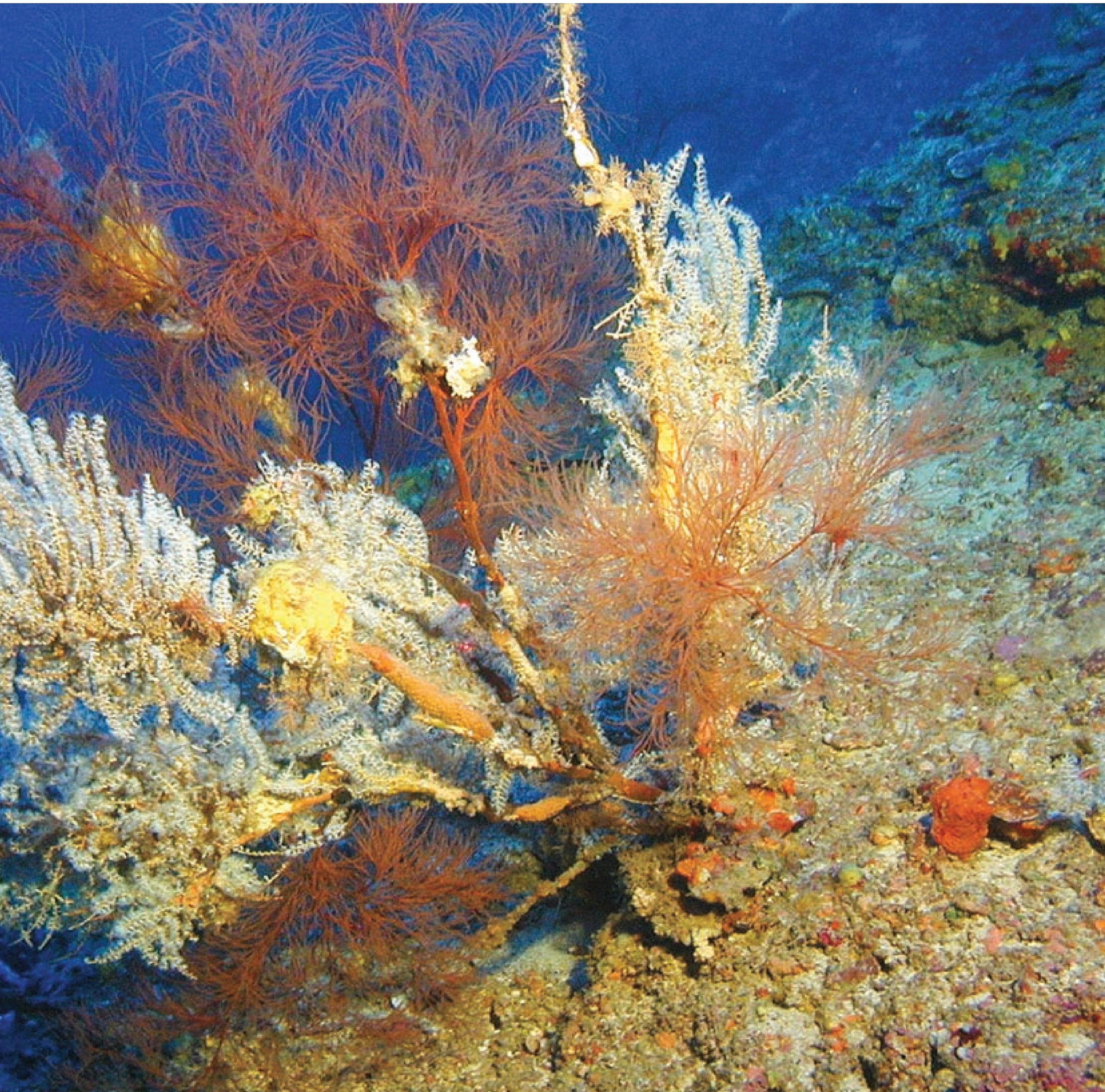
Marine Menace

Alien invasive species in the marine environment



About this booklet

This booklet is targeted at the general public to highlight an important but often overlooked issue, and to serve as a source of information and inspiration.

The material presented in this booklet is based on a large volume of work by many institutions and scientists around the world researching marine invasive species and developing means to prevent, manage and mitigate bioinvasions. Their work is gratefully acknowledged.

This booklet does not present new or primary information, but rather a synthesis of current issues and trends, including several examples of some of the worst marine invasive species, their spread and impact.

The text of this booklet was written by Maj De Poorter of IUCN's Invasive Species Specialist Group, with contributions from C. Darby and J. MacKay.

This booklet has been produced by IUCN's Global Marine Programme through projects supported by the Total Corporate Foundation.

Photographs
Front Cover: Samuel E. Kahng; p 2: Stefan Nehring; p.3 left: Jerker Tamelander/IUCN; right: Jim Wilke – Palau; p.4: Samuel E. Kahng; p.5: Dan Minchin; p.6: Both photos: Bella Galil ; p.7 left: Dan Minchin; right: Steve Coles; p.8: IUCN Photo Library © Imène Meliane; p.9: Dan Minchin; p.10: Top photo: Imène Meliane. Bottom photo: Jim Wilke; p.11 Top Photo: Imène Meliane. Bottom photo: David Luquet "Zoom on the invasives - IUCN-Fuji photo competition"; p.13: Jerker Tamelander/IUCN; p.14: Imène Meliane; p.15: IUCN/SCMRT-MPA Seychelles; p.16: IUCN Photo Library © Imène Meliane; p.17: IUCN Photo Library © Christian Laufenberg; p.18: Dan Minchin; p.19: Maria Degerlund; p.20: Audun Rikardsen, University of Tromsø, Norway; p.21: Samuel E. Kahng; p.22: Ron Offermans; p.23: Anna Occhipinti Ambrogi; p.24: CSIRO; p.25: Luigi Rignanese; p.26: Top photo: David Luquet "Zoom on the invasives - IUCN-Fuji photo competition". Bottom photo: Soili Saesmaa; p.27: MIT Sea Grant College Program; p.28: IUCN Photo Library © Imène Meliane; p.29: Stefan Nehring; p.30: USGS; Back Cover: Samuel E. Kahng

Design and Layout
åtta design sàrl, Geneva, Switzerland

IUCN

Fondation D'ENTREPRISE TOTAL Pour la biodiversité et la mer

Marine menace —an overview of the marine invasive species issue

More than 70% of the earth is covered by oceans and major seas and there are more than 1.6 million kilometres of coastline. Our marine habitats are biologically rich and extremely varied, from shallow coastal waters to deep sea trenches. People depend on the resources provided by oceans and coasts for survival and well-being in many ways. More than a billion people rely on fish as their main or only source of animal protein. Other marine resources such as shellfish and seaweed provide livelihoods through sustainable harvesting while coastal tourism provides employment and generates income. In the Florida Keys alone, reef-based tourism generates more than US$ 1.2 billion every year.

Yet our marine world is under threat: over-exploitation of its resources, habitat destruction, pollution and climate change are all driving biodiversity loss. Arguably the most insidious threat however, is the one posed by marine invasive species.

Marine habitats are populated by different species of animals, plants and microorganisms that have evolved in isolation, separated by natural barriers. But humans have overcome these barriers with shipping, air travel and other transport means. As a result, species are now moving far beyond their natural ranges into new areas.

Species that have been moved, intentionally or unintentionally, as a result of human activity, into areas where they do not occur naturally are called ‘introduced species’ or ‘alien species.’ Many of them perish in their new environment but some thrive and start to take over native biodiversity and affect human livelihoods—these are known as invasive species. When a species establishes in a new environment, it is unlikely to be subjected to the natural controls that kept its population numbers in balance within its natural range. Without such control by predators, parasites or disease, such species tend to increase rapidly, to the point where they can take over their new environment. Marine invasive species have had an enormous impact on biodiversity, ecosystems, fisheries and mariculture (breeding and farming marine organisms for human consumption), human health, industrial development and infrastructure. Alien species can be transported by various means: in ship ballast water or by attaching to hulls, as ‘hitch-hikers’ clinging to scuba gear or packaging, as consignments of live organisms traded to provide live bait or gourmet food and as pathogens, carried by other organisms.

Oceans in motion

Marine organisms have been moved around the world for thousands of years, with ocean currents and attached to driftwood, and later aided by human travel overseas for migration or trade. What is new is the speed and volume at which marine organisms are transported. Rapid increases in trade and shipping mean we are now capable of moving more organisms around the world (in the ballast water of ships) in one month, than we used to in one century. It is estimated that 7,000 species are carried around the world in ballast water every day and 10 billion tonnes of ballast water are transferred globally each year.

Archaeological records show that after the Vikings discovered North America, their longboats carried the American soft shell clam *(Mya arenaria)* back home with them, presumably for food. The clam is now widespread throughout Northern Europe. To quote James T Carlton, a marine invasives expert: «we set the biological world of the ocean in motion a long time ago and continue to do so today».

Ships provide the perfect transport for many species, both marine and terrestrial. The sailing ships used by explorers in the 15th and 16th centuries would have been packed full of marine hitchhikers. The bilge water could contain planktonic larvae picked up in Lisbon, Portugal and transported across the Atlantic to North America. The wooden hull of the ship below the waterline would probably be teeming with life from seaweed and barnacles to shipworms and crabs (the crabs living in holes drilled in the hull by shipworms). Many of these organisms would not survive the journey but enough of them did and were released into new locations. At each new port, an exchange of organisms would take place with new ones colonising the ships and being taken to other foreign locations.

In the 1800s, trans-Atlantic shipping increased dramatically and many species were transported between Europe and the east coast of North America. The periwinkle *(Littorina littorea)* was transported in the early 1800s and is now widespread from Canada to New Jersey. It has profoundly altered the ecology of these shores and has displaced the native eastern mud snail *(Nassarius obsoleta)*. In turn, the eastern mud snail was taken overland to the Pacific coast of the US where it displaced the Californian horn snail *(Cerathidia californica)*. Also in the early 1800s, the European green crab *(maenas is misspellt maenus)* was transported to America burrowed in holes made in ships by shipworms. Similarly, the American mud crab *(Rhithropanopeus harrisii)* was transported to Europe in the late 1800s. The European green crab in particular has caused enormous environmental damage (see case study on p 27).

Great and small

Organisms, from the smallest to the largest, can become invaders. Microscopic Japanese algae have recently been found in the North Sea, while giant, metre-long alien Pacific crabs are roaming off the Norwegian coast (see case studies on p 19). Around the world, fish, crabs, mussels, clams, jellyfish, corals, sea squirts, seaweeds, seagrasses or marsh grasses as well as microscopic disease-causing pathogens are just some of the life forms that have created havoc after they were introduced. The impacts from marine invasions are wide ranging: cord grass plants can colonise vast areas of mudflats and estuaries, destroying shellfish beds (see case study on p 29); caulerpa seaweed can do the same on the seafloor; European green crabs are voracious predators that are eating their way through marine life worldwide; and swarms of poisonous jellyfish are forming a 'jellyfish belt' off the coast of Israel. Climate change is likely to favour introduced species in many areas, and may intensify their impacts.

Even Marine Protected Areas are not safe. Increasing numbers of visitors to these areas means they are at far greater risk of biological invasion. Many ecologically-rich areas have suffered from marine invasive species. The Wadden Sea is the largest unbroken stretch of mudflats worldwide and the largest European wetland. Over the last 100 years, it has been invaded by numerous alien species. A similar story is being repeated from the Baltic and Arctic Seas and the North Atlantic to the Mediterranean, from tropical coral reefs all the way to the southern shores of Tasmania, Australia. Even the Antarctic is no longer free of alien marine species.

While the picture may seem bleak, there are many ways to fight back. It is much harder to eradicate an alien species in a marine environment than on land, but not impossible. If eradication is not feasible, some form of control may be achievable, even though this will need to be ongoing. In all cases, it is better to prevent the introduction in the first place. Prevention through management of ballast water is gaining much attention at the international level and our ability to assess risks, predict invasions and therefore prevent them, is growing. Surveillance and monitoring are improving, increasing the chance that a new arrival can be dealt with before it turns into a major new invasion. Communities are becoming more aware of the threats of marine invasions and are keen to participate in efforts to keep them at bay. There is more and more we can do, even as individuals, to make a significant difference in the battle against marine invasive species.

Did you know?

An estimated 7,000 species are carried around the world in ballast water every day.

Archaeological records show that the Vikings brought home with them a species of large North American clam, probably for food.

The comb jellyfish was introduced into the Black Sea through ship ballast water in the early 1980s and by 1994, the area's anchovy fishery had almost disappeared (see case study on p 22).

The estimated cost of dealing with the freshwater zebra mussel introduction in the US for the period 1989-2000 is between US$ 750 million and US $1 billion (see case study on p 18).

An invasion of black striped mussels in a Northern Australian marina was discovered in time to successfully eradicate it. The operation involved using sharpshooters to protect divers from crocodiles.

Invasive impacts

There are an estimated 500 alien marine species within the coastal waters of the US. Around 200 of these are found in San Francisco Bay alone. Worldwide the number is far higher. Why does this matter? Why should we be worried about it, when many intentionally introduced alien species provide us with food, recreation or jobs? The answer is that while many species that are introduced into a new environment do no harm, many others have significant ecological, economic, and human health impacts. Invasive seaweeds have smothered seabeds, invasive crabs roam the sea floor eating everything in their path, invasive jellyfish have led to the collapse of fisheries and people have been killed by pathogens carried around in ballast water. Sometimes the impacts are quick and dramatic but more often they are indirect and subtle and may escape notice for some time.

Impacts caused by marine invasive species include:

Environmental impacts

Loss of native biodiversity due to:

- preying upon native species
- decreased habitat availability for native species
- additional competition
- parasites and disease
- smothering and overgrowth
- hybridisation, causing genetic dilution

Changes to ecosystem function

Changes in nutrient cycles

Decreased water quality

Impacts to human health and wellbeing

- Parasites and disease, sometimes lethal
- Decreased recreational opportunities, e.g. algal slicks, overgrowth of aquifers and smothering of beaches

Economic impacts

- Interference with biological resources that support fishing and mariculture (e.g. when fish stocks or shell fish stocks collapse, or when mariculture is affected by invasive species or pathogens)
- Interference with fisheries (e.g. fouling or tearing of nets)
- Disruption to tourism
- Damage to infrastructure (through fouling of pipes, wharves, buoys etc.)
- Costs of clean up or control
- Costs of treatment or quarantine

Cultural impacts

- Competition with native species used for subsistence harvesting
- Degradation of culturally-important habitats and resources such as waterways

Examples of damage caused by marine invaders

The Red Sea jellyfish *(Rhopilema nomadica)* entered the Mediterranean through the Suez Canal. Each summer, huge swarms appear along the Eastern Mediterranean shores. At certain times there are 25 jellyfish per square metre forming a 'jellyfish belt' about 1 km offshore. This is having a big impact on fisheries and coastal infrastructure. Coastal fisheries are disrupted for the duration of the swarming due to clogging of nets and the inability to sort catches. In Israel, tonnes of jellyfish have to be removed from the seawater intake pipes at the two largest power plants, at an estimated cost of US$ 50,000 per year. Coastal tourism and fishing industries are affected across Israel, Egypt, Lebanon, Turkey and Cyprus.

The zebra mussel *(Dreissena polymorpha)*, native to Europe, is a freshwater species that has become a prolific invader overseas. It has spread rapidly throughout the waterways of North America, having 'travelled' to the US in ballast water. Zebra mussels encrust any solid structures in the water and block water pipes. Estimates for the cost of controlling this species in North America are close to US$ 1 billion over 10 years. The alien mussel is affecting native ecosystems, smothering native mussels whose populations can fall dramatically within just a few years of its arrival (see case study on p 18).

One of the worst marine invasions occurred in the early 1980s when the North American comb jelly *(lediyi is misspelt)* was introduced into the Black Sea and Sea of Azov. The species arrived in ship ballast water and rapidly took hold in the food-rich and predator-free waters of the Black Sea until, in 1989, there was an estimated 1 billion tonnes of the alien species. The jellyfish ate vast quantities of fish eggs and larvae as well as the zooplankton that commercially-important fish feed on, leading to the collapse of fish stocks within the Black Sea. By 1994 the anchovy fishery had almost disappeared. The alien comb jelly has completely altered the food web within the Black Sea (see case study on p 22).

Damage to the environment, the economy and human health is being caused by 'red tides'. These are created during blooms of some microscopic algae known as dinoflagellates that produce powerful toxins. The toxins accumulate in filter-feeding organisms such as oysters, scallops or mussels, and can poison people who eat them. The effects on other native animals that feed on shellfish are mostly unknown, but one study reported a fatal toxin poisoning of 14 humpback whales over a five-week period. The toxin produced by the algae *Gymnodinium catenatum* for instance can cause Paralytic Shellfish Poisoning which, in extreme cases, causes muscular paralysis, respiratory difficulties and even death.

The spread of this algae has led to closures of shellfish farms and bans on gathering wild shellfish while the blooms occur. Dinoflagellates can be accidentally spread by aquaculture and fisheries equipment such as in oyster cages or on mussel ropes and have also been transported over long distances in ballast water.

Alien species can also cause environmental damage when they 'escape' from enclosures such as aquariums, zoos or fish farms. Large areas of seabed in the northern Mediterranean are now carpeted by caulerpa *(Caulerpa taxifolia)*, an invasive seaweed which pushes out native marine life, disrupts ecosystems and fishermen's livelihoods. Mediterranean bream *(Sarpa salpa)* eat caulerpa but they accumulate toxins from the plant in their flesh, making them inedible. Caulerpa is thought to have entered the Mediterranean accidentally via the Monaco Aquarium, where it was used in fish tanks (see case study on p 25).

Many marine species including oysters (see case study on p 28 and fish have become invasive through deliberate introduction to an area as a food source or for erosion control, with little knowledge of the devastating impacts they would have. The freshwater fish species Tilapia for example, have been introduced in many countries. Originally occurring in Africa and the Middle East, they have been brought to the US and Asia for aquaculture, to provide food, even sometimes as part of international development aid efforts. It was not anticipated that they would escape, establish wild populations, destroy native habitats, native fish and other species. And it was certainly not anticipated that they would be able to tolerate salt water to the extent they do. Tilapia are now spreading from one river basin to another, colonising via the sea (see case study on p 30).

In the early 1900s, numerous attempts were made to introduce the Atlantic salmon, which is native to parts of Europe and the east coast of North America, to the west coast of the US. Eggs or juvenile fish were released to try to establish self-sustaining populations, but these attempts failed. In the late 1980s however, salmon farms were established in British Columbia and Washington State, where Atlantic salmon, introduced from Eastern Canada, are successfully reared in salt water net pens. Tens of thousands of these alien salmon are regularly found in the North Pacific Ocean, either as escapees, or because of deliberate release of small fish (see also case study on p 20).

The experience from the early 1900s led many to believe that such releases would not be a problem but studies show that the salmon can spawn successfully in the wild and that juvenile Atlantic salmon compete against native juvenile Pacific salmon. The difference may be due to the fact that the escapees are adults, or that the Atlantic salmon have had time to adapt better to local conditions in the fish farms. The Alaskan Department of Fish and Game now considers wild Atlantic salmon as a serious threat to native Pacific salmon species. This example and many others show why it is necessary to treat intentional introductions with caution. It also serves as a reminder that 'alien' and 'native' refer to ecological boundaries, not to country, state or other political boundaries. A species can be native in one part of the country, and alien, and even invasive, in another.

Invasional meltdown

It is difficult to predict which species will become invasive. Sometimes a species can be present for a considerable length of time at low numbers, lulling human observers into a false sense of security until conditions change and become suitable for populations to expand. One example of this is the Chinese mitten crab *(Eriocheir sinensis)* which was present off the shores of the UK for around 60 years without noticeable signs of being invasive. Then a series of very dry summers in the 1990s reduced the flow of rivers in the south of the country allowing the crabs to settle, reproduce and boom in number. The crabs travel long distances upstream, feeding on native species. They also burrow into stream and river banks leading to bank collapse. British zoologists fear that the Chinese mitten crab could both eat and out-compete vulnerable freshwater species and that native crayfish (which are already in decline) could be affected.

Another example involves the alien gem clam *(Gemma gemma)* which was introduced from eastern US to the west coast via the oyster trade in the late 1800s. Gem clams and two native clam species *(Nutricola tantilla* and *Nutricola confusa)* coexisted in Bodega harbour until the arrival of a new alien species upset the balance. European green crabs *(Carcinus maenas)* were introduced to San Francisco Bay in 1989 and they arrived in Bodega harbour in 1994. These alien crabs selectively eat the larger native clams rather than the smaller gem clams, reducing the population of native clams and allowing the alien gem clams to expand (see case study on p 27). An added complication is caused by the life cycle of the native clams. As the native clams grow larger they change sex from male to female. By eating the larger clams, the crabs remove the reproductive females from the system and hasten the decline of the native clams. This is a perfect example of 'invasional meltdown' where two introduced species interact to cause declines in a native species.

Guilty until proven innocent

Not all alien species become invasive. The problem is predicting which ones will. Even species that at first may seem 'harmless' may become invasive given the right change in local conditions. This could include the introduction of another alien species, environmental changes or other factors that give it a biological advantage. Because such changes can occur either after a long time lag, or quite suddenly, any new introductions into the local environment should be subject to close scrutiny. Considering the devastation caused by those alien species that do become invasive, it is necessary to treat all alien species with caution—any alien species should be considered 'guilty unless proven innocent'.

How are marine species introduced?

Unintentional introductions are those where species enter new areas as 'hitch-hikers' or 'stowaways' through trade, travel and transport. They include the major long distance, shipping-related causes of introduction:

- Ballast water transfer, mainly associated with large ships; and
- Hull fouling, associated with ships as well as yachts and smaller crafts

Unintentional introductions, including over shorter distances can also be associated with many other activities. They can occur as a knock-on effect of intentional introductions. Examples include:

- Fouling of buoys
- Transport on fishing or diving gear
- Transport on pleasure craft or other small boats
- Alien pathogens in shellfish and other aquaculture introductions

Species can become invasive by moving in natural ways such as swimming or floating where humans have created artificial connections between areas that were previously separated such as:

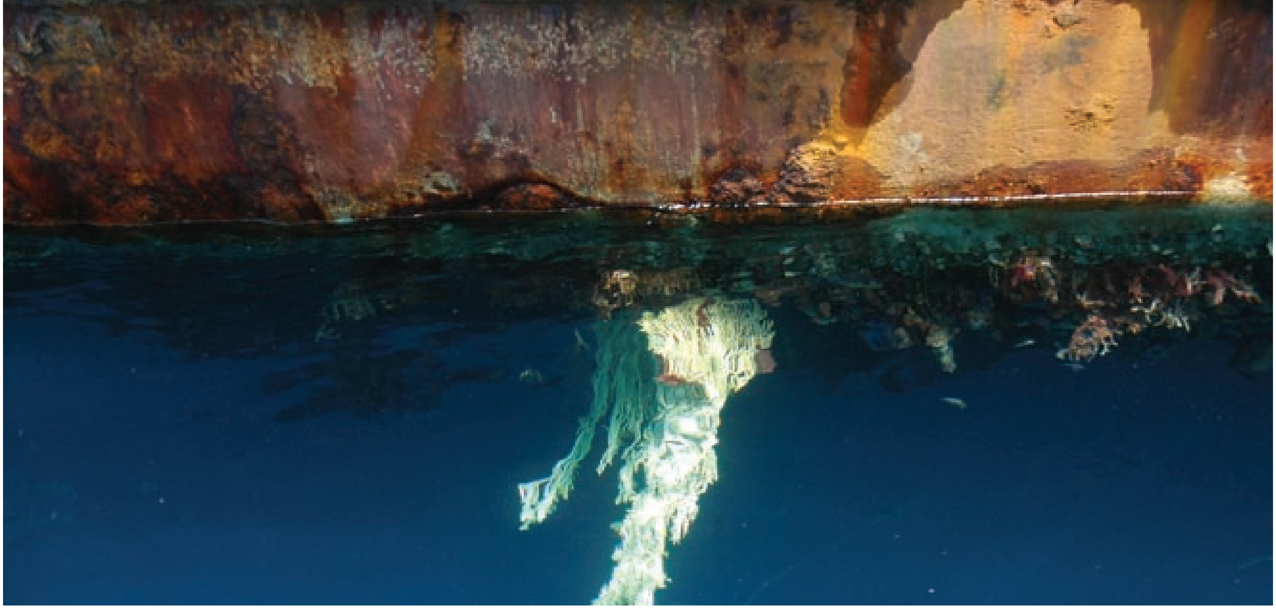
- Canals
- Water diversion schemes

Intentional introductions are those where the transfer of the organisms was planned. Some alien species are introduced for release into the wild such as:

- Fish species released to increase local catches
- Plants introduced for mudflat or dune management

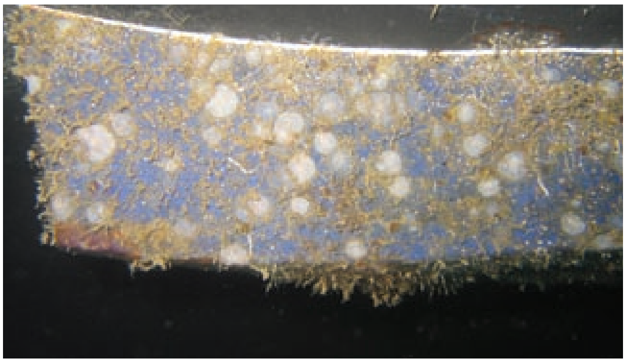
Many alien species are introduced into some form of containment, or for a use that does not mean them to be released in the wild. But very often such species 'escape' or are discarded into the environment. This category includes:

- Mariculture (farming of oysters, salmon, etc. (see case studies on p 20,28)
- Aquarium use
- Live seafood trade
- Live fish bait trade
- Seaweeds used in packaging (e.g. of bait)



Unintentional introductions

In the 19th century, shipping changed. Steel hulled ships replaced wooden hulls and engines replaced sails. One of the biggest and most important changes was the shift from solid ballast to using water. Ballast is any material used in a ship to stabilise it. An empty cargo ship may contain a lot of ballast which is dumped when cargo is loaded. Solid ballast was



a major pathway for many land-based invasive species; the shift to water ballast proved disastrous for the marine world. Tanks inside the hull of the ship are filled with water to weigh it down. This water may then be released at the next port of call, releasing with it any organisms that survived the journey. Depending on conditions, extra water may be taken up in different areas so the water in any one ship's ballast tanks may have come from a number of sources. Ballast water can contain a huge variety of organisms from microscopic plankton to 12 cm-long fish. The tanks themselves often have a layer of sediment in the base which is colonised by yet more organisms and the walls may also be colonised. Conditions inside ballast tanks are not ideal for many species but enough are able to survive to cause a problem. Nowadays, samples of ballast water find an amazing variety of life and hundreds of life forms, from cholera (see case study on p 29) and botulism bacteria to plankton, invertebrates and fish. Ballast water transfer is considered the primary cause of introductions today.

Many species attach to the underside of a vessel—the hull—and are transported vast distances. In some regions of the world such as the South Pacific or Indian Ocean islands, hull fouling may well be a more important vector than ballast water. Paints containing tributyltin were used as antifouling, but are now being phased out in many countries due to environmental concerns. In the absence of anti-foulants that are as effective, it is likely that fouling of vessels will increase and that more species will be transported this way in future. Organisms do not only attach to the hull but also to propellers and propeller shafts, anchors and anchor chains. Neither does fouling only affect ships—drilling platforms and floating dry-docks can be equally affected. Even amphibious vehicles or sea planes can transport species.

Transport within the same country can also cause problems. Many marine organisms, particularly plants, can tolerate drying out periods and remain dormant until conditions improve. Moving a small boat, fishing tackle or scuba gear from one island to another, or from one area of coast to another without cleaning it may be responsible for spreading an already invasive species further. So can moving a marina pontoon from one bay to the next without scraping or cleaning it first.

Human activities have led to large amounts of floating debris moving around on the ocean surface. Organisms have always attached themselves to bits of debris such as floating wood or coconuts but the amount of debris is increasing and it floats for longer. Plastic provides an excellent surface for organisms to attach to and it can remain afloat for years.

In 1869 the Suez Canal was completed. For the first time in 20 million years, the Mediterranean Sea was linked to the Red Sea allowing ships to travel to the Middle East and beyond without having to navigate around the Horn of Africa. Yet marine species also found a new route. Prevailing conditions through the canal mean that more species travel from the Red Sea to the Mediterranean than in the other direction. Nearly 300 species of Red Sea and Indo Pacific origin have settled and invaded in this way and these species have had a large impact on marine life in the Mediterranean. The jellyfish responsible for the 'jellyfish belt' off the coast of Israel is one of them.

Intentional introductions

Fish and shellfish have been intentionally introduced all over the world for mariculture, providing food and jobs. There are two main dangers associated with this. Species that are moved can escape and become a threat to native species, ecosystem function or livelihoods. Pathogens or parasites that may be associated with the stock that is moved can infect native as well as commercial species, or even be a risk to human health. Tilapia (see case study on p 30) and Atlantic salmon (see case study on p 20) are both examples of the first danger. These species have been transported around the world to fish farms and have escaped and naturalised in many areas causing damage to native species and habitats. The list of invasive species introduced accidentally with mariculture is long. Many are associated with oyster movements such as the sea squirt (*Styela clava*) which is posing a major threat to the shellfish aquaculture industry in New Zealand. The species was probably introduced with imports of Pacific oysters from Asia. It is estimated that 30% of all introduced marine algal species worldwide were moved accidentally in association with mariculture.

Recreational fishing is also to blame for the spread of many invasive species in the US. Bait worms from Maine on the east coast are popular as fishing bait throughout the country and beyond. They are commonly packed in seaweed which contains many other organisms. If the seaweed is discarded, either the plant itself or the organisms growing on it can colonise new areas. The snail *Littorina saxatillis*, the seaweed *Codium* fragile *spp tomentosoides* and the European green crab *(Carcinus maenas)* have all spread this way from the east to the west coast of the US. The green crab is now spreading further up the west coast with the prevailing currents (see case study on p 27).

Trade in alien species for aquarium use can also result in marine invasions: many people worldwide keep exotic fish, marine plants, invertebrates or corals in aquariums. In most cases these organisms would not be able to survive outside 'in the wild' but some do. One of the most infamous marine invaders, the cold-tolerant strain of the tropical seaweed *(Caulerpa taxifolia)* now carpets large areas of the Mediterranean Sea having escaped from the Oceanographic Museum in Monaco (see case study on p 25). Divers around Florida are being exposed to a new hazard—the beautiful but poisonous lionfish *(Pterois volitans)*. This species was first noticed after a hurricane in 1994; it probably escaped from an aquarium destroyed in the hurricane.

The rate at which marine organisms are being introduced worldwide is accelerating rapidly due to the increased volumes of trade and shipping, as well as the ever-increasing connectivity of ports and harbours. It is not surprising that we are now capable of moving more marine organisms around the world in one month, than we used to do in a whole century.

Fighting back —what can be done?

Because of the scale of the problem, marine invasive species should be tackled at the international and regional level as well as at the national and local level. Managing invasive species in the marine environment presents many more challenges than on land. One of the problems is the continuity of the marine environment—it is almost impossible to seal off an area. Any treatment applied to an area, such as poison, is likely to spread beyond the target area. It is also very easy for reinvasion to occur. Working under water adds an extra level of complexity. Even though there have been a few successful eradications of marine invasive species, it is clear that it is far better and more cost effective to prevent an invasion in the first place than to try to eradicate the species once it has taken hold.

Options for managing invasive species

Prevention of marine invasions is by far the best option.

– No intentional introduction of any alien species (e.g. for mariculture, bait, etc) should take place unless the introduction has been authorised and a decision on whether such authorisation can be given is based on prior assessment of the risk of invasiveness (including in case of escape).
– Unintentional introductions of any alien species should be minimised. This means that vectors and pathways (such as ballast water transfer, hull fouling etc) need to be identified, assessed and addressed (e.g. through ballast water exchange, treatment etc).
– Provisions should be in place for early detection and rapid response so that a new incursion can be eradicated before it spreads. Baseline surveys, surveillance, monitoring and contingency planning are all important.
– Community participation and awareness are critical to prevention.

Preventing unintentional introductions

Most of the world's trade is carried out by ship, currently involving some 35,000 vessels. With so many introductions occurring unintentionally through ballast water and hull fouling, addressing these two pathways is paramount.

International instruments include the International Convention for the Control and Management of Ships' Ballast Water and Sediments, developed by the International Maritime Organisation (IMO). This outlines procedures for minimising alien species introductions from ballast water discharge while protecting ships' safety and will provide a uniform, standardised regime for managing ballast water.

Recommended procedures involve a vessel transferring ballast water in the open ocean before arriving at its destination. Organisms picked up with ballast water in a port are likely to be adapted to estuarine or river conditions so they will not be able to survive in the open ocean if they are released there. The ship then refills its ballast tanks with water form the open ocean and organisms picked up there should not be able to survive in ports and harbours. Unfortunately, it is not always possible for ships to use this method due to safety issues, for instance, in rough seas. Also, emptying the water does not remove the layer of sediment or film on the walls of the tanks so many organisms survive even if ballast water is transferred. So while open water transfer can contribute significantly to preventing marine invasions, we can not rely on it as the only measure. Research is being undertaken into methods of destroying marine organisms in ballast water, for instance, using sterilisation, ozone or heat. Another option is the introduction of treatment plants in ports which take ballast water from ships and sterilise it before releasing it or returning it to another ship.

At present there is no international legislation regarding hull fouling, but concern about its importance as a vector is growing. Anti-fouling paints protect vessel hulls from being colonised, usually because they contain chemicals that prevent the juvenile stages of marine plants and animals from settling. While tributyltin-based paints are being phased out, there are various alternative anti-fouling paints available that do not contain TBT. Their use is fairly specific, in that the size of the boat and its purpose determine the type of anti-fouling product to use. Inspection for fouling can be carried out and, where necessary, the organisms can be removed from hulls. It is important that fouling material does not become dislodged into the water column while cleaning. All fouling material removed from the hulls should be disposed of either by burning or burial and should not be dumped into the water.

This does not only apply to vessels arriving from foreign ports. Vessels including small recreational boats arriving from domestic ports where invasive marine species are established also pose a high risk. Moving equipment such as oyster cages, buoys, or lines that have been in the water long enough to get fouled, can also lead to introduction or spread of marine invasives. There must be sufficient awareness of the risks at the local level so that individuals know what action to take.

Preventing species travelling through canals is also technically possible. Management options within the Suez Canal for instance could include inserting a strong saline barrier, or a lock system where water is chemically or biologically treated to kill any organisms present.

Preventing invasions when a species is introduced intentionally

Some international instruments address the issue of invasions that occur after a species has been intentionally introduced such as for aquaculture, the aquarium trade, or sport fishing. These include the Convention on Biological Diversity and the Food and Agriculture Organisation's Code of Conduct for Responsible Fisheries, which discourages the use of invasive alien species in aquaculture (including mariculture) and calls for accurate assessments of the risks of using alien species.The International Council for the Exploration of the Sea's Code of Practice on the Introduction and Transfer of Marine Organisms is one of the most comprehensive instruments to help in the responsible use of introduced species but is only voluntary.

Early detection, rapid response

Once a species has been introduced to an area it is important to locate it and take action quickly before it has a chance to establish and spread. This can be challenging given the open nature of the marine environment. But if an invader is found while it is still in a relatively small containable area, it may be eradicated if the response is quick enough. This is why surveys are so important. They can be site-specific such as focussing on ports where an alien species may be introduced, or on areas of particular value that need the highest protection; species specific (targeting species that have been found to pose the highest risks); or more general. Surveys can be carried out by networks or organisations that have specific responsibility for detecting invasive species, often focused on high-priority targets, high-risk locations, or high value resources. They can also be carried out by organisations or individuals who may detect invasions as they carry out other activities. Employees in industries that have a high risk of being affected, or people with recreational or other interests in the marine habitat can form very useful networks in tackling invasions. Members of the public often know their local area extremely well and are likely to notice any changes.

Baseline surveys that identify and record what marine life presently exists in a particular location including exotic species that have already become established are also useful. They can be undertaken in all ports and marinas where invasions are most likely to occur. Monitoring is then needed to detect any new arrivals.

Awareness and education

As well as encouraging the public to look out for new species, education and awareness programmes should also be used to maximise community involvement. Encouraging fishermen to take their excess bait and wrappings home at the end of the day, or to clean their boats before moving them to another stretch of coastline, will help them to play their part in preventing the introduction or spread of invasive species. The hulls of recreational yachts travelling long distances should be cleaned regularly and in dry dock. Encouraging people to dispose of their home aquarium contents responsibly could prevent seaweed or fish species from establishing in new areas. Most members of the public are receptive to requests such as this as most would not wish to deliberately harm the environment. Education at school level is also important. As part of a campaign to educate people in Hawaii about the dangers of introduced species, a team developed colourful trading cards depicting 'good' native species and 'bad' invasive species. The cards were distributed in schools to educate children about the dangers of introduced species and to encourage them to look out for these species whenever possible.

Eradication and control

It is extremely difficult to control a marine organism once it becomes established. To date there has only been one successful eradication of a marine organism; the eradication of the black striped mussel from a marina in Australia. Chemicals were used to kill everything in the marina, including all native marine life. The operation involved chemically treating three marinas and 420 vessels, engaging 270 people (including sharpshooters to protect divers from crocodiles) over four weeks at a total cost of 2.2 million Australian dollars.

Various methods have been used to reduce the numbers of marine invasive species in established populations but while there may be some success in lowering the numbers, these activities will have to be maintained indefinitely at great cost. The port of Hobart in Tasmania, Australia has been invaded by the Japanese sea star *(Asterias amurensis,* see case study on p 24). Attempts have been made to control it using chemicals as well as by manual removal, but so far there has been little impact on the population (see case study on page 25).

In California's San Fransisco Bay, 'crabzilla' has been put to work—a 2.5 m wide, 6 m high travelling device that scoops up Chinese mitten crabs on a giant revolving wheel while allowing fish to slip through the mesh openings. The fish are returned to the Bay and the crabs are ground up as fertiliser. In Hawaii's Kaneohe Bay a 'super sucker' has been deployed from a barge to remove invasive alien algae *(Gracilaria salicornia)* that forms a thick mat smothering and killing coral. In many countries, biological control methods are being investigated but this a very complex approach, fraught with difficulties including the risk that a control agent may escape and affect non-target species.

You can help

It cannot be overstated: Prevention should be the top priority. Efforts should be stepped up to reduce and prevent the introduction of new species into the marine environment. All means of introduction should be addressed including intentional introductions. A system for early-warning and rapid response is needed. Marine invasive species should be addressed at all levels, from international conventions to regional agreements, national planning and at local levels, encouraging and empowering communities to be involved. All aspects of management should be based on the precautionary principle. This means that any alien species should be considered a potential risk.

Things you can do

- Find out more about the issue of invasive marine species and how it can affect your local area.
- Keep your eyes open and notify relevant authorities or scientists if you notice an unusual animal or plant.
- If you fish, dive or go boating: check your gear and your boat and clean it if necessary, so you don't give a ride to unwanted organisms.
- Do not discard unused bait or weed that was used as wrapping in places where it could find its way into local waterways or the sea.
- Do not empty fish bowls, contents of ornamental ponds or aquaria in natural waterways (and remember that many drains in urban areas may carry organisms to a river or to the sea).
- Encourage your family and friends to get involved; raise awareness.
- Encourage monitoring efforts in your local area.
- Encourage decision makers to address marine invasive species as an important issue.

Information on marine invasive species online

The Invasive Species Specialist Group (ISSG) of IUCN's Species Survival Commission (SSC)

ISSG aims to reduce threats to natural ecosystems and the native species they contain by increasing awareness of invasive alien species, and of ways to prevent, control or eradicate them. ISSG also produces the newsletter 'Alien', and maintains a listserver.

http://www.issg.org

ISSG manages the Global Invasive Species Database which aims to increase awareness about invasive alien species and to facilitate effective prevention and management activities.

http://www.issg.org/database

The Global Invasive Species Programme (GISP)

GISP is an international partnership with the aim of conserving biodiversity and sustaining livelihoods by minimising the spread and impact of invasive species. GISP provides support to the implementation of Article 8(h) of the Convention on Biological Diversity and has contributed extensively to the knowledge and awareness of invasive species through the development of a range of products and publications.

http://www.gisp.org

Invasive Species Information Node of the National Biological Information Infrastructure

The Invasive Species Information Node provides links to invasive species data sources including a catalogue of invasive alien species information systems, databases and datasets.

http://invasivespecies.nbii.gov/dbases.html

GloBallast Partnerships

Building Partnerships to Assist Developing Countries to Reduce the Transfer of Harmful Aquatic Organisms in Ships' Ballast Water, or the GloBallast Partnerships Project (GBP) helps vulnerable developing states and regions to implement sustainable, risk-based mechanisms for the management and control of ships' ballast water and sediments to minimize the adverse impacts of aquatic invasive species transferred by ships.

http://globallast.imo.org/

IUCN Global Marine Programme

IUCN's Global Marine Programme focuses on eight broad themes, one of which is managing marine alien invasive species. Activities include field projects on detection and management of marine alien invasive species, capacity building and awareness raising, as well as policy work to strengthen international regulations to manage marine species introductions.

http://www.iucn.org/marine

The Convention on Biological Diversity (CBD)

The Convention on Biological Diversity sets commitments for maintaining the world's biological diversity. The Convention establishes three main goals: conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of the benefits from the use of genetic resources. Article 8h of the Convention calls on parties to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species; and several Plans of Work under the CBD specifically mention invasive species.

http://www.biodiv.org

Case studies

The zebra mussel billion dollar meltdown

The zebra mussel *(Dreissena polymorpha)* is native to the Caspian and Black Sea and the Sea of Azov. It is a freshwater species but is included here as it is a graphic example of the damage that can be caused by an invasive species. Carried to North America in ballast water, it is now one of the most infamous examples of biological invasion. The species is now established in the UK, Western Europe, Canada and the US. In the US the mussel has spread through all the major river basins east of the Rocky Mountains. Zebra mussels multiply rapidly—one female can produce several million eggs a year and they can cover any surface, even each other. The mussel competes with zooplankton for food and interferes with native molluscs, often suffocating or starving them.

The devastating impact of the zebra mussel is clearly demonstrated in the American Great Lakes where it was introduced unintentionally in the mid-1980s. It has smothered natural ecosystems and altered the water conditions, severely affecting fisheries. It has also cleared the way for large-scale invasion by other alien species, leading to a situation known as 'invasional meltdown'. The mussel causes a large amount of damage to infrastructure. Between 1989 and 2000, the financial damage incurred in the US is estimated at between US$ 750 million and US$ 1 billion. The economic, social and environmental effects were so dramatic that in 1990 the US introduced the first national legislation on ballast water.

One of the concerns surrounding the zebra mussel is the ease with which it spreads. It was introduced between continents and among the Great Lakes in the ballast water of ocean-going vessels. Introduction to smaller lakes is likely to have taken place by overland transport, on boat hulls, anchors and trailers. Larvae may be transported on divers' wetsuits, in scientific sampling equipment or during fish stocking. The spread within North America has also been very rapid due to downstream transport of planktonic larvae. It is thought that even ducks could transport larvae in their feathers.

There are several ways to remove mussels from infested water intakes or on fouled man-made surfaces but none of these methods work for control in the wild. It is therefore of paramount importance to prevent further unintentional spread. For long-distance travel, exchanging ballast water in the open ocean should reduce the risks of introduction. Community participation is important to help prevent invasions, ensuring that boats, trailers and equipment are cleaned if they are moved from one body of water to another. Awareness campaigns can play a critical role in managing this species.

Arctic invasion the giant red king crab

Ecologists and fishermen in Norway are warning of the threat posed by invaders advancing from Russia with alarming speed along the coast of Norway—the giant red king crab *(Paralithodes camtschaticus)*.

The species is native to the north Pacific around the Kamchatka Peninsula of Siberia, south as far as Hokkaido in northern Japan and eastwards along the Aleutians towards Alaska. It is a voracious omnivore eating large quantities of any edible plant or animal matter it finds including fish eggs and other crabs. It takes about 10 years to mature, may live for 30 years and can reach a weight of 10 kg (22 lbs) and a size of 1.5 m (4'9"). It has no natural predators in Europe.

In 1960, Soviet economists approved the introduction of the crab to increase the catch levels of local fisheries. Crabs were caught on Russia's Pacific coast, transported overland, and released into the Barents Sea. For about two decades nothing much changed, but then, in the late 1980s, crabs began to spread to the West and since 1992 the species has occurred in significant numbers in Norwegian waters. It has since reached the Svalbard Islands and is now spreading south down the Finnmark coast of Norway. The crab is predicted to eventually reach as far south as Portugal and, as of 2006, it had reached the Lofoten Islands.
The crab has caused serious problems for local fisheries along the Barents Coast; it kills commercially-valuable fish and clams and damages fishing nets. However, some people have started catching the crabs and turned them into a lucrative source of income—live crabs are exported to exclusive restaurants in London.

But the ecological impacts of the crab are not fully known. As a result, while affected fishermen and environmentalists have been expressing concern about the growing numbers and spread of the crab, those with a commercial interest in it point out that there is no absolute proof that the alien king crab is causing widespread ecological damage.

Unfortunately, if there is one thing that we should have learned from biological invasions worldwide, it is that absence of proof is not proof of absence. If we wait until an introduced species is clearly invasive, it is then too late to do anything about it. This is why alien species must be treated with the precautionary approach: every alien species needs to be managed as if it is potentially invasive, until convincing evidence indicates that it presents no such threat.

In the case of the king crab, further spread should be prevented. Norwegian and Russian authorities have agreed that crabs west of 26 degrees E (the Norwegian North Cape) are under Norway's national management. Norway encourages the catching of crabs west of the North Cape to try to stop further spread. However, given that commercial crab fishermen operate in the areas of high crab density, rather than at the lower density 'expansion front', it remains to be seen how effective these crab fisheries will be in minimising further spread.

On the run
Atlantic salmon

The Atlantic salmon *(Salmo salar)*, native to the Atlantic Ocean starts life in freshwater lakes and rivers. It is only as it matures that it migrates to the ocean where it can grow to about 9 kg. Salmon are often fished for sport, particularly in Europe, and are one of the most commonly-eaten fish worldwide. When this species began to be shipped around the world for aquaculture, it created job opportunities and brought economic benefits. But there have also been negative effects including pollution from fish farming and impacts on native species through escape and hybridisation, disease transmission and competition. Atlantic salmon are now found as far afield as Australia, New Zealand and Chile as well as on the West Coast of the US and Canada.

Historically, the five species of wild, native salmon on the Pacific coast played an important role in defining the Pacific North West and Alaskan character and economy. However, dams, urbanisation and deforestation took their toll, and the great Pacific salmon runs are a thing of the past in many areas. The US National Marine Fisheries Service has listed some of the native salmon species as threatened. As the runs of wild salmon declined, price increases and technological improvements made salmon farming a feasible and economically viable option and farming of the native Pacific salmon began in the 1970s in the Pacific Northwest (but not in Alaska).

In the late 1980s, instead of farming native species, salmon farms in British Columbia (Canada) and Washington State (US) began to import Atlantic salmon from the Canadian east coast and Europe. While some of these transfers were within Canada (east coast to west coast), they nevertheless constitute an introduction of an alien species, because they involved crossing a huge ecological boundary that the fish would not have been able to cross on their own.

It could be asked why it matters that the Atlantic salmon is an alien species when salmon aquaculture represents a large part of food exports and creates jobs. It was even thought that the farmed salmon would reduce the fishing pressure on the already beleaguered native salmon. The reality however, is that the large supply of farmed salmon to the world market resulted in a drop in price, and in response, commercial fishermen declared that they had to increase catches of native salmon to maintain their income. Farmed Atlantic salmon are often grown in large pens erected in natural water bodies. Tens of thousands of them are released into Pacific coastal waters each year, either accidentally or by the deliberate release of fish that are deemed too small. This massive 'biological pollution' and the threat that it constitutes for native Pacific salmon is a major concern.

Atlantic Salmon are now regularly found in the wild in their alien range: 7,833 adults were caught in British Columbia in the year 2000 by sport, research or commercial fisheries. Sexually mature Atlantic salmon are commonly found even as far North as Alaska. In 1998, the first confirmation came (from British Columbia) that the alien salmon could also spawn in the wild. Wild juvenile Atlantic salmon in their native range are very aggressive. The fingerlings produced from spawning in their alien range on the North American West coast may be the greatest threat to native salmon through competition with native juveniles, as well as through predation on the native pink salmon and chum salmon fry.

The Alaskan Department of Fish and Game now considers wild Atlantic salmon a serious threat to the State's native Pacific salmon species. It would like to see salmon farming limited to land based farming and storage instead of marine pens, a ban on releasing Atlantic salmon into the wild and a commitment not to allow farming further north than the present locations in British Columbia. But the Department has no jurisdiction in British Columbia or Washington State and those regions cannot stop salmon from crossing the political boundaries. Effective invasive species management relies on cooperation across political boundaries.

Not so soft
the snowflake coral

The snowflake coral *(Carijoa riisei)* is a soft coral also known as branched pipe coral or orange soft coral. It occurs naturally in the Western Atlantic and the Caribbean, from Florida to Brazil. It was first reported in Hawai'i in 1972 but it is not known exactly how it spread.

Snowflake corals are voracious feeders that consume large quantities of zooplankton and can out-compete the more desirable native species for food. Reproducing rapidly, the coral can outgrow or overgrow existing life-forms. It can attach itself to almost any hard surface including those where it is not welcome such as natural communities of corals and shellfish, metal, plastic and concrete structures, as well as artificial reefs that are important for recreational divers. Consequently, the snowflake coral has rapidly become a serious pest, seriously affecting Hawaii's ecology and economy.

In favourable conditions, the coral is capable of explosive growth, occupying any available space down to depths of 120 m. In 2001, a survey off Maui revealed that the coral had smothered up to 90% of black corals which are harvested commercially.

When it was first reported, the snowflake coral was thought to be benign and little attention was paid to it but now it is regarded as the most invasive of the 287 non-native marine invertebrates in Hawai'i. It has caused enormous damage to the ecosystem and seriously threatens the US$ 30 million annual revenue from sales of coral jewellery and souvenirs. No practical method of controlling it has been found so far.

The comb jelly *(Mnemiopsis leidyi)* is a carnivorous predator that reaches 10 cm in length, eating all forms of zooplankton including fish eggs and larvae, disrupting the food chain of the areas it has invaded. Comb jellies, or ctenophores, superficially resemble jellyfish but are biologically quite different and belong to a different phylum. Originally from the Atlantic estuaries of the Americas where its abundance is restricted by native predators and parasites, it tolerates an extremely wide range of temperature and salinity. Comb jelly populations follow 'boom and bust' cycles and can reach very high densities.

In the early 1980s, the comb jelly was accidentally introduced via ship ballast water to the Black Sea. It was also introduced into the Caspian Sea via the ballast water of oil tankers. In its new predator-free habitat, the jellyfish wreaked havoc on the entire ecosystem of the Black Sea. The situation was made worse by nutrient and other pollution. By 1992, the annual losses caused by drops in commercial catches of marketable fish were estimated at least US$ 240 million.

Black Sea disaster
the comb jelly

The comb jelly's proliferation has had a cascading effect through all levels of biodiversity—even predatory fish and dolphins have disappeared. Fish stocks in the Black Sea and Sea of Azov have suffered from the comb jelly eating eggs and larvae. Impacts on the Caspian Sea ecosystem were felt quicker and greater than in the Black Sea. By 2001, repercussions were felt at all levels—even the top predator, the Caspian seal was affected.

In a strange turn of events, in 1997, another invader, incidentally another comb jelly, *Beroe ovata* was found in the north-eastern Black Sea. It feeds on *Mnemiopsis leidyi* and caused a dramatic fall in their number, helping the Black sea ecosystem to recover. Improved conditions have been seen for zooplankton, phytoplankton, dolphins and fish as well as fish eggs and larvae. It is possible to use *Beroe ovata* as a biological control for *Mnemiopsis leidyi*. However, using an alien species for biological control is a last resort, given that it carries its own risks. In any case, deliberately introducing such species should only be considered after thorough risk analysis that looks at all the costs and benefits—including environmental ones.

The seaweed *Undaria pinnatifidia* (also known as wakame or Japanese kelp) is a native of Japan, China and Korea where it is harvested for food. Growing up to 3 m in length, the seaweed tolerates a wide range of conditions, although it prefers colder waters. *Undaria* can grow on any hard surface, including rope, pylons, buoys, boat hulls, bottles, floating pontoons and plastic. It can also inhabit a wide range of natural surfaces and grow on the shells of abalone, bivalves and invertebrates, and on other seaweeds. *Undaria* may form dense forests,

Undaria
killer seaweed

competing with native species for space and light and often outcompeting them, especially where there are no large native seaweeds. In New Zealand, it has been nicknamed 'gorse of the seas' because the damage it does can be as severe as that caused by gorse, a major terrestrial plant pest.

Undaria was intentionally introduced into Brittany, France for commercial use and was then recorded in natural communities in the UK, Spain and Argentina. It was also unintentionally introduced into Australia, New Zealand and Italy. Unintentional introduction can be via ballast water or ships' hulls, aquaculture and fisheries activities and the live food trade.

The effects of *Undaria* invasion are far-reaching. The species can interfere with marine farming by attaching to cages or ropes, increasing labour and harvesting costs and either slowing the growth of, or displacing the farmed species. By infesting the underside of vessels, Undaria significantly decreases their efficiency in the water, adding to operating and maintenance costs.

The best way to manage *Undaria*, as with other invasive species, is to prevent introduction and new infestation. Because *Undaria* spreads freely by microscopic spores eradication is difficult, but can be possible through sustained effort.

An example of early detection and successful rapid response comes from the remote New Zealand Chatham Islands. In 2000 a fishing boat which had been infested by *Undaria* sank. The New Zealand Ministry of Fisheries ordered the vessel to be moved (using its powers under the Biosecurity Act) but bad weather prevented salvage attempts. It was then decided to use new techniques to eradicate the seaweed from the hull. The hull was heat-treated to kill the microscopic stage of undaria. Plywood boxes with foam seals were attached to the hull by magnets. Electric elements (powered by a diesel generator on the surface support vessel) inside the boxes heated the seawater to 70ºC for 10 minutes, with a flame torch used for inaccessible areas. It took divers four weeks to complete the treatment, but a monthly monitoring programme over three years indicates the eradication has been successful. The Chatham Islands' shoreline has been surveyed regularly for undaria and no plants have been found.

Monterey Bay National Marine Sanctuary off the coast of California is working to fight off *Undaria* which has already invaded nearby Monterey Harbour. *Undaria* was seen as a potential threat to the sanctuary's native kelp forests. State and sanctuary officials launched a formal *Undaria* management programme in October 2002. This involved a team of volunteer divers removing *Undaria* manually from harbour docks and pilings, with research volunteers collecting data on Undaria locations. So far, it appears that the *Undaria* is keeping pace with the eradication effort, probably because spores are being carried beyond the confines of the harbour. It is recognised that eradication is not possible because even if all *Undaria* were removed from Monterey Harbour, there are no mechanisms in place to prevent reintroduction by vessels entering from other infected harbours. However, ongoing management of the existing population can reduce the rate of spread.

Trouble Down Under
Japanese starfish

The large yellow and purple Japanese starfish *(Asterias amurensis)* is another of those attractive creatures that appear harmless but can have disastrous consequences when they invade new habitats. The species is native to Japan, northern China, Korea, Russia and the far North Pacific. It is thought that introduction of the species in Tasmania (Australia) could have been as larvae through ballast water or as a fouling on ships from Japan. In 1995 the density in the Tasmanian Derwent estuary was found to be the highest anywhere in the world (1,100 per m^3). An estimated 30 million individuals may be present there.

This voracious predator eats anything it can find that is no longer than one of its own arms (up to 50 cm). It is especially fond of shellfish, crabs, sea-urchins, other starfish, fish eggs and sea-squirts and can detect and dig-out prey that is buried in sand. The starfish has, since its arrival in Tasmania, become the dominant invertebrate predator in the Derwent Estuary. The native sea star *Coscinasterias muricata* is unable to compete in number and is under great threat

from the foreign invader. Aquaculture farms, including mussel ropes, oyster trays, scallop lines and salmon cages which may provide easily accessible prey, can also be threatened by the Japanese starfish, although much less so when suspended mid water.

No practical method is known to eradicate this species after it has become established. Physical removal by divers has only had limited success where infestation was sporadic over time and had a density of less than 2 per m^2 but diver collection as a control method for large populations is not effective. In May 2000, community divers in Hobart (Tasmania) collected 21,000 individuals which was estimated to be just 5% of the starfish population in the dock area. Removal by hand, by dredging or with traps, have also not been effective. Netting and commercial harvesting (for grinding into fertiliser) have drawn limited success.

Some species could be used for biological control of the Japanese seastar and the feasibility and safety of using them is being examined. The only practical defence against the Japanese starfish invasion is continual vigilance at all potential points of entry, and rapid reaction if an introduction occurs. To maximise prevention of further spread, information about this species has been distributed throughout coastal Australia to educate the community and encourage the reporting of sightings. In New Zealand, legislation has been enacted to prevent discharge of ballast water that has been taken from the Derwent Estuary and Port Phillip Bay during the seastar's spawning season.

The Mediterranean mussel *(Mytilus galloprovincialis)* also known as the blue mussel or bay mussel is a native of the Mediterranean coast and the Black and Adriatic Seas. Dark blue or brown to almost black in colour, it is generally between 5–8 cm in length but has been known to grow to 15 cm. The mussel is dispersed unintentionally in ballast water and by fouling ships hulls, and is now well established in temperate regions around the globe, including southern Africa, north-eastern Asia and North America. In Japan and China it is widely cultivated for food.

Mussling in

The Mediterranean mussel is highly tolerant and can survive on surfaces ranging from exposed rocks to sandy bottoms. This invasive species appeared in South Africa in the 1970s—its arrival was thought to be unintentional, through shipping. Once established, the mussel can expand its range by up to 5 km a year. In South Africa mussel larvae disperse with the speed and direction of surface currents. The mussel has displaced several native mussel species from their habitats, reproducing much quicker than the indigenous species. It has also invaded the Pacific coast of the US but because of the similar appearance of the blue mussel and native mussels, changes occurred undetected for several decades. It appears to out-compete its close relative, the native *Mytilus trossulus*, in sites with warmer water of more constant salinity (such as in San Francisco Bay) and it smothers another native mussel, *Mytilus californianus*, in wave-protected areas in southern California. Hybridisation with native species has also been reported from some areas, such as Oregon.

Unintentional introductions could be better prevented through ballast water management. In some areas a new technique is used in the aquaculture industry to reduce the risk of invasion. Mussels are manipulated to have three or four sets of chromosomes, which makes them sterile, thereby reducing the risk of wild populations establishing. However, the method is not perfectly safe as mussels may revert to 'normal' and escape and spread.

Most caulerpa species are attractive-looking algae. In the late 20th century, the species *Caleurpa taxifolia* became an international favourite as the aquarium trade grew throughout the world. However, an escaped 'aquarium strain' of the species proved to be ecologically and economically disastrous when it invaded locations as far apart as Australia, the US and the Mediterranean. The seaweed has already achieved infamy as one of the 100 of the world's worst invasive species.

One of the worst cases of invasion happened in the Mediterranean: a major public aquarium in Monaco obtained a *Caleurpa taxifolia* hybrid from dealers who had probably sourced their original stock from northern Australia. Soon small pieces of the new seaweed were released into the wild via the aquarium wastewater system. It rapidly covered 13,000 hectares of seabed along 190 km of coast. By 2001, it had hitch-hiked to many other popular tourist harbours around the Mediterranean on boat anchors or fishing nets.
Caulerpa taxifolia can invade many types of seabed, mud through sand to hard rock, irrespective of other life-forms. It starts its invasion by over-growing and shading the resident seaweeds or sea-grasses and goes on to affect sea animals such as fish and lobsters which rely on the existing native ecosystem for food. Animals that cannot move away quickly, for example shellfish, are simply smothered. The aquarium strain of *Caulerpa taxifolia* can cover the entire seabed in a dense mat, leaving no space for other species. The invasive seaweed protects itself from being eaten by sea urchins or fish by producing a toxin. The few species that can eat the seaweed such as Mediterranean bream can accumulate toxins in their flesh to an extent that makes them unfit for consumption by humans. This seaweed also interferes with various economic interests. A solid carpet of one type of seaweed is of little interest to recreational divers, snorkellers or tourists. Commercial fishermen are affected through reduced catch levels caused by damage to fish habitat, and through entangling of nets and boat propellers.

Smothered by seaweed

A relatively small infestation in Southern California was eradicated by covering the seaweed with plastic sheets and poisoning it with chlorine; other treatments can be used. The costs of the Southern Californian eradication were $US 2.33 million in 2000–01, for control and monitoring, with an ongoing annual surveillance cost of $US 1.2 million until 2004. Application of coarse sea salt at a concentration of about 50 kg/m² has been used with moderate success in Australia, eradicating non-native *Caulerpa taxifolia* from an area of almost 5,200 m² in one case, although in another instance, an area of 3,000 m² showed a reduction in seaweed density but not a full eradication. Croatia attempted eradication by covering the seaweed with plastic sheeting. This was reasonably successful, but the area involved was only 512 m2. Eradication has also occurred in South Australia and New South Wales, Australia, and manual removal by scuba divers was successful in eradicating a small patch of *Caulerpa taxifolia* in the French Mediterranean. However, these methods are very resource intensive and if even a tiny piece of the weed is missed, the species can easily re-invade.

The fishhook water flea *(Cercopagis pengoi)* is native to Southern Europe, more specifically to the Caspian, Black and Azov Seas and small coastal lakes in that area. The species can tolerate a wide range of salinity and temperature, not surprising that it has become invasive in fresh water, such as the Great Lakes of the US and Canada, as well as in marine environments, such as in the Baltic Sea. The water flea travels widely using the same vector as so many other devastating invaders: ballast water. The water flea's small size—less than 2 mm—belies its potential to cause a huge amount of damage.

Small flea big impact

One of the first impacts of the fishhook water flea is the clogging of nets and fouling of boats. In North America, the water fleas were first discovered in Lake Ontario in July 1998 and their rapid advance through the lakes was easy to follow: in August 1998, Canadian anglers began reporting that gelatinous blobs, consisting of hundreds of these fleas were fouling their fishing lines and jamming their gear. Within a month, these effects were reported all over Lake Ontario. Trading vessels or pleasure craft probably carried the species from Lake Ontario to Lake Michigan as by mid-September, fouling was reported from there as well. While for sport fishers this is an annoyance, for commercial fishermen it is financially damaging. In the Baltic Sea losses reported from just one fish farm in the eastern Gulf of Finland were at least US $50,000 each year, due to fouling of fishing equipment.

The water flea affects native biodiversity both directly and indirectly. Harmful algal blooms can occur because the water flea eats the planktonic size native 'grazers' that would keep such blooms in control. By eating zooplankton, the water flea reduces the food supply for larger species such as fish, potentially creating a 'bottleneck' to the productivity of the fish community. This tiny creature can disrupt an entire food web and affect water quality.

Measures to avoid further spread of the species include ballast water exchange to lower the chances of further introductions. At the local level, avoiding the further spread of already introduced populations is also critical, and the following measures can contribute: bait or bait-water should not be released into a water body; boats and equipment should be washed with hot water (more than 40°C), washed with a high-pressure water spray, or boats and equipment should be completely dried out for at least five days before re-entering a water body; motors, bait buckets and fishing gear should be thoroughly drained and cleaned.

Green crab
a crushing blow

An adult green crab *(Carcinus maenas)* is about 6–7 cm long but can grow larger. Green crabs can out-compete and out-manoeuvre other crabs with ease. They feed on many seashore organisms, particularly bivalve molluscs such as clams, oysters, and mussels and small crustaceans. Green crabs are quicker, more dexterous, and can open shells more easily than other crab species.

Green crabs are native to Europe and were first transported to the US inside small tunnels bored by shipworms into wooden ships. Green crabs were noticed on the east coast of North America in 1817 and now occur from Nova Scotia to Virginia. The crab is believed to be at least partly responsible for the destruction in the 1950s of the soft-shelled clam fisheries which affected thousands of people. Catches fell from 14.5 million pounds in 1938 to 2.3 million pounds in 1959, a period during which the range of the green crab extended into the clam fishery area.

In 1989 crabs from the east coast population were found in California. They 'laid low' for a while in their new habitat as population numbers built up, then rapidly expanded northwards. Invasion sites were found in Oregon in 1997, Washington in 1998 and British Columbia in 1999. It is believed that the green crab could eventually extend along the entire Pacific coast of North America from Mexico to Alaska.

Green crabs have invaded South Africa, and have also been recorded in Australia in Tasmania and Victoria, Brazil, Panama, Madagascar, the Red Sea, Pakistan, Sri Lanka, Myanmar, Japan, Patagonia and Hawaii, although it is not known yet whether they are invasive in all these locations.

Oysters international travellers and invaders

Shellfish, especially oysters, have been intentionally introduced all over the world for mariculture, providing food and work. The introduced oyster itself can become a threat to native biodiversity or livelihoods but it can also carry pathogens or parasites that may infect and damage native and commercial species, or even be a human health risk.

Various species of oyster have been moved around the world for the last five to six centuries with various impacts. The Pacific oyster *(Crassostrea gigas)*, while farmed in some areas in Australia, is considered a pest species in others. Similarly, in The Netherlands, this species is used for mariculture, but in the Wadden Sea where it has established 'in the wild' it is seen as a potential ecological threat because of its capacity to generate solid reefs and compete with native species. It also causes economic damage, fouling and clogging intake pipes and interfering with power station cooling systems.

Many organisms have travelled with oysters and have been unintentionally introduced, including the oyster disease MSX *(Haplosporidium nelsoni)*. The disease agent was originally given the name MSX for "multinucleated sphere X", or unknown). Other pests have also travelled with oysters, threatening native species as well commercial oyster cultures. The sea squirt *Styela clava* is posing a major threat to the shellfish aquaculture industry in New Zealand. It is thought to have been introduced with imports of Pacific oysters from Asia. Human diseases such as cholera can be transported with introduced species, establish in local shellfish populations in the new area, and then infect humans.

Intentional introductions of alien species such as oysters can create risks but they can also have desirable effects, such as enhancing food security or creating jobs through aquaculture. Many species that are introduced elsewhere will not become invasive at all. In other cases, risks posed can be kept at acceptably low levels through specific management measures. The trick is to increase our ability to use alien species that are beneficial while also minimising the risks. This is why an intentional introduction such as for oyster farming, should only be authorised after a prior risk analysis has ruled out likely invasiveness, or has been able to establish effective management measures.

Spartina
an insidious invader

The common cord grass *Spartina anglica*, also known as rice grass, townsends grass or simply spartina, inhabits salt marshes, wetlands and estuarine mudflats. *Spartina anglica* is a hybrid between England's native *S. maritima* and *S. alterniflora*, which was introduced to England from the Atlantic seaboard of the US. *S. anglica* has a high metabolic rate which leads to large amounts of organic matter entering the ecosystem and is a major source of nutrients entering marine ecosystems.

Spartina has been widely planted for commercial purposes such as coastal protection, sand dune stabilisation and land reclamation. Intentional introductions for this purpose have taken place in the UK and New Zealand. The grass has also spread through unintentional introductions, via birds, floating grains and ship ballast water. The spartina grasslands that establish as a result provide a food source and habitat for many creatures, but usually lead to the exclusion of native plant species and the loss of feeding habitat for marine birds, particularly waders.

Another spartina species, the Atlantic spartina *(Spartina alterniflora)*, native to parts of the US, is also widely used for land conversion purposes including in areas where it is not native. Invasion of Willapa Bay, Washington State, is rapidly and dramatically transforming a large area of tidal mudflats into meadows of dense vegetation, affecting many thousands of migratory waterfowl, shorebirds, and wading birds that forage in the open mudflats. In other parts of the US where Atlantic spartina is not native, such as San Francisco Bay, it has hybridised with different native Spartina species, threatening the native flora in marsh areas. These hybrids are tougher than their 'parent' species and as a result become even better invaders. The spread of hybrids between Atlantic spartina and the native *S. maritima* in the UK is another well known case of plant invasion by hybridisation.

A simple but very effective strategy to fight back is to identify new arrivals of the invasive spartina in valuable sites early by surveying vulnerable areas and eliminating them before they spread. Several methods have been used to remove larger infestations. In small areas, smothering, burning, burying or digging out the grass are all feasible. Larger areas are usually treated with herbicide where this is possible and acceptable. The Washington State (US) Department of Agriculture approved the introduction of a planthopper (a group of insects that resemble plant leaves and 'hop' like grasshoppers) *Prokelisia marginata* into Willapa Bay, as a biological control agent against *S. alterniflora*.

The story of cholera

Cholera is one of the best known fatal diseases. Caused by various strains of *Vibrio cholera* bacteria, symptoms of the disease vary from mild to acute diarrhoea accompanied by abdominal cramps, nausea, vomiting, dehydration and shock. In the most severe cases, a healthy person can become dehydrated within one hour of the onset of symptoms and be dead two hours later. Fortunately for most people, 20th century improvements in sanitation, hygiene, waste disposal, food handling and domestic water supply, have resulted in a significant decline in the disease.

So why mention this disease in a book about marine invasive plants and animals? The answer is that the bacteria which cause cholera have not disappeared. Like most other human pathogens, they are capable of mutating into new strains and they are still able to cause epidemics. They are also able to 'travel' widely in ship ballast water.

In the 1980s, a new strain of *Vibrio* cholera appeared, possibly in Indonesia, and local epidemics flared-up across much of eastern Asia. In 1991, a ship from Asia brought a new, virulent strain of the disease to the port of Lima in Peru, probably through contaminated bilge water. The bacteria soon infected shellfish and then spread to humans, rapidly reaching epidemic proportions. In Peru alone there have been a million cases of cholera and up to 10,000 deaths.

Tilapia friend and foe

Tilapia *(Oreochromis spp.)* is the common name given to more than 70 species of fish, of which at least eight are used for aquaculture. Tolerance to water temperature and to salinity varies greatly between species. Nile tilapia *(Oreochromis niloticus)* are the least cold tolerant of the farmed tilapia and prefer tropical to subtropical climates whereas blue tilapia *(Oreochromis aureus)* are able to tolerate temperatures as low as 8-9°C, making it more likely to establish in countries with pronounced seasonal temperature variations. Tilapia usually live in freshwater but some species and hybrids can tolerate a wide range of saline concentrations. About 85 countries farm tilapia including China and many South East Asian countries, as well as parts of Central America, Africa and the South Pacific islands. Up to 98% of farms are outside the tilapia's native range.

Tilapia are well adapted to being farmed as they gain weight quickly and reproduce without special management or infrastructure. Selective breeding to reproduce 'genetically improved' tilapia and hybridising have also been used to create increasingly adaptable, hardy and fast growing fish. However, the same qualities that make the species ideal for fish farming make them formidable invaders when they escape. The preferred system of farming uses cages. This carries a fairly high risk in terms of environmental impact but it is the cheapest method in terms of start up costs and is the preferred option for small scale farmers, and usually the only option for poor communities.

There are many cases where tilapia introduction has led to declines in native fish, aquatic plants, and changes to the habitat. In Lake Nicaragua, farmed tilapia, grown for export to the US, escaped and destroyed natural habitats, replaced native cichlid fish (the family of fish to which tilapia belongs) and caused problems for the local people because they are more difficult to catch than the native species they replaced. As a result, local communities around the lake have less access to protein in their diet even though those that own the fish farms are better off due to the export dollars generated. In many countries, tilapia escape and their ecological impacts are not well monitored and the impacts are, if anything, underestimated. The salinity tolerance of some of the tilapia species means they can spread from one river basin to another as they can survive in coastal areas between river mouths.

The problem does not lie with the farmed fish, but with those that escape and establish in the wild. There are methods available that allow fish farming to continue, but without the high environmental costs. Improvement and implementation of methods that would result in fewer escapes or fewer impacts from escapes may be possible. Intentional introductions of alien species for aquaculture should only be permitted after risk analysis in which environmental costs are taken into account, and environmentally sustainable management options are identified. The possibility of using native fish for aquaculture (especially in areas where native fish species are vulnerable to tilapia) should be explored.

Founded in 1948, IUCN (International Union for Conservation of Nature) brings together States, government agencies and a diverse range of non-governmental organizations in a unique world partnership: over 1000 members in all, spread across some 160 countries.

As a Union, IUCN seeks to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable.

IUCN builds on the strengths of its members, networks and partners to enhance their capacity and to support global alliances to safeguard natural resources at local, regional and global levels.

The IUCN Global Marine Programme provides vital linkages for the Union and its members to all the IUCN activities that deal with marine issues, including projects and initiatives of the Regional offices and the 6 IUCN Commissions. The IUCN Global Marine Programme works on issues such as integrated coastal and marine management, fisheries, marine protected areas, large marine ecosystems, coral reefs, marine invasives and protection of high and deep seas.

INTERNATIONAL UNION
FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland, Switzerland
mail@iucn.org
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org

Fondation D'ENTREPRISE TOTAL
Pour la biodiversité et la mer