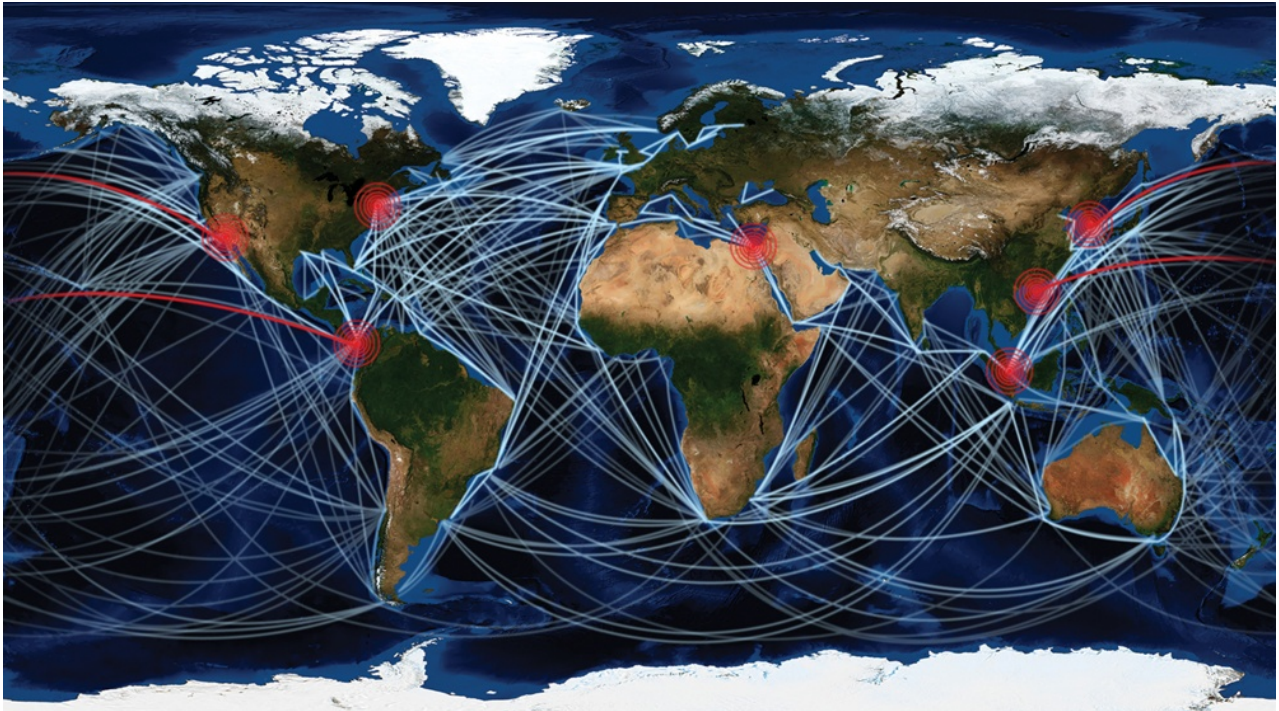
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AN INTRODUCTION TO MARINE INVASIVE SPECIES

Written by the MAR 442 course
of the University of New England
2014

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Preface

Countless marine species are invading new environments with devastating effects on the ecosystem, the local and global economy, and on human health. The frequency of marine invasions has been increasing in recent decades with a respective raised interest of invasive species in the scientific community, and the general public. The Aquatic Invasive Species class (MAR442) at the University of New England offers an informative overview of invasive species, targeting educated readers with a general interest in invasive species biology.

Students in the MAR 442 class have worked on identifying the most important topics on marine invasive species, have reviewed the respective literature and written chapters that provide both a broad overview of the general aspects on marine invasions, as well as a set of individual case studies that illustrate different specific aspects of marine invasions. The class, comprised of fifteen junior and senior marine biology students, selected the different topics, presented the material, wrote the drafts, edited the drafts and assembled the final versions into this book. With a wealth of information on invasive species assembled in peer-reviewed articles, books, other literature, websites, data-bases and more, this book cannot claim to be all inclusive. However, we think that this book will provide an excellent broad overview of the most important aspects of marine invasion biology, and will furthermore provide very specific information on selected topics.

Kiera O'Donnell
Wyler Scamman
Markus Frederich

Biddeford, Maine, December 2014

The photo on the cover page illustrates global shipping routes that present the most important vector for transporting marine invasive species. See more on the topic of shipping as a means for transporting marine species around the globe in the chapter on vectors (page 16).

Photo credit: <http://discovermagazine.com/galleries/2014/march/invasive-species>

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Introduction

By Abby Doane and Angela Henrich

Edited by Hanna Pultorak, Kiera O'Donnel, Blaise Jenner, and Ashleigh Novak

What is an invasive species?

What exactly is an invasive species? According to Merriam-Webster the word “invasive” (adj.) means, “tending to spread”. Therefore, the basic meaning behind the phrase “invasive species” is “a species that tends to spread”. This spread can be seen as extremely harmful, having some benefits, or it can have no visible effect on the invaded ecosystem. Due to all of the possible meanings for invasive species, this book will use one definition. The chosen definition states that an invasive species is “any species reported to have become established outside its native range” (Molnar *et al.* 2008). The focus of this book will be on marine invasive species.

Any species found outside of its native range is seen as invasive, and they are usually introduced via anthropogenic vectors; see Chapter three. However, one important distinction is whether or not the range expansion of a species into a new ecosystem makes it an invader. According to the chosen definition, an invader is anything established outside its native range. Since range expansion is when a native species expands its habitat, then these species must be considered invasive. One study looked at the recent expansion of bivalves out of the tropics (Berke *et al.* 2014). The researchers found that bivalves now inhabit regions that they have not been in previously. Bivalves are highly adaptive and are evolving to survive in their new habitats. Since these bivalves are now found further north than ever before it shows that range expansion leads to the establishment of invasive species.

Another interesting study looked at how hurricanes can affect range expansion of certain species. It was found that in salt marshes, the harsh winds and expansive floods from hurricanes create dead patches in the marsh (Bhattarai *et al.* 2014). The invasive common reed, *Phragmites australis*, is the

first of the reeds that is able to grow back in a dead zone because they out-compete the native species and are able to quickly take over the area. The disturbance caused by hurricanes is suggested to facilitate range expansion in *P. australis*. No matter what causes range expansion in a species, once a species enters a new range it is officially an invader.

A species is considered invasive when it is found outside of its native range and therefore, it is important to know when the invader first arrived. Marine invasive species have been a problem for as long as ships have been traveling the seas (STS 2012). Traveling from one geographic location to another allows for the introduction of non-native species. These early introductions were due to species attaching to the hulls of wooden ships and being transported to a new habitat (NISC 2014). As the frequency of travel by sea increased, the number of invasive species worldwide soon followed. One of the earliest introductions on record for a marine non-native species is the European green crab, *Carcinus maenas*, which was first found in 1817 on the east coast of the United States (Carlton *et al.* 2003). Although some marine invasive species have been in an area for hundreds of years, they are never fully considered natives.

Understanding when and where a species came from can aid in finding a way to handle the effects of invasive species. Alien species can have an enormous amount of negative impacts on an ecosystem, which will be discussed in detail in the following chapter. However, some key numbers that illustrate these impacts are that in the U.S. there are approximately 50,000 non-native species and the country loses \$120 billion per year due to invasive species (Pimentel *et al.* 2004). These numbers are a broad overview of the impacts of both terrestrial and marine invasive species. Another number that is important to know is that 42% of the species on the

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Threatened or Endangered Species lists are at-risk because of non-native species (Pimentel *et al.* 2004). It is clear that invasive species are a costly problem, which is why it is so vital to know about them.

Overview of Book Chapters

This book will cover a wide range of information about marine invasive species including impacts, distribution, barriers & vectors, adaptations, climate change and possible solutions for invasive species. Through these topics, the idea is to gain a greater knowledge about the invaders around the world. On top of information about the invaders themselves you will also begin to understand the involvement human beings have with the growing topic within the science community. To conclude, this book will outline various case studies that show examples of the topics detailed in the following chapters.

The second chapter of this book, after this introductory chapter, will cover the impacts invasive species have on society, the economy, the environment, and on human health. Socially, invasive species can clog fishing gear, creating problems for fishermen as well as being a contributor to erosion. Fishermen start to have trouble with their businesses while erosion can decrease the property value and lead to problems for seaside homeowners. Economically, invaders cost the United States a lot of money through the effects it has on the fishing and fishery industries as well as affecting the tourist industry. Invasive species also have some pretty harmful effects on the environment. They can push out native species and affect the habitat and water quality of the area they take over. Impacts regarding human health can include cholera that can be transferred through ballast water and algal blooms can lead to gastrointestinal disease.

Chapter three will discuss the distribution patterns of invasive species. This chapter will cover topics like the factors that make certain habitats better for invasive species. It will discuss how some historical attributes can contribute to distribution, Chapter three will also touch on adaptations that contribute to the distribution of invasive species with a more detailed chapter on adaptations later in the

book. On top of these areas of distribution, the chapter will go into possible hot spots and invasive free zones and how these areas fit into such a category.

Chapter four will cover the natural barriers and vectors of invasive species. Barriers like landmasses and the physical attributes of water contribute to the successfulness of an invasion but the successful invaders have many means of getting to their non-native location. After detailing some of the natural barriers, this chapter will also talk about the four main vectors that invasive species use to get from one location to another. Shipping (both from ballast waters and fouling), aquaculture, aquarium trade, and canals are four common vectors that account for a large percentage of all vectors invaders use. This chapter will go more in depth about how these vectors are used.

Chapter five will go on to talk about the evolutionary adaptations that invasive species have acquired to be successful. These creatures have gained certain reproductive adaptations, like producing a greater number of offspring, they have also gained various survival adaptations, including; burrowing and other behavioral adaptations that make them better competitors during harsher weather. Invasive species have also gained feeding and physical adaptations by becoming generalists when they eat and having structures that make them more resilient to their new habitat. This chapter will describe why some of these adaptations are so helpful to the invaders and give examples of species that use them in various situations.

Chapter six of this book is about climate change and the effects it has on invasive species. With temperatures rising, the ocean's chemical composition is changing, giving it qualities that may be aiding invasive species. This chapter will talk about what is happening to the oceans and what that has to do with the effects on invasive species. It will also discuss range expansion and the factors contributing to this idea as well as whether or not species moving because of range expansion are actually invasive.

To conclude, chapter seven will talk about some of the things that are and can be done about invasive species. It will discuss research, prevention,

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education, management, and awareness. These ideas encompass not only scientists and educators but also “citizen scientists” and everyday people who need to be aware of the species invading in their area. It will also discuss how invasive species could be utilized, as well as the possibility of removal. As an example, some studies are being done to market invasive species as food such as lionfish and green crabs. Chapter seven will go into more detail.

After discussing the information on invasive species, this book will go on to include many case studies on species from around the world. They include both floral and faunal examples of invasive species and all have their own stories attached. All case studies will show real life examples of the information laid out in chapters two through seven of this book. After reading through the information provided as well as the case studies, this book will give a comprehensive overview of invasive species and the human interaction that comes with them in the marine environment today.

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Impacts of Invasive Species

By: Jake Farrell & Chris Lockwood

Edited by Hanna Pultorak & Kiera O'Donnell

Issues from invasive species are becoming more widespread and more common as we are becoming more aware of how these problems affect everyday aspects of life. When looking at this issue, we can break up the impacts marine invasive species cause into a few subtopics. This chapter will discuss the major ecological, social, and economic impacts and their resulting affects.

In order to discuss the impacts caused by marine invasive species, first we must discuss the ecological effects. When an invasive species is introduced to an ecosystem 99% of the time it does more damage than good to the ecosystem it's residing in (Bax 2003). One of the most common effects that an invasive species has on an ecosystem is that it competes with native species. This is a major stress factor for natives because with this new introduction there is an increase in competition for resources. Native species are often out-competed by invasive species when it comes to acquiring resources. In some circumstances natives can even be driven from their habitat since they are not able to compete. An example of an organism that was introduced and began out-competing native species is the European green crab (*Carcinus maenas*). *C. maenas* was first

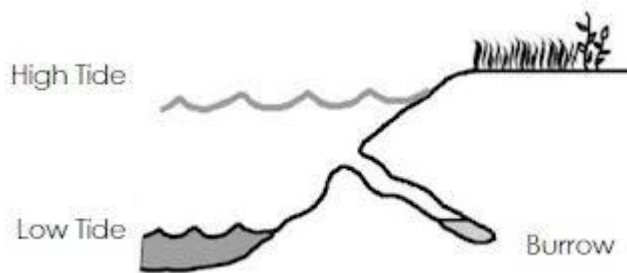


Figure 1. Chinese mitten crab burrows.

introduced to the United States in 1817 accidentally. It quickly began to flourish and expand. Once *C.*

maenas was introduced it started competing with many species such as clams, mussels, snails and other crabs. This new competition by *C. maenas* has had extreme negative effects on the bivalve industry. Another impact is that *C. maenas* indirectly affects the life of terrestrial organisms. One example of this effect is *C. maenas* preys upon mussels that are favored by local oceanic birds. This predation removes a major food source for these birds, thus indirectly affecting the life of these terrestrial organisms. Some other examples of invasive species include green algae (*Pediastrum boryanum*), comb jellyfish (*Beroe spp*), and the Asian clam (*Corbicula fluminea*). All of these species have negative impacts that range anywhere from destroying fisheries to having negative health effects on humans.

Invasive species do not only have ecological effects but they come with multiple social impacts as well. The most common impact is the effect a certain invader has on fishing gear and fishing activities. Examples are the cladoceran water flea (*Daphnia*) which is known to clog fishing gear and fishing nets or an invader such as *C. maenas* preying heavily on a certain native species, which lowers the number of harvestable fish. The issues that are not always in the spotlight vary; one important example is the Chinese mitten crab (*Eriocheir sinensis*). *E. sinensis* burrow into the edges of riverbanks which causes embankments to erode which can decrease property value.

Visitors from all across the United States visit coastal towns to enjoy beaches, attractive views, and inviting coastal waters. However this can all be affected by invasive toxic algae (*Caulerpa taxifolia*), which can create large algal blooms. An algal bloom is a large accumulation of algae in an aquatic system. These blooms produce natural toxins that can kill large amounts of marine life and can cause the

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closure of public beaches and other marine activities. This can affect tourism and recreational activity.

The largest impact that invasive species have is their effect on families' incomes and on the economy, whether it is from loss of income or required taxes to use public area. An example of taxation is the Maine milfoil sticker, which is Maine's way to pay for efforts to reduce the spread of invasive Milfoil throughout the state. Invasive species are typically very expensive to control and prevent.

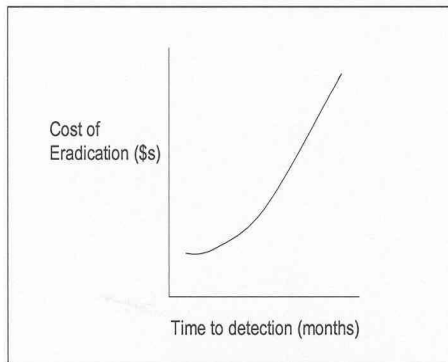
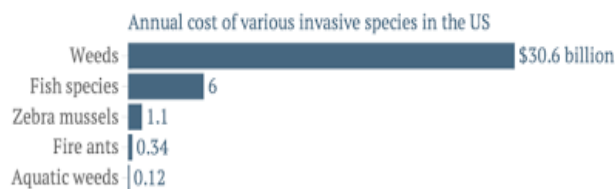


Figure 2. Cost of eradication.

One of the most spotlighted invasive species, the zebra mussel (*Dreissena polymorpha*), has made a huge impact on intake pipes to factories and irrigation ditches. *D. polymorpha* had a projected cost to the United States of around one billion dollars between the years 1989-2000.



Quartz | qz.com

Data: "Economic Impacts of Invasive Species," University of Oregon

Figure 3. Estimated costs of invasive species.

D. polymorpha has cost the state of Massachusetts over \$350,000 a year while having to pay for staff, equipment, prevention, control packets/presentations and boat ramp monitors. Another invader, which has been in the spotlight for destruction, is *C. maenas*. It has been a nuisance for the bivalve shellfish industry. *C. maenas* have worked their way north eroding wetlands and depleting the number of juvenile clams, in turn

threatening Maine's \$25 million bivalve industry (Bryne 2013). These crabs reduce the number of clams available for harvest, which limits the amount of clams caught by the fisherman and therefore removing large sums from their income. These large invasions not only hurt the fisheries but damage an area's tourism revenue as well. Invasive species affect recreational activities, which deter tourism causing less money to be spent in a certain area that relies on the tourism industry. For example, lionfish can have negative impacts on coral reefs, which are a large source of tourism for some countries such as Jamaica. Marine invasive species cost the United States billions of dollars every year and with new invaders being discovered everywhere the United States could be looking at a debt of \$134 billion by the year of 2050 (NDW 2011).

Aside from ecological, social, and economical impacts, these invasive species also have quite a few health impacts. Blue green algae (*Cyanophycota*) has been known to cause many adverse health effects that range from small illnesses like skin and eye irritation or even death. This alga contains toxins that are essentially harmless in small doses but when there is an algal bloom, large amounts of the toxins can be harmful on human health, and fish and shellfish health. Fortunately enough there have been no recorded human deaths due to an algal bloom to date. There was one occurrence where a woman passed out due to the lethal gas emissions (Chrisafis 2009). On the other hand, there have been deaths to various marine species such as otters and manatees. Harmful algal blooms are also referred to as "red tide". Red tides are caused by large amounts of dinoflagellates, which are often red or brown in color and make the water appear red. These have primarily the same effects as *Cyanophycota*, as contaminated shellfish when consumed by humans may cause gastrointestinal illness, neurological damage and possibly death. Another major health risk caused by invasive algae is cholera (*Vibrio cholerae*). This disease affects millions of people worldwide each year. Ingesting the bacteria via drinking or eating contaminated water and food transmits cholera. It is transported through ballast water and some foods. The health effects of the disease are diarrhea, vomiting, dehydration, and unless it is not treated, death. There is much more to

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learn about these species and how to combat their negative effects.

When it comes to invasive species it is extremely difficult to find one that has positive impacts on the environment. Most invasive species compete with native species or have no effect at all. The New Zealand screw shell (*Protoma capensis*) is one of the very few invasive organisms that have shown positive effects to the environment after being introduced. *P. capensis* was introduced to New Zealand as well as other surrounding countries in 1920. When introduced *P. capensis* began to start spreading, it reproduced in large numbers and spanned all over the continental shelf. Along the continental shelf is soft sediment; while *P. capensis* spreads along the shelf it covers the shelf with a calcareous material that hardens the substrate. This new hard substrate is a positive effect because it creates homes for many different species of marine flora and fauna. When *P. capensis* eventually dies, it leaves its vacant shell scattered along the seafloor, which creates homes for hermit crabs and other organisms.

Impacts of invasive species have become an uphill battle stressing the boundaries of ecological ecosystems, damaging native habitats, and causing dwindling resources within these areas. These invaders have had strong social impacts affecting people's livelihoods, property value, and shutting down public locations. Economically invasive species can have detrimental effects on fisheries and recreational tourism. Invasive species are always going to be present in our ecosystems. Learning how to cope with the impacts of invasive species will always be difficult while we try to alleviate their negative impacts.

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Distribution of Invasive Species

By: Teresa Berndt, Natasha Bourdon, and Laura Doyle

Edited By: Abby Doane, Jake Farrell, Angela Henrich and Chris Lockwood

Invasive species can be found in almost every place on earth, but there are some areas that have more invasions. This chapter will start by looking into what makes some location more susceptible to invasive species than others. Then it will continue on to look at specific areas with high amounts of invasive species as well as areas with extremely low amounts of invasive species.

Before looking at the specific distributions of marine invasive species it is best to understand what makes those locations different from the rest of the world. Certain places in the world are considered invasive hotspots, meaning they have a high amount of invasions, while other areas experience very few invasions. There are influences that make certain places more susceptible to invasions than others. The top three influences are the climate of the location, the amount of introductions a species has in the area and the history of invasions in the location. These influences, among many, need to be present for the rest to be effective (Hayes and Barry 2008).

Climate

The first influence is climate. The environment of a location is determined by many components and organisms can only live within these certain areas. The best environment for an invasive species is one that is similar to their native environment. Components to the climate include, temperature, water composition, sunlight and depth. The closer to the climate of the native range, the easier it is for the organism to thrive. Some locations may even have conditions that are better for the organism than their native ones. A recent study in Iceland shows how similar temperatures make it easier for a species to invade. The study looked into the reasoning behind a recent invasion

of Atlantic rock crab, *Cancer irroratus* (Gislason *et al.* 2014). In the past, larvae for the species have been observed in the ballast water from ships coming from North America, but they never matured into adults. In 2006 a colony of mature breeding Atlantic Rock Crabs were found in a fjord in Iceland. After studying the population, one of the main reasons discussed for the sudden establishment was temperature change. Over the last 10-15 years the waters around Iceland have been warming. The temperature of the water is now closer to the temperature of the Atlantic rock crabs native habitat. The researchers suggest that this temperature change is the main reason the Atlantic rock crab has finally become successful in Iceland.

Research is being done to look into new ways to predict which area a species can successfully invade. The most promising of these methods is ecological niche modeling. This modeling system uses “climate-matching” to determine the best locations for an organism to thrive. Climate-matching involves first looking into the elements that make up an organisms native niche. It then looks for those same elements in other areas, labeling them “currently at risk” for an invasion. The model can also predict areas that the organism is able to survive versus areas it will have a high rate of success. One example of the use of this model was done on the freshwater plant, *Hydrilla verticillata*. (Peterson 2003) This plant is native the Southeast Asia, but has recently invaded the United States. The ecological niche modeling was used to model its native habits and then look at what areas in the United States are possible invasion areas. This model has not yet been used to model marine environments yet. The researches are modeling freshwater and terrestrial organisms to gather more information about the application of

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the model before they work on marine species. The figures below illustrate the models created.

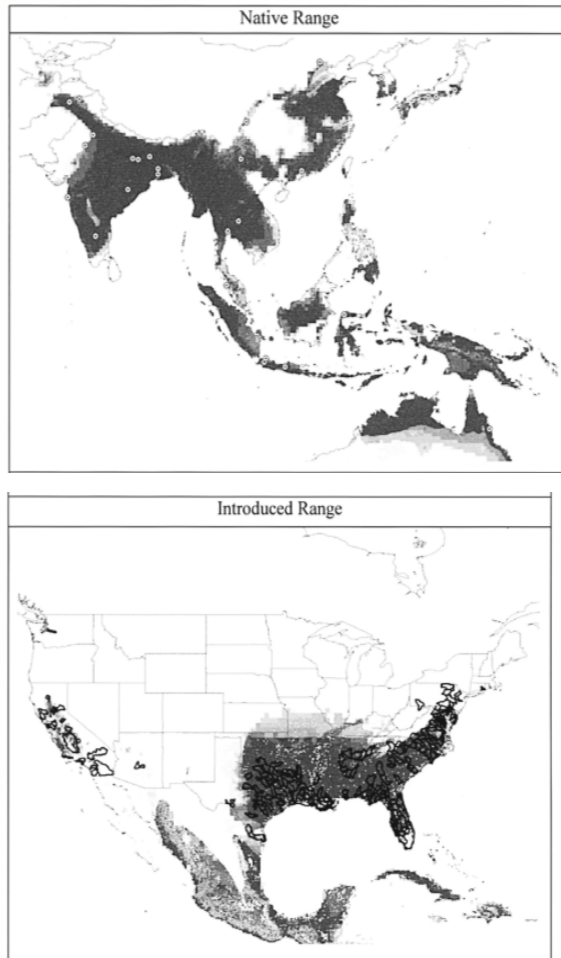


Figure 1: The top image is this figure shows the projected native ecological niche model for *Hydrilla verticillata* in Southeastern Asia and the Australo-Pacific. The bottom image shows the projected ecological niche model of the species invasion in North America. The darker regions indicate a higher confidence in presence of the species. The areas outlined in black show water shades that have been invaded. (Peterson 2003)

On the map featuring the plant's native range, the darker the shading the higher abundance the plant is found in. On the map of the United States the darker shading indicates areas of greater confidence that an invasion will be successful. The areas outlined in black show places the researchers tested and found established colonies of *Hydrilla*. These areas were tested to show the accuracy of the modeling system. This model can now be used by scientists to plan ways to prevent the species from

traveling to new areas, because they know the spots they are most likely to invade next.

Amount of Introductions

The second influence is the amount of introductions. An introduction is when an organism is deposited into a new location. This can be done by many different vectors, which will be discussed later in this book. The more introductions a species has to a new location the higher its rate of success. Introductions help to create a base population of the invaders. The more introductions, the larger the base population will be, which help the organism acclimate to a new location much more quickly. Large numbers help invaders better fight against any native species that will compete against them. Large numbers also help non-native species to produce more offspring, which creates generations of established adults. Areas that receive a species from many different kinds of vectors are more likely to have an invasion. One of the most common places for invasive species population to start is in a port. Species are commonly released in to new ports due to shipping vessels. Those ships deposit larvae from ballast water and adults from hull fouling (these methods will be explained in a later chapter) Ports with high amounts of shipping have ships coming in from the same locations, bring the same species into the port. This high number of introductions occurring in one place makes ports highly susceptible to invasions (Hayes and Barry 2008).

History of Invasion

The third influence of an area's likelihood for an invasion is the location's history of invasion. If an area has had invasions in the past it usually means that the first two influences are already present. Also, past invasions may have altered the natural ecosystem to allow some niches for new invasive species. The most common reason of the open niches is that a previous invasive species has pushed a native species out. The species that was pushed out could have been a predator to the newest species coming in or it could have eaten the same food source. The loss of the native species could open up a habit for the invader to live in or on that was previously occupied. The past invasive species could also help the new one to thrive by being a

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food source for the new invaders. They could provide a living space or protection to the new species (Hayes and Barry 2008). One example of an invasive species helping another involves the Pacific oyster, *Crassostrea gigas*. These oysters is native to eastern Asia but has spread around the globe primary due to aquaculture. *C. gigas* is known for carrying ‘hitchhikers’ with them. Hitchhikers are organisms that attach to the inside or outside of the oysters shell. The oyster then acts as a transport vessel for the other invader. One of the most noted species that *C. gigas* has helped is the Japanese Kelp, *Undaria pinnatifida*. *C. gigas* has been named the cause of the *U. pinnatifida* invasion currently occurring in Europe. *U. pinnatifida* is known as one of the most invasive species in Europe. *C. gigas* is responsible for bringing one of the most invasive species to an area that has already been invaded by several invasive species. (Science for Environment Policy 2014)

Hotspots

There are invasion hotspots across the globe. Hotspots are places with high amounts of invasive species. Invasions can be seen most in areas of heavy ship traffic. Coastal areas are highly susceptible to invasions because the ecosystem is so fragile. Ship ballast water is the reason for coastal shipping ports being invasion hotspots. This vector of invasive species transport will be explained in more detail in later chapters. It has been proven that ballast water is the cause for many invasions. The comb jelly, *Ctenophora*, came from North America to Europe via ballast water and virtually wiped out the entire anchovy stock in the Black Sea (Akoglu *et al.* 2014).

Marine invasive species are found in all continents across the globe. There are a few select areas that have more invasive species than others. Figure 2 illustrates the amount of marine invasive species along to coasts of continents. Europe, North America, and the Mediterranean Sea are the three areas with the most invasions (Molnar *et al.* 2008).

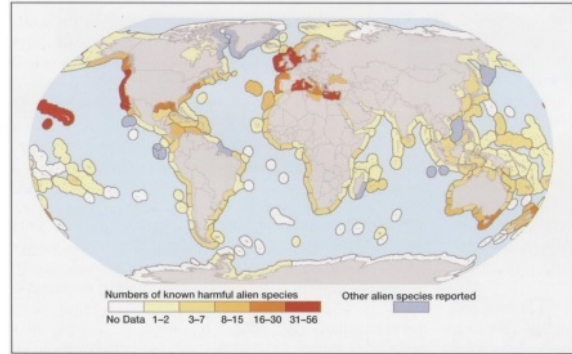


Figure 2: Map of the number of harmful alien species by coastal ecoregion, with darker shades indicating a greater number of species with high ecological impact scores (3 or 4). Ecoregions in which only less harmful species have been documented are shown in dark blue. (Molnar *et al.* 2008).

The North Sea in Europe houses many of the invasions in Europe, with eighty invasive species alone. One of the organisms that has taken over in this area and is continuing to expand rapidly throughout Europe is *Balanus improvisus* (Bay barnacle). This is a barnacle that has become a highly renowned competitor. This barnacle is able to outcompete native species as well as foul organisms, such as blue mussels or oysters. In a study, scientists were looking for safer anti-fouling techniques to keep organisms such as *B. improvisus* off of ship hulls. These barnacles can put boats out of commission if they manage to get into pipes or an engine. This study found that by using a type of marine sponge, it could prevent *B. improvisus* from settling in the first place. It would also be a less toxic alternative to very harmful current anti-fouling paint (Sjogren *et al.* 2004).

The Mediterranean Sea, with massive shipping ports and the connection to the Suez Canal, is home to over 500 invasive species (Galil 2007). A mussel species, *Brachidontes pharaonis* was first recorded in 1876, making it one of the Mediterranean Sea’s earliest invaders, entering through the Suez Canal. After arriving in the easternmost part of the Mediterranean Sea, *B. pharaonis* out competed a native mussel, *Mytilaster minimus*. Over time a series of studies were conducted, analyzing the rate of this invasion. As of the early 1970’s, *B. pharaonis* was still less abundant than the native species (Safriel and

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Sasson-Frostig, 1988). In the 1990s, however, *B. pharaonis* population increased, with dense populations of 300 mussels per 100 cm² (Rilov et al., 2004). The displacement of the native species, *Mytilaster minimus*, by this larger, thicker shelled species, altered the feeding patterns of predators.

Another invasive species in the Mediterranean Sea is the green algae, *Caulerpa taxifolia*. This species was released in the Mediterranean in 1984, due to aquarium trade. With its high growth rate, and ability to form dense fields on variety of different substrates *C. taxifolia*, could be considered a ‘model invader’. Upon replacing the natural algae, *C. taxifolia* in its peak releases a toxin that prevents other marine species from feeding on it, which can eventually result in a major decrease in biodiversity (Galil 2007).

The Mediterranean Sea has a large amount of marine invasive species. However, the impact of each of these species is not well known. It is believed that many invasive species have an effect on the keystone species causing major shifts in the food web and biodiversity.

In North America there is a recorded total of 298, non-native species; an insignificant number compared to the 500 recorded in the Mediterranean Sea. In South America many of the invasive species are not well known, therefore their impacts are not well known. A study conducted in 2000, showed the invasion rates of North American coasts: East, West, and Gulf from 1790 up until 1970. (Ruiz et al., 2000)

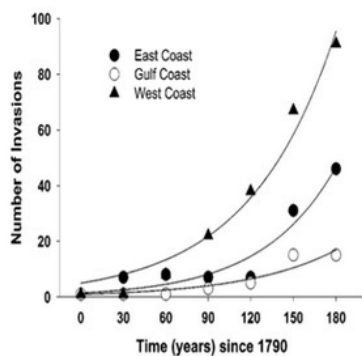


Figure 3: Rate of reported marine invasions of invertebrates and algae for each coast of North America since 1790. Filled triangles indicate the number of new invasions for the West Coast. The East Coast is filled circles and the Gulf Coast is open circles. Data is plotted in 30 year intervals. (Ruiz et al. 2000).

There is a clear trend that shows that as the years progress the number of invasions increase. (Figure 3) The figure shows that the West coast has a higher rate of invasions, compared to the East and Gulf Coast. This is possibly because the West Coast has a larger number of shipping ports, in comparison to the East and Gulf Coasts.

The subphylum, Crustacea and the phylum Mollusca, both have a high number of invasions in North America (Ruiz et al., 2000). The crustacean, *Carcinus maenas* (European green crab) is one of the most successful marine invaders, in not only on the West and East coasts of North America, but in Australia, South Africa, Japan, Tasmania, Northern Canada and Argentina (Darling et al., 2008). *C. maenas* was first introduced to the East coast in the early 19th century, and then spread north along the East Coast. In the early 1990s, *C. maenas* was found in the San Francisco Bay, where it then continued to spread north and south of the bay (Grosholz and Ruiz, 1996). Having the ability to endure a large range of salinity and temperatures allows *C. maenas* to potentially be a successful invader anywhere it lands. With a high reproduction rate, the green crab is a major threat to not only the biodiversity in the oceans but a threat to aquaculture. Populations of *C. maenas*, due to its success and reproduction rate, are almost impossible to control. This topic will be discussed further in a later chapter.

Invasive Free Areas

Not all areas of the planet have invasive species. Places that do not have invasions are areas where the conditions are too harsh for organisms that were not already presently living there. Places such as deep-sea geothermal vents are not likely places that invasions will take place. Vents are hot, acidic places where reduced hydrothermal fluids mix with cold, alkaline, oxygenated seawater to create sulphate deposits (Reysenbach et al. 2006). These hydrothermal fluids have very low pH levels, below 4.5, but no thermophilic bacteria have been excluded from these areas (Reysenbach et al. 2006). Living in these conditions is very harsh for non-natives, which not have already adapted to this environment.

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Places like the pelagic zone of the ocean are also not likely places for invasion. This area is the open ocean between the surface and the floor, away from coasts. Most organisms living there are free floating and don't need substrate to survive. It is incredibly difficult for a benthic creature that was able to survive the trip from its native country to the invasion site to be able to survive living in the pelagic zone. Invasive organisms end up in the pelagic zone due to the catch and release of ballast water. Releasing ballast water into the pelagic zone allows for possible invasions.

The last area that is invasive free is the deep ocean. This area is extremely dark, with zero light penetration, and has incredibly high pressures. With that being said, it would be difficult for a species living in a coastal zone to live down in the deep sea, as well as any creature needing sunlight to produce food. The deep sea is not affected by small changes in the earth's dynamics, therefore, the organisms living there are not affected very much either, leaving the area in stable living conditions (Maggio *et al.* 2008).

There are many different climate factors that make an area conducive for invasions. Organisms that can vary in a wide range of environmental conditions are usually the ones who are able to survive in the invasive areas. With the impending threat of climate change, which will be discussed in a later chapter, this could increase areas that are vulnerable to invasive species. As technology increases, possible invasion locations can be identified earlier, and things can be done to prevent invasions.

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Overcoming Natural Barriers: Vectors and Pathways

By Alec Stromeyer and Wyler Scamman

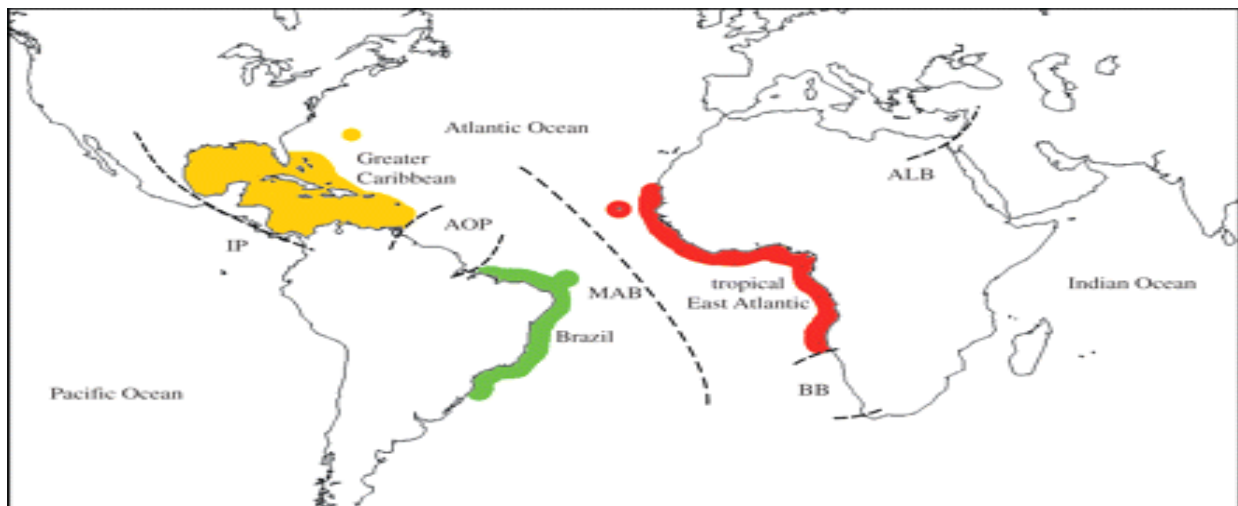
Edited by Laura E. Doyle, Teresa Berndt, and Natasha K. Bourdon

Vector and Pathway Definitions

Transportation vectors and pathways are terms that describe how an invasive species was introduced to an environment. There are several interpretations as to what the exact definitions are for vector and pathway. For example: the definition used by the United States Department of Agriculture's National Invasive Species Information Center (NISIC) is that pathways "are the means by which species are transported from one location to another" and a vector is a type of pathway specifically for diseases or parasites (National 2013). In contrast, the Smithsonian Environmental Research Center uses the terms "vector" and "pathway" interchangeably to mean a mechanism responsible for spreading any invasive species (Marine 2004). While there are many conflicting interpretations among academics, they tend to identify at least one of the two terms in a similar way as the Smithsonian's synonymous definition. Because of this commonality and the intended focus of this chapter the Smithsonian interpretation will be used.

While many species expand their range of habitat over time, there are many natural barriers that prevent a species from colonizing beyond contiguous ecosystems. These barriers are not traversable boundaries, which inhibit species from reaching otherwise habitable areas. Barriers can act as literal walls, as is the case with continental landmasses, or they can be large expanses of inhospitable conditions that most species can not pass, such as the low salinity Amazon-Orinoco Plume or large stretches of deep oceanic water such as the Mid-Atlantic Barrier (Luiz 2012). Figure 1 shows how different natural barriers separate biogeographic provinces. Invasive species use vectors to get around or move through such barriers. These vectors can be either natural or anthropogenic.

Figure 1. Distinct biogeographic provinces for tropical reef fishes in the Atlantic Ocean and the barriers that help shape them. Key: IP, Isthmus of Panama; ALB, Arabian Land Bridge; AOP, Amazon-Orinoco Plume; MAB, Mid-Atlantic Barrier; BB, Benguela Barrier (Luiz 2012).



Natural Vectors

A natural vector is any method a species uses to move between ecosystems that are not human-mediated. Many invasive species have taken advantage of natural occurrences as well as their life cycle stages to cross barriers and reach new habitats. While these natural vectors tend to represent a much smaller portion of invasions than anthropogenic vectors, and they have limitations on the distance that they can span, natural vectors are still an important source to consider when examining how to manage and study invasive species. The natural vector with any significance is natural dispersal.

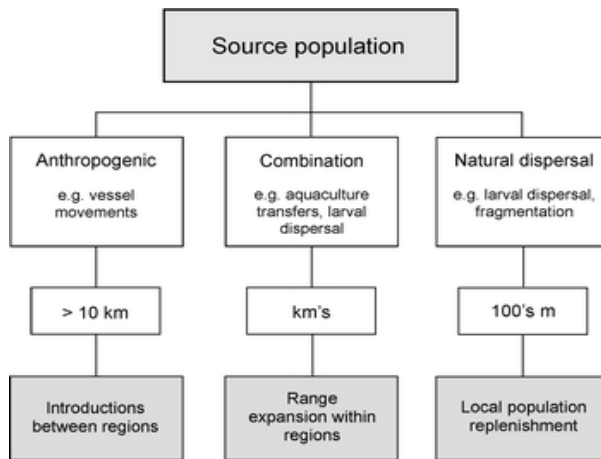


Figure 2. A conceptual model of vectors of expansion from established *D. vexillum* populations. Represents three vector types: anthropogenic (human-mediated spread); a combination of anthropogenic and natural dispersal (Scheltema 1986).

Natural dispersal is when free floating planktonic larval stages of species take advantage of ocean currents and storms to move. This method tends to be only effective for relatively short distances. For example the invasive ascidian *Didemnum vexillum* is sessile and is only able to move during its' larval stage. A study of natural dispersal mechanisms on *D. vexillum* showed that the species has the potential to colonize a few kilometers away from any established breeding population (Fletcher 2012). Figure 2 is a conceptual diagram, which defines and categorizes the likely vector used by *D. vexillum* for different dispersal distances. The cut offs for deciding which vector is most likely responsible for an invasion by a species with a planktonic larval form is different for each

species (Scheltema 1986). The factor that controls how far a species can naturally disperse is how long the planktonic larval stage lasts. Larval stages, depending on the species, can remain planktonic from several minutes to a year (Scheltema 1986). The reason that length of time of the planktonic stage is important for larger distances of natural dispersal is because it allows for ocean currents more time to transport them.

Ocean currents need a long time for any significant transport to occur. For instance, the median transit time for dispersal from Australia to New Zealand, a distance of roughly 2000-kilometers, would require two to three years (Gillespie 2012). The time required for such voyages can however be shortened significantly under certain conditions. In the case of the Australia-New Zealand voyage, a study showed that under rare oceanographic conditions the dispersal time required would be less than a year (Chiswell 2003). In the same study, *Jasus edwardsii* (southern rock lobster) was found to be capable of completing the journey under those rare conditions given the fact its' larval stage can last from nine months to two years. This 2000-kilometer natural vector is dwarfed the distances traveled using anthropogenic vectors. For instance, *Carcinus maenas* (European green crab) traveled more than 5000-kilometers crossing the North Atlantic Ocean from Europe to Massachusetts in the early 1800's in ship ballast water (Carlton 2003).

Anthropogenic sources

Natural barriers' effectiveness at stopping invasions has been thwarted with the rise of human interaction with these environments and their ability to travel great distances with relative ease. Humans have become an enabler for invasive species, moving them through these barriers on multiple pathways. Many human inventions used to speed trade and make economics gains also unknowingly transported invasive species into habitats never before available to them. These pathways can be grouped into four main categories, which cover 98% of all marine invasive species (Molnar 2008). Figure 3 can be used to see proportions of all marine Invasive pathways utilized, including:

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shipping, aquaculture, canal construction, and aquarium trade. These top four pathways are selected to go into greater detail due to their overwhelming proportion of all pathways. Shipping is the largest of these pathways and will be discussed first, with the others coming in order of decreasing proportionality.

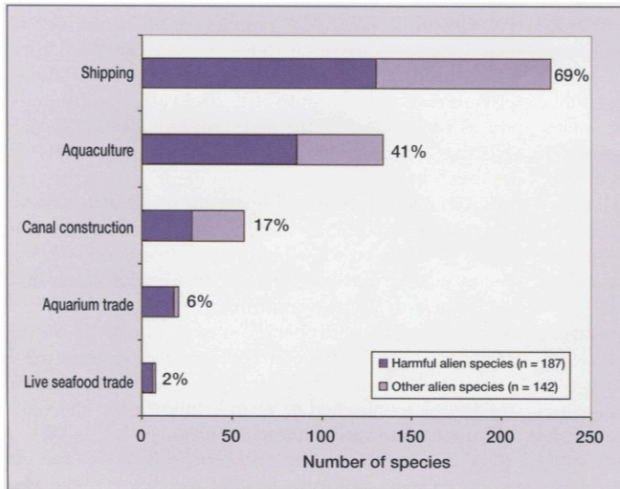


Figure 3. Percentage of marine invasive species documented or suspected of using these human-assisted pathways. Darker proportions are labeled as having high ecological impacts. Percentages are based off of a total population of 329, with overlap occurring when multiple pathways are suspected (Molnar 2008).

Shipping

A modern container ship can be nearly 400 meters long and 55 meters wide; it is used to deliver mass amounts of freight, more than 400,000 cubic meters each, all over the world. According to the World Shipping Council there are roughly 4,900 of these container ships currently in use for international trade (World 2012). With such an international cargo fleet in use it comes as no small surprise that shipping is one of the best ways of getting lots of things from one place to another, including invasive species.

Invasive species utilize shipping through two different methods; ballast water transport and hull fouling. Hull fouling involves sessile organisms growing on or attaching themselves to the outside hulls of ships. Such organisms which can use hull fouling as a means of transport include

species of barnacles, sea stars, mussels, sea squirts, and much more. It has been reported that, if left untreated, an active service vessel could accumulate up to 150 kilograms of marine life per square meter of hull (Fathomshipping 2013). Ballast water transport happens when cargo ships take on and off load cargo in ports. The purpose of ballast water is to stabilize a ship that is traveling without cargo. A cargo-less ship tends to be high in the water and prone to tipping and swaying. To counteract this, ships have adopted the practice of flooding special compartments with seawater in order to weigh down the ship and make it sit lower in the water. The trouble with this practice is that ships tend to take on ballast water, teaming with planktonic organisms, in one port and dump that ballast water in a foreign port as it takes on cargo (see figure 4). Thus with each trip a vessel transports millions upon millions of planktonic organisms between any two locations it makes port with. *Balanus glandula*, a common barnacle native to the Pacific coast of North America, has used both ship fouling and ballast water transport methods to successfully invade the Atlantic coast of Argentina, the southeast Atlantic coast of South Africa, and the northwest Pacific coast of Japan (Alam 2013). With a larval stage that only lasts for two to four weeks, *B. glandula* has reached much further than it could have ever reached through natural dispersal by taking advantage of the shipping industry.



Figure 4. Man standing next to heavily fouled vessel (Fathomshipping 2013).

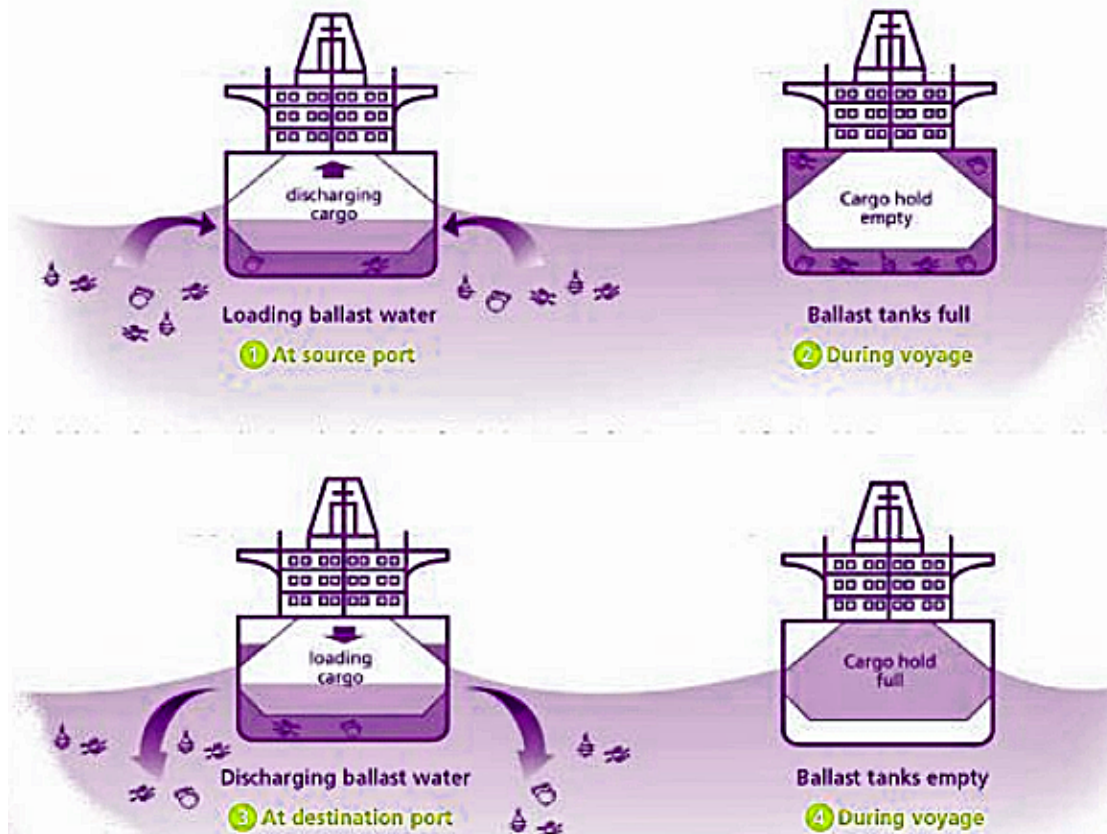


Figure 5. Diagram featuring how ballast water transports invasive species (GloBallast 2000).

Aquaculture

Aquaculture can be a major economic boost to coastal areas allowing them to grow non-native marine species, which are in high demand. This economic boost comes with a price however, in that implanting these species almost always leads to an invasion. Aquaculture based invasions can account for 41% of all marine invasive species (Molnar 2008). Many countries outweigh the risks of a possible invasion with the potential profit of the organism. This leads to repeated invasions of known invasive species across the world. There are three unique pathways within aquaculture, which can lead to invasions. The first is a deliberate invasion from the controlled culture of algae. The other two pathways labeled unintentional are: escape of organisms from controlled cultures, and transfer due to association with a cultured organism (Carleton 2003). Deliberate release of invasive

species for profit has been a regular occurrence for nearly 100 years as countries look to make profits. The cultivation of brown and red algae is the most commonly used invasive. China first cultivated *Laminaria japonica* (brown algae) in 1925 and in 1996 was the world's largest producer with 3,900,000 tons of fresh weight (Carleton 2003). Brown algae is produced for many purposes; while it is used culinary in many cultures it also has research purposes within the medical field.

Another deliberate release of an invasive is *Crassostrea gigas* (pacific oyster). In Figure 6 we can see that the oyster was released across the world for economic uses. This oyster can also be used to describe another pathway through aquaculture. Oysters contain a natural hold of seawater within their shells and transport of an oyster can also mean the transport of its holding seawater. This transported seawater can be a breeding ground for other invasive species. This pathway is the largest pathway among aquaculture and can be connected to 30% of all marine invasive species (Carleton 2003).

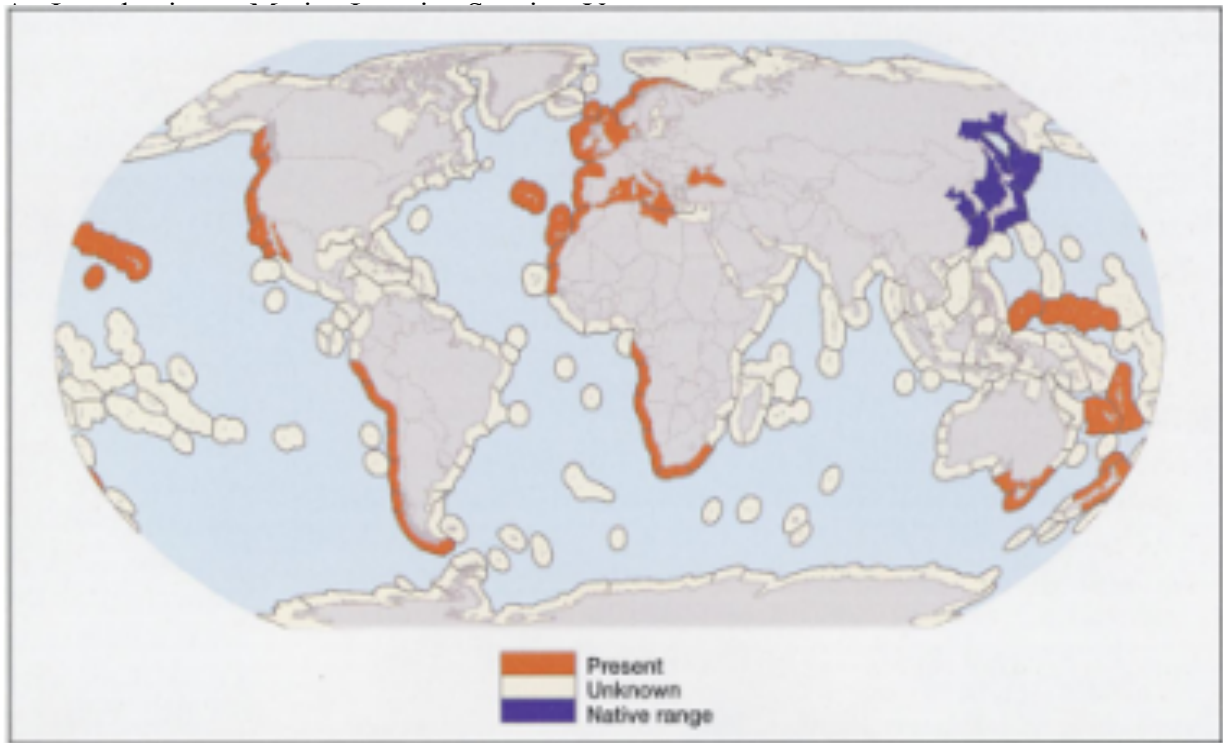


Figure 6. *Crassostrea gigas* (pacific oyster) is shown as invasive in orange and native in blue (Molnar 2008).

The third of these pathways can be described using the case of *Undaria pinnatifida* (wakame) in Europe. On the coasts of Brittany, wakame was first cultivated in 1984 with experts stating that the plant wouldn't be able to reproduce due to water temperature preventing gametophytes to mature. However the experts did not assume correctly and there are now wild populations of wakame along the coast of France (Carleton 2003). Therefore, France unintentionally released this invader into their coasts.

While many of these invaders may have been unintentionally released into waters, they all could have been avoided through simple regulation and foresight. Ireland does not allow many types of dangerous aquaculture and therefore is relatively invasive free in comparison with its surroundings. Invasive species like these are highly detrimental to the local ecosystems and are extremely hard to remove. France for example has embraced that it cannot remove wakame from its coast and now does everything it can to cultivate and utilize their invader.

Canals

Compared to the other human-mediated vectors canals work slightly differently. While shipping, aquaculture, and aquarium trade all involve instances where an organism is physically transferred from one location to another by human means, canals act to open new pathways species can navigate on their own. Canals provide a route between bodies of water that are normally separated by an impassible land barrier. This means that there is free flow between the bodies of water as well as swimmable or walkable path that adult organisms can navigate. These canals can be massive such as the Suez Canal, which is the largest canal that does not contain locks (Global). The Suez Canal connects the Mediterranean Sea with the Red Sea and stretches over 190 km, is over 205 meters wide and is nearly 24 meters deep. Since its' construction in 1869, the Suez has been responsible for roughly 300 species being introduced into the eastern Mediterranean Sea (Galil 2002). The zooplanktonic jellyfish *Rhopilema nomadica* is an invasive species that entered the Mediterranean Sea via the Suez Canal (Zenetos 2005). *R. nomadica* was introduced in the 1970's and within ten years had started producing annual swarms which greatly diminish local fisheries.

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Aquarium Trade

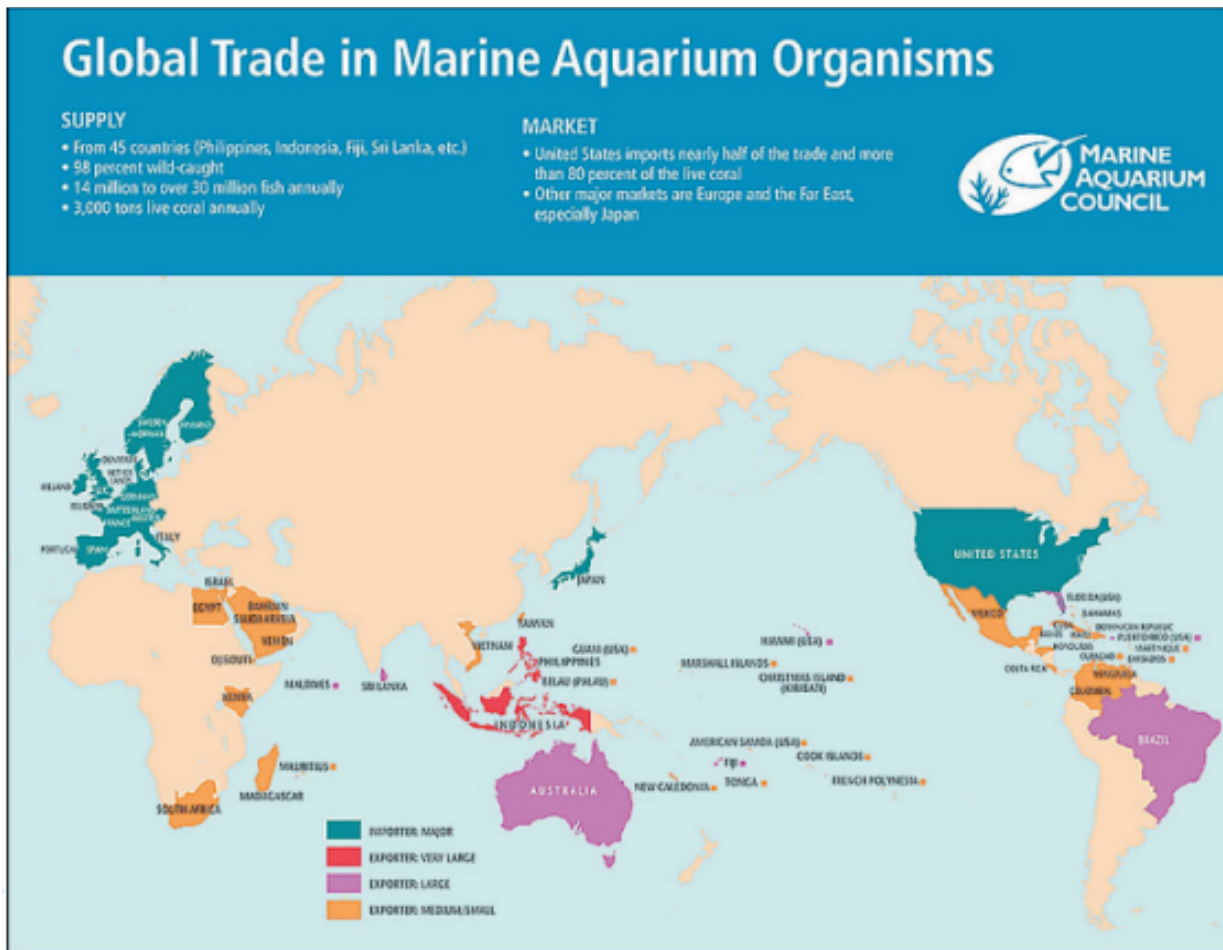
All across the world aquariums can be found in people's homes and businesses. While owning an aquarium is completely legal and safe to the environment, release of aquarium based species has been increasing and showing negative effects on ecosystems. One third of all the harmful marine invaders can be linked to the aquarium trade as being sold commercially (Padilla 2004). As many people discredit aquarium releases as a major factor in invasions, new evidence is proving that it can be substantial.

There is a \$25-billion industry in selling aquarium pets to owners across the world and this market has been growing by 14% annually (Padilla 2004). In figure 7, we can see the major importers and exporters of aquarium species across the world. The United States alone imports more than 80% of marine corals annually. This massive market spreads invasive species all across the world where they are raised and treated as pets. While they are not invasive in their tanks, simple things such as

dumping the water from a tank into a storm drain can release spores of invasive vegetation into the ecosystem.

Caulerpa taxifolia is one of the most invasive marine vegetations that is almost solely transferred through aquarium releases. In the Mediterranean scientists used molecular testing in order to prove that the wild invasive populations of *C. taxifolia* is genetically identical to the most widely used and commercially sold species. This means that they have confirmed the invasive was brought to the coasts of the Mediterranean through either public or private aquarium releases (Jousson 1998). In figure 8 we can see where the native and invasive populations of *C. taxifolia* are present throughout the world. Many of these populations have been genetically tested and proved to have been introduced through aquarium releases.

Figure 7 Major importers and exporters of the global aquarium market (Padilla 2004).



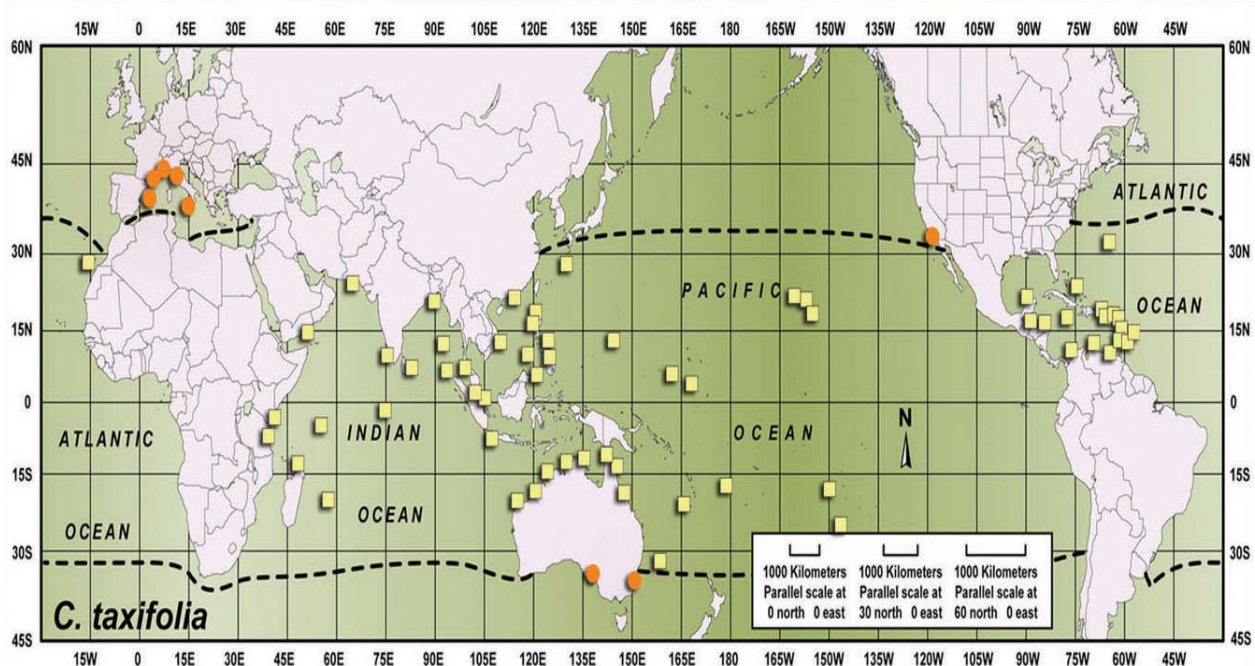


Figure 8. Native and invasive populations of *C. taxifolia* (Walters 2004)

With the recent rise in aquarium-based invasive species more people are becoming aware of this as a problem. Many states within the United States have even decided to ban many species in order to try and minimize the possibility of outbreaks from that species. The major problem in trying to maintain a policy of this nature is that many Invasive species can be bought online and shipped directly to your house (Jousson 1998). This present a unique problem that may not have a clear answer. However, policies which ban certain species and aquarium dumpings are mandatory and becoming much more popular. This may be the most effective way to attempt to subdue aquarium dumpings and prevent further invasions.

Summary

Throughout history natural barriers have stood in place to prevent species from spreading beyond their natural habitat. These barriers were circumvented from time to time through certain vectors but mainly these barriers stood impassible. This was the case until the humans developed international travel and trade via shipping. Human travel and economics have allowed for many

species to jump these natural barriers with relative ease. Whether they swam through a man made canal or caught a ride in the ballast of a shipping vessel, the human role in the invasions has been extremely prevalent. With human intervention being linked to 98% of all invasive species we can only blame ourselves and look towards conservation and prevention of future invasions.

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Evolutionary Adaptations

By Rebecca Buchanan and Keenan Tilsley

Edited by Teresa Berndt, Natasha Bourdon, and Laura Doyle

Introduction

Invasive species are an enormous threat to biodiversity, and can have ecological and economic impacts (Molnar et al 2008). Invasive species are excellent adaptors and are capable of competitively excluding the native species, disrupting ecosystems, and altering nutrient cycling (Molnar et al 2008). Invasive species are able to do so because they have certain traits and characteristics that enable them to survive in their non-native range. These features have evolved over time, giving these species an advantage over other species, therefore making them unstoppable invaders in their non-native ranges. Evolutionary adaptations must be understood in order to predict and prevent future invasions from occurring, developing tactics for removal efforts, and apprehending the true hardiness of an invasive species. In this chapter, we will discuss the evolutionary adaptations that invasive species have developed, and how these traits have enabled them to become more successful than native species.

Reproduction

One of the most important aspects of a species being invasive is the establishment of a permanent population in a non-native area. In order to do this, an invasive species must be a successful breeder. A successful invader produces a large quantity of offspring during each reproductive cycle. One such example is the Chinese Mitten crab, *Eriocheir sinensis*. This species of crab produces large quantities of offspring per breeding cycle; one female can produce 250,000-1,000,000 eggs (Department of Fish and Wildlife). This means that they can

overwhelm any native species by producing more offspring. These offspring are also often widely dispersed, giving them an even greater advantage than native species. *E. sinensis* is a perfect example because its free floating larvae and juveniles can migrate hundreds of miles from where they were spawned. (Department of Fish and Wildlife)

Breeding cycles of invasive species take place at different times of the year than native species. In certain ecosystems, predators feed on the young of a native species, capitalizing on the abundance of food during this time of year. However, predators do not know the breeding cycles of invasive species and do not feed on their young during a breeding cycle. Given favorable environmental conditions, some invasive species can breed multiple times a year. This helps an invasive species quickly establish itself and allows it to quickly overwhelm a region that it is not native to.

Invasive species reach reproductive maturity quickly, often before the native species. An invasive species of snowflake coral, *Carijoa riisei*, reaches sexual maturity in 6 months, while the native species of black corals take 10-12 years to reach sexual maturity (Kahng et al 2005).

Asexual reproduction is advantageous because it allows a species to reproduce without having to find a mate. The invasive tunicate species, *Didemnum vexillum*, reproduces asexually by fragmentation, thus expanding its range (NOAA). Fragmentation is when a small piece of an organism breaks off and is able to colonize a new area and survive. An invasive algae, *Caulerpa taxifolia*, is also able to

reproduce by fragmentation. Fragments of this plant as small as 1 cm are able to grow. (Hodde 2009).

The rusty crayfish (*Orconectes rusticus*) displays many of these reproductive advantages in its populations. *O. rusticus* is an invasive species in the upper Midwest of the United States. Although it is a freshwater species, its reproductive advantages should be noted. In both environmental and laboratory settings the rusty crayfish can out compete and push native species simply due to vast advantages in reproduction. *O. rusticus* hatches more quickly than most native species in the invaded areas. The eggs hatch in 3-4 weeks, while the native species in the upper Midwest hatch in about 5 weeks. It also reproduces at a different time of year. Rusty crayfish breed during the fall and lay eggs in spring where they hatch rapidly. (Sargent, Lodge) This, compared to the native Dwarf Crayfish, *Cambarellus shuffeldii*, whose larvae don't hatch until the summer (Crayfish). The larvae then grow much faster than the native species and have a higher survival rate. This allows the invasive *O. rusticus* to establish itself quickly and push out native crayfish populations.

Predation and Size

All species that do not produce their own food must be able to catch and consume prey in order to survive. Some species have evolved certain adaptations to become better at finding, catching, and consuming prey. Invasive species are typically generalists, meaning their diet is comprised of a variety of foods (Rappahannock 2013). It seems that the simpler a creature is, the better it is at being an invasive species. This is believed to be true because these more simple creatures are usually generalists and can use multiple resources to survive, where more evolved creatures are usually specialists and need a certain resource to survive. By having more options, the invasive species are able to feed on their competitors prey choice as well as other items. This broadens the invaders resources, and decreases the native species resources. Invasive species have also evolved

stronger and faster feeding techniques. A study looked at the competition for consuming a mussel between a native rock crab species (*Cancer irroratus*), and an invasive green crab species (*Carcinus maenas*). This study showed that over 90% of the time, the invasive *C. maenas* was able to grasp the mussel before the native *C. irroratus*. This study demonstrated that *C. maenas* can outcompete the *C. irroratus* for food (Matheson et al 2012). *C. maenas* also clip eel grass. In invasive regions of this species, eel grass is cut down in huge areas in their search for food. In native areas, salt marsh grass is cut but not nearly as much. (Garbary et. al 2014)

Size has all sorts of impacts on the survival of a species. Not just with avoidance of predation, but also with food. *C. maenas* competes with crabs as well as other types of organisms. One such example is *C. maenas* affecting the predation of dogwhelks, *Nucella lapillus*, on blue mussels, *Mytilus edulis*. *C. maenas* is a voracious kleptoparasite, and steal food from *N. lapillus*. In the presence of *N. lapillus*, *C. maenas* has an increased consumption of *M. edulis*, often stealing the mussels from the *N. lapillus* or eating the mussels before *N. lapillus*. *C. maenas* is using their size to their advantage, "pushing" *N. lapillus* out of feeding on *M. edulis*. Thus, this has a negative impact on *N. lapillus*, dwindling the population size due to increased competition with *C. maenas*. (Boudreau et al 2013)

Co-evolution

Some predators have co-evolved with a certain prey to both become more specialized. For example, the prey will become harder for the specific predator to catch and eat, and the predator responds by becoming better at catching or eating it. (Lynch 2009). Furthermore, a specific type of seabird may have evolved to be able to eat a certain mussel species, but if a new invasive mussel species arrives, the sea bird is not evolved to feed on the new invasive species. The invasive species will not be preyed upon, which allows it to thrive.

Ability to Learn

Some invasive species change their behavior in order to survive in a non-native region. Many invasive species have the ability to learn, giving them an evolutionary advantage over native species. An invasive species can learn survival tactics, different feeding strategies; ways to find food and/or be better at capturing it. Here in the Northeast, one thing many invasive species have to overcome is winter and successfully survive. These behaviors are learned behaviors because they are not witnessed in the native range of an invasive species. Two of these behaviors are migrating to deeper water for more constant temperatures, and burrowing in sediment to be protected from the brutal cold of winter.

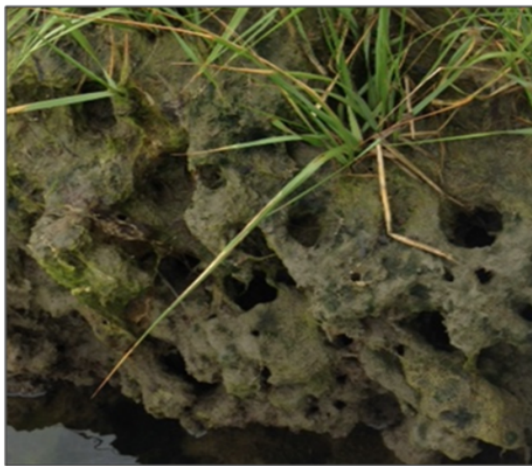


Figure 1.) A salt marsh suffering erosion due to invasive crab burrowing (Mass Great Outdoors Blog).

Such behavior is often seen in *C. maenas* in more northern regions of the northeast. It is often noted that the *C. maenas* juveniles will burrow themselves in sediment (Lee 2002). These burrows can cause salt marshes to erode, damaging the habitat of native species. Adult *C. maenas* have been noted by divers to move to greater depths, in more moderate temperature water at depth during the winter (Guide). Most populations of *C. maenas* in their native habitat do not have to deal with such harsh winters and have other physical

characteristics to survive in their native range. *Eriocheir sinensis* has also displayed burrowing behavior, and contribute to erosion of native salt marshes (FWS).

Physiological and Morphological Adaptations

Physical adaptations enable a species to survive in a non-native environment. Tolerance to temperature, salinity and depth are three of the most important adaptations that invasive species display. Other adaptations include a stronger exoskeleton, venom, and higher tolerance of oxygen levels. A tolerance to a wide range of temperatures, salinities, oxygen, and depth enable a species to survive in many different environments. Venom, and a stronger shell make a species a better competitor, and harder for prey to catch and consume.

Exterior Protection

The two largest groups of invaders are crustaceans and mollusks (Molnar et al 2011). Both groups have about sixty species that are marine invaders. The figure below depicts the number of invasive species in each type of marine group.

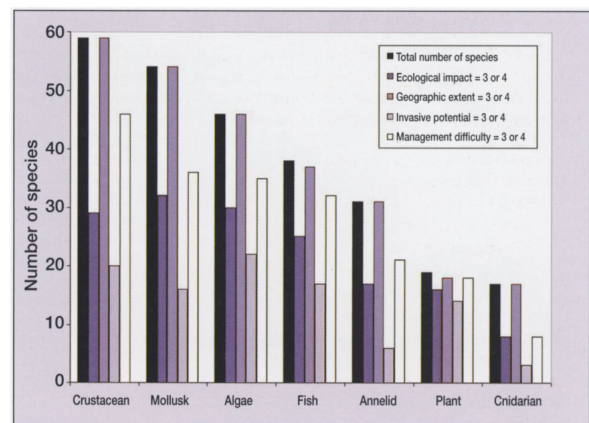


Figure 2.) The number of marine invaders represented in different groups (Molnar et al 2011).

These two groups both have a hard exterior coating. The crustaceans have a hard exoskeleton, and many types of mollusks have a shell. This outer layer of protection makes these species harder to consume, which is one of the reasons why these two groups are so successful.

Venom and Toxins

A marine invasive species, the lionfish (*Pterois*), is a venomous fish. The lionfish has been able to expand its population in non-native and because of its venomous spines, few species will consume them. Large groupers are thought to avoid *Pterois*, even during periods of extreme starvation (Morris et al 2009). *Caulerpa taxifolia* contains a toxin caulerpenyne, which if consumed by fish can cause the fish to be inapt for human consumption (Hoddle 2009). Due to the toxicity within the plant, this algae does not have many predators, increasing its survival (Hoddle 2009).

Salinity

The tolerance for a broad range of salinity levels is another advantage that marine invasive species display. Often, a species will be able to survive for long periods of time in very high salinities, or very low salinities. For example, *Pterois* is able to survive for extended periods of time in a low salinity environment.

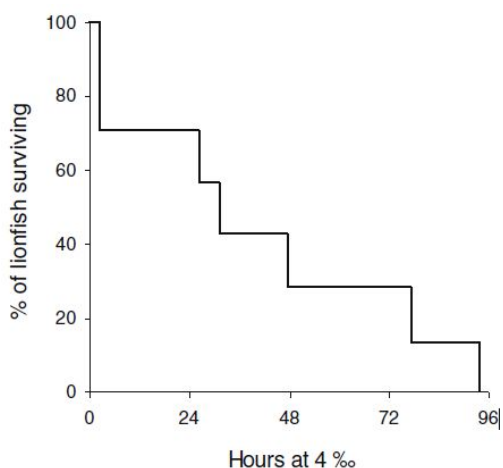


Figure 3. The number of hours lionfish were able to survive in a low salinity (Jud et al 2014).

The figure below shows the amount of time the *Pterois* can tolerate low salinity.

About 20% of the *Pterois* were able to survive for over three days in a low salinity environment. This ability to tolerate low salinity allows this species to colonize more regions such as estuaries, further invading non-native ranges. (Jud et al 2014)

Temperature

As global temperature increases, invasive species are predicted to be more successful because they tend to have higher temperature tolerances (Zerebecki et al 2011). In extreme heat, the proteins in an organism will begin to denature. Heat-shock proteins (Hsp) are molecular chaperones that refold denatured proteins, which prevents damage to cells. Recent studies have shown that the concentration of Hsp70 is directly related to temperature tolerance (Zerebecki et al 2011). A higher temperature tolerance is present if the organism has more Hsp70, or induce Hsp70 more quickly (Zerebecki et al 2011). Below is a graph depicting the level of heat shock proteins found at different temperatures in a native species and invasive species of sea squirts (*Diplosoma listerianum*) in California. Graph A is the invasive *Diplosoma*, and graph B is the native *Diplosoma*. A higher relative pixel intensity means that the level of heat shock proteins was also higher.

The invasive *Diplosoma* has a higher level of heat shock proteins at all of the temperatures. This is especially important in the high temperatures, which is when the proteins will begin denaturing. The invasive *Diplosoma* responds with a higher concentration of heat shock proteins, meaning it will tolerate and survive at higher temperatures (Zerebecki et al 2011). *C. maenas* have an extremely flexible physiology that allows them to cope in the extreme range of temperatures they can experience throughout the year. Their cardiac physiology allows them to survive the extremes of hot and cold they experience in native and

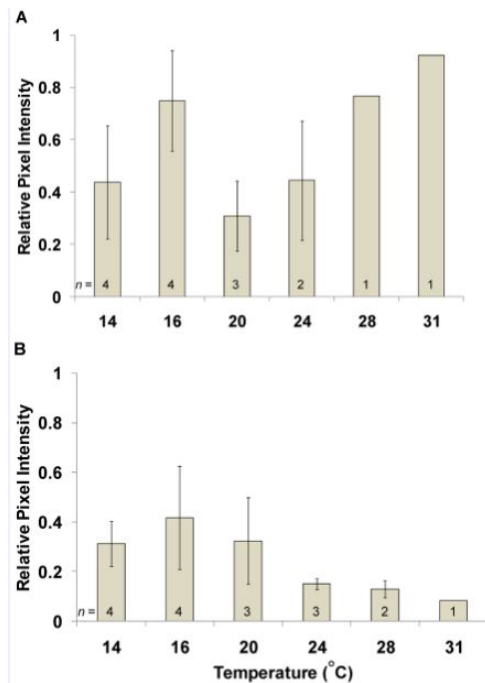


Figure 4. A comparison of two *Diplosoma* species, and the level of heat shock proteins within each species. The invasive species (A) shows a higher level of heat shock proteins than the native species (B) (Zerbecki et al 2011).

invasive ranges. *C. maenas* have the ability to acclimate their bodies to extreme hot and cold. The crabs survived when exposed to temperatures ranging from 0°C -37.3°C. The experiment showed that *C. maenas* has a broad thermal tolerance, which is an important reason they can survive in a variety of new environments (Tepolt 2014).

Emersion

C. maenas, once again is a master of survival. They are capable survivors of emersion; being out of water. Along the Pacific coast of North America, native red rock crabs (*Cancer productus*) and invasive *C. maenas* live together in the intertidal zone. Both experience emersion during low tides. However, *C. maenas* are simply better at it. When it comes to air exposure, their smaller size allows them to simply maintain or even increase oxygen consumption in air. This allows them to still move around during emersion and still be able to

function properly. However, the native *C. productus* have to burrow in sand and cannot survive through emersion, significantly reducing their oxygen consumption to survive (DeFur et al 1984). Thus, *C. maenas* has a competitive edge on the native crabs. In field studies, it was shown that during low tide, *C. maenas* hides under rocks and large masses of seaweed. Temperatures under the rocks and in the seaweed were half the ambient air temperature, with almost twice the humidity. These conditions where *C. maenas* was located during low tide make it much easier for these creatures and other crustaceans to survive. However, no other crab species were located where *C. maenas* was located. Thus, *C. maenas* seems to be competing better for places to hide during low tide events. (Simonik et al 2014) Animals are not the only invasive species able to survive emersion; the invasive algae *C. taxifolia* is able to survive out of water for 10 days (Hoddle 2009).

Genetics

Invasive species are able to establish a population with only a few founding individuals. The bottleneck effect states that the founding population will have a very low genetic diversity, because there is a small number of reproducing adults (Frankham 2005). Usually, this prevents a species from thriving due to natural selection. The more diverse a population, the higher chance that the population will thrive, because there are more genetic variations within a species. However, invasive species are able to survive past the bottleneck phase and into a strong population. Many invasive species solve the problem of low genetic diversity by being asexual or self-fertilizing, having a high reproductive rate, which purges alleles, and high migration rates with repeated introduction events (Frankham 2005). This combination of qualities will overcome low genetic diversity and inbreeding.

Some genes could have a profound effect on a species ability to colonize. The fire ant, *Solenopsis invicta*, invaded Southeastern USA from South America about sixty years ago.

A typical *S. invicta* colony has one queen, but colonies in the USA have multiple unrelated queens (polygyne colony). The worker ants in a polygyne colony possess a gene, *Gp-9*, which encodes a pheromone binding protein. This gene or related genes affects an ant's ability to detect the queen and regulate the size of a colony. Loss of self-recognition leads to a larger colony size, which is advantageous when invading a new territory (Lee 2002). Although *S. invicta* is not a marine species, this could be a potential advantage in colony forming marine invasive species.

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Conclusion

Invasive species are quickly spreading all over the globe. Due to their evolutionary adaptations, they are able to survive in non-native areas and compete with the native species. These traits include higher tolerance for temperature and other abiotic factors, the ability to learn new behaviors, improved feeding strategies, and underlying genetic advantages. Understanding these traits and characteristics may help us to prevent future invasions and help treat current invasions.

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Handling the Invaders: Prevention, Management, and Eradication

By Kiera O'Donnell and Hanna Pultorak

Edited by Ashleigh Novak J. and Blaise Jenner

In this chapter we explore different methods of managing marine invasive species. These methods cover the government processes and laws put in place to counteract invasive populations, as well as actions the community can take to fight invaders. We will cover preventive measures along with the control and removal of invasive populations. When looking at preventive measures that governments and communities take, it is important to think about how alien species first are introduced into an ecosystem (for a more in-depth look, see Chapter 3). Common vectors for introducing invasive species are shipping, aquaculture, aquarium trade and canals. These are the vectors that governments focus on in order to intercept invasive species entering an ecosystem. However, once an invasive species is established in an ecosystem, the plan changes to control the populations and protecting the native animals and habitats. Removal efforts are put in place if the invasive species becomes a threat. Specific management options used for each of these cases will be discussed further in this chapter.

Prevention

Early awareness of possible invasions, early detection of non-native species, early assessment of size and breadth of an invasion, and early implementation of management options all contribute to preventing the success of future invaders. The first step in managing marine invasive species is recognizing how to prevent them from spreading. Many different preventative measures have been explored and

research is still being conducted to aid in the fight against invasions. Physical and electrical barriers are ways to prevent marine invasive species from moving between bodies of water. Regulations regarding ballast water can also help prevent invasions. The aquarium trade can also be analyzed for preventative measures. In this section we will explore how different methods of prevention contribute to keeping invasive species at bay.

Physical barriers can be utilized in hydrologic separation to prevent invaders from moving into new bodies of water, such as lock systems, jetties, and dams. These barriers have shown some success along the Mississippi River (Patel, 2010). Electrical barriers have also shown to be successful in preventing the movement of invaders into new habitats. These barriers are composed of electric cables running perpendicular across a waterway anchored to the substrate. The cables emit a low, pulsing voltage through the water that deters fish and other aquatic animals from wanting to pass through (Patel, 2010). The voltage of the electric pulsing is low enough to deter aquatic animals without harming them.

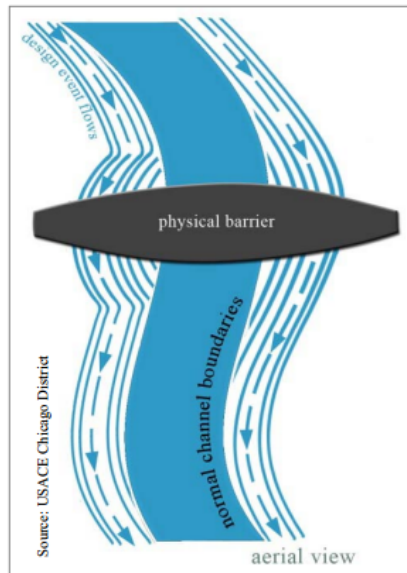


Figure 1. Physical hydrologic barriers must be engineered to accommodate heavy flooding and high tides.

Ballast water treatments and regulations can also aid in preventing invasive species from spreading. This topic will be discussed in greater detail later in this chapter but for now it is important to note how these regulations and guidelines are preventative measures. If a ship takes in ballast water from one port, moves across the globe to another port where it dumps its ballast hold, many non-native organisms may be introduced into a new environment, which can facilitate a new invasion. Treatment of ballast water can include filtration, chemical treatment, and heat treatment. The method of treatment depends on the regulations followed by the individual vessel. Other regulations are much simpler, requiring ships to empty their ballast before coming close to the coast to keep shore invaders away. While some international organizations have developed regulations and guidelines for ballast water, individual countries and even states have also formulated their own, strict policies.

Other methods of prevention may seem less regulated, like prohibiting the release of aquarium plants and animals into the wild. The aquarium trade has had a huge impact on the spreading of invasive species such as the

speculated introduction of the lionfish, *Pterois volitans*, into the Atlantic Ocean as well as the spread of numerous marine invasive plant species. Because of this, aquarists should be aware of what species their tanks hold and should be knowledgeable of how “hardy” these organisms are. Many aquarium species have the potential for invasion if released into nearby lakes, streams, or larger bodies of water.

It is important to assess preventative measures when dealing with the possible outbreak of invasion. Choosing the best method of prevention is not easy and takes many years and research to come to a conclusion. However, once a species has been established, immediate response to the control and management of the species is of the utmost importance.

Invasive Control

Organizations like The Nature Conservancy and The National Invasive Species Council make it their goal to find the most cost effective policies in order to control invasive species. This section will talk about a few of the possible actions that can be taken to control the alien species in an invaded environment. The regulations required depend on the invader and the environment they are invading. Therefore, research in this field is important in order to not only understand the invasive species better but to use the best management techniques. Research leads to proper policies that either restrict the growth of invasive species or help the natural species survive. Once policies are put in place, efforts move towards educating the public and getting communities involved in the fight against invasive species. When people are educated about the threat of invaders they are more likely to become involved in the many community efforts against invaders.

Research about invasive species has led to many discoveries and possibilities of control methods. Many different groups such as the Nature Conservancy fund this research in order to “focus prevention and control efforts on the most damaging invaders” (The Nature

An Introduction to Marine Invasive Species: Prevention and Management

Conservancy, 2014). Knowledge has led to proper management regulations being put in place such as antifouling on ship hulls. Research has determined appropriate chemicals that can be sprayed on ship hulls in order to remove the many different types of invaders that would potentially attach there such as sessile organisms like barnacles and sea anemones (Martin et al. 2013). Previous chemicals used like the use of copper sheathing was first abandoned due to the expensive and difficult application (Almeida et al, 2007). Once studies found that paints such as the copper sheathing or mercury based paints were harmful to the water and humans, these paints were banned and research started to find new tin-free, and biocide-free paints (Almeida et al, 2007). Studies about invaders have also discovered how the invasive species are attacking ecosystems. Through these studies companies, like the Nature Conservancy, know where their efforts would best be used such as protecting the native animals, the habitats, or trying to eradicate the invasive species altogether.

Invasive species research has also found new uses for invaders, such as *C. maenas* as lobster bait, or using aquatic plants as a process for absorbing oil spills. For three years in Nova Scotia, lobstermen have found that the use of *C. maenas* as bait is just as effective and is better for the economy (Deese and Arnold 2014). With herring at \$1.30/lb and *C. maenas* at \$0.83/lb, *C. maenas* is not only cheaper to buy for bait but puts less pressure on herring populations (Deese and Arnold 2014). This study has also removed over one million *C. maenas* individuals, causing the eelgrass to rebound by ten percent each year of the study (Deese and Arnold 2014). Another study has found that two free-floating aquatic plants *Pistia stratiotes* and *Eichhornia crassipes* can be used as efficient oil sorbents in water (Yang et al. 2014). This study was looking at the physical sorbent powers of the plants in a lab based setting. The methods included testing the weight and oil absorbed by the cut up leaves in pure oil tubes and a mix of oil and water tubes at varying temperature (Yang et al. 2014). The study found that the plants' high capillarity and

hydrophobic surfaces make these plant materials good oil sorbents in a wide range of temperatures (Yang et al. 2014). Therefore these plants have potential to be beneficial to the environment.

Because of research, many policies are put in place acting against invasive species depending on the invader, the type of habitat they are invading, the government where the invasion is happening, the budget, and how detrimental the invasive species are to the environment and economy. Local policies can usually be found on an individual state's website, which discusses what communities can do to preserve and protect their ecosystems as well as what laws will be enforced. For example, the state of Maine explicitly outlines laws regarding the protection of its wetlands against invaders on the Department of Environmental Protection section of the government-funded website. State websites will focus on specific species invading their coasts and the management options available for dealing with those species. Being one of the most common vectors, it is crucial for ballast water to be regulated in order to prevent the spread of invaders. Because of this, ballast water is the most regulated vector in most states. Even though many regulations and guidelines can be unique to country, territory, or even individual state, there are also international regulations. The International Maritime Organization (IMO) outlines many guidelines for different ballast water practices internationally, from sampling for living organisms to proper locations to exchange ballast water to on-board treatment facilities. Some examples of the guidelines are the internationally accepted methods of ballast water exchange: sequential, flow-through, and dilution methods. These methods are all accepted by IMO as safe and efficient methods of ballast water exchange that reduces the spread of invasive species. For more information regarding these as well as other international guidelines for ballast water management, visit the International Maritime Organization's website at www.imo.org.

The education of the public is another important management technique. The Nature Conservancy states that developing public laws

requires that we build awareness among the public and lawmakers about the effects of invasive species on natural areas, the economy, and human health (The Nature Conservancy, 2014). When people are more educated about invasive species they are more likely to take part in community efforts and support the government policies put in place. There are many educational programs supported by government groups like the Environmental Protection Agency (EPA), the United States Geological Survey (USGS) and the National Estuarine Research Reserve (NERR). These agencies have outreach programs for students that dedicate time to educating them about invasive species. Teachers can bring their students on field trips to go out into the environment and learn about invasive species on site. Groups such as NERR also have monitoring programs, which give people the chance to learn more about their surroundings and help government groups find the alien species that are invading the environment. These government groups, along with others, have personal websites to inform people about what invasive species are, where they are invading, and what you can do to protect against them. Along with websites, there are also smart-phone applications that act as an identification key for invasive species. All of these education efforts can potentially lead to civilian scientists who volunteer and help researchers and government workers to better understand the effects of invasive species.

Along with all of these government actions against invasive species, the community also acts in the fight against invaders. Communities have put a lot of effort into controlling invasive species by their own means, such as “harvesting non-natives for human consumption,” organizing a hunting event, or even just getting involved in the government efforts listed above (Nunez 2012). There have been many efforts to get humans, the ultimate predator, to eat invasive species such as the publishing cookbooks like “Conservation through Gastronomy” that have recipes for invasive species or cooking contests to find the

best recipes for invasive species (Nunez 2012). The idea is to make invasive species appealing to people, causing overharvest of the species, therefore, significantly affecting their populations. Communities have also hosted large events that award prizes to those who hunt the most of an invasive species. In February, Roatana Marine Park in New York created a competition like this with *Pterois sp.* Participants caught over 1,300 *Pterois sp.* which was used as the main item in a cooking contest after the hunting was finished (Choi 2011). This event put a dent in the *Pterois sp.* population in surrounding waters. Even though these efforts would not truly eradicate invasive species populations, they help maintain control of the invaders.

Removal and Eradication of Invasive species

Once an invasive species has been established, the process of controlling it and attempting to remove it begins. Care should be taken when attempting to eradicate invaders because the process can be both severely difficult and incredibly expensive. Taylor and Hastings in 2004 found removing a large portion of the original invasion every year, called the “meadow-first strategy,” the best strategy when attempting to eradicate a *Spartina alterniflora* (saltmarsh cordgrass) invasion. The “meadow-first” strategy involves removing a large portion of the original invasion of *S. alterniflora* every year (Taylor and Hastings, 2004). However, they also noted that while being the best strategy, it also heavily relied on outstanding resources. Financially speaking, this method may not be best to practice considering the impracticality of using large amounts of funds for removal. They concluded in their research that in order to select the best methods of removal, researchers need to understand the biology of the invader as well as the “annual commitment of resources” (Taylor and Hastings, 2004). While these conclusions make eradicating invasive species appear to be nearly impossible, there have been successful removals of invasive species that have

progressed the restoration of the native environment.

The invasion of *C. maenas* in Kejimikujik National Park in Nova Scotia is directly tied to the mass clearing of eelgrass in Basin Lake, just northwest of the Little Port Joli Basin (McCarthy, 2013). In 1986, eelgrass expanded the entirety of Basin Lake. However, by 2010, only a small portion of eelgrass remained. The mass destruction of eelgrass resulted from *C. maenas* “chopping” down stalks in order to find softshell clams for food. Researchers, along with volunteers, deployed traps and began catching *C. maenas*. The crabs were sold to fishermen to use as bait, creating a demand for the harvest. In an effort to bring back the eelgrass population, scientists developed a transplant system. With the decline in *C. maenas* due to harvesting combined with the transplanting of eelgrass, the population of eelgrass in Basin Lake began to grow back (McCarthy, 2013).

Another eradication technique commonly used is biological control, the introduction of a natural enemy to the invading plant or animal. Most invasive species thrive in new environments because they are missing their natural predators, therefore by introducing these predators to the affected ecosystem we can control the invasive species (Secord 2002). However this newly introduced predator can cause more harm and become a new invasive species to the specific region. Therefore the decision to implement a biocontrol agent depends on the host specificity and maximizing damage to the pest (Secord 2002). A good biocontrol agent will inflict the most damage to the invasive species and minimal damage to the native species, while also creating minimal damage to the surrounding ecosystem. Many different biocontrol agents have been discussed for invasive species such as *Mnemiopsis leidyi* in the black sea, *C. maenas* in its introduced range, and *Asterias amurensis* in the south Pacific (Secord 2002). Most biocontrol suggestions are researched thoroughly before being implemented to prevent a new invasion of the biocontrol agent. One example of a biocontrol agent in

place is the sea urchin *Tripneustes gratilla* controlling the invasive red algae *Kappaphycus* sp. In Kane'ohe Bay, Hawaii *T. gratilla* was able to decrease the abundance of *Kappaphycus* spp. within an enclosure in five months from 62.5 percent to 15.9 percent (Conklin et al. 2005). In controlled areas biocontrol has proven to be an effective strategy with agents that are not good invaders.

Not every invasion will have a successful eradication. The costliness of invasive removal as well as the overall commitment of individuals and organizations can have a great impact on how successful a removal attempt is. Also, the individual invasive species' life cycle, food preference, and hardiness can make its removal extremely difficult. As Taylor and Hastings stated, “the optimal control strategy depends on both the biology of the invasive species and on the available annual commitment of resources” (Taylor and Hastings, 2004). One common theme is apparent through research done on invasive species removal: it is not an easy task. Because of this, it is especially important to do all that can be done to prevent future invasions.

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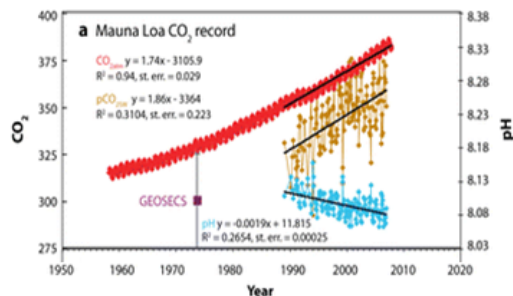
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Invasive Species in the Face of Climate Change

By Ashleigh Novak and Blaise Jenner

Edited by Wyler Scamman and Alec Strohmeyer

Since the dramatic rise of greenhouse gases at the onset of the industrial revolution, the climate of the earth has been quickly changing in relative evolutionary time (Occhipinti-Ambrogi 2007). The past 250 years have shown a rise of 40% in the amount of CO₂ in the atmosphere, which is the quickest rise observed in millions of years (Figure 1) (Doney et al. 2009). Climate change has been an increasingly important area of research as it is becoming more important to understand the effects it has had and will continue to have on the environment. This chapter will discuss how warming waters, ocean acidification, and the expansion of hypoxic regions are some of the more influential aspects of climate change that are affecting marine invasive species. All three of these alterations to the environment have been shown to affect ecosystem dynamics in multiple ways (ICPP 2007).



Doney SC, et al. 2009. *Ann. Rev. Mar. Sci.* 1:169-92

Figure 1. Graph A is depicting the rising level of CO₂ in the atmosphere over a 50+ year period monitored at the Mauna Loa station in Hawaii. Additionally, graph A is showing the decrease in pH in specifically coastal seawater (Doney et al. 2009).

The interaction between alien species and the environment is very complicated as there are both direct and indirect influences that have to be considered (Sorte et al. 2010). An ecosystem is very fragile as well as dynamic and has evolved to function as efficient as possible. When a new species is suddenly introduced to a new location direct effects such as immediate competition for resources can begin and eventually, indirect consequences can arise such as energy flow within the system (Occhipinti-Ambrogi 2007).

In addition to these direct and indirect ways that invasive species can affect an ecosystem, the combination of environmental conditions such as warming sea temperatures, can have confounding impacts, making these two issues extremely important to understand as a whole (Hellman et al. 2008). Climate change is often considered a benefit to alien species, which can use warmer ocean waters to better travel and spread. However, this isn't always the situation as there has been some research done on the negative influences that climate change can have on invasive species. Altered impacts such as the distribution, transport, and establishment of existing invasive species are all considered to have potential negative effects on non-native species facilitated by climate change (Hellman et al. 2008).

Both native and invasive species are facing possible benefits and consequences of climate change and arguably one of the most important factors contributing to those changing experiences is the warming of ocean temperatures globally. One study aimed to document the effects that warmer waters were having on a marine fouling community in

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Bodega Harbor, Bodega Bay, California (Sorte et al. 2010). The researchers gathered various sessile invertebrates of both native (n=3) and introduced (n=7) species by collecting them from a floating dock. First, the researchers conducted temperature tolerance treatments to determine which species were more tolerant of increasing water temperatures. They performed this component of the study by submerging plastic tiles in ambient water and then increased the temperature increments by 1°C until the desired temperatures were reached. After a 24-hour period all organisms were assessed for survival through the trial. It was determined that the seven invasive species were far more likely to survive this experiment than the three native species, suggesting that climate change will have a disproportionate effect on the natives compared to the introduced species (Sorte et al. 2010).

The second aspect of the study was to determine if warmer ocean temperatures would alter the growth and ultimately survival of juveniles of the ten species. Aforementioned methods were performed for the field collection of the invertebrates (Sorte et al. 2010). In the laboratory 18 plates with the sessile organisms attached were placed in three varying temperature treatments, which included the ambient temperature of Bodega Harbor, and two increased expected temperature levels that had been previously predicted for the specific region of the study. Ultimately, non-native species were predicted to increase in abundance due to the combined factors of growth and survival, whereas native species are suspected to decrease in abundance in response to the change in ocean temperature (Sorte et al. 2010).

An additional study was conducted in Long Island Sound, Avery Point, Connecticut with the goal of accessing recruitment times, total recruitment, and growth rates of three invasive ascidian (sea squirt) species. In this study four replicates of 100 cm² PVC panels were lowered approximately 1m below the surface of the water from a floating dock. The panels were exposed for continuous one week periods during May-October (the recruitment season) from 1991 to 1997 and then

continuously from 1997 until 2002 when this research was published. Every week the panels were removed and all individuals were taken off, counted, and identified. (Stachowicz et al. 2002)

The results of this very simple experiment were profound. Over the 12 years of the study it determined that there was a strong negative correlation with winter (January and March), water temperatures, and recruitment dates of the three most abundant alien species of ascidian (*Ascidella aspersa*, *Botrylloides violaceus*, and *Diplosoma listerianum*). In other words, all three introduced species of ascidians recruited earlier in the year when the water was a warmer temperature. This relationship can be seen in Figure 2 (Stachowicz et al. 2002).

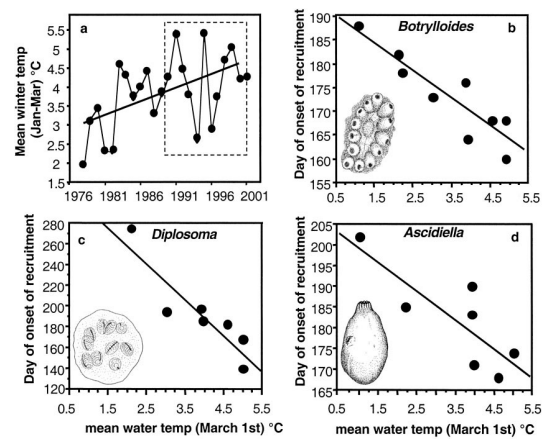


Figure 2: (a) Annual mean winter (January 1-March 31) water temperature (°C) for 1976-2001 at Millstone, CT. The dashed box shows the time period for which recruitment data was collected at Avery Point. (b, c, d) The negative correlation between the day of recruitment (y-axis) and the mean water temperature (x-axis) for the three nonnative species, *Botrylloides*, *Diplosoma*, *Ascidella*. The y-axis is measured in days since the beginning of the calendar year (i.e. day 181 = July 1st) (Stachowicz et al. 2002).

The negative correlation of early March temperatures and earlier recruitment is concerning because these changes are able to give the invasive species an earlier reproductive start. Therefore, allowing them to become well established before the native species have a chance to recruit. Increased winter water

temperatures can have potentially negative impacts to native species leading to a shift in community dominance toward alien species (Stachowicz et al. 2002).

Total annual recruitment of invasive species showed a positive correlation with mean winter temperatures (January and March) (Figure 3). On the other hand, native species showed a negative correlation between annual recruitment and winter water temperatures (Figure 3). This data suggests the warmer winter waters increase the total number of introduced species while simultaneously reducing native species. This trend leads to a potential shift in community dominance toward invasive species, which can be seen in Figure 3 (Stachowicz et al. 2002).

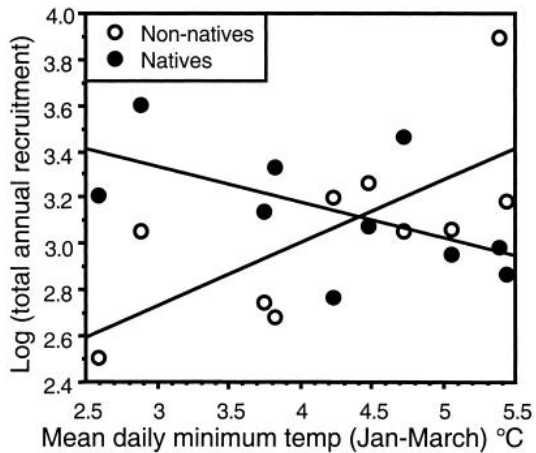


Figure 3: The total annual recruitment of nonnative species is positively correlated with mean water temperatures during the preceding winter and native species recruitment is negatively correlated. Total recruitment data was log-transformed to meet the assumptions of ANCOVA (Stachowicz et al. 2002).

Not only does an increase in temperature lead to both earlier and higher amounts of total recruitment of the invasive species, but it also affects the growth rate of both native and nonnative species. A laboratory experiment was performed to determine these effects. The experiment consisted of three species of ascidians, one native sea star ascidia, (*B. schlosseri*) and two introduced (*Botrylloides* and *Diplosoma*) species. All three organisms

were collected as new recruits from the field and maintained in a 1 liter container of unfiltered seawater in a temperature controlled water bath. Every day the colonies were transferred into new containers with fresh unfiltered seawater. After one week the change in the number of zooids, a single animal that is part of a colonial animal, was used as a measurement of growth. All three species (invasive and native) showed increased growth rates with an increase of temperature but the growth curve was steeper for the two introduced species. At lower and moderate temperature increases (<19°C) this relationship is less pronounced but as the temperatures became more extreme (23°C) the growth rates of the introduced species were clearly higher than that of the native species. (Figure 4) (Stachowicz et al. 2002).

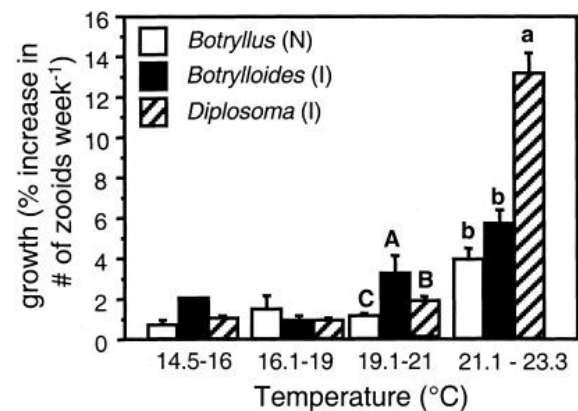


Figure 4: Both native species (*Botryllus*) and introduced species (*Botrylloides*, *Diplosoma*) showed similar growth rates at moderate temperatures, but at more extreme temperatures the nonnative species showed much higher growth rates than native species (Stachowicz et al. 2002).

Besides the research showing how warming waters are affecting invasive and native species, ocean acidification, or the decrease in pH of the ocean caused by the uptake of carbon dioxide from the atmosphere, can cause potential changes in a given ecosystem (Doney et al. 2009). This significantly changes the basic chemistry of the seawater and can alter many biochemical pathways some species require to survive. Marine organisms that require calcium

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carbonate to create their shells have been observed with a reduction in calcification ability, which therefore alters growth (Doney et al. 2009).

One specific study aimed to understand the interaction that ocean acidification would have on the vulnerability of a native oyster species (*Ostrea lurida*), to an invasive snail (*Urosalpinx cinerea*), in Tomales Bay, California (Sanford et al. 2014). Specimens collected were separated into glass jars and both the native and invasive species were raised and cultured apart from one another. The native oyster, *O. lurida*, was raised in two conditions, one at an ambient sea water temperature and ambient partial pressure of carbon dioxide (pCO₂) in the water. The other condition was held at an elevated temperature, which also had a higher pCO₂, which were determined by the predicted values for future ocean conditions in that region (Sanford et al. 2014). Eventually, to determine predation, wedge-shaped tiles of *O. lurida* were placed into new glass jars with nine jars per temperature and pCO₂ condition. Once the invasive snails, which drill a hole into the oyster, were placed in the jars with *O. lurida*, predation could be observed (Sanford et al. 2014).

Results indicated that oysters raised in the elevated conditions experienced a 20% increase in the amount of drilling predation and 48% more oysters were consumed under those increased conditions (Sanford et al. 2014). An interesting observation found in this study, through implementation of a scanning electron microscope, revealed that *O. lurida* raised in the elevated conditions did not have a thinner shell thickness than those oysters raised in the ambient conditions (Sanford et al. 2014). However, the oysters raised in the elevated conditions were significantly smaller than the control *O. lurida*, suggesting that the high stress environment was affecting the reduction in prey size, allowing for the observed increase in predation. The invasive snails, *U. cinerea*, were not affected by the experimental conditions and did not alter feeding behavior based on the raised water temperature and pCO₂ surroundings (Sanford et al. 2014).

Ultimately, ocean acidification can result in a stressful environment leading to copious pathways, which have the potential to be extremely beneficial to invasive species.

This is only one selected example of how climate change, through ocean acidification, is having a negative impact on the growth and survival of native species, which then allows for the invaders to take advantage of these sensitive situations. Hypoxia, or low oxygen conditions, is yet another key determining factor affecting how well native and introduced species survive. Half of all estuaries in the United States are now experiencing at least some hypoxic event annually (Jewett et al. 2005). Coasts are specifically susceptible to climate change and this is where the majority of invasions occur, making these areas in need of long term research.

A study conducted in the lower Chesapeake Bay, Virginia, aimed to determine if low dissolved oxygen (DO) could possibly have an effect on the community dynamics of the shallow epifaunal community. This type of ecosystem allows easier succession of marine invasive species into that region (Jewett et al. 2005). Similar to other studies assessing how climate change is affecting exotic species, a settling plate design was implemented which allowed for the researchers to collect sessile invertebrates that would settle onto it. Once recruitment had occurred on the plates they were redeployed in shallow areas in the York River subestuary during known low DO (<4mg/L) episodes. The DO was then monitored for variable amounts of time in 2000 and 2001, with DO being much lower overall in the later year. This experiment did require multiple manipulations over the study period which included physical removal of the plates, then exposures to differing DO conditions for 24 hours, and finally returning them to the study site in the York River until the next manipulation (Jewett et al. 2005). Ultimately, the four introduced species in the study area showed a higher abundance and coverage of the plates in low DO conditions compared to native species. This result is yet another advantage that invasive species have in their ability to tolerate and

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flourish in a variable environment. These low concentrations of DO, specifically in coastal shallow regions, which are most vulnerable to climate change, will enhance the success of invasive species (Jewett et al. 2005).

The idea of a range shift qualifying as an invasion is often debated, but this type of movement can have just as great of a community-level effect as a “traditional invasion” can (Sorte et al. 2010). A range expansion can be considered an invasion because even though there is no direct human influence in range expansions it still involves the movement of individuals from a donor community into a recipient community. Range shifts are often facilitated by the warming ocean waters which have been attributed to climate change. A review by (Sorte et al. 2010) showed that 75% of range shifts in the literature have been in a poleward direction, which suggests climate change could be the cause of these observed shifts. It was also found that community effects of these range shifts were predominantly negative and the magnitudes of these effects were often similar to those of introduced species.

In total, 129 marine species from 55 different studies that have been identified as species, which have shifted their range due to climate change (Sorte et al. 2010). These 129 species consisted of primary producers (phytoplankton, macroalgae, and higher plants), molluscs, fishes, crustaceans, birds, cnidarians, sponges, protists, echinoderms, annelids, and insects. Additionally, marine range shifts seem to occur at a much faster rate of 19.0 km/year (± 3.8) than terrestrial range shifts 0.61 km/year (± 0.24), which is shown by the relationship in Figure 5. However, marine introductions are over twice as fast as marine range shifts (44.3 ± 10.8 km/year) (Sorte et al. 2010). This is extremely critical to understand, as the oceans are extremely sensitive to changing environmental conditions.

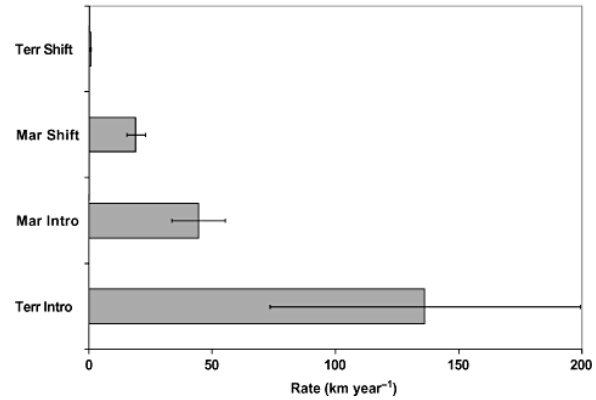


Figure 5: This graph depicts the rate of range movement (km/year) for terrestrial range shifts, marine range shifts, marine introductions, and terrestrial introductions.

Out of the 129 species shifting their ranges, eight were found to have community and ecosystem level effects. The effects included nutrient inputs, competition, herbivory, predation, and disease. For example, the urchin *Centrostephanus rodgersii* has been linked to a more than 4000% decrease in algal biomass in areas where the range of *C. rodgersii* have expanded to. This extreme decrease indicates that the invasive urchin species has a significant effect on algal biomass. Overall, each of the eight species displayed negative impacts on the ecosystems in which their range had expanded into (Sorte et al. 2010).

Climate change, including warming ocean temperatures, decrease of pH, and a decrease in dissolved oxygen, are all having varying effects on the marine native and invasive species. Most changes are facilitating an increase in ultimate survival of introduced species. In comparison, the shifting environmental conditions are having a negative impact on native species. These changes are fairly recent in evolutionary time and need to be researched in much further detail, especially as the climate of the earth continues to change at an increasingly alarming rate.

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Case studies

The following section illustrates on selected animal and algae species how invasive species affect different ecosystems, their respective transport mechanisms, their adaptations that made them successful invaders, their response to climate change, and more.

Caulerpa taxifolia

By: Jake Farrell

Caulerpa taxifolia is a marine invasive species, which is part of the seaweed, alga genes of *Caulerpa*. This invasive species was first discovered in 1980 at the Wilhelma Zoo in Germany due to its hardiness and survivability in cold environments. This caused *C. taxifolia* to sky rocket in the in the popular aquarium trade until 1984 when it was first discovered within the Mediterranean Sea where it has covered over 7,400 hundred acres in ten years of infestation. *C. taxifolia* can be identified by its dense mats of vertical fronds that rise 3-10 cm upright from the seafloor in depths of up to 250ft. This species can tolerate multiple substrates such as mud, sand, and rock and thrives within low nutrient, high pollution areas such as Marinas, Harbors as well as low temperature areas. With high growth rates within these varieties of substrates it causes *C. taxifolia* to out compete other aquatic plants in the area.

The characteristic that makes this species a successful invasive and uncontrollable is the caulerpenyne that its leaves contain. This toxin protects it from any plant eating herbivores causing it to have no natural predators. Caulerpenyne affects the predator's regulation of their intracellular pH in many different sea urchin species. This allows these dense patches to spread along the sea floor driving natural seaweeds and organisms away.

While *C. taxifolia* is native in small patches to tropical oceans and seas such as the Caribbean, Florida, Australia and the Philippines, it is not native to the waters of the Mediterranean, and off the coast

of Huntington Harbor, California. The first invasion of *C. taxifolia* was believed to be spread by the dumping of aquarium water near the Oceanographic Museum of Monaco. This invader has spread ever since by fragmentation in ballast water, being caught in fishing gear, boat anchors and naturally by sea currents.

Invasive *C. taxifolia* does not always have a negative impact on an environment, as this invader can inhabit highly polluted areas, such as sewage outfalls and active seaports. A study within the French Bay of Menton found that large mats of *C. taxifolia* reduced the pollution that was present within the bay and aided in the return of Posidonia Seagrass.

Unfortunately like every other invasive species the negative impacts out weigh the positives. *C. taxifolia* has multiple impacts that effect ecosystems, economies and food chains. While the seafloor becomes a hot spot for species trying to rally for space, the *C. taxifolia* disrupts this ecological system by forcing out native seaweeds, and algae. The number of Mollusca, amphipods is also greatly reduced within the dense mat areas due to loss of livable habitat. Due to *C. taxifolia*'s high toxicity, native herbivores are left without eatable food, causing them to have to move on or die off. This can cause delays in the food chain.

The removal of this invasive species has a very high price tag and affects economies that have to pay this expensive bill. In Huntington harbor, California from 2000-2005 it cost the state over \$7 Million dollars to eradicate this species from the harbor. That comes to over \$1 million dollars a year to control and eradicate this invasive species.

While several methods have been tested in controlling this invasive species, the only successful method has been to cover the large dense mats of *C. taxifolia* with a tarp injecting liquid chlorine through tiny slits. This kills the *C. taxifolia*, but also kills everything under

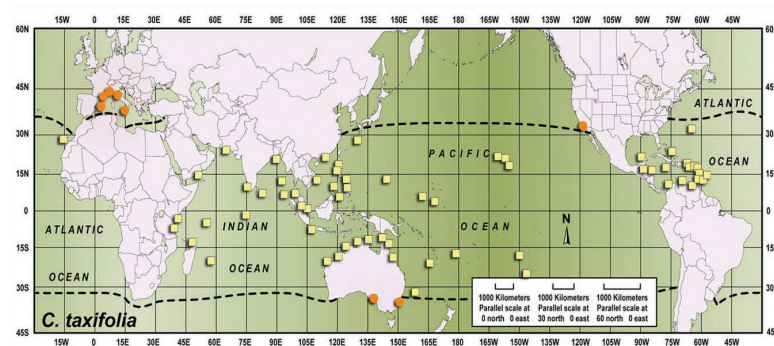


Figure 1 Distribution of *Caulerpa taxifolia*

the mats. This control method is a very effective but a non-selective way to control the spread of this species. Another way of control is laws and regulations to make it illegal to own or dump an unwanted invader into a sewage system. These methods have come after several failed control methods including suction pumps, dry ice and hot water methods. Rules and regulations have been put into place to help save pure waters from being tainted by these invasive invaders.

C. Taxifolia since discovered in 1980 has caused ecological issues ever since. While it affects ecosystems, economies and food cycles the removal methods are expensive and highly destructive. While countries struggle to pay for the high costs, the daily shipping commutes and tidal currents continue to spread *C. taxifolia* continuously throughout the seas.

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Invasive Corals: *Tubastraea coccinea* and *Carijoa riisei*

By Rebecca Buchanan

Edited by Natasha Bourdon

Introduction

Many people do not think of delicate corals as being invaders, but there are some species that are spreading into non-native ranges. This case study will describe two known invasive corals, *Tubastraea coccinea* and *Carijoa riisei*.

Tubastraea coccinea

“Orange-cup coral,” or “sun coral” is a type of large polyp stony coral. This means that it is not a reef building coral, but still produces a hard skeleton. *T. coccinea* is pictured in Figure 1.



Figure 1.) *T. coccinea* pictured in Brazil (Sampaio et al 2012).

T. coccinea has an orange cup like appearance with yellow translucent tentacles. These tentacles appear when the coral is feeding. *T. coccinea* does not have symbiotic zooxanthellae, but rely on suspension feeding to catch small zooplankton. Each colony can grow to 25 centimeters in diameter. *T. coccinea* has a growth rate of 3.02 cm² per year (Sampaio et al 2012). The native range of *T. coccinea* is the Indo-Pacific Region. The first *T. coccinea* to be found outside of its native range was in Puerto Rico, 1943 (da Silva et al 2014). Today, it has been found invading areas of the Southwestern Atlantic, the Northeast Coast of Brazil, Asia,

Africa, Australia, North America and South America. The vector of transport is most likely ship ballast water and hull fouling (Sampaio et al 2012). The map below depicts the native and non-native regions.

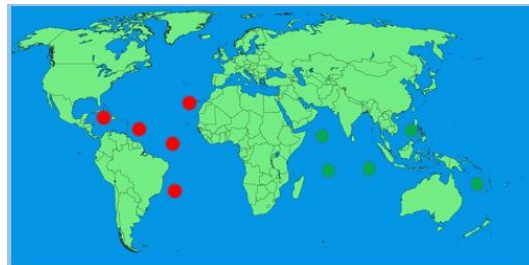


Figure 2.) The green dots indicate the native range of *T. coccinea*, and the red dots indicate the most impacted invaded regions.

In the bay region of Ilha Grande, Brazil, the spread of *T. coccinea* has been well documented. The density and distribution of the *T. coccinea* colonies has increased drastically (Silva et al 2014). In Figure 3, the increase in *T. coccinea* density is pictured.

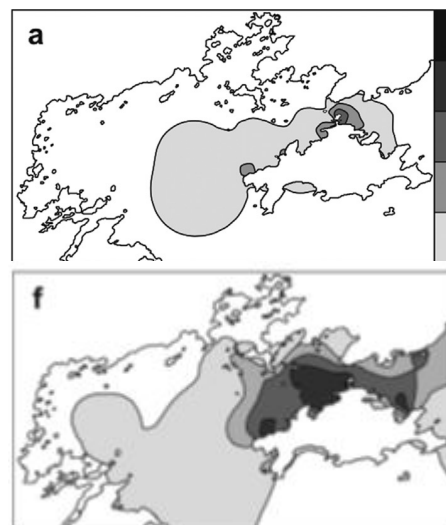


Figure 3.) The distribution of *T. coccinea* in the year a.) 2000 compared to f.) 2011 in Ilha Grande, Brazil (da Silva et al 2014).

As a successful invader, *T. coccinea* has many adaptations that enable it to establish populations in non-native areas. One of these adaptations is an early reproductive maturity of 1.5 years (Sampaio et al 2012). *T. coccinea* can reproduce both sexually and asexually (Sampaio et al 2012). This is advantageous because it does not have to rely on other individuals within the population to produce offspring. A second advantage is that *T. coccinea* lives at depths greater than 100 meters and is not limited by light (Sammarco et al 2014). As noted earlier, *T. coccinea* does not depend on photosynthetic zooxanthellae for food, and instead captures zooplankton with its tentacles, making it an excellent competitor.

In the non-native regions, *T. coccinea* competes with the native species, disrupting natural ecosystems (Sampaio et al 2012). This species has been known to displace native sponge species and alter community interactions (Sampaio et al 2012). *T. coccinea* settles on oil platforms in the Gulf of Mexico, but it is not known if they will affect the structure of the platforms (NOAA 2014).

There are ways to help control the spreading populations of *T. coccinea*. One option is to start reef monitoring programs in regions where *T. coccinea* is invading (Sampaio et al 2012). In the bay region of Ilha Grande, Brazil, a program called Project Sun Coral was developed, encouraging the sale of *T. coccinea* as souvenirs. Families who collect and prepare *T. coccinea* for sale can earn an extra \$150 a month (CODIG 2011). Orange cup coral can be physically removed from a reef, and can be somewhat successful as shown in Figure 4 (NOAA 2014).



Figure 4.) Colonies of *T. coccinea* removed from a coral reef in the Gulf of Mexico (NOAA 2014).

T. coccinea is a successful invader that is quickly spreading throughout the world. Its many adaptations make it difficult to remove. *Carijoa riisei* is another invasive coral that is becoming a threat to other corals.

Carijoa riisei

C. riisei is commonly referred to as “snowflake coral,” and is a soft coral that is white with eight tentacles (Pagad 2008). *C. riisei* is pictured in Figure 5 (NCCOS 2011). This coral does not have symbiotic zooxanthellae and suspension feeds (Kahng et al 2006).



Figure 5.) A close up photograph of *C. riisei* (NCCOS 2011).

The native range of *C. riisei* is the Southern Atlantic Ocean, including areas from South Carolina, Gulf of Mexico, Brazil, and the Caribbean. The invasive regions are Hawaii, the Western Pacific, and the Indian Ocean. A map depicting the distribution is shown in Figure 6 (Concepcion et al 2011).

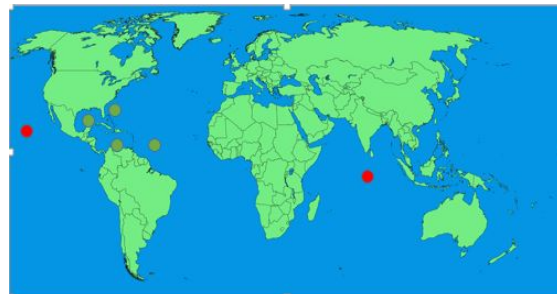


Figure 6.) The green dots indicate the native range of *C. riisei*, and the red dots indicate the most impacted invaded regions (Concepcion et al 2011).

The first sighting of *C. riisei* outside of its native range was in 1972 in Pearl Harbor, Hawaii (NCCOS 2011). This region has heavy boat traffic, and the most likely vectors are hull fouling and ballast water (Concepcion et al 2011).

C. riisei is a successful invader, and has many adaptations that enable it to overcome native species. *C. riisei* displays early reproductive maturity, at 6 months (Kahng et al 2005). Native black coral in Hawaii takes 12 years to reach sexual maturity (Kahng et al 2005). *C. riisei* also displays high fecundity, continuous breeding both asexually and sexually, and has a growth rate of one inch every two weeks (Kahng et al 2005). Black corals only grow about two inches per year. The polyps are only millimeters in length, but gather in branches of many polyps reaching up to 30 cm in length (NCCOS 2011). *C. riisei* is not limited by light because it does not rely on photosynthetic zooxanthellae, and it only has one group of predators, nudibranchs (Concepcion et al 2010). *C. riisei* can grow in caves and dimly lit areas, and are found at depths greater than 100 m (Carijoa riisei Guide). The large threat caused by *C. riisei* has left it named the #1 worst invasive species in Hawaii.

C. riisei has a detrimental impact on the ecosystem, especially in Hawaii. *C. riisei* has such a fast growth rate that it is able to overgrow the native species of corals, black corals pictured in Figure 7 (Kahng et al 2005).



Figure 7.) *C. riisei* has overgrown black coral, which has a reddish hue. The black coral on the left has been smothered (Leone 2006).

The black corals are the Hawaiian state gem, and there is a \$30 million coral industry based around the harvest and sale of black corals

(Kahng et al 2005). A study was done in Hawaii, and found that some black coral colonies experienced 90% coverage by *C. riisei* (Kahng et al 2005). The data from this study is shown in Figure 8.

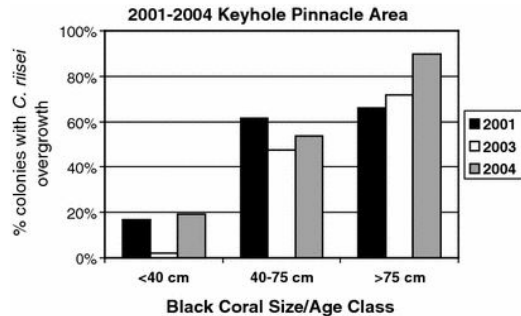


Figure 8.) The percentage of overgrowth experienced by black coral colonies. The largest black coral colonies experienced the worst overgrowth (Kahng et al 2005).

Many actions can be taken to try and stop the spread of *C. riisei*. Reef monitoring programs are important in assessing damage to specific areas (Kahng et al 2005). Another idea suggests raising the minimum size of black coral that can be harvested in order to protect the native species. There is currently a Coral Reef Conservation Program in place that is run by NOAA. Introducing two predator species of nudibranch (*Tritoniopsis elegans* and

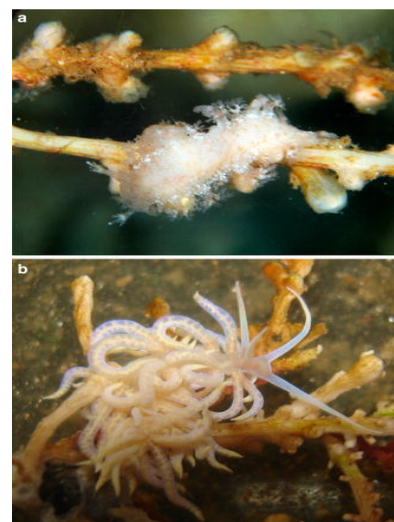


Figure 9.) The two nudibranch species that prey upon *C. riisei* (Concepcion et al 2010).

Phylloidesmium poindimiei) could potentially help control the population, but has not been attempted (Concepcion et al 2010). The two nudibranchs are shown in the figure below.

Climate Change and Corals

The threat of climate change means that warmer waters are likely to be in the near future. Corals have a very small range of tolerances and if climate change raises the water temperatures by only a few degrees, it can cause the corals to be stressed (Murray, University of Maryland). Corals that have zooxanthellae will expel their symbiotic algae when stressed, causing bleaching, or the loss of color to a coral. If the temperature remains out of their comfort zone, the corals will be permanently damaged and most likely die (University of Maryland). However, *T. coccinea* and *C. riisei* do not have zooxanthellae, and will not risk losing their



source of food production in warmer waters. A photo of bleached coral is shown in Figure 10.

Figure 10.) A bleached coral that has expelled zooxanthellae and lost color (Murray, University of Maryland).

Increasing amounts of carbon dioxide in the atmosphere leads to ocean acidification, making it difficult to maintain a skeleton made out of calcium carbonate, and corals will suffer (Murray, University of Maryland). *C. riisei* is a soft coral, and does not build an extensive calcium carbonate skeleton, so it may not be as affected as other corals. *T. coccinea* has been shown to withstand a number of environmental

conditions that cause bleaching and mortality in other species (Sammarco et al 2014). Perhaps, these two species of invasive coral will thrive during climate change while native species suffer.

Conclusion

Although corals may seem fragile and non-threatening, they are capable of causing significant damage in non-native areas. These two invasive corals do not need zooxanthellae, and have an early reproductive rate, which contribute to its success. Climate change may not be a threat to *C. riisei* and *T. coccinea*, and they should be monitored carefully in the future.

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Mnemiopsis leidyi

By Laura Doyle

Edited by Abby Doane

When it comes to successful invaders, characteristics like high reproduction rate, being a generalist, and having high tolerance to salinity and temperature changes play a huge role in the species success. The ctenophore, *Mnemiopsis leidyi* or the Sea Walnut, is one of these very successful species. Ranging from 7-12 centimeters in length, this species of comb jellyfish, is destroying the bodies of water it has invaded.

Mnemiopsis leidyi is holoplanktonic, and its anatomy is fairly simple; being 95% water the species is made up of two layers of cells, eight rows of ciliated combs or tentacles, and both male and female sex organs, making the species hermaphroditic. *M. leidyi* reproduces at night, releasing sperm and eggs into the water (Main, 1928). Being hermaphroditic, a single individual of *M. leidyi*, should essentially be able to establish a new population. Along with being hermaphroditic, the species can regenerate from fragments larger than one-quarter of an individual's size allowing its population to bloom. Another positive attribution of *M. leidyi* is that reproduction can occur year round with the right conditions. Warmer waters and a greater food supply will mean a successful reproduction. Being a generalist, the species tends to feed on fish eggs and larvae, zooplankton and occasionally other ctenophores (Shingonova et al. 2001). *M. leidyi* can eat up to 10x its weight per day, which means a successful reproducing season of the comb jelly can severely deplete the fish populations. Populations along the coast tend to have a more varied diet than those in open water. Its high thermal tolerance, 1.3°C to 32°C, and high salinity tolerance, 3.4 to 75.0 parts per thousand, are other factors that make it a successful invader (Ivanov et al. 2000). However, the species tend to prefer temperatures of

about 9°C to 23°C, as those are the ideal temperatures for breeding.

Mnemiopsis leidyi is native to the western part of the Atlantic Ocean, mainly occurring in the open seas, with some populations in the coastal waters. It currently ranges from Northern Massachusetts to the Southern coast of Argentina, with gaps along the equator (Bayha et al. 2014). Its invasive range consists of many European Seas including: the Black Sea, the Mediterranean Sea, the Sea of Marmara, the Sea of Azov, the Caspian Sea, the North Sea and the Baltic Sea. The vectors that were used to transport these organisms range from human mediated to natural vectors, such as currents.

Ballast water is the main transport vector for *M. leidyi*. The species is holoplanktonic, located in the top layer of the ocean where ships intake water for their ballast tanks. *M. leidyi*, also eats larvae which is also likely to be taken up in ballast water. Therefore, the ctenophore tends to have plenty to eat during travel. Possibly leading to a successful reproduction. The species can also go several weeks without feeding, making it an excellent candidate for ballast water travel. Its free floating nature, also allows it to be easily transported by current, making this another important vector. Semi-closed seas like the Black Sea, are much more sensitive to the invasion of alien species, compared to open seas. In the early 1980s, when the number of invasions over the world greatly increased, *Mnemiopsis leidyi* invaded the Black Sea, through the transfer of ballast water. From the Black Sea *M. leidyi* would travel south invading the Sea of Marmara, through the Bosphorus Strait, due to currents in the Black Sea. The species is now present year round in the Sea of Marmara (Shingonova et al. 2001). Continuing south, the species is now found in the Aegean Sea, the most north-east part of the Mediterranean Sea. Initially, the species spread north

due to currents produced by the wind, but the spread north would later be aided by a canal. Wind currents directed this free floating ctenophore north entering the Sea of Azov through the Kerch Strait. In the late 1990s *M. leidyi* would continue to advance north, while also spreading further east (Shingonova et al. 2001). With the benefit of the Eurasia Canal, the species would travel to the Caspian Sea. Ballast water, again, was the main vector of transport but due to its free floating nature it's possible the movement of the water also guided this invasion (Ivanov et al. 2000).



Figure 1. Shows the Black Sea, Mediterranean Sea, the Sea of Azov, the Sea of Marmara, and the pathways that connect them (Hogan 2013)

The most recent invasion, the populations in the Baltic and North Seas, were determined to be a separate invasion. Genetic markers show that the invasion of the North and Baltic Seas come from north of Cape Hatteras, South Carolina. The initial population in the Black Sea comes from South of Cape Hatteras, more specifically the Gulf of Mexico (Bayha et al. 2014). The invasion in the Baltic and North Seas, were also facilitated by ballast water.

M. leidyi, is an actively hunting carnivore that has a tendency to hunt at night. The species uses its cilia to create a current, which propels their free floating prey towards them. The species can eat ten times its weight per day. In a study done in the Black and Mediterranean Seas a sample of the ctenophore was found with eight fish eggs in its stomach (Shingonova et al. 2001). In the Black Sea and in the Mediterranean Sea the main prey of choice is: Black Sea anchovy (*Engraulis encrasicolus ponticus*), Mediterranean horse mackerel (*Trachurus mediterraneus ponticus*), and the Sprat (*Sprattus sprattus phalericus*) (Shingonova et al. 2001). These three species were not only the main choice of *M.*

leidyi but to the fisheries as well. They became the main commercial species in the 1980s, after the demise of larger pelagic fish. The main commercial fish species were already threatened by the factor of overfishing, but were now threatened by this very successful invader. With the invasion of *M. leidyi* in the Black Sea, came a region of little to no predators and a vast amount of untouched food. The ctenophore would severely deplete the fish populations (Fig. 2), therefore destroying the main source of income in that area, fisheries. Warmer months brought larger, more severe blooms of *Mnemiopsis leidyi*. The Black Sea anchovy, which breeds during the summer, had a massive decline in the summer of 1990 (Shingonova et al. 2001). The species would prove to have a major impact on not only the species it preys on but on competitors.

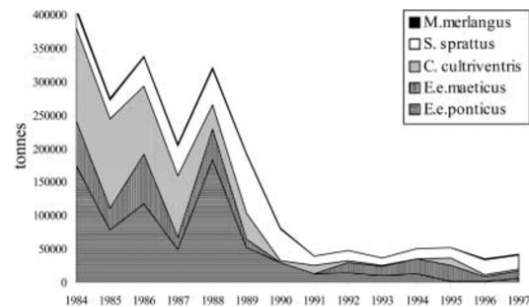


Figure 2. Displays the impact of *M. leidyi* on the catch (tonnes) of five fish species in the Black Sea from the year 1984 to 1997. (Shingonova et al. 2001)

With *Mnemiopsis leidyi* reproducing fast and in large abundance, this meant a lack of food supply for other species of fish, jellyfish and some mammals. The severely threatened jellyfish was *Aurelia aurita*, or commonly known as the moon jellyfish. *Aurelia aurita*, has a very wide distribution; located in coastal waters from 70°N and 55°S (Dawson & Jacobs, 2001). The distribution of *A. aurita*, interferes with the invasive range and the native range of *M. leidyi*. However, the competition in the native range is practically nonexistent, due to the fact that in its native range *M. leidyi* tends to be in open waters rather than coastal waters as *A. aurita* prefers. In the Black Sea, however, *A. aurita* was not accounted for in the 2000s surveys. *M. leidyi* had out competed and completely diminished the population (Ivanov et al. 2000). In the Caspian Sea the *M. leidyi* population

was increasing even faster than that of the Black Sea (Ivanov et al. 2000). The population in the Caspian Sea, remained high and steady, causing the need for more food. *M. leidyi*, began to feed on kilka (*Clupeonella cultriventris caspia*) eggs (Ivanov et al. 2000). Kilka is the favorite food of the main predator in the Caspian Sea, the Caspian Seal or *Phoca caspica*. The mammal has already been under stress due to natural environmental pressures, a low female reproduction rate, and viral infections, but with the introduction of *M. leidyi* the species has been classified as endangered. The ctenophore is also thought to be responsible to the decline of the dolphin population in the Black Sea, but no direct correlation can be officially made (Konsulov & Kamburska, 1998).

In its native range *Mnemiopsis leidyi*, is causing little to no damage. This is assumed to be because of predators and competitors that have been successful in managing this ctenophore. The invasive species, *Beroe ovata*, is the main threat to populations of *M. leidyi* in its invasive range; mainly the Black Sea. *B. ovata* is approximately 1 to 12 centimeters in length, essentially the same size of *M. leidyi*. The species of *ovata* also has cilia that they use for feeding and movement of short distances; much like *M. leidyi* (Fineko et al. 2002). When feeding, if the prey is smaller it is simply engulfed and if it's larger than *B. ovata* the species will cut the prey into smaller pieces; this is the process that has been observed when feeding on *M. leidyi*. The native range of *B. ovata* includes, the Western Atlantic Ocean, the Mediterranean Sea, the North Sea, and the Gulf of Mexico (Fineko et al. 2002). The species spontaneously appeared in the Black Sea in 1997 due to ballast water; the population is thought to come from the Mediterranean Sea through the Sea of Marama (Ivanov et al. 2000). The first bloom of *B. ovata* was recorded in the summer of 1999, with that the number of *M. leidyi* drastically declined (Shingonova et al. 2001). The introduction of *B. ovata* would restore the ecosystem in the Black Sea. As *M. leidyi* decreased, the number of zooplankton, fish egg and larvae populations began to increase and the overall number of species began to increase (Ivanov et al. 2000). Off the coast of North America *Beroe ovata* primarily feeds on *M. leidyi*; a very important aspect as to why the populations of *M. leidyi* in its native range are not as destructive as

those in its invasive range. Along with *B. ovata*, another possible predator is the American Butter Fish, *Peprilus triacanthus* (Ivanov et al. 2000). Both of these species are found in *M. leidyi*'s natural range, and have successfully survived with the invasive ctenophore.

While the invasion of *B. ovata* to the Black Sea was accidental, it was successful in significantly lowering the populations of *M. leidyi*. Since the population in the Caspian Sea, has had rapid growth, there has been discussion about introducing *B. ovata* in to the Caspian Sea to reduce populations (Ivanov et al. 2000). However, in this case the negatives may out way the positives. The introduction of *B. ovata*, while possibly eliminating the threat of *M. leidyi*, could pose its own threat to the ecosystem (Ivanov et al. 2000). With its lack of predators and having practically the same habits and life style of *M. leidyi*, the introduction of this other ctenophore could cause the same amount of damage to the ecosystem in the Caspian Sea, if not worse. Besides the impact *B. ovata* has on the species, eradication efforts have been unsuccessful

While the species can survive wide temperature range, 1.3°C to 32°C, it prefers warmer waters. Cold winters in the Black Sea, with temperatures below 4°C, the population of *M. leidyi* did not survive. In the proceeding spring the populations, were significantly smaller in number and in general size (Shingonova et al. 2001). *M. leidyi*, tends to move into open waters rather than the coast with colder waters. With the warming temperatures of the ocean due to climate change, it is predicted that the species of comb jelly will flourish.

While *M. leidyi* has been, in a sense, contained by the populations of *B. ovata*, the blooms are still a need for concern. Its impacts on the local fisheries and the ecosystems of the seas, proves, even with its small size, *Mnemiopsis leidyi* is a harmful species, when it moves outside its native range.

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Chinese Mitten Crab - *Eriocheir sinensis*

By Abby Doane

Edited by Rebecca Buchanan

The Chinese mitten crab (*Eriocheir sinensis*) is on the Global Invasive Species Database list of the “100 of the World's Worst Invasive Alien Species”. These crustaceans are generalists who can survive in a wide range of temperatures and salinities. However, *E. sinensis* is limited by their necessity to live in fresh water, but breed in salt water. They are widely distributed across the Northern Hemisphere. *E. sinensis* have major negative economic and biological impacts within their non-native ranges. Controlling *E. sinensis* has come with limited success, which is why they are considered among the world’s worst invasives.

E. sinensis can be identified by dense patches of setae on its claws, which give the crab its “mitten” name (NEMESIS 2006) (Benson and Fuller 2012). The tips of their claws are white and usually the same size in both males and females. *E. sinensis* have a central frontal notch and four spines that are sharper than those of similar species (Figure 1). Its carapace is broad and slightly rectangular. Their legs are usually twice as long as its carapace width. Adult *E. sinensis* range in size from 30-95mm, with an average of 60mm. These features are important to know in order to determine if *E. sinensis* has been spotted in a new range.

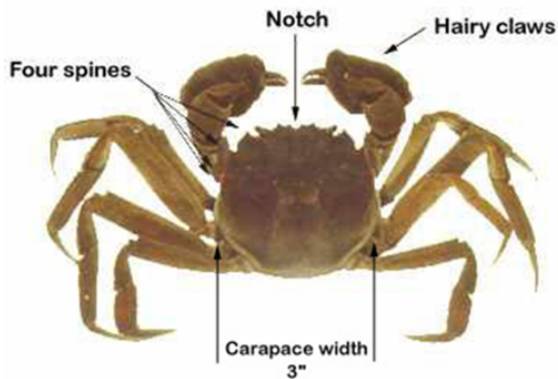


Figure 1. *E. sinensis* identifying features (CDFW 2014)

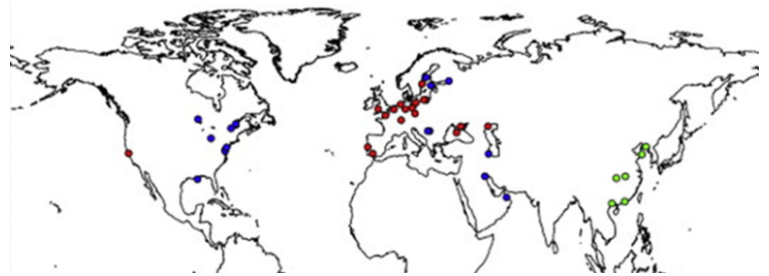


Figure 2. The distribution of *E. sinensis* populations. Green represents its native range. While blue represents non-established populations and red dots represent established populations. (Dittel and Epifanio 2009)

E. sinensis lives in temperate and tropical regions in the Northern Hemisphere. It is native to the Western Pacific, specifically China and Korea ((NEMESIS 2006). There are established populations throughout Europe and in the San Francisco Bay in the United States (Figure 2). The first known establishment of *E. sinensis* in Europe was in 1912 in Germany (GISD 2009). They became established in the San Francisco Bay in 1991 (NEMESIS 2006). There are non-established populations of *E. sinensis* in the East Coast of the US, the North American Great Lakes, parts of Europe, and the Middle East (Figure 2). One interesting case is how they first appeared in the North American Great Lakes in 1965 (de Lafontaine 2008). This was only six years after the St. Lawrence Seaway was opened, allowing ocean vessels in. During the next forty years, fourteen additional crabs have been sighted in the Great Lakes, primarily in Lake Erie where there are major commercial fisheries. However, due to its catadromous nature, which will be discussed a little later, *E. sinensis* has never become established in the region. Looking at all of the places *E. sinensis* has been spotted or established, the vectors for their transportation have been determined. The most common vectors are: ballast water, hull fouling, aquarium trade, live food trade, smuggling, and

natural dispersal in their planktonic stage (GISD 2009) (Cohen and Carlton 1997). No matter which vector brought them, it is evident that *E. sinensis* are widespread throughout the Northern Hemisphere.

E. sinensis have many characteristics that allow them to be successful in non-native regions. The first characteristic is that they are catadromous, meaning they spend their larval and juvenile lives in salt water, while as adults they live in fresh water (NEMESIS 2006). *E. sinensis* make mass migrations in the spring time from up river to the mouth in order to breed in salt water. These crabs produce 600,000 young per spawning event. *E. Sinensis* larvae are planktonic for 45-99 days. Their long planktonic stage combined with the amount of brood released in one event means that *E. sinensis* has a high survival and spread rate. These characteristics make *E. sinensis* a good invader because it allows them to spread to new regions during their long planktonic stage. Another important characteristic of *E. sinensis* is that they can survive in a wide range of temperatures, 0-30°C, and salinities, 0-35‰. This ability to survive in extreme temperatures and salinities means that *E. sinensis* is able to live in a wide range of environments. However, one study looked at the effects on climate change on *E. sinensis* in the Iberian Peninsula finding that it results in a loss of suitable habitats (Capinha *et al.* 2012). As water temperatures increase, the areas, which have a suitable temperature for *E. sinensis* to survive in, will decrease. Monitoring future climate change and the response of *E. sinensis* is important.

In general these main features aid *E. sinensis* in establishing new populations in non-native regions. Widespread establishment of *E. sinensis* comes with various negative impacts to their new habitats. One major impact of *E. sinensis* is a reduction in biodiversity in their new ecosystem (GISD 2009). They have this effect because they are opportunistic omnivores who eat aquatic plants, algae, detritus, and fish eggs, which reduces the diversity of species in the area. Another impact of *E. sinensis* is that they create physical disturbances in river banks via burrowing activity (Figure 3). These disturbances damage dikes and increase river embankment erosion, which leads to the weakening or collapsing of banks. Their burrowing can also destroy levees. The destruction of levees and the

weakening of river banks is a major threat to flood control and water supply systems affecting public safety.

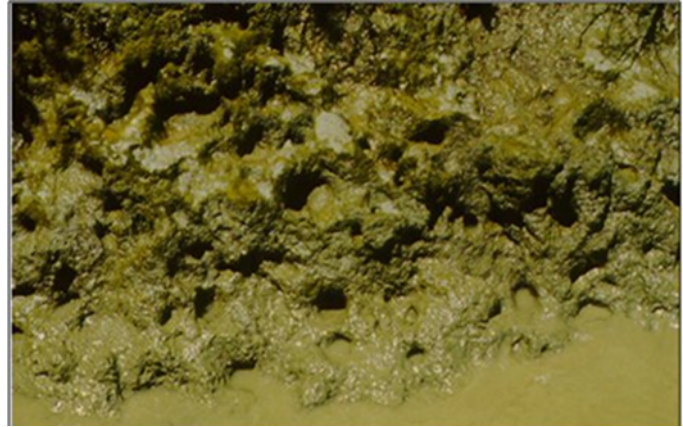


Figure 3. Holes created by the burrowing activity of *E. sinensis* weakening the bank. (CDFW 2014)

Another impact of *E. sinensis* is the economic cost it takes to manage and repair the damage they have caused to river banks. Since 1912, Germany has spent over €80 million due to the negative effects of *E. sinensis* and trying to manage their populations. *E. sinensis* hurt the fishing industry by stealing bait and damaging fishing gear. Both of these actions hinder fishermen's ability to catch what they need to in order to survive, which hurts local economies. An additional impact of *E. sinensis* in non-native regions is how their mass migrations for reproductions affect an area. In the spring, hundreds of adult crabs head for the ocean. These massive aggregations block water intake pipes for irrigation and water supply structures. Adult *E. sinensis* in migration clog water treatment and power plant pipes (Cohen and Weinstein 2001). One last impact of *E. sinensis* is that it is a known host for the human lung fluke parasite in Asia and can affect human health (Gollasch 2011). The crab acts as an intermediate host, while humans are a final host. If ingested, the parasite settles in the lungs causing significant bronchial damage or in some cases it makes its way to the brain causing neurological illnesses. There have been no cases in Europe; however, it has occurred in Asia where the crab is seen as a delicacy. *E. sinensis* negatively affects biodiversity, river bank integrity, local economies, and human health.

Although there are a lot of negative impacts caused by *E. sinensis*, there are ways that countries have tried to control their populations. One major form of control is through catching and exporting the crab to Asia. In one year Germany sold approximately €3-4.5 million worth of *E. sinensis* to Asia for consumption (GISD 2009). Another way to control *E. sinensis* is through commercial use. Some uses for them are: bait for eel fishing, food for cattle and chicken, fertilizer for agriculture, and material for the production of cosmetics. In the 1930's and 40's, Germans tested a new form of control for *E. sinensis*. Since they migrate in masses in the spring, scientists decided to put two types of migration boarders in the river. The first one was an electrical screen placed on the bottom of the river. Pluses were sent out that disabled and killed *E. sinensis*. The second experiment involved placing barricades along the bottom of the river forcing *E. sinensis* to crawl out of the water onto the bank to go around it. Traps were set up on the bank to catch the crabs. Both of these methods saw limited success because the sheer number of *E. sinensis* was too great to be affected by these small decreases in their population. One last form of control is through public awareness. On the east coast of the U.S. *E. sinensis* has been spotted, but it is not yet established. It is important to get the public involved in identifying *E. sinensis*, so that scientist can monitor their invasion and try to prevent them from becoming established.

E. sinensis is an extremely adaptive species which makes it such a great invasive species. Although it is limited by its catadromous nature, *E. sinensis* does not let this inhibit its ability to take over a new habitat. Due to ballast water it can be found in lakes, but *E. sinensis* cannot become established because there is no salty water nearby for it to reproduce in. However, in areas where it can become established there is a wide range of negative impacts from economic to public safety through the weakening of river banks. There are a number of methods to control *E. sinensis*, but most have seen limited success. So, it is imperative to monitor their populations before they become established to prevent them from causing major damage to the area. Considering all of the negative effects and how difficult it is to control *E. sinensis*, it's clear to see why it is considered such a serious invader.

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Veined Rapa Whelk

By Teresa Berndt

Edited By Keenan Tilsley

The Veined Rapa Whelk (*Rapana venosa*) is a marine gastropod that is found in coastal waters off the coasts of south eastern Asia. This whelk is also a very destructive invasive species in places like Europe. This case study will discuss the vectors that led to this invasion as well as adaptations that help this species survive in its new habitat. Impacts, as well as what can be done about those impacts, will also be addressed.

The Veined Rapa Whelk has distinctive black veins along the shell which makes it noticeable compared to native whelks. The inside of the shell is a deep orange and they can grow six to seven inches long (Chesapeake Bay Program 2012). There is no other gastropod in European waters that can be mistaken for *R. venosa* (Nobanis 2010). These are carnivorous marine snails. Most of their diet consists of mollusks, such as oysters or clams (USGS 2012). Unlike other gastropods, Rapa Whelks smother their prey and pull apart both shells in order to feed through the open valve (USGS 2012).

R. venosa produces eggs that settle to the substrate and resemble a yellow shag carpet (USGS 2012). Females can lay multiple egg cases a year containing 1,000 eggs at a time (Europe Aliens 2006). Eggs don't hatch until 18-26 after fertilized so they have plenty of time to move with the currents and to settle in different locations, which ideal for a species to become an invasive species (Chesapeake Bay Program 2012). Once the eggs hatch, they grow very

quickly within their first year and can reproduce by their second year. (Chesapeake Bay Program 2012, Nobanis 2010). It has been observed that female Rapa Whelks can lay viable eggs for at least 5 years after their last mating event. Also, a single egg mat, laid by one female can have as many as 15 million eggs (Chandler *et al* 2008).

Distribution

The Veined Rapa Whelk's native range is the Yellow Sea, Bohai Sea, East China Sea and the Sea of Japan. These areas have a high population diversity, but the populations are in decline because they are being exploited (Yang *et al* 2008). In these areas of southeastern Asia, *R. venosa* is considered a delicacy, used in cooking. The populations are being overfished.

Veined Rapa Whelks are invasive to Europe. They first invaded in the Black Sea in 1946. Between 1959 and 1972 most of the Black Sea and the Sea of Azov had been invaded (Nobanis 2010). From then, this species traveled south by currents and invaded other seas in Europe. By 1974, it was in the Adriatic Sea off the Mediterranean and in 1997 it had made its way to the Atlantic coast off Brittany, France. In 2007, it was found off the Atlantic coast of Spain (Nobanis 2010). There have been other areas such as the Pacific coast of North America as well as Uruguay and Argentina, where *R. venosa* has been spotted, but there were not enough to say that there is an established population.

In a study done in 2008, a group of scientists took on the daunting task of finding genetic information on *R. venosa* in native populations as well as invasive areas to find out how many populations there could be in the wild. Figure 1 represents nucleotide and mitochondrial data from native populations as well as introduced populations. Haplotype H1 is the most ancestral haplotype and is seen in both Korean and Chinese populations. *R. venosa* DNA was tested at three different Black Sea locations, all resulting in the same haplotype, suggesting that all Black Sea *R. venosa* originated from the same female. There is also a lack of genetic diversity in collections such as the Adriatic Sea, the Chesapeake Bay, France, and the Netherlands, which suggests that the population from the Black Sea is the one that invaded in these areas (Chandler *et al* 2008).

Vectors

There are a few ways that have been suspected as to the cause of *R. venosa* invasions and they are ship ballast, aquaculture and shellfish trade, and possibly via other marine species. It is not clear how the Veined Rapa Whelk first got into the Black Sea. It has been suspected to have been from ship ballast that went along with the transportation of oysters. Along with this theory comes another, which is that hull fouling is the cause of the Black Sea invasion. The egg casings could have latched on to the hull of a vessel and were transported to the Black Sea. Ballast water is also the suspected pathway from the Black Sea or the Mediterranean to the Chesapeake Bay in Virginia and Maryland in North America. Since these species are related by haplotype, it isn't

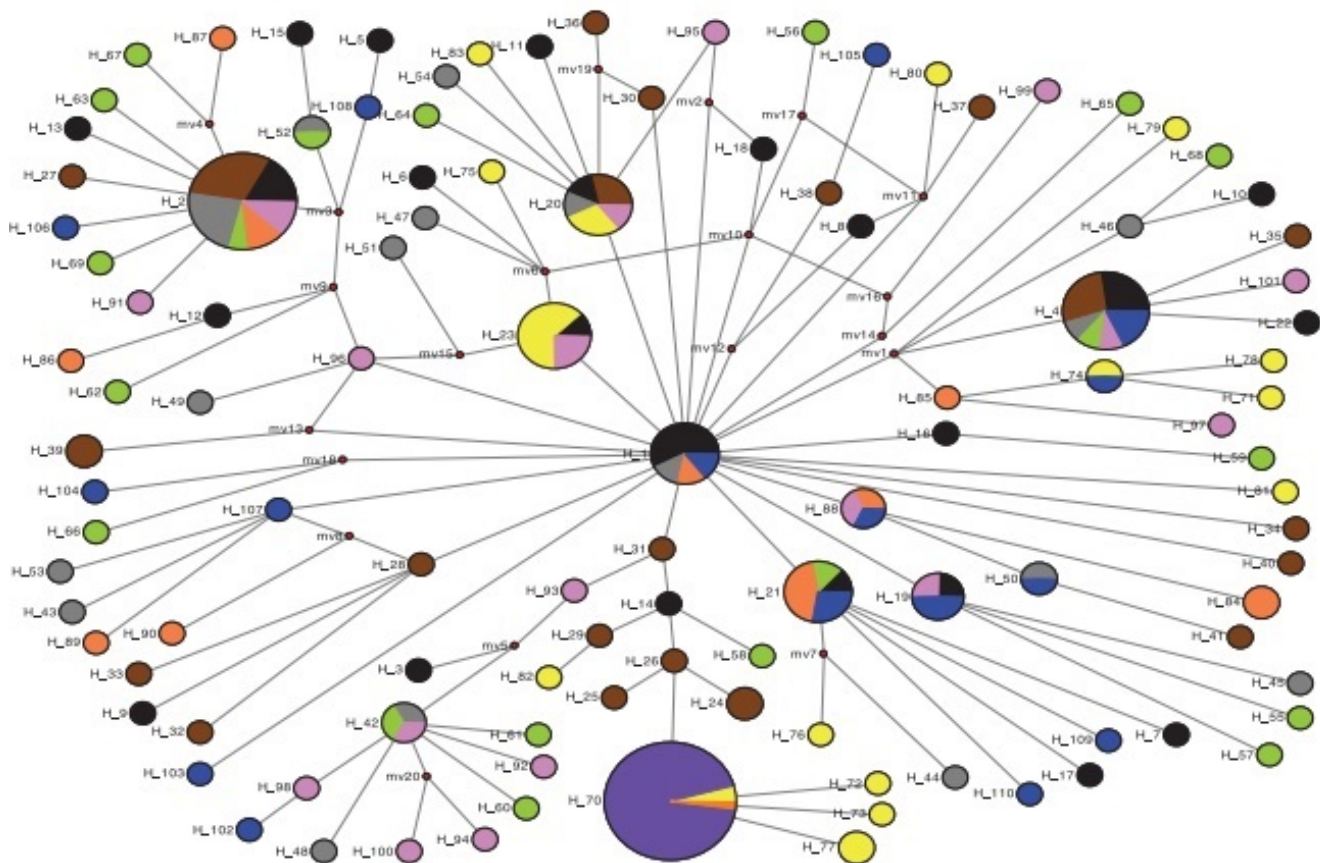


Figure 1: Minimum spanning network of combined COI and ND2 haplotypes. Color coded as follows: Laizhou Bay, China, black; Yantai, China, brown; Qingdao, China, grey; Xiangshan Bay, China, green; Mikawa Bay, Japan, yellow; Cheju-do, Korea, orange; Inch'on, Korea, pink; Tongyeong, Korea, blue; all introduced collections, purple. (Chandler *et al* 2008).

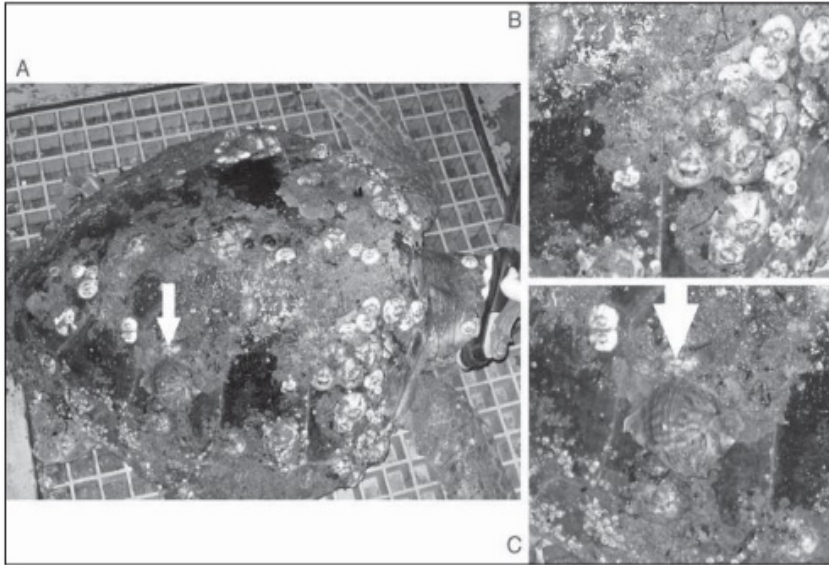


Figure 2: Photographs of A: the juvenile loggerhead turtle, B: close-up of the turtle carapace, C: close-up of the posterior right quadrant of the carapace with the veined rapa whelk. Arrows point to the approximate position of the whelk.

clear as to exact origin (Nobanis 2010).

A study in 2011 found that Loggerhead sea turtles could be a possible vector to move *R. venosa* along the Atlantic coast of North America. The whelks made the journey from the Chesapeake Bay in Virginia to Wassaw Island off the coast of Savannah, Georgia. In figure 2 above, there is a distinct Veined Rapa Whelk that survived the journey from Virginia to Georgia. While there are no established populations off the Georgia coast, the more trips that are made, the more likely there will be established populations.

Adaptations

There are many reasons that *R. venosa* proves to be an excellent invader. One is that *R. venosa* thrives in polluted water. Locations such as the Chesapeake Bay, are highly polluted which helped establish a population in this area (USGS 2012). This species is also able to live in areas with low dissolved oxygen (Harding *et al* 2008, USGS 2012). *R. venosa* can also handle fluctuating salinities as well as fluctuating temperatures. There is also the fact that they can lay such large clutches of eggs, as many as 15 million, multiple times in a summer, which was mentioned earlier in this case study. Eggs don't

have to hatch right away either, the eggs could survive on the sandy substrate for up to five years (Chandler *et al* 2008).

Impacts

The impacts of *R. venosa* do not go unnoticed. Sandy substrate is disturbed in areas that have been invaded by this species. Veined Rapa Whelks also feed on oyster and clam populations. This is a major problem in areas such as the Chesapeake Bay because the oyster populations are already at

very low levels. If the Veined Rapa Whelk eats what is left of the Eastern oysters, this will not be good for the Chesapeake Bay fisherman. In areas such as the Black Sea, *R. venosa* is responsible for the collapse of local oyster populations as well as the depletion of the mussel populations (Zolotarev 1996, Europe Aliens 2006). The fishing industry in the Adriatic Sea is also suffering from *R. venosa*, specifically the cuttlefish industry. There they use nets to capture the cuttlefish and the whelks are weighing down the nets, which will not allow fisherman to catch cuttlefish. Veined rapa whelk's have also become competitors to drilling oysters as well as moon snails in its invaded areas. The moon snails and the drilling oysters cannot find as much food as they used to because the Veined Rapa Whelks have taken over.

What Can Be Done?

There are many things that can be done to effectively remove Veined Rapa Whelks. One thing that is quite obvious is to fish them. If they are unwanted in areas, there wouldn't need to be regulations set in place. Fishing them to the masses would be desired. Places such as Turkey and China are dealing with low populations

An Introduction to Marine Invasive Species: *Rapana venosa*

because of fishing them for food (Yang *et al* 2008, Nobanis 2010).

At the Virginia Institute of Marine Science, scientists have put out a bounty on *R. venosa* and are paying fisherman for every whelk brought into the lab for scientific research. This may not dramatically decrease the populations, it can help scientists learn about this species and possibly come up with other ways to eradicate them.

There was also a natural event that helped eradicate a small population of *R. venosa* in the Lower York River in Virginia in 2007. *Alexandrium monilatum* bloomed in this river and caused a red tide event. This red tide created extremely high levels of dissolved oxygen. As mentioned earlier, *R. venosa* likes low dissolved oxygen levels. This resulted in paralysis and mortality of all of the *R. venosa* in this river, with 0% mortality in the oysters and quahogs in the area (Harding *et al* 2009). While red tide events aren't wanted in areas where there is high fishing and boating, this could help naturally dispose of all of the whelks that are causing havoc in the Chesapeake Bay. The more this species invades, the harder people will continue to try and eradicate it from invasive areas. Early detection is key to keeping this harmful species out of a country's waters.

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Bluespotted Cornet Fish - *Fistularia commersonii*

Blaise P. Jenner

Edited by Angela M. Henrich

Introduction:

The Bluespotted Cornet fish (*Fistularia commersonii*) is an invasive fish species that falls into the classification of lessepsianmigrators or invasive species. Lessepsian migrations refer to the unidirectional movement of species from the Red Sea through the Suez Canal and into the Mediterranean Sea. (Taylor et al. 2012). The Suez Canal was constructed in 1869 and is approximately a 193 km long connection between the Red Sea and the Mediterranean. The Suez Canal is the major vector for invasions into the Mediterranean Sea, with currently more than 80 invasive fish species recorded in Mediterranean waters. *F. commersonii* invaded the Mediterranean in 2000 and quickly expanded throughout the basin; it has been placed on the list of most successful invasive species of the Mediterranean. *F. commersonii* reaches a total length of 160cm total length (TL) and inhabits different areas ranging from rocky substrate and reefs to sand, mud, and seagrass meadows. Due to *F. commersonii*'s high fecundity, long period of reproduction, rapidly expanding population, high genetic diversity, and generalistic feeding behavior it has proven to be an extremely productive invader that has the potential to have a high impact on its environment. (Cycles and Basin 2010)

Reproduction:

Until (Taylor et al. 2012) investigated the spawning behavior of *F. commersonii*, there was little known about the reproductive cycle including gonad morphology, length at maturity, and reproduction in relation to temperature. Sampling was conducted weekly in the eastern Mediterranean in Lebanon, specimens were obtained from fishermen who used beach seines, fixed seines, and encircling trammel nets. Researchers found that the size at sexual maturity differed from male to female fish; for males 50% maturity occurred between 51 and 100 cm TL and

between 65-113 cm TL for females. This relationship can be seen in Figure 1.

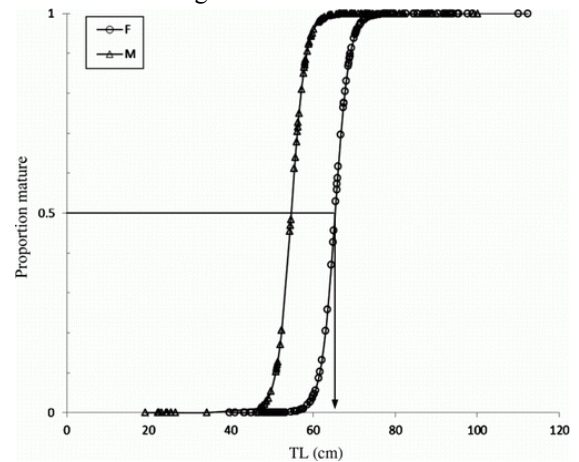


Figure 1: Shows the relationship between total length (x-axis) and the proportion of fish that were mature (y-axis) (Taylor et al. 2012).

The periodicity of reproduction was determined through the distribution of gonad maturity stages, the gonadosomatic index (GSI) that is the relationship between gonad weight and total weight of the organism. Large differences in GSI were observed between the two sexes, sexually mature females GSI ranged from 1.9 to 18.2 and 0.3 to 1.7 for males, therefore males showed insignificant cyclical pattern in GSI compared to a typical female. Temporal fluctuations of GSI showed that the ovaries of females started to develop in April and peak in August. While the GSI decreased starting in September, reproduction could still take place as late as November due to the occurrence of mature developed ovaries. Males showed no cyclical difference with the same mean GSI value over the whole year. While it was not statistically significant, a slight increase was observed from June to September, which coincides with peak Female GSI. A significant correlation between water temperature and GSI was found for females; the peak GSI in August corresponded to a mean water temperature of 28.4° C compared to the lowest GSI value which occurred in February with water temperatures of 18°

C. This relationship can be seen in Figure 2. Interestingly enough, other lessepsian species have been observed to have reduction in their spawning period. It is significant to note that *F. commersonii* still has a six-month spawning period. The long spawning period and significant dependence on temperature leads to the belief that this species has the serious potential to become even more fecund as ocean temperatures warm. The Mediterranean is a shallow ocean basin, so it is more susceptible to global climate change than other oceans, and this increase in temperature could lead to an even longer spawning period for *F. commersonii* leading to a higher fecundity (Taylor et al. 2012).

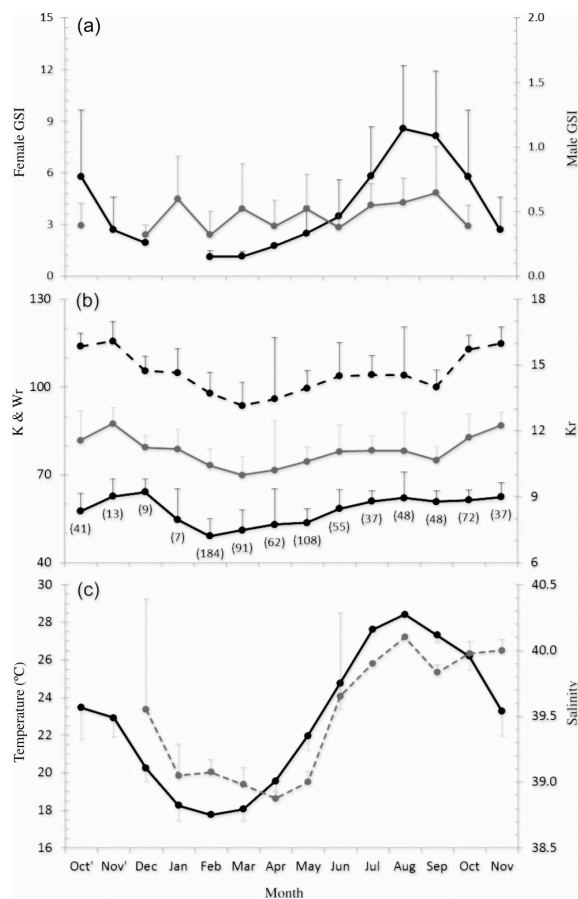


Figure 2: This figure shows the relationship between male and female GSI and month (top). Two different condition indices compared to month (middle), and temperature and salinity compared to month (bottom) (Taylor et al. 2012).

Genetics:

In theory lessepsian immigrants should display significant genetic bottlenecking due to the circumstance where only a few individuals would enter the Mediterranean Sea, and the population

would grow from those few individuals, therefore there would be very low genetic diversity. Contrary to this hypothesis, lessesian immigrants have showed relatively low genetic bottlenecking and high genetic diversity. All previous genetic work had been based on mitochondrial DNA and had revealed only two different haplotypes in the Mediterranean suggesting genetic bottlenecking. Another previous study used mitochondrial loci and found that a total of five mitochondrial lineages among the individuals that they sampled. This study was aimed to expand the coverage of mitochondrial markers and also to expand previous research by using nuclear markers as well.

In this study, three total markers were analyzed. Two were different mitochondrial makers; control region (CR) and cytochrome oxidase I (CO1), and one was a nuclear marker (rhidopson, (ROD)). In total, 96 and 91 individuals were analyzed for two different mitochondrial markers, CR and CO1 respectively, and 78 individuals were analyzed for nuclear marker ROD. Researchers found that in the native Red Sea population haplotype, diversity was very high with over 40 different haplotypes for the combine mitochondrial markers and 8 for the nuclear marker. In the invading Mediterranean, population haplotype diversity was much lower, and only three different haplotypes were seen between the two-mitochondrial markers. Statistical analysis found that the difference in haplotypes between the Red Sea and the Mediterranean was significant. In contrast, the nuclear marker showed higher than expected diversity levels with six haplotypes found in the Mediterranean population; therefore, there was no significant difference in genetic diversity of the nuclear marker between native and invasive populations. Figure 3 compares the different haplotypes (both mitochondrial and nuclear) with the sampling site and shows how the haplotypes that are apparent in the Red Sea are much less prevalent in the invasive population. It also shows that the invasive population exhibits different haplotypes than the native population suggesting that mutations in the Mediterranean population could be occurring (Tenggardjaja et al. 2014).

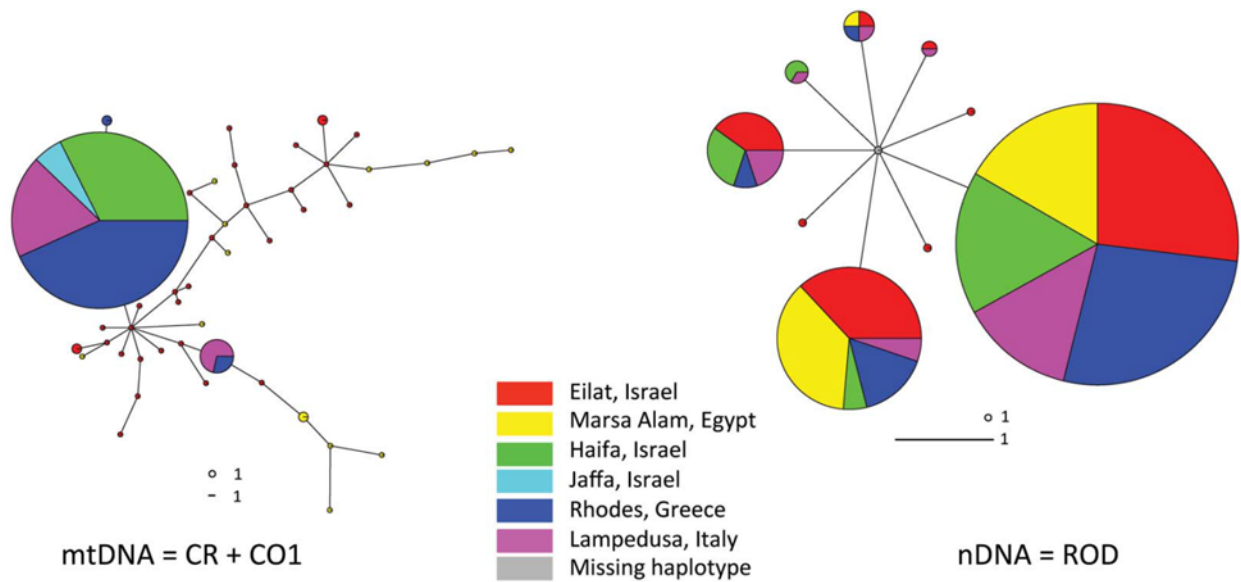


Figure 3: Haplotype networks based on two mitochondrial markers (CR and CO1) and a single nuclear marker (ROD). Each color represents each sampling site; the area of the pie diagrams is proportional to the number of individuals within each pie. The six sampling sites can be seen in Figure 4 (Tenggardjaja et al. 2014).



Figure 4: A map showing the six different sampling sites: two in the Red Sea and four in the Mediterranean Sea (Tenggardjaja et al. 2014).

Several hypotheses are available to explain the discrepancy in haplotypes between the two different types of haplotype makers. There were two main patterns revealed as a result of this work, the first is that there is most likely a difference in male and female population dynamics. The second is natural selection, mitochondrial DNA is often used for phylogeographic studies because it is passed down maternally through the DNA; therefore, it is also important to analyze nuclear markers. The high nuclear haplotype diversity compared to the mitochondrial diversity suggests that a few female lineages could have migrated through the canal in comparison to a much larger number of males. Considering the maternal lineage of mitochondrial markers and the low diversity of mitochondrial haplotypes, it is reasonable to believe that a small number of females compared to males could have established the invasive population. While no ecological studies of sex ratio have been conducted, that would be conclusive in establishing this theory. Alternatively, natural selection could be the reason that the diversity of mitochondrial markers and nuclear markers differ. It is possible that at the establishment of the invasive population, certain mitochondrial haplotypes were selected over others selected in the natural populations, reducing the diversity of haplotypes in the Mediterranean population (Tenggardjaja et al. 2014).

Diet:

A diet study was performed on the stomach contents of 245 specimens collected between September 2004 and March 2005, the goal of this research was to describe the feeding ecology of *F. commersonii* in an attempt to evaluate the potential impact of this lessepsian invader on native food web dynamics. The study also looked at the size relationship between the predator and the prey. The research was conducted by collecting the stomachs of 245 specimens, which were then dissected, and the contents were identified to the lowest classification possible. The study found that fish were the predominant prey item making up 96% of the stomach content by number and 99.95% by weight. Two different families, Sparidae and Centracanthidae with 29.4%, and 28.3%, dominated prey biomass respectively. The relationship between the size of *F. commersonii* was as expected; the size of the prey

increased with the size of the predator for all prey fish with measurable standard lengths (SL). The relationship between SL of the predator and SL of the prey can be seen for fish in three different prey habitats in Figure 5 (Kalogirou et al. 2007).

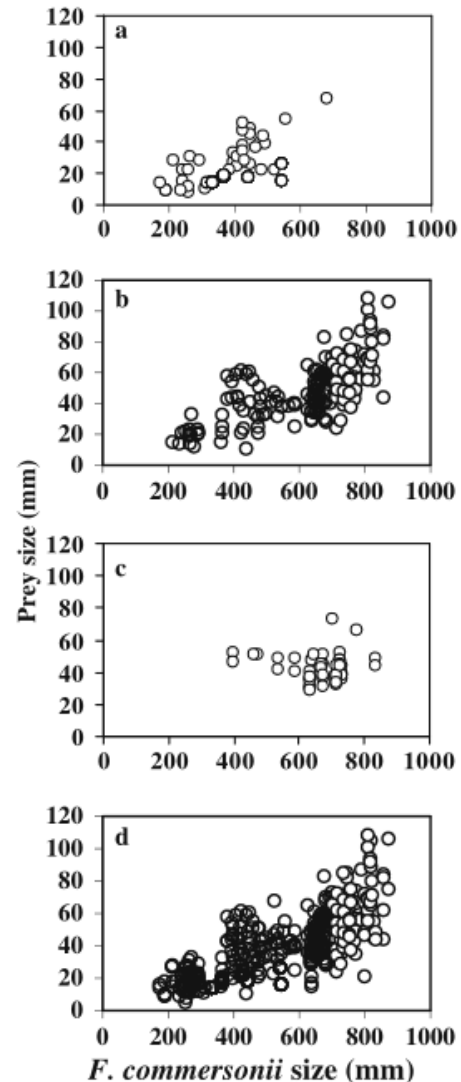


Figure 5: The relationship between size of *F. commersonii* and size of prey for four different prey habitats (a: benthic, b: suprabenthic, c: pelagic) and for all prey with known SL (d) (Kalogirou et al. 2007).

Conclusion:

F. commersonii is a relatively recent invader of the Mediterranean Sea (first observed in 2000); therefore, its full impact is yet to be discovered and studied in detail. What is understood at this time is that it has a long reproductive cycle, which could lengthen due to global climate change, which leads to

An Introduction to Marine Invasive Species: *Fistularia commersonii*

high fecundity. It has high genetic diversity and low genetic bottlenecking which has allowed it to spread rapidly throughout the entire Mediterranean basin. It is also a generalist feeder who is almost exclusively piscivorous. Combining these attributes results in a species that has the potential to have a large ecological impact on its newly colonized habitat; therefore, it is important to gain a larger knowledge of this species so that not only the ecological, but social and economic impacts can be better understood.

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Invading an Invader: The Asian Shore Crab

By Wyler Scamman

Edited by Hanna Pultorak

Range and Introduction

Hemigrapsus sanguineus, commonly referred to as the Asian shore crab, is one of the most rapidly expanding invasive species in the Atlantic. *H. sanguineus* is native to the east coast of Asia, but first invaded in North America near Delaware Bay in 1988 (Schab 2013). Since then *H. sanguineus* has also invaded the Atlantic coast of Europe in 1999 and have established populations along the northern coasts of Germany, Belgium, the Netherlands, and France (Fig.1; Dauvin 2009). Also by 2008, the Asian shore crab had expanded from its initial introduction in Delaware Bay and had colonized the entire coast from North Carolina to Maine (Fig.2; Delaney 2008). *H. sanguineus* is believed to have been initially introduced to both North America and Europe through ballast water (Dauvin 2009). Once a population was established at the initial sites on each coastline, *H. sanguineus* spread via larval dispersal.

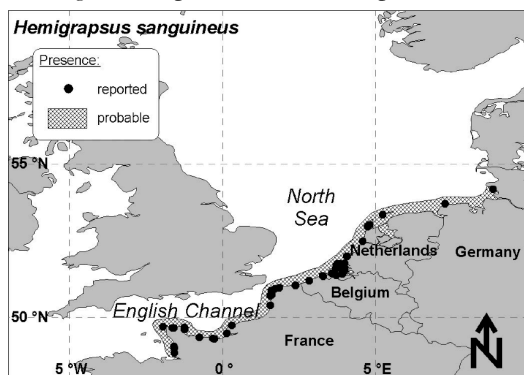


Figure 2 European range of the invasive crab *H. sanguineus* as of July 2008 (Dauvin 2009)

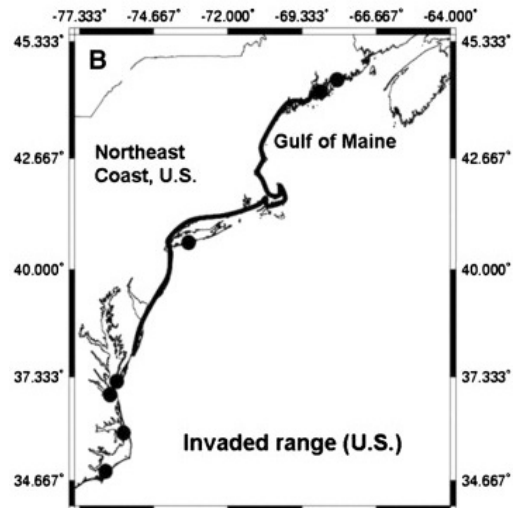


Figure 3 Invaded range of *H. sanguineus* in U.S. (Epifanio 2013)

Description and Habitat

For *H. sanguineus*, an adult male's carapace can grow up to a width of 40 mm and the females, which are often smaller, can grow up to 35 mm (Epifanio 2013). They often have dark colorations that include hues of orange, purple, and green (Fig.3). Juvenile and adult *H. sanguineus* can be identified by their square-shaped carapace which has three distinct ridges located near each eye. Additionally, the walking legs of *H. sanguineus* have zebra-like stripes of alternating light and dark bands (Epifanio 2013).



Figure 4 An adult specimen of *H. sanguineus* (Perry 2014)

H. sanguineus tend to inhabit temperate zones and often establish populations on rocky coastlines (Dauvin 2009). They usually have a high degree of success in areas of with a high degree of hydrodynamics, such as large tidal fluxes and wave action. *H. sanguineus* primarily are found in the intertidal zone. However a study that was looking at how these crabs survive during cold periods in Northern climates, has also shown that *H. sanguineus* are found in the subtidal zone during winter months (Kraemer 2007).

Invasive Adaptations

While *H. sanguineus* is often smaller than most other crabs it competes with in its invasive ranges, it has a few adaptations that allow it to thrive over other species. The first of these adaptations is that *H. sanguineus* is a generalist and opportunistic predator (Epifanio 2013). Its diet includes but is not limited to mollusks, macro algae, carrion, and other crustaceans.

H. sanguineus also has a staggeringly great fecundity. *H. sanguineus* sexually mature after two years and can produce up to 50,000 eggs per clutch and can have up to four clutches per spawning season (Epifanio 2013). Since these crabs can have a maximum lifespan of eight years each individual crab can potentially produce over six spawning seasons. That means a single female *H. sanguineus* has the potential to produce over one million eggs over the course of its life.

After the eggs reach the planktonic larval stages they are subject to natural dispersal by coastal currents and to anthropomorphic introduction through ballast water. Since the larval stages can last between 16 and 55 days depending on temperature, *H. sanguineus* has ample time to take advantage of both vectors (Epifanio 2013).

The full success of *H. sanguineus* as an invader is not entirely due to its own natural adaptations. A large portion of this success is ascribed to a lack of parasitism in non-native habitats (Epifanio 2013). In Japan, where these crabs are native, an overwhelming proportion of them are infected with one several parasites. One such parasite is *Polyascus polygenea* and in some areas of Japan it has infected more than 80% of the adult *H. sanguineus* population (McDermott 2011). The effects of parasites that infect crabs in the native range can include a decrease in growth, sterility, and egg predation. While these parasites severely hinder *H. sanguineus* in its native range, they are not found in crab populations that have been established in the Atlantic (Epifanio 2013). The reason for this lack of parasites is that they only infect adults. Since the initial individuals that established invasive populations arrived as planktonic larva, they never had an opportunity to be infected (McDermott 2011).

Impacts

H. sanguineus is often likened to *Carcinus maenas* (European green crab) when its ecological and economical impacts are discussed. Given this, the impacts usually ascribed to an invasive population of *H. sanguineus* includes the displacement of other crab species and a notable decrease in prey populations such as the commercially important *Mytilus edulis* (blue mussel) or other mollusks, crustaceans, and seaweeds (Epifanio 2013). While the scientific community generally accepts that *H. sanguineus* does have ecological and economical impacts similar in nature to *C. maenas*, the actual quantitative effects of *H. sanguineus* is not well studied and are unclear (Epifanio 2013).

Since its first reported sighting in Maine, concerns were raised over *H. sanguineus*'s potential impact on a single native species. This species is *Homarus americanus*, the American lobster, one of Maine's most iconic fishing industries. Faculty at the University of Maine conducted a study in 2006 that investigated if *H. sanguineus* would prey on juvenile lobsters. They found that adult *H. sanguineus* preferentially preyed on juvenile lobsters even though other food sources were still in excess (Demeo 2006). Of the 36 lobsters used in the 48-hour tests, 32 were eaten by nine adult *H. sanguineus*. However the authors urged that the topic requires further investigation before any conclusions can be drawn concerning the true interaction between the two species.

Out-Competing *Carcinus maenas*

C. maenas is one of the most iconic invasive crabs in the world. The European green crab has successfully invaded every continent except Asia and has been well established on the east coast of North America since its introduction in 1817 (Perry 2014). It has achieved this by out-competing every crab species it encounters. *C. maenas* was the dominant crab species in much of its invasive range in New England. That is until now.

H. sanguineus has now invaded both the East coast of The United States and the coasts of Europe. *H. sanguineus* has begun out competing *C. maenas* both in North America and in *C. maenas*'s native range (Epifanio 2013). This claim is primarily based on competition for shelter and food, as well as overall abundance.

Both *C. maenas* and *H. sanguineus* take shelter under rocks and are important for the survival of juvenile crabs. Juvenile *C. maenas* occupied 100% of suitable shelter in areas lacking a *H. sanguineus* population. However, if *H. sanguineus* is present in the area, the percentage never exceeds 25% (Epifanio 2013). In regards to competition over food resources, studies have shown that *C. maenas* is better than *H. sanguineus* at obtaining food. Nonetheless, *C. maenas* significantly reduces feeding while *H. sanguineus* is present (Epifanio 2013).

The overall abundance of *H. sanguineus* and *C. maenas* depicts the general trend of the competition between the two species. The domination of the of *H. sanguineus* over the old invader *C. maenas* is clear as it has been systematically conquering the east coast of North America (Fig.4) (Delaney 2008).

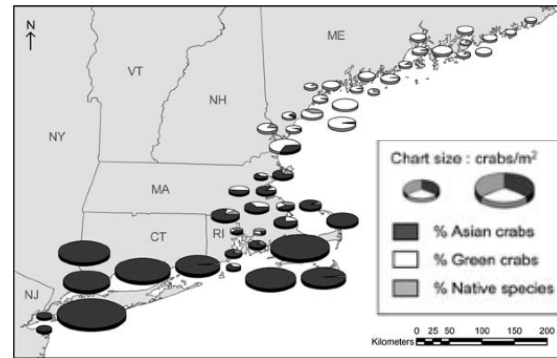


Figure 5 Relative abundance of intertidal crab species between New Jersey and Maine (Delaney 2008)

While the European green crab has been the center of attention for decades due to its invasive and destructing tendencies, the baton may soon be passed. The Asian shore crab has begun to replace *C. maenas* as the dominant invader. The dominance *C. maenas* established over two centuries is starting to be over-thrown in roughly an eighth of that time. The need to more fully study the exact impacts of *H. sanguineus* will be essential as this crab only continues to expand.

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Invasive Species in Antarctica

By Natasha Bourdon

Edited by Teresa Berndt

Introduction

Antarctica is the world's southernmost continent and is home to the South Pole. (See figure 1 and 2 for a Map of Antarctica) The continent itself is 13,829,430 km² of land. 68% of the land is covered with ice that extends past the land and over the waters the surround the continent. 90% of all the world's ice is located in Antarctica.



Figure 1: This figure illustrates the placement of the world's continents. Antarctica is the white, southernmost continent. (Source: Frank ok Fun)



Figure 2: This image is a map of the continent of Antarctica. (Source: 3 Below Zero)

Some of that ice is located over the Southern Ocean. The Southern Ocean circulates

the continent of Antarctica and is the fourth largest ocean (NOVA in the News). (See figure 3 for map of Southern Ocean) The International Hydrographic Organization declared it the fifth ocean in 2000. It is 20.3 million km² in size and is 7,235 meters deep at its deepest point.

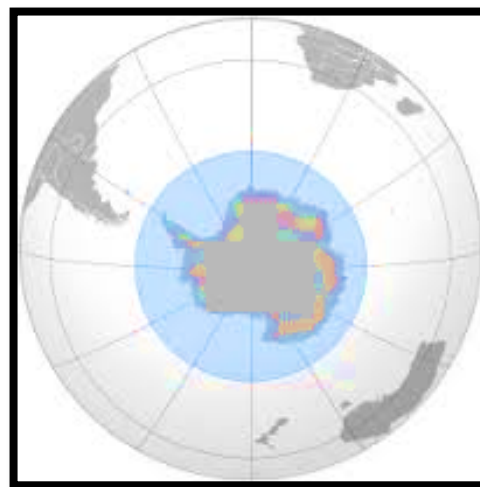


Figure 3: This image is a map of Antarctica that highlights the Southern Ocean. (Source: International Hydrographic Organization)

Due to its extreme environment, Antarctica has had minimum invasive species until recent years. As the amount of human activity in Antarctica has increased so has the number of invaders. Human traffic to Antarctica is offering invasive species vectors that were not previously available. Climate change has also enabled invasive species to invade.

The Climate of Antarctica

Antarctic is one of the world's most extreme climates to live in. Mawson station in Antarctica is the windiest place on earth. The average wind speed there is 37 kmh. The world's

highest wind speed of 248.4 km/h was recorded there. Antarctica is the coldest place on earth. The average summer temperature at the South Pole is -27.5°C and the average winter temperature is -60°C . The lowest recorded temperature on earth was recorded to be -89.2°C at the Vostok station.

The Southern Ocean's climate is just as extreme as on land. The sea temperature varies between -2°C to 10°C (NOVA in the News). Due to the cold temperature of the water, the Southern Ocean is very dense. It also holds large amounts of nutrients needed to sustain life, but it lacks iron, which many organisms need to survive. This water circulates around the continent of Antarctica in an eastward direction. This flow of water is the world's largest ocean current, the Antarctic Circumpolar Current. This current is the only current on earth that can travel around the globe without being interrupted by land. At any point in time the Antarctic Circumpolar Current is transporting 100 times more water than all the world's rivers combined.

History of Invasive Species

Historically Antarctica has remained relatively invasive free. It was one of the few places on earth to remain undisturbed. Its extreme climate made it difficult for any species that did not specifically evolve to live there. The Antarctic Circumpolar Current also prevents organism from entering the area. The current is too strong for most species to cross on their own. Any species that was strong enough to enter the current would remain there because they are not strong enough to get out of it. The Antarctic Circumpolar Current limited the vectors invasive organism had to enter Antarctica.

Recent human activity in Antarctica has changed how difficult it is for an invasive species to enter the area. Human traffic has created vectors for organisms that were previously absent from the area. Human fossil fuel use has also been linked to climate change. As the climate changes, Antarctica's climate becomes more tolerable to species that previously could not survive there.

Human Exploration of Antarctica

William Smith and James Bransfield first discovered Antarctica in 1820 (Polar Discovery). They had discovered the South Shetland Islands and the shore of the Antarctic Peninsula. It was not until 1821 that Captain John Davis set foot on the continent, Antarctica, in hopes of finding a new hunting ground for seals. Exploration of Antarctica did not pick up until the 1890's when Norwegians began whaling. In the early 1900's many countries sent research teams to investigate this new area. The South Pole was not reached until December 14, 1911 by Norwegian explorer Roald Amundsen. Organization of research teams and the construction of research stations continued to increase through the mid 1900's.

Currently 30 countries have established research claims on Antarctica. There are now over 60 research stations. These 60 stations are depicted in figure 4 below. Within those stations an average of 4,000 live on the continent during the short summer. 1,000 individuals live there in the winter. There are no indigenous people in Antarctic, only researchers and tourist.

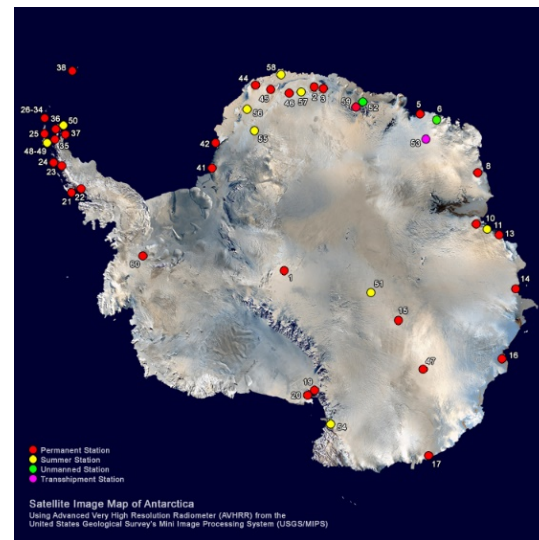


Figure 4: This image shows the location of research stations on Antarctica. (Source: Eco-Photo Explorers)

Antarctica has become an increasingly popular tourist destination. The majority of the Antarctic tourist companies reside within Chile and Argentina. They take people on both day and

overnight trips were they can explore both the land and the Southern Ocean. Each year 30,000 to 40,000 tourists visit Antarctica during the summer months. Both tourist and research activity in Antarctica have increased the amount of vectors invasive species have to the area.

Boat traffic is one of the new vectors that humans have enabled invasive species to use. Invasive organisms can now enter Antarctica by ballast water and haul fouling. Organisms are able to attach to large ships as well as small kayaks that tourists use. The organisms can then detach once they enter the Antarctic water and begin the process of invading. Humans themselves have also been observed acting as a vector for invasive species.

A study has shown that tourists are acting as vectors to invasive plants (Shaw, JD. *et al* 2014). It was found that each visitor carries an average of 9.5 seeds on them as they make their way towards Antarctica. These seeds can be found on the people's clothing, bags, and shoes. The most common place they are found is on the tongue of shoes between the laces. It is hypothesized that researchers bring in larger amounts of invasive species based on their large amounts of gear they carry.

Researchers have been directly linked to invasive species establishing in Antarctica. *Poa annua*, also known as annual bluegrass is a terrestrial grass species native to Eurasia (Pagad, S. 2010). It had previously invaded all continents but Antarctica. *P. annua* has now established on the Antarctica Peninsula (Black, R. 2012). (See figure 5 for image of *P. annua*) It can be found growing around four researcher stations. It is only seen around those four stations so it is believed that the researchers are responsible for the introduction. This species is known for dominating native vegetation of sub-Antarctic islands. If the species goes unattended it could possibly spread throughout the continent. *P. annua* may not be a marine invasive species but it can be used as a model to see the direct relation between increased human activity in Antarctica and increased invasive species.



Figure 5: This image shows *Poa annua* growing around a research station in Antarctica.

Effects of Climate Change

Antarctica's cold climate has made it difficult for many species to live there. Global climate change is causing an increase in the temperature of Antarctica. The Antarctica Peninsula is experiencing the highest rate of temperature increase due to climate change. The Southern Ocean is also warming at a rate faster than the rest of the world's oceans. The Southern Ocean has risen 1.7⁰C since 1950. As the temperature increases, invasive species with lower temperature tolerances are able to survive better than previous. The rising temperature also makes it harder for some native species to live there. Species that are native to Antarctica generally are evolved to live within a small threshold of cold temperatures. As temperature increases species may be pushed to the maximums of their threshold. This could lead to the die off, of native species. If a native species dies off this could create an opening in the ecosystem for an invasive species to take over.

Temperature changes are not the only effect climate change is having in Antarctica. Climate change is also causing an increase in the acidity of the Southern Ocean. The Southern Ocean is the world's largest sinking site for atmospheric carbon dioxide. 40% of the carbon dioxide that humans release into the atmosphere is reabsorbed into the Southern Ocean. The increase in the amount of CO₂ causes the pH of the ocean to rise. The pH of the Southern Ocean has changed from 8.1 to 8.2 since 1970. Increase

acidity is another factor that could affect the native populations.

What can be done?

The best action that can be taken to help preserve Antarctica is to monitor and prevent invasive species. With the information humans have about invasive species and the Antarctic environments, people are more knowledgeable about the threats to Antarctica. There are no current legal regulations about the prevention of invasive species in Antarctica. With humans being the main vector source for invaders it is the responsibility of the people to help prevent invasions.

Some people are taking responsibility for the problem and developing plans to reduce the impact they are having. Many research stations have developed procedures to check gear for invaders. They also developed routine cleaning of transport vessels including ships, zodiacs, and helicopters that travel to and from Antarctica. Cement helicopter pads have also been create in hopes that it will prevent invasive species from entering the ground from the helicopter's rails before the rails can be cleaned.

Tourist companies have also been developing their own policies for preventing invasive species. The International Association of Antarctic Tour Operators has supplied tour companies with information about invasive species and suggested ways to prevent the spread. The tourist companies then have come up with their own set of rules. Those rules include the cleaning of ships and kayaks as well as rule for the guests. Some companies make the tourists change into new, clean clothes before stepping foot in Antarctica as a way to prevent spread. Many companies also make the tourist wear a different pair of shoes than the ones they wore on the main land.

Developing a set of legal rules about the inspection for and prevention of bringing invasive species to Antarctica would be an idea step to take. This would make sure that everyone entering the continent would have taken some kind of action to reduce the chance of bringing an invasive species in. People also need to continue monitoring for new invasive species

arriving in Antarctica. Many species are on the brink of moving in to Antarctica. Monitoring those species will help people better prepare for the prevention of them entering or for dealing with them once they have arrived.

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The Mediterranean mussel (*Mytilus galloprovincialis*)

By Ashleigh Novak

Edited by Blaise Jenner

Marine mussels under the genus *Mytilus* have three separate sibling species, which include *M. edulis*, *M. trossulus*, and *M. galloprovincialis*. Each of these species occupies different locations worldwide and they are only reliably distinguished by genetic analysis (Zardi et al 2006). Despite morphological similarities between *Mytilus spp.*, the Mediterranean mussel (*M. galloprovincialis*) (Fig. 1) is the only one classified as an invasive species. Even with the negative connotation associated with the term ‘invasive’, this mussel species has a multitude of benefits that have aided in its establishment on a global scale.



Figure 1. The invasive Mediterranean mussel (*M. galloprovincialis*).

Listed under the Global Invasive Species Database as number sixty-two in the “100 of the World’s Worst Invasive Alien Species”, *M. galloprovincialis* is initiating a large amount of research based on its relatively recent spread (Global Invasive Species Database 2014). Native to the Mediterranean Sea, this species now inhabits the temperate zones of the northern and southern hemispheres, with established populations in Africa, North America, and Japan (Fig. 2; Zardi et al 2006). Most research has been conducted on the western coast of South Africa where the mussel was first

discovered in the late 1980’s and off the western coast of North America.

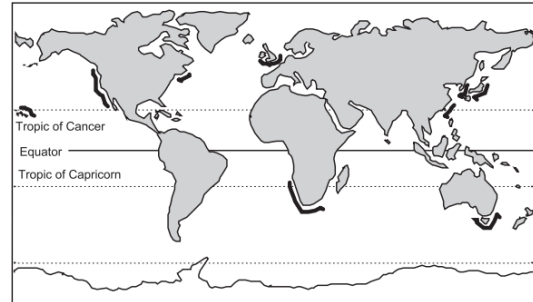


Figure 2. Locations of *M. galloprovincialis* throughout the world (Branch and Steffani 2004).

Many characteristics of *M. galloprovincialis* give them advantages when invading new areas. Similar to other mussel species, they have a larval planktonic stage, which allows for them to be passively transported in ballast water (Branch and Steffani 2004). Additionally, mussels have byssal threads, which are strong, silky fibers made of protein (Fig. 3), which allows them to attach to hard substrates such as the hulls of boats and ships (Wonham 2004). Definite vectors that have caused the spread of this species have only been suggested and are not precisely known. In contrast to incidental introductions, *Mytilus spp.* are cultivated on a global scale which has expedited the spread of *M. galloprovincialis* by direct introductions for the aquaculture industry in southern South Africa, British Columbia, and Washington State (Branch and Steffani 2004).



Figure 3. Byssal threads help mussels attach to hard substrata including boat and ship hulls.

Biologically, mussels have the potential to be an ideal invasive species due to their planktonic larval stage and their byssal threads. Other adaptations that have enabled the successful invasion of *M. galloprovincialis* include fast growth, a high reproductive rate, and a high filtration rate (Fig. 4). Reproductive advantages include the capability of the invasive mussel to spawn more than once a year and also producing 20-200% more offspring than native mussels (Branch and Steffani 2004). Aforementioned evolutionary advantages are possible reasons why *M. galloprovincialis* became an invasive species while the other mussel species did not, but this question is still undergoing investigation within the scientific community.

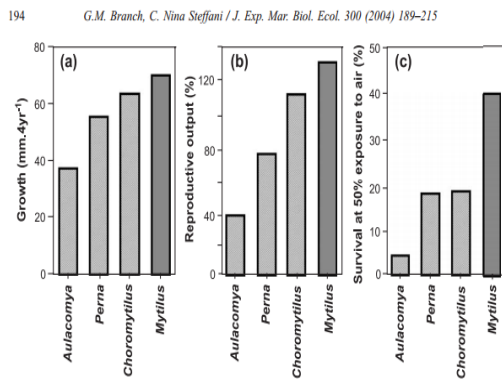


Figure 4. Growth, reproductive output, and air exposure, of three native mussels and the invasive mussel shown under *Mytilus* (Branch and Steffani 2004).

This invasive species is more tolerant than other mussel species to warmer and higher salinity ocean waters due to its evolutionary roots in the Mediterranean Sea. Like most species, *M. galloprovincialis* has an optimal range of preferred abiotic conditions, which increase growth and ultimately ensure survival of the species. As an invader on the west coast of the United States, *M. galloprovincialis* has invaded areas once inhabited by the native mussel, *M. trossulus* (Fig. 5) (Lockwood and Somero 2011). Due to *M. galloprovincialis* only being able to survive in warmer waters, the species has a latitudinal boundary marked by cooler waters. As the climate of the earth

continues to change, the oceans are becoming increasingly warmer which has the potential to facilitate the range expansion and ability to establish new invasive colonies of *M. galloprovincialis* (Occhipinti-Ambrogi 2007).

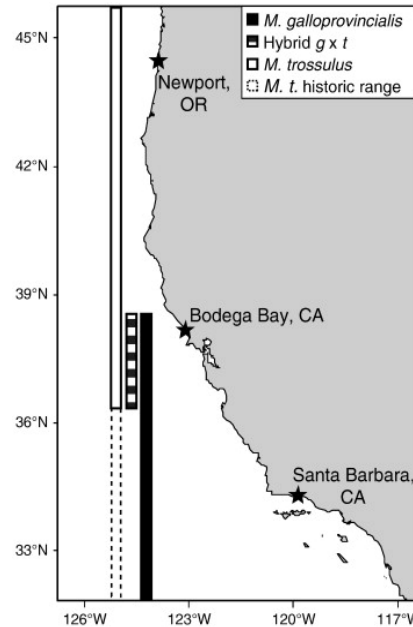


Figure 5. The range of *M. galloprovincialis* is shown in black whereas the native mussel, *M. trossulus* is shown in white. A hybrid zone does occur where the range of the two species overlap (Lockwood and Somero 2011).

Like many invasive species, *M. galloprovincialis* has been shown to displace native species including other *Mytilus spp.* (Branch and Steffani 2004). Ultimately, this displacement results in a lower species diversity of the invaded area and can potentially lead to alterations in the flow of the native food web ecosystem. A specific example of this happened recently in South Africa, where researchers witnessed a mass mortality of a native swimming crab species (*Ovalipes trimaculatus*) (Fig. 6).



Figure 6. The swimming crab, *O. trimaculatus*.

Over 2 million crabs washed up along the shore in a total of five mortality episodes recorded (Branch and Steffani 2004). *M. galloprovincialis* was attributed to this event because their larvae was observed settling on the eyestalks and exposed carapaces of *O. trimaculatus*. The effects on the South African ecosystem following this mortality event are not currently understood, but has the potential for negative influences due to the removal of a native species.

Despite the negative impacts that *M. galloprovincialis* has introduced, the species does have global benefits. As mentioned previously, *M. galloprovincialis* was purposely introduced into new areas for aquaculture purposes. After the incidental invasion of *M. galloprovincialis* on the western coast of South Africa, it was then deliberately introduced to the southern coast of South Africa for mariculture (Branch and Steffani 2004). British Columbia and Washington State also culture *M. galloprovincialis* over *M. trossulus* because the native suffers from haemolytic neoplasia, which is a disease that prevents it from surviving to a large size (Wonham 2004). Globally, the production of *M. galloprovincialis* in the aquaculture industry has increased significantly in the last thirty years (Fig. 7) (Food and Agriculture Organization 2014).

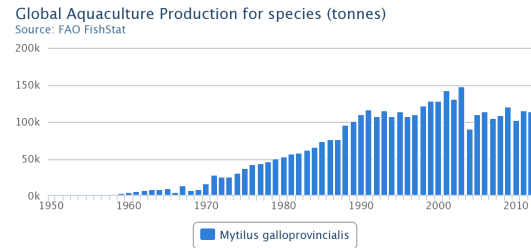


Figure 7. The global aquaculture production for *M. galloprovincialis* over the last fifty years (Food and Agriculture Organization 2014).

On the western coast of South Africa, where *M. galloprovincialis* incidentally spread, the Fishing and Mariculture Development Association initiated an experiment, known as the Northern Cape Mussel Project. In hopes to establish a small scale fisheries for *M. galloprovincialis*, an experimental fishery operated by two poor coastal communities was facilitated (Robinson et al 2007). Being the dominant invasive species in South Africa, the experiment was designed to create biomass models for the mussel, which predicted changes in the exploited population based on various applied fishing pressures. Maximum sustainable yield peaks were determined, which happened to coincide with the peak spawning times of *M. galloprovincialis*. Ultimately, if the invasive was harvested within the peaks, the fishery was suggested to be a sustainable industry that could be further established into the community (Robinson et al 2007).

Besides the associated benefits with harvesting *M. galloprovincialis* as a food source for human consumption, the mussel has been shown to benefit other species as well. This invasive has been documented in providing an additional and crucial source of nutrition for higher predators such as the African Black Oystercatcher (*Haematopus moquini*) (Fig. 8). Listed as a near threatened bird species, the remaining population exists exclusively in southern Africa. An increase in the *H. moquini* population, from 4,800 to 6,700 individuals, was attributed to the introduction of *M. galloprovincialis* (Scott et al 2012). Additionally, a diet study on *H. moquini* documented a preferential feeding behavior

displayed by the chicks for *M. galloprovincialis* over native mussel and limpet species (Branch and Steffani 2004).



Figure 8. The African Black Oystercatcher (*H. moquini*) carrying a mussel.

Overall, the benefits associated with *M. galloprovincialis* seem to outweigh the negative impacts resulting in minimal eradication efforts being established. A new technique designed for the aquaculture industry includes producing triploid and tetraploid mussels. Polyploids are any organism that has one or more additional sets of chromosomes. This human mediated method can help eliminate the risk of wild populations from establishing because the mussels become functionally sterile (Piferrer et al 2009; Branch and Steffani 2004).

Although the Mediterranean mussel is classified as an invasive species, it has overwhelming benefits that seem to be aiding in its global dispersal and establishment. A high growth rate and a high reproductive output compared to native *Mytilus spp.* are just some of the evolutionary advantages that have facilitated some of the recent invasions. Unlike other invasive species, *M. galloprovincialis*, is cultured in its native range and elsewhere and also has the ability to create new fisheries in impoverished communities.

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Kappaphycus alvarezii

By Kiera O'Donnell

Edited by Ashleigh Novak

The invasive species *Kappaphycus alvarezii* is a fast growing red algae that was purposefully introduced around the world. The algae is grown and cultivated in many different places globally. They are native and grown naturally in the Philippines, which is depicted in figure 1. However this red algae species has some economic benefits if it is maintained properly. *K. alvarezii* is one of the few algae species that produce the economically important carrageenan, which is a jelling agent used in the production and packaging of many different food substances.

This invasive species comes in a variety of colors including; shiny green, yellow-orange, and greenish brown. *K. alvarezii* is therefore identified by its tough and firm but fleshy features instead of color (Doty et al. 1996). This algae grows up to 2 m tall and is a branching alga. Therefore they have branches like trees which grow from a base and continue to split (figure 2). Since their branches are heavy and irregular they can form dense tangles of seaweed (Kamalakaran et al. 2014). They are found in water depths between 1-17 m and are either attached to benthic coral or floating in the surface waters. When floating at the surface they form large mats that can float to a new location and distribute further displayed in figure 3 (Kamalakaran et al. 2014). These identifying features are important to understand due to their invasive nature.



Figure 1. *Kappaphycus alvarezii* being grown in the Philippines (SIA 2014)



Figure 2. A broken branch of *K. alvarezii* growing out into new branches (SIA 2014)



Figure 3. Tangles of the branches of *K. alvarezii* (SIA 2014)

Once people can identify the species, the areas where they inhabit are the next important feature to study so the distribution can be better predicted. Due to their firm and heavy features they are able to grow in areas of strong tidal currents (Doty et al. 1996). This alga also prefers areas with higher salinity, and bright light. *K. alvarezii* prefers water temperature of 21°C or more (Doty 1996). Therefore the changing climate may have the ability to change their range of invasion. They tend to grow over bottoms of sand, coral and rock and can grow in slow or fast flow rates (Cronklin et al. 2004). Therefore this species is a well-adapted invader due to their unspecific substrate selection. In a study by Russell (1983) as cited by Conklin (2004) the *K. alvarezii* species was predicted to not escape the farms in Hawaii and not be able to invade the surrounding waters (Conklin et al. 2004). Due to this study the invasive species was introduced to Hawaii for cultivation and spread rapidly taking over the surrounding waters. Even though *K. alvarezii* is well adapted to be perfect invasive species, they are still intentionally moved to new areas to be cultivated (Conklin et al. 2004).

K. alvarezii is cultivated in so many areas due to its production of kappa carrageenan. This algae is one of the many that can be used to produce carrageenan, however it is special due to its production of a specific type, kappa carrageenan. Carrageenan is a gelling agent that

builds strong, neutral tasting, and transparent gels. Since the 1960's, when they were first farmed in the Philippines, carrageenan has been used in many different products such as dairy-based preparations, texture manipulations, or egg substitutes (Kamalakanna 2014). Currently, the total market value for carrageenan is approximately \$300 million (Porse et al. 2002). Therefore farming of this alga, along with others became important in producing carrageenan. *K. alvarezii*, along with another type of algae (sp. *Eucheuma*) are the two algae used the most to produce carrageenan around the world, they make up 88.5% of algae harvested for carrageenan production (Table 1.) (FAO 2013). Therefore areas that wanted the commodity began growing and cultivating *K. alvarezii*. There are many different applications of carrageenan causing it to be produced all over the world, mainly in Europe, North and South America, and the Asia-Pacific (Guiry, 2014). Farming of algae will always be present due to the food we use and the packaging we need for the human population; therefore the invasive algae will most likely continue to be used.

Table 1. Tonnes of dry weight of algae used in carrageenan production around the world as of 2001 (FAO 2013)

Chondrus		
Canada	2 000	
France, Spain and Portugal	1 400	
Republic of Korea	500	
Subtotal	3 900	2.3%
Eucheuma and Kappaphycus		
Indonesia	25 000	
Philippines	115 000	
Tanzania (Zanzibar)	8 000	
Others	1 000	
Subtotal	149 000	88.5%
Gigartina		
Chile	14 000	
Morocco, Mexico and Peru	1 500	
Subtotal	15 500	9.2%
Total	168 400	100%

K. alvarezii are native to the Philippines and has expanded to other areas of the world through different cultivation technologies. A study published in 2004 documented that *Kappaphycus sp.* have been introduced in 19 countries, with the most studied area of invasive *K. alvarezii* in Kane'ohe Bay, Hawaii (Conklin et al. 2004). *K. alvarezii* were intentionally introduced into the fringing reef surrounding the Hawaii Institute of Marine Biology (Conklin et al. 2004). Due to the morphological plasticity and lack of sexually mature individuals of *K. alvarezii* they were believed to not be able to attach to surrounding substrates and reproduce. Therefore they were transplanted to open reef cultures on nets and in wire holding pens in 1974. However their plasticity did not limit their substrate selection, and they were able to quickly reproduce through fragmentation instead of sexually.

Their invasion became very severe in Hawaii because they were unprepared for *K. alvarezii* to invade surrounding waters. Since their introduction to Kane'ohe Bay they have spread at a rate of 260 m/year (Conklin et al. 2004). Due to the severity of this invasive species, the Nature Conservancy partnered with the State of Hawai'i in 2005 to develop management techniques (nature.org 2014). Additionally this invasive species was also introduced to the Gulf of Mannar in India, where the impact of the removal techniques were evaluated hoping to more successfully remove the invasive than in Kane'ohe Bay, Hawaii (Kamalakaran 2014). There are also more sites of invasion such as Banda Sea Indonesia, Brazil, Fiji, France, and the South China Sea (FAO 2013). However the studies on the spread and control of the invasive species are not as well documented in these areas due to the severity of the invasion and the low economic stability of the government.

The *K. alvarezii* species are found in different locations globally due to intentional and incidental human vectors that transport it in a variety of ways. One introduction pathway is through cultivation purposes and eventually the algae can spread further by fragmentation once it is brought to the new location (Castelar et al.

2009). There have been no records of ballast water or canals being the cause of this invasive species, only human introduction through cultivation. Due to the ignorance on the possible invasive algae, *K. alvarezii* was cultivated with an open pen. This was open to the water and *K. alvarezii* could easily escape and grow in the surrounding waters (Conklin et al. 2004). This alga species can spread rapidly by fragmentation, once the branches break off they can survive floating in the water column. They are spread through physical parameters such as winds, waves, discharge, and storms. When they reach a new area they can settle and multiply. Since the spread of this invasive is so high, management techniques are being researched.

There are three main management techniques used to try and eradicate *K. alvarezii*. The simplest management technique is to manually remove the species by diving and plucking the algae off of the corals (Kamalakaran et al. 2014). This technique is being used by the Tamil Nadu Forest Department in India. Even though they are able to remove some of the species, the efforts do not have a lasting effect. One reason why this invasive species is so good at invading is it can grow from very small amounts of algae. If residual algae are left on the corals from plucking, then the algae can grow back (Conklin 2004). Studies of their growth over time have proven that hand picking is not enough to remove the invasive species (figure 4). The study by Conklin believed that the algae's ability to grow back so quickly from the residual algae was also from the lack of native predators in the surrounding waters (Conklin 2004). Therefore efforts are being carefully studied to introduce a bio-control species.

Tripneutes gratilla, also known as the collector urchin, is one of the bio-control species being studied in Kane'ohe Bay (Treacy, 2011). Scientists believe that if they are introduced after the alga is physically removed they could help prevent *K. alvarezii* from growing back (Figure 5). In order to test this hypothesis the researchers placed *T. gratilla* and *K. alvarezii* within an enclosure together. After five months the cover

of *K. alvarezii* was reduced from 62.5 percent to 15.9 percent (Treacy, 2011). This technique demonstrated the potential that *T. gratilla* has for controlling *K. alvarezii*, however bio-control methods are dangerous and requires vigilant supervision so a new invasive species is not created.

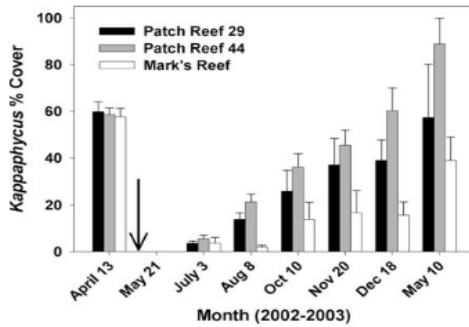


Figure 4. Conklin et al 2004 studied the growth of *K. alvarezii* after hand removal, the arrow shows when the hand removal of the species took place.

Overall, *T. gratilla* have shown to be efficient at feeding on the invasive algae without harming the native corals (Treacy, 2011). Therefore, they should be able to reduce the invasive species found now without becoming an invasive species themselves. Researchers believe that *T. gratilla* would be easier to control than *K. alvarezii* have been. Therefore, the hope is to have better control of new invasive species if they do have adverse effects (Conklin 2004). Since bio-control is a dangerous method, and hand picking is strenuous, new methods have been created to quickly remove mass amounts of invasive species.



Figure 5. *T. gratilla* grazing on *K. alvarezii* (Tracy 2011).

An underwater vacuuming system in Kane’ohe Bay, built by the Nature Conservancy staff, is also being used to remove the invasive algae. It is a barge-mounted underwater vacuum, which can remove up to 10,000 pounds of invasive algae a day (figure 6). Divers help feed the algae into hoses which lead back up to the barge and is put into bags to be distributed for compost at local farms. This control technique removes more algae at a quicker rate, however *K. alvarezii* can still grow back due to residual tissue left (Conklin 2004). Many believe that introducing *T. gratilla* after the removal of *K. alvarezii* will help keep the invasive species at bay due to *T. gratilla*’s ability to consume the algae once they start growing back (Treacy, 2011).



Figure 6. The barge made by the Nature Conservancy to vacuum the invasive algae species from the water. (The Nature Conservancy 2014).

Once this invasive species is introduced to an area, their genetic ability to grow from residual tissue and survive in many different environments are beneficial in ensuring the persistence of the species. Even with the many management techniques used today, *K. alvarezii* is still a problem due to the continuous use of the algae as kappa carrageenan producers. The ultimate goal of many governments, like the Nature conservancy, is to keep *K. alvarezii* from invading the surrounding waters. The complete eradication of this species is unlikely due to its continued cultivation, but by utilizing better management techniques the spread of this species can be reduced.

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The Invasion of *Asterias amurensis*

By Hanna Pultorak

Edited by Kiera O'Donnell

Identification

Asterias amurensis is more commonly known as the North Pacific sea star. It can grow up to fifty centimeters in length from the tip of one arm to another. This sea star tends to accumulate in large quantities, usually over a food source (Byrne et al 1997). *A. amurensis* is easily identifiable amongst other sea stars in that it exhibits bright color hues ranging from yellow to orange to purple on its surface. The underside of the sea star is a bright yellow color. The key to correct identification of *A. amurensis* is the slight upturn of the tips of the arms (ISSG).



Figure 1. Image of *Asterias amurensis*.

History and Distribution

The native range for *A. amurensis* expands the northern Pacific waters of Japan, Korea, China, and Russia. In the last twenty-five years, *A.*

amurensis has been unintentionally introduced to two distinct locations: Tasmania and Australia (Ross et al 2004). *A. amurensis* was first recorded to be found in Tasmania in the 1980s where it was discovered in the major shipping port of Hobart (Byrne et al 1997). From there it spread along the coastline of Storm Bay as well as up into the Derwent River Estuary (Figure 2) and eventually found its way along the southern coast of Australia (Byrne et al 1997).

Two main vectors have been identified as being responsible for the spread of *A. amurensis*: ballast water and currents. Ships can take in *A. amurensis* polyps with its ballast water then distribute them elsewhere when the ballast water is released (Byrne et al 1997). The duration that *A. amurensis* spends in the larval stage is long enough to last most shipping excursions, allowing the polyp to be easily distributed through ballast water (Dunstan and Bax 2008). Because these polyps cannot actively swim, currents can also contribute to the spread of the invasive sea star into non-native environments (Byrne et al 1997, Dunstan and Bax 2008). The currents are able to move larvae along the coastline, which can contribute to future established populations further along the Tasmanian and Australian coasts.

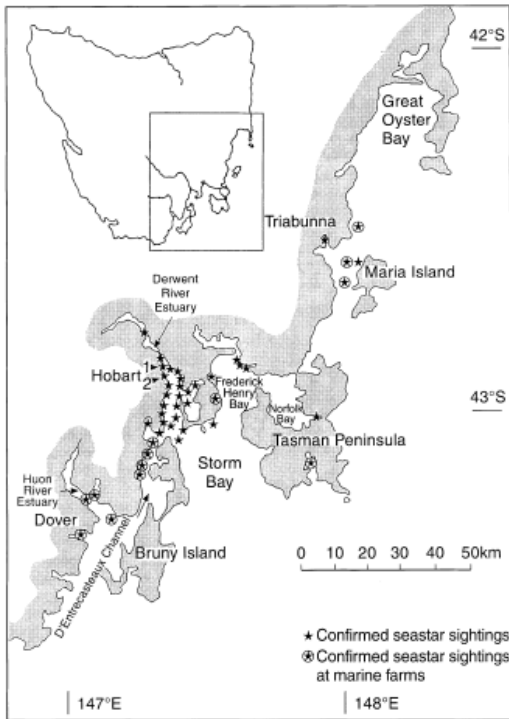


Figure 2. Confirmed *A. amurensis* sightings in Tasmania as of 1995 (Byrne et al 1997).

Adaptations and Behavior

Asterias amurensis has developed two main adaptations that allow it to out-compete many native species and be a successful invader. First, *A. amurensis* is a voracious feeder, meaning it will eat everything and anything it can. Its diet includes bivalves, molluscs, barnacles, crabs, crustaceans, worms, echinoderms, ascidians, sea urchins, sea squirts, and even other sea stars (ISSG). This poses a threat to bivalve aquaculture in Tasmania and southern Australia as these sea stars tend to swarm over mussel beds as well as climb up long lines used to grow bivalves for aquaculture (Ross et al 2004).



Figure 3. *A. amurensis* swarming and feeding on mussels removed from a ship's hull (Byrne et al 1997)

Another adaptation that enables *A. amurensis* is the sea star's extremely high fecundity. *A. amurensis* can reproduce sexually and it can also reproduce asexually by fragmentation. This sea star is capable of producing up to twenty million eggs. Its reproduction season is from June through October in its non-native region and *A. amurensis* can spawn multiple times in one season (Byrne et al 1997). Female *A. amurensis* individuals are capable of reaching sexual maturity after one year of age or after its size is about ten centimeters or larger (ISSG). This allows for *A. amurensis* to reproduce in large numbers and very often, helping it establish invasive populations.

A. amurensis is capable of surviving in a wide range of salinities and temperatures. It has slowly adapted tolerance to temperatures much higher than its preferred, native range's, which is why it has been able to establish populations in Australia and Tasmania (ISSG). It will primarily inhabit areas of low wave action, making estuaries and other protected areas ideal environments for *A. amurensis* to thrive.

Managing *A. amurensis* Populations

While there has been no successful eradication of *A. amurensis* in Tasmania or Australia, there are multiple efforts in effect to try to decimate the populations. Introduction via ballast water has been deemed as the major vector in which *A. amurensis* is able to spread (Dunstan and Bax 2008). Australia is currently working to regulate the intake as well as expulsion of ballast water in order to

prevent *A. amurensis* from spreading further along its coast and is emphasizing the need to report any first encounters or detections of *A. amurensis* in a non-native region (Dunstan and Bax 2008).

The physical collection of *A. amurensis* has proven to be unsuccessful as well. There is hardly a market for use of *A. amurensis* besides the souvenir trade. The University of Tasmania attempted to use and market collected and dried *A. amurensis* that had been ground up as fertilizer but this attempt was not successful as farmers showed little to know interest in using the sea star this way (McEnnulty et al 2001). Tasmania has also dedicated a few days each year to involve the public in the hunt for *A. amurensis* (Shah and Surati 2013).

Biocontrol has been a topic of controversy for controlling many invasive species, including *A. amurensis*. A suggested biocontrol method against *A. amurensis* is the use of the protozoa *Orchitophrya stellarum* (Secord 2002). *O. stellarum* primarily affects male *A. amurensis* individuals' reproductive organs, ultimately castrating them and leaving them unfit to reproduce (Secord 2002). However, *O. stellarum* does not select only for *A. amurensis*. *O. stellarum* could also affect a native keystone species of sea stars, *Pisaster ochraceus*, the northeast Pacific starfish. Further studies must be conducted in order to determine future biocontrol methods to counteract *A. amurensis* invasions.

Future Implications

Currently, *A. amurensis* is responsible for an estimated one billion dollar loss in the Tasmanian fishing industry alone (Shah and Surati 2013). Both Tasmania and Australia are working on regulating the discharge and uptake of ballast water in its ports, especially during spawning season, in order to prevent the spread of *A. amurensis* larvae (Dunstan and Bax 2008). Prevention is key in disrupting further invasions of *A. amurensis*, especially since its biological attributes enable it to be a successful invasive species. Future studies should encompass effective control and management options, understanding the impacts of *A. amurensis* on the local economies, and learning how it affects a native region's biodiversity.

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The alewife - *Alosa pseudoharengus*

Christopher Lockwood

Edited by Blaise Jenner and Ashleigh Novak

The alewife (*Alosa pseudoharengus*) is a fish that has not been known to be an invasive species for a long time. It is an Atlantic species of fish that began its spread in the 20th century. Its native range is in North American bodies of water including Labrador, Nova Scotia, northeastern Newfoundland, Canada extending its range down to South Carolina. *A. pseudoharengus* are an anadromous species meaning that they spawn in freshwater, then mature at sea along the eastern coast of North America. When the fish becomes reproductively mature it journeys back to streams and reservoirs where they will complete their life cycle and reproduce. When this species is introduced to new bodies of water, such as lakes or reservoirs, is when they can become invasive. *A. pseudoharengus* is a relatively small species of fish that are sliver in color with a greyish green back. Average total length is approximately 6 inches long (Brown 1967), with their size having a positive correlation to the size of the body of water they reside in. Essentially *A. pseudoharengus* will grow to larger sizes if the area they invade is larger.

This species was not abundant in North American bodies of water, until people began to make canals as well as additional means of transportation. Before the 20th century *A. pseudoharengus* would travel from the St. Lawrence River all the way to Lake Ontario. Prior to the human made Welland canal in the mid-1800s, *A. pseudoharengus* could not travel further inland because of Niagara Falls. Once the canal was built as a shipping path, *A. pseudoharengus* slowly began spreading further inland and eventually became an invasive species. Therefore shipping pathways and human influences have allowed *A. pseudoharengus* to become a successful invader.

Since *A. pseudoharengus* is an anadromous species they can have impacts on both salt and freshwater environments. The introduction of this species has caused major economic problems for many regions. *A. pseudoharengus* has become a problem in many landlocked bodies of water including the Great Lakes, which have been among one of the most heavily impacted. Most of the negative impacts this species have caused are mainly on people, businesses that depend on tourism, and fisheries. *A. pseudoharengus* tend to travel in large schools which cause issues because they are known to have massive periodic die-offs. These die-offs end up creating large piles of decaying fish that will wash up on the shores of lakes. One of the possible reasons for these die-offs is due to the fish's inability to pump water out of its body when in freshwater. Since *A. pseudoharengus* spend most of their lives in salt water, their bodies are not well adjusted to freshwater. This facilitates the large amounts of water into the cells in the fish, which can ultimately cause premature death. This species are very fragile



Figure 1. Welland Canal (Agyle 2007)

when it comes to any changes in the environment, and since they tend to travel in large schools if a disturbance occurs such as temperature or salinity change, the whole school will most likely die.

These mass die offs result in a large amount of decomposing organic matter which results in an unpleasant smell that disturbs local communities. This bothers all residents, and can also be extremely expensive to clean up. In 1967 there was a large die-off of *A. pseudoharengus* occurred on Lake Michigan and cost approximately 100 million dollars to clean up. *A. pseudoharengus* is a large part of the diet for some salmonoids including different trout and salmon species. The growing *A. pseudoharengus* populations has led to an increase in stocking salmonoids which in turn has created positive impacts on the local community. A multimillion dollar recreational fishery for salmon and trout has been created due to the invasion of *A. pseudoharengus*.

A. pseudoharengus has had significant impacts on the ecology on the environment they have invaded leading to many economic impacts. Upon introduction to a new body of water they can begin to degrade an ecosystem through size selective predation. This means that these *A. pseudoharengus*



Figure 2. Alewife Die off

will consume the majority of the larger planktonic organisms such as zooplankton, only leaving smaller zooplankton therefore trophic competition with other juvenile fish, mainly the salmonoids is created. Size selective predation can lead to decreased populations of both recreational and commercially important species. One of the major effects is a disease that these *A. pseudoharengus* can spread to other important species such as the salmonoids. *A. pseudoharengus* contains an enzyme called Thiaminase. This enzyme breaks down thiamine, also known as vitamin B1, which can cause thiamine deficiencies in other fish species. This disease is also called Reproduction Disorder M74. Certain types of salmon, mainly Atlantic salmon that feed primarily on *A. pseudoharengus* can be susceptible to this disease. Thiamine is essential to biological functions because it aids in converting carbohydrates into glucose, therefore individuals with this disorder will produce young with a thiamine deficiency leading to a rapid death after hatching from their eggs.

There are only a few ways that the invasion of this species can be controlled. Many anglers are fans of using live bait such as *A. pseudoharengus*, if individuals are thrown back into the water or escapes from the hook then it can then lead to further invasion. Prohibiting the use of live *A. pseudoharengus* in recreational fishing can help prevent the problem of this invasive species. A second solution to the problem would be to increase the populations of predatory fish such as the salmonoids through the process of stocking. The increase would lead to a higher level of natural mortality and hopefully result in a decrease in the populations of *A. pseudoharengus*.

In conclusion *A. pseudoharengus* are a very easily distributed throughout numerous bodies of water. If it weren't for manmade canals and other means of transportation between bodies of water then the invasion of *A. pseudoharengus* could possibly still be contained to only one of the great lakes. The only way we can help prevent further invasiveness is keep pushing the implemented prevention methods. Making more people aware of what can happen when alewife are introduced is also a big factor on controlling *A. pseudoharengus*.

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The Invasion of the White Spotted Jellyfish (*Phyllorhiza punctata*)

By Keenan Tilsley

Invasive species have become a huge problem all over the world. By either accident or on purpose, some species of animals and plants have spread to new areas and have become nuisances that cause many problems. The White Spotted Jellyfish is no exception to this rule. In this case study, *Phyllorhiza punctata* will be examined on its aspects of being an invader and the impacts on the regions it has invaded.

P. punctata is native to the Western Pacific, from Australia to southern coast of Japan. However, it has been located in other parts of the world. The regions that were invaded are Hawaii, which was noted to be invaded in 1945, California in 1981, the Gulf of Mexico by 1993, the Caribbean Sea in the 1970's, and the Mediterranean Sea in 2003. With the invasions to the eastern part of the Pacific and Mediterranean, ship fouling and ballast water are the primary causes of the invasion. (Verity et al. 2011) This is because the juvenile medusae of the jellyfish are small and can be taken up in the ballast tanks very easily. With ship fouling, *P. punctata* is often found near shore and in shallow depths, meaning that they get caught along the keels of ships as they travel. When the ships stop, the jellyfish can fall off the keel, being introduced into a new region. With the invasion of *P. punctata* to the Atlantic, the shipping lane responsible is the Panama Canal. This man made structure, which has benefited shipping on an extraordinary scale, has allowed *P. punctata* to invade and spread to the Caribbean and the Gulf of Mexico (Texas). They have become a huge nuisance ever since they appeared. A special point to be made with the invasion to Hawaii is that the increased shipping traffic to the western

Pacific during World War II is believed to be the cause of the invasion. (National Geographic)

Invasive species cause a variety of impacts in their non-native regions. Some are beneficial, others not so much. With *P. punctata*, the impacts are not beneficial in the least. Wherever they invade, it is presumed they have an impact on the ecosystem and economy. However, in the regions of Hawaii and the Mediterranean, the impact of *P. punctata*, has not been studied. (Hawaii) The invasive populations in the Atlantic are a different story however.

P. punctata are prolific filter feeders and can filter out over 13,000 gallons of water in a single day. This has very significant consequences because the jellyfish consume anything planktonic. They devastate phytoplankton, zooplankton, and fish populations by consuming planktonic crustaceans and fish eggs. This impacts commercial fishing in the Gulf of Mexico and other parts of the Atlantic. In a study in the Gulf of Mexico in 2003, populations of White Shrimp, *Penaeus setiferus*, decreased by 25% around the time of the harvest. (Invasives) Other populations have been affected, but the numbers have been skewed with the BP oil platform incident and remain intangible at this time due to the impact the oil spill has had on the local environment.

Other impacts that invasive *P. punctata* has is that it is competing with native species and can completely change the balance of an ecosystem. The extent of the competition is not yet known, however it is reasonable to assume that other taxa are at risk due to being out competed for food resources by *P. punctata*. Not only directly,

but an ecosystem can be affected indirectly by the invading jellyfish. Zooplankton populations are at risk through physical and chemical changes in water. (*Phyllorhiza*) There have been regions in the Gulf of Mexico that have been reported to have high dissolved organic material loading by swarms of *P. punctata* causing foam streaks; upper parts of the water column where there are higher amounts of dissolved matter. There is also mucus shedding by *P. punctata* when they are in a swarm. The mucus shedding changes the viscosity of water and also elevates toxins in the water as mucus bound nematocysts of the jellyfish are discharged into the water. These all have effect the local ecosystem and everything that lives in it, but no further studies have been conducted. (White)

The biggest impact caused by *P. punctata*, however, is the economic impact with the destruction of fishing gear. Estimated economic losses are in the millions of dollars. The reason why fishing equipment is the most susceptible to damage is because trawling for shrimp occurs in the same pelagic zone that the jellyfish live in. *P. punctata* get caught up in the nets which get weighed down, causing extreme damages to the nets or cause them to break off, being forever lost.. (Texas) Boat intakes are also at risk of being clogged and damaged by the jellyfish. This has led to the closing of productive fishing areas to any sort of fishing activity, in order to reduce the risk of equipment loss to *P. punctata*. (Abstracts)

With all this talk about how *P. punctata* impacts ecosystems and economies, the reason why they can be a nuisance has yet to be discussed. The “why”, lies within the adaptations *P. punctata* has evolved in order to survive. To begin, they are composed of 96% water with a very simple body structure. They are large, with a 20 inch bell and up to 24 inches in overall length, and have been observed as larger in non-native areas. *P. punctata* has eight thick, but short tentacles with stinging cells on the end in a bunch. They are only slightly venomous to humans.

(Opposite) The size and stinging cells allow them to be very capable predators, especially with zooplankton and other small animals. The fact they can filter over 13,000 gallons a day is also very useful and a great adaptation for survival. These characteristics make them very effective predators allowing them to out compete other species that feed on planktonic creatures. (Abstracts)

P. punctata, are also generalists and opportunistic feeders; whatever they can capture when filter feeding, they can eat. When they swarm, come together in huge groups, they can clear out thousands of cubic meters of water of most, if not all, planktonic creatures. Another aspect that allows *P. punctata* to be invasive is the lack of predators. Sea turtles eat jellyfish in the medusa stage, but the primary predator is *Argonauta argo* (Heeger et al 1992), a cephalopod species that feeds on the polyp stage of *P. punctata*. With no predators, the jellyfish go unchecked, grow large, and become a nuisance of a species.

As a species, *P. punctata* may benefit from climate change. It is said that jellyfish species would be animals that would benefit from increasing ocean acidification and temperature and *P. punctata* is no exception. Moderate salinity and warmer temperatures are key, to the survival of *P. punctata*. Climate change will increase ocean temperatures and the jellyfish will thrive because of it, further expediting the invasions and spreading. This will cause more problems in the future as *P. punctata* spreads. It will cause more economic and ecological damage as the spreading gets worse due to climate change. (Verity et al)

There really isn't too much that can be done to stop the spread of *P. punctata*. New policies on ballast water discharge and intake have helped limit invasions for species around the world and can help with halting the invasion of *P. punctata* to new areas. Prevention of ship fouling with hull cleaning and materials can also help but are not useful in eradication. One such proposal for eradication of *P. punctata* in non-native

regions is the introduction of *A. argo* to these areas to prey on the polyps of *P. punctata* to control and try to eradicate the population. However, biologists disagree on whether it would be a benefit or are the introduction of a new invasive species that preys on native species. With that, further study will need to happen to assess the possibilities. (Heeger et al 1992)

P. punctata is an important invasive species to study. There is very little information out there on the species. It has been in Hawaii for over 60 years and nothing is known on how it affects the local ecosystem. More needs to be done for studies. *P. punctata* could provide a model for future invasive species of jellyfish as climate change continues. With further study, important insights can be made to help prevent further spread of *P. punctata* and other species like it.

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Lionfish - *Pterois volitans*

By Angela Henrich

Edited by Jacob Farrell

Introduction

Lionfish are a large and charismatic fish species. Figure 1 shows an example. They are brightly colored and have many unique attributes that have allowed them to become extremely invasive in the Atlantic Ocean. They also have an interesting vector that allowed them to be where they are today. Finally, because this species is so invasive, there are many efforts going on to stop the harm that could potentially befall the Atlantic tropical ecosystem. They include utilizing both the natural biology of the area and human interactions as well.

Background

P. volitans are native species in the Indo-Pacific region of the world. They prefer tropical water temperatures and can live in a variety of habitats. *P. volitans* are carnivorous



Figure 1: Photograph of *P. volitans* taken in the Atlantic Ocean by a NOAA employee.

predators that eat many species of prey. They have venomous spines, which offer them protection against predators. In total, *P. volitans* have eighteen venomous spines. There are thirteen on the dorsal fin, three anal spines, and one on each pelvic fin. Each spine is flanked by a venom tract that has a venom producing tissue surrounding the spine. The venom is a

neurotoxin making it harmful to organisms that may want to prey on *P. volitans*. Their reproduction cycle lasts all year long, so they have the ability to reproduce more than once a year. *P. volitans* have many adaptations that allow them to be a successful invader (Morris et al. 2009).

Feeding

P. volitans are carnivorous ambush predators. They are generalists that feed on primarily various fish and crustacean species. A study done on *P. volitans* feeding ecology showed that there was a correlation between size and what the *P. volitans* ate. The stomach contents of larger organisms displayed primarily other fish species while stomach contents of the smaller organisms revealed more crustaceans, especially shrimp. After further examination, the same study showed that the consumed fish species included twenty-one families and forty-one species including two economically relevant species: yellowtail snapper and the Nassau grouper (Morris & Akins 2009).

P. volitans have many different methods of consuming their prey. One strategy is to corner their prey by waving their large pectoral fins. They also use these fins to stir out benthic organisms from the substrate by quickly waving them, creating wave action on the bottom. *P. volitans* additionally have a specialized swim bladder they can alter to manipulate their center of gravity and position in the water column. This allows them to hover and then ambush their prey. To consume their food, *P. volitans* expand their buccal and operculum cavities, and then quickly dart forward to swallow their prey (Morris & Akins 2009). The various methods of predation make them effective hunters.

Overall, the *P. volitans* surveyed between the hours of 7:00am and 11:00am had the highest stomach contents. The *P. volitans* surveyed after had fewer contents in direct correlation with the times later in the day. In total, 71.2% of the number of prey were fish while 28.5% were crustaceans. Prey size ranged from nearly half the size of the *P. volitans* to a minimum of 0.02% in comparison (Morris & Akins 2009). With their generalized feeding habits, how much they consume, and various hunting methods, *P. volitans* have the potential to decimate reef ecosystems.

Invading the Atlantic

The vector used by *P. volitans* to populate the Atlantic was aquarium trade. While aquarium trade is a widely known vector for freshwater species, less is known for introductions into the marine environment, and even less still for marine fish species specifically. *P. volitans* is not the first invasive fish species to be found in the marine environment, but it the first non-native species to have a successfully established population from the arrival through aquarium trade. *P. volitans* are a commodity for aquarists because of their flashy look; however, because of their predatory behaviors described earlier, they don't make the easiest species to keep with others. This leads can lead to intentional releases of *P. volitans*. This coupled with unintentional releases is how *P. volitans* are thought to have been introduced the Atlantic Ocean (Semmens et al. 2004).

The first *P. volitans* recorded was spotted and captured near Dania Beach, Florida in 1985. In 1992, Florida was hit with Hurricane Andrew. The aftermath of Andrew included an aquarium that had been broken near a seawall in Biscayne Bay, Florida. At least six *P. volitans* were said to have been spotted off the shore near the broken aquarium. Since 2001, there have been reports of juvenile *P. volitans* as far north as New York, New Jersey, and Rhode Island. The Gulf Stream is thought to pull eggs and larvae up the coast. While *P. volitans* have been spotted in more northern areas, the fish do not have a chance to grow out of their juvenile stage

because of the colder temperatures at the higher latitudes in the winter months (CORIS 2014).

Around 2000 is when *P. volitans* started making their way up the coast of the United States. In 2004 they made their way into the Bahamas. Starting in 2007, there were reported sightings on the shores of Cuba, by 2009 there were

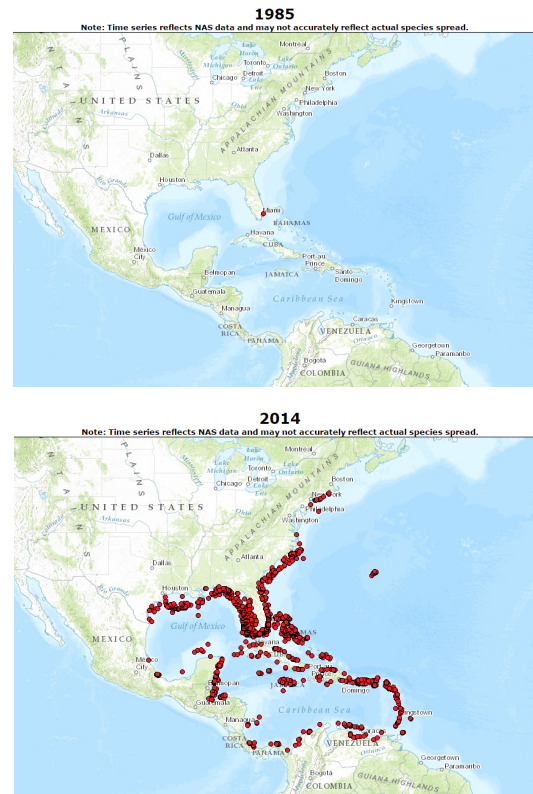


Figure 2: Shows the first sighting of *P. volitans* in 1985 (above). The second map shows the sightings up to 2014, a twenty-nine year difference (below).

sightings around the rest of the Caribbean as well as Central and South America. Finally in 2010, there were multiple reports of *P. volitans* in the Gulf of Mexico (USGS 2013). They have continued to multiply rapidly through all of the areas mentioned. Figure 2 shows the first sighting compared to the present day spread of *P. volitans*.

Impacts

P. volitans can have very harmful effects on the ecosystem they inhabit. They can live in various places such as reefs, mangroves, and sea grass areas. This gives them more of a

chance to search for food. As stated before, *P. volitans* are generalists when it comes to feeding. They pretty much eat what they can get ahold of. By feeding in one area, *P. volitans* can destroy the reef ecosystem structure. They can decimate large populations of fish and other invertebrate species in very little time. This is not only harmful for the fish populations they are consuming, but also the fish on the next or same trophic level; *P. volitans* can out compete predators for their food creating problems within the food chain. They are in direct competition to some of the predators in the reef ecosystem, putting those species in danger as well.

Some fish species *P. volitans* may be harming are also economically important, like grouper and snapper, these species may not be able to replenish when being consumed or in competition with the *P. volitans* (NOAA 2013). As of now, there has not been enough research to predict whether or not *P. volitans* will have a significant impact economically on the fishing industry.

Another human impact the non-native species has is on the tourist industry. A sting from *P. volitans*, while not fatal to humans, can cause them a lot of grief. A sting may cause nausea, vomiting, allergic reactions, or cardiovascular problems. Medical attention is the best way to treat a *P. volitans* sting (CORIS 2014). Where there have been many sightings of the invasive species, beaches have started to put up warning signs to make the public aware of the danger that could be. With the knowledge of what the sting from a *P. volitans* can do, people could be turned off from going to a particular beach. However, it is important to keep in mind, like with the effects on the fishing industry, there is not enough research yet on the impacts *P. volitans* will actually have on the tourist industry.

Fixing the Problem

There are a lot of unique things going on to deal with *P. volitans* invading the Atlantic Ocean, both human and biologically centered. Biologically, there are efforts being made to “create” predators for the *P. volitans* using sharks and grouper. On the human side, there is a

lot of education available to the public. There are also *P. volitans* derbies and restaurants have taken to offering specials centered on *P. volitans*.

Sharks are known as one of the major predators in the ocean. Trained divers have begun feeding sharks *P. volitans* to get them to associate the non-native as a type of prey. The sharks avoid the fish’s spines by eating it face first. The big problem with this method is that while divers are “training” the sharks to eat *P. volitans* by giving the fish to them, the divers may be creating a correlation with people and food instead of the fish just being a stand-alone food source. One dive group talked some about how while feeding the shark a lively *P. volitans*, the fish escaped. The hungry shark tried to go after the spear or cameras (Fears 2014).

The second predatory groups that people are attempting to train are the groupers. In about the same process as sharks, divers started to feed *P. volitans* to grouper. They started with pieces, then speared fish, and finally progressed to live netted fish. Groupers are quick learners and with the help of trained divers, began finding *P. volitans* to have as a meal in the Cayman Islands (Management 2010).

People are the final predators to be discussed in the efforts to eradicate *P. volitans*. People participate in events called “Lionfish Derbies” that are essentially fishing competitions. In REEF.org sponsored derbies, there are prizes for the most, largest, and even smallest *P. volitans* caught. People use both netting and spearing methods to try and capture as many *P. volitans* as they can during the derby; there are no set limits set. These derbies are also used as large educational events. Participants must go to a meeting the night before that teaches about the non-native, how to safely catch them, and gives derby rules. During the derby itself, there are opportunities to learn about *P. volitans* and taste samples of *P. volitans* dishes that are made by vendors. The derbies are meant to remove large amounts of *P. volitans* while also creating an educational experience for the public and just generally raising awareness about *P. volitans* in the Atlantic (Derbies 2012).

While people may get to try some dishes at these derbies, some restaurants are

taking it a step further and offering *full P. volitans* entrees. It is called the “invasivore movement.” According to many people, when cooked properly, *P. volitans* are safe to eat and actually quite delicious. The one problem with marketing *P. volitans* is the concern that it creates a place for them in the market, and instead of eradicating them completely, people will want to sustainably manage them (Miller 2014).

Conclusion

P. volitans have started making some strides in harming the seas they have invaded. Because of their flashiness, they are desired in the aquarium scene; however, because of the carnivorous nature, they are often too much and are released back into the ocean. These intentional releases as well as unintentional releases are the manner in which they arrived on the southern east coast of the US and in Caribbean and Gulf waters. They have no natural predators in the Atlantic and their venomous spines make them difficult for potential predators to eat. *P. volitans* are harmful to the ecosystem they are in, as well as potentially to the economy around the shore areas. There are some efforts to eradicate the *P. volitans*, and while some may be slightly controversial, they will hopefully all work to diminish the population of invasive *P. volitans* in the Atlantic.

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Crassostrea gigas, a good problem?

By Alec Strohmeier

Introduction

Off the coast of Japan, *Crassostrea gigas* has been grown commercially for hundreds of years. With the success they've had in growing the oyster it grew worldwide interest as a product. This has led to many nations importing *C. gigas* in order to begin growing their own. While the profit from these oysters is substantial, the damage caused by them can be much worse. Many countries have accepted these damages due to profits, meaning this species has been implanted many places across the world even with its known invasive capabilities.

Physiology

C. gigas is a hard shelled filter feeder. They form colonies by attaching to hard substrate or even each other. This allows for the oyster to live in many areas throughout the coast and even having the capabilities to form hard substrate areas on their own. This give *C. gigas* the unique ability to invade areas that may not be suitable to other hard shelled filter feeders. (Wrange 2009) The filter feeding abilities of *C. gigas* is also an advantage due to its superiority to other related species. In a study done on the filter feeding capabilities of different oysters and mussels, it was found that *C. gigas* had the largest possible filtration rate. This means that a large colony of the oyster can filter massive amounts of water providing little food to other filter feeders in the area. Table 1 shows these filtration rates.

Table 1
Filtration rates measured (as clearance rates) for mussels *M. edulis*, cockles *C. edule*, Pacific oysters *C. gigas* and European oysters *O. edulis*, given per individual and per standardized gram dry-tissue-weight.

Species	Dry tissue weight (g)	Temperature (°C)	Individual filtration rate (l h ⁻¹ ind ⁻¹)	Bodymass-specific filtration rate (l h ⁻¹ g ⁻¹)	References
<i>M. edulis</i>	0.06-0.5	10-20	1.5-6.0	0.7-11.0	1-7
<i>M. edulis</i>	0.5-1.0	10-15		9.2	12
<i>C. edule</i>	0.3-0.5	10-15	1.3-5.0	0.7-7.4	1, 7-9
<i>C. gigas</i>	1.0-2.0	5-25	1.2-12.5	2.0-5.9	4, 10-11
<i>O. edulis</i>	0.5-2.0	20-22	5.7-10.3		4

Native vs. Invasive Range

C. gigas is naturally found along the pacific coast of Asia and is now known to have naturally expanded its range beyond that. However human intervention has placed the oyster all over the world. This includes: the United States, Australia, Europe, Africa, and Southern America. The spread of *C. gigas* can be seen in figure 1. An area of particular importance

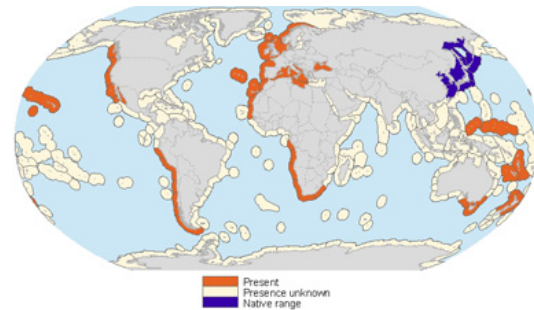


Figure 1: Natural (blue) and invasive (orange) populations of *Crassostrea gigas* on a global scale. (Molnar 2008)

is the Wadden Sea, on the Northern coast of Germany. This sea has seen an invasion of *C. gigas* mainly due to human implantation. However, the reason this area is of importance is due to the regions close examination and documentation over a long period of time. This documentation allows us to see the entire invasion and track its growth. (Diederich 2005)

Characteristics of Success

While taking into account the filter feeding capabilities of *C. gigas*, it is useful to also note the other many characteristics that the oyster has which allows it to be extremely successful in an invasive sense. The first and perhaps one of the most important traits is that the oyster has extremely high colonization properties. This is due to its high fecundity, rapid

growth, and rapid sexual maturity. This allows populations to grow extremely quickly. Another trait that enables it to be invasive is the lack of natural predators it finds in these areas. In Europe the oyster is immune to all of the parasites that affect the natural oyster species of the area. This further increases the growth of the population by not limiting the population.

Further increasing the probability of success of *C. gigas* is the ability for it to live in a wide variety of coastal areas. In table 2 it can be seen that *C. gigas* is able to survive in all of the regions as the many other species studied. So while these other species may live together in harmony due to their specific niche, *C. gigas* can disrupt all of them. (Kochmann 2013)

	<i>Crassostrea gigas</i>	<i>Mytilus edulis</i>	<i>Cerastoderma edule</i>	<i>Mya arenaria</i> *	<i>Macoma balthica</i>
Tidal range	Low intertidal to subtidal	Mid intertidal to subtidal	High intertidal to shallow subtidal	High intertidal to shallow subtidal (to 200 m depth)	High intertidal to subtidal
Sediment	Attachment to hard surfaces, bed occurrence on any substrate	Attachment to hard and filamentous surfaces, bed occurrence on any substrate	Sand, soft mud, gravel	Firm mud/sand	Mud to muddy sand
Salinity	Estuarine to fully marine	Estuarine to fully marine	Estuarine to fully marine	Estuarine	Estuarine to fully marine
Burrowing depth	-	-	<5 cm	~15 cm	5-10 cm
Exposure	Semi-exposed to sheltered	Exposed to sheltered	Semi-exposed to sheltered	Sheltered	Semi-exposed to sheltered

Table 2: Comparison of possible niches between local populations of filter feeding organisms. (Kochmann 2013)

Impacts

It is clear to see that the invasion and overpowering of the natural oyster and mussel species in a region is a negative effect. However not every instance of *C. gigas* invading an area has been solely noted as negative. With the oyster’s ability to turn soft substrate areas into oyster reefs; these newly formed ecosystems can have many benefits. It is known that these oyster reefs can provide homes to many small animals further increasing the biodiversity. (Kochmann 2013) While there may not be as many species of oysters or mussels within the region, the benefit of these reefs can be immense. This is especially important in areas where human interaction has destroyed hard substrate areas. The reefs can be used as a way to counteract some of this destruction. In figure 2 the growth of the amount of substrate covered by these oysters’ shows that these reefs can grow extremely quickly and can become extremely massive. (Troost 2010)

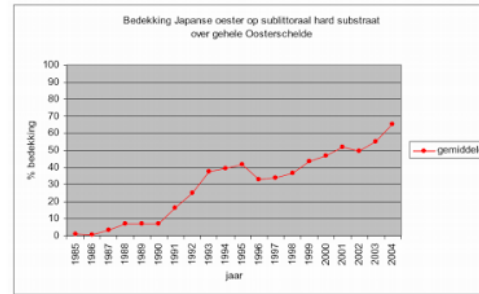


Figure 2: Graph of % seafloor bedding by *Crassostrea gigas* over time. (Buttger 2007)

Global Warming

Global warming can be most easily noticed by monitoring the temperature of the oceans. Their constant increase has been used as proof of global warming. This increasing temperature has massive effects on all organisms across the world’s oceans. While many of these effects have been linked with negativity, in terms of *C. gigas* there is little downfall to warming oceans. The oyster larvae have been studied and showed increased survivability in warmer waters, further increasing the speed of the growth populations can show. (Nehls 2006)

Future Possibilities

Populations of *C. gigas* are known to be extremely hard, if not impossible, to remove. Complete removal of a population becomes a daunting task due to the ability for larvae to survive in the water column for an extended period of time. (Nehls 2006) Therefore, most invaded areas have decided to embrace the invasion and allow for local harvesting of wild populations. This is extremely popular across the world and many people even make a living off of oyster farming. So while there may be some immediate downfalls to the invasion, a positive light can easily be thrown on the oysters as a boost the local economies and even perhaps a boost to local ecosystems.

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