Marine Biofouling and invasive species: Guidelines for Prevention and Management

MARINE BIOFOULING & INVASIVE SPECIES:

Guidelines for Prevention and Management

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&
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MARINE BIOFOULING AND INVASIVE SPECIES: AN OVERVIEW OF RISKS AND MANAGEMENT INITIATIVES

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MARINE BIOFOULING AND INVASIVE SPECIES: GUIDELINES FOR PREVENTION AND MANAGEMENT

1. INTRODUCTION AND BACKGROUND

1.1 Invasive species in the marine environment

An invasive alien species is one which has been introduced by human activity to a new geographic area or ecosystem outside of its natural distribution range, and which has then established and spread threatening ecosystems, habitats and/or other species, and potentially causing economic and/or environmental damage, or harm to human health. It is important to note, however, that native species may also become invasive, usually under altered environmental conditions.

Invasive Alien Species in the marine environment are called by a variety of names including ***Introduced Marine Pests*** (***IMPs***) (Australia and New Zealand), ***Aquatic Nuisance Species*** (***ANS***) (United States), and ***Harmful Aquatic Organisms*** (IMO Ballast Water Convention).

For a number of marine species, the original, natural distribution has been blurred by centuries of transfers *via* sailing ships, canals, barges, aquaculture, etc., so that it is now difficult to tell whether they are alien or not. In fact, in some regions many historical introductions had been assumed to be part of the native marine community until recent studies raised questions. Examples include several common fouling organisms and wood-borers, such as the infamous bivalve ‘shipworm’ (*Teredo navalis*), the ship or striped barnacle (*Balanus amphitrite*), both blue (*Mytilus*) and brown (*Perna*) mussel complexes and some oyster species. These widespread and so-called ‘cosmopolitan’ marine species are known as cryptogenic species (Carlton, 1996a).

Invasive alien species are now generally recognised as one of the greatest threats to biodiversity globally. In marine and coastal environments, invasive species have been identified as one of the four greatest threats to the world’s oceans along with:

- land-based sources of marine pollution,
- over-exploitation of living marine resources, and
- physical alteration/destruction of marine habitats.

Marine invasives affect biodiversity by displacing native species, by altering community structure, food webs and ecological processes, and have now been documented in the majority (84%) of the world’s 232 marine ecoregions, with particularly high levels of invasion in Northern California, the Hawaiian Islands, the North Sea, and the Eastern Mediterranean (Molnar *et al.*, 2008):

- 253 introduced species have been reported in San Francisco Bay alone (Cohen and Carlton, 1995; Nichols and Pamatmat, 1988), with approximately 350 non-native marine invertebrates and algae being considered established in US waters (Ruiz *et al*., 2000);
- 343 alien marine species have been found in Hawaii (Godwin, 2003);
- In the North Sea Gollasch (2002) reported established populations of 80 introduced species. On open coasts in that region, they made up 6% of macrobenthic species; while in estuaries this figure was up to 20% (Reise *et al*., 1999);
- In the Mediterranean, Galil (2008) reported 573 alien marine metazoan species, the majority thermophilic species introduced *via* the Suez canal, although there are

distinct differences between the western and eastern Mediterranean, with far fewer introductions in the west.

Invasive species also impact on commercial fisheries, including mariculture, and other natural-resource based industries, with serious economic implications for those communities dependent on them. In addition, fouling of physical structures by introduced species has major impacts on other industries by, for example, decreasing the speed of vessels and clogging water intake pipes.

The comb jelly, *Mnemiopsis leidyi,* for example, was introduced from the American Atlantic coast into the Black Sea, where it was first recorded in 1982. It became well established, occurring in massive numbers, and spread rapidly to the Azov, Marmara and Eastern Mediterranean, and towards the end of 1999, was recorded in the Caspian Sea. *Mnemiopsis* feeds on the same zooplankton as many of the commercial fish species in the area, so the invasion had a devastating impact of fisheries such as anchovy, Mediterranean horse mackerel and sprat, and kilka in the Azov and Caspian. Landings of anchovy, for example, dropped to one-third of their previous levels, causing losses of around $ 500 million per year, and causing many fishermen to abandon fishing. Similar reductions in the biomass of kilka were experienced in the Caspian (Shiganova *et al*., 2004).

The zebra mussel – *Dreissena polymorpha* – which is native to the Black Sea area, was introduced to western and northern Europe, including Ireland and the Baltic Sea and to the eastern half of North America (Great Lakes). It is an encrusting species that forms large clumps of individual mussels grouped tightly together fouling all available hard surfaces in mass numbers. It displaces native aquatic life and alters habitats, the ecosystem and the food web. It causes severe fouling problems on infrastructure and vessels and blocks water intake pipes, sluices and irrigation dikes. Economic costs for attempting to clear Zebra mussels from industrial facilities in the USA alone were estimated at around US$ 750 million to 1 billion between 1989 and 2000 (O'Neil, cited in Carlton, 2001).

The escalating numbers of invasive species in the marine environment, together with an increasing awareness of the implications thereof, have stimulated a substantial amount of research aimed both at gaining a better understanding of marine invasions and at finding ways to prevent and/or manage them. The purpose of this review is to provide an overview of those initiatives dealing with biofouling as a pathway for marine invasions.

1.2 Biofouling as a pathway of introduction

Alien marine species may be introduced into new geographic areas in a number of ways. For example, they may be introduced deliberately for fisheries and other purposes. However, many are introduced unintentionally, for example *via* ballast water or biofouling – the accumulation of unwanted organisms on hard surfaces such as the hulls and other submerged parts of vessels (including oil rigs and barges), the shells or carapaces of other species, equipment associated with fishing, mariculture or diving, and even marine debris.

While there appear to have been few, if any, assessments of biofouling as a whole, a number of studies have looked at the relative importance of shipping in relation to other pathways, and some at hull-fouling as a sub-vector of shipping. Such studies are complicated by the facts that i) information is often incomplete; and ii) numerous species have probably been introduced by several vectors at different times and in different geographic areas (Galil *et al*., 2007). However, a recent analysis by Molnar *et al.* (2008)

drawing on information from over 350 databases and other sources, showed that for the 329 marine invasive species considered, shipping was the most common pathway (69%), with others being aquaculture (41%), canals (17%), the aquarium trade (6%), and the live seafood trade (2%)[1]. Of the 205 species introduced *via* shipping – and for which sufficient information was available – 39% were introduced by hull-fouling, 31% via ballast water, and the remainder by both.

A study on ship-related vectors of introduction into the North Sea between 1992 and 1996 found that samples of hull-fouling, taken from 186 commercial vessels visiting German ports, had more than twice the number of non-native species as those from ballast water – 74% of the species identified. The study concluded that, despite inevitable differences in sampling methodology, hull-fouling was an important – if not the most important – vector for introductions (Gollasch, 2002).

A paper recently submitted to the IMO (BLG 12/11) reported that "biofouling has been estimated to be responsible for:

- 74% of non-indigenous marine invertebrates transported to the Hawaiian Islands (Eldredge and Carlton, 2002);
- 42% of marine species unintentionally introduced into Japan (Otani, 2006);
- 69% of adventive marine species arrivals in New Zealand, with a further 21% possibly as biofouling or in ballast water (Cranfield *et al*., 1998);
- 78% of introduced marine species in Port Philip Bay, Australia (Hewitt *et al*., 2004);
- more than half of the ship-mediated species introductions into the North Sea (Gollasch, 2002); and
- 70% of the species that have invaded coastal North America *via* ships have either been moved by biofouling alone, or could have been moved by biofouling and ballast water (Fofonoff *et al*., 2003)."

Hull-fouling has also been identified as the most important vector in a number of other studies – for example, in British waters (Eno *et al*., 1997) and in various European countries (Croatia, Italy, Netherlands) (Gollasch, 2007).

Fofonoff *et al*. (2003) reported that of 316 nonnative marine invertebrates and algae in North America, shipping was considered responsible for introducing 52%, and multiple vectors, including shipping, for another 27.5%. However, the authors concluded that for a variety of reasons – the multiple life stages of many species, the emphasis of hull fouling assessments on sessile species, and of ballast water studies on holoplankton, the role of other sub-vectors such as sea chests, changes in shipping patterns and temporal changes in management strategies for both ballast water and hull-fouling – it was difficult to determine the relative contribution of each of these sub-vectors. Nevertheless, of the species attributed solely to shipping, 36% were considered to have been introduced by hull fouling alone, and 20% by ballast water alone, with the remainder being undetermined.

More recently, Drake and Lodge (2007) conducted a thorough study of the hull-fouling communities on a transoceanic bulk carrier entering the Great Lakes and concluded that in terms of the number of species potentially introduced, and abundance, hull-fouling represented a greater risk than ballast water.

In Hawaii, 90% of the 343 marine alien species are considered to have been introduced by hull fouling (Godwin, 2003).

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[1] The numbers total more than 100% because some species have been introduced by more than one vector.

Galil (2008) reported that, although modes of introduction often had to be deduced, the majority of marine species introduced to the Mediterranean came *via* the Suez Canal (54%), another 10% through the canal but assisted by vessels, 21% directly by vessels, and the remainder *via* aquaculture, with some secondary spread by vessels. This pattern varies from the west to the east, with mariculture being the main source in the west (42%), and the Suez Canal in the east (81%).

Some of those species listed amongst the IUCN's 100 Worst Invasive Alien Species (2001) have been introduced – at least in some areas - by biofouling (see Table 1 below).

Other species introduced by biofouling which have had a high impact include the Asian green mussel (*Perna viridis*) in the Caribbean; the clubbed tunicate (*Styela clava)* and sea vase (*Ciona intestinalis*) in Canada; the seaweed *Hypnea musciformis* in Hawaii; and the Black-striped mussel (Mytilopsis sallei) in Darwin Harbour, Australia (BLG 12/11).

Table 1. Species introduced by Biofouling and included in IUCN's 100 Worst Invasive Alien Species.

Species	Area and mechanism of introduction	Impacts
The European shore crab or green crab – *Carcinus maenas.*	Native to Europe and northern Africa, it has been introduced to Australia, South Africa and the USA by a variety of pathways including hull fouling.	It is a voracious predator and has caused the decline of other crab species and some bivalves.
The Mediterranean mussel *(Mytilus galloprovincialis)*.	Native to the Mediterranean, Black and Adriatic Seas, it has established in mainly temperate areas around the globe – mostly near ports. Hull fouling and ballast water were the most common pathway.	Outcompetes and displaces native mussels, and has associated impacts on the entire benthic community.
Asian kelp *(Undaria pinnatifida)* into the Mediterranean, Australia and New Zealand.	Introduced to the Mediterranean with oysters, but *via* hull fouling and/or ballast water to the coastal waters of Argentina, Australia, New Zealand and North America.	Heavy infestations of *Undaria* slow the growth of mussels, and foul finfish cages, oyster racks, scallop bags and mussel ropes, which impact on the mariculture industry.

1.3 Biofouling communities

When a new surface – be it a ships hull, a jetty, or a mariculture raft - is placed in the marine environment, it is generally very rapidly colonized by a variety of marine species. Although the majority of these fouling species are small-sized sedentary, burrow-dwelling or clinging species (Galil and Zenetos, 2002), they also include mobile species such as crabs, brittle stars and small fish, as well as parasites and diseases (Minchin, 2007a).

The colonisation process usually takes place as a succession, with biofilms the first to establish, followed by the gradual development of macro-fouling species, as follows:

- biofilms (bacteria, cyanobacteria and diatoms),
- filamentous green algae (often *Enteromorpha* spp.),
- turfing red and brown algae,
- sessile animals,
- mobile benthic and epibenthic animals,
- commensals, parasites and pathogens.

In some cases however, particularly where niche areas are available on the substrate, higher fouling organisms may settle ahead of other species (Chambers *et al*., 2006).

1.3.1 Biofilms

Within minutes of the immersion of a clean surface in water, it adsorbs a molecular film consisting of dissolved organic material. This is then colonized within hours by bacteria, unicellular algae (especially diatoms) and/or cyanobacteria (blue-green algae) which together form a biofilm – an assemblage of attached cells, also called micro-fouling or slime (Callow and Callow, 2002). These microorganisms adhere to the surface by secreting sticky substances (extracellular polymeric substances (EPS)). The biofilm is thus a gel matrix comprising the microorganisms and the EPS, and changes the chemistry of the surface making it more amenable for the settlement of macro-fouling species (Chambers *et al*., 2006).

1.3.2 Attached macro-fouling communities

Pioneering macro-fouling species include green filamentous algae, bryozoans, serpulid tube worms and barnacles. As they grow and age, they provide amenable substrates and micro-crevices that attract further settlements. The diversity of a fouling community typically increases on surfaces which are subject to long periods of immobility (e.g. drilling rigs, barges, floating docks and laid-up or decommissioned vessels), and it can include a range of foliaceous green and brown seaweeds, sponges, sea anemones, bryozoans, sea squirts, soft corals and even hard corals depending on the location, substrate, and season, as well as biological factors such as competition and predation (AMOG, 2002; Bright *et al.,* 1991; Callow and Callow, 2002; DeFelice,1998; Rainer,1995).

Many fouling species can adhere strongly, grow quickly and reach sexual maturity before their eventual dislodgement due to size-induced drag, hull cleaning or natural senescence. All spread *via* broadcast spawning, with varying durations of larval life.

Heavy fouling on laid up vessels may carry an average of 5 kg of material per square meter (Walters, 1996).

1.3.3 Mobile communities

Early researchers surmised that mobile organisms associated with ship's hulls would be washed away by the water currents generated by the ship's movement. However, there is now abundant evidence that mobile benthic and epibenthic animals avoid dislodgment by either:

- clinging and grasping to other fouling species or the sheltered parts of the hull;
- nestling in microspaces amongst established or dead encrusting species; or
- sheltering within hull apertures and pipework (includes small fishes).

Gollasch (1999), for example, reported finding the crab *Hemigrapsus penicillatus* inside empty barnacle shells on a ship's hull.

Mobile benthic and epibenthic animals frequently found in fouling communities include errant polychaete worms, skeleton shrimps, amphipods, isopods, crabs, nudibranchs, whelks, crinoids and territorial fishes (especially Gobiidae and similar forms).

1.3.4 Commensals, parasites and pathogens

There may be a range of commensals, parasites and pathogens intimately accompanying members of the above biota.

A study on ship's hulls in the North Sea showed that the fouling community was primarily made up of Crustacea - mainly barnacles - (53.6%) and Molluscs - mainly bivalves - (27.3%) (Gollasch, 2002). Fouling was up to 30cm thick on some hulls, and 21% of organisms were mobile (mainly amphipods, isopods, decapods and other crustaceans).

The change in fouling communities over time provides the basis for the methodology developed by Floerl *et al*. (2005) to assess levels of fouling on small craft. The index goes from 0 – 5, with, for example, 0 indicating no biofilm or macro-fouling; 2 indicating light fouling - hull covered in biofilm, with 1 – 5% of the surface with small patches of macro-fouling; and 5 indicating very heavy fouling – 41 – 100% of hull surfaces covered with diverse assemblages of fouling species.

1.4 Impacts of Biofouling

As is true for invasive species as a whole, the impacts of marine invasives can be divided into three categories:

- impacts on biodiversity, habitats or ecological processes,
- economic impacts,
- impacts on health (human, plant and animal).

The impacts of biofouling can similarly be addressed under these headings, although it is important to note that many of the impacts – especially economic impacts - occur whether or not the species comprising the biofouling are alien and/or invasive or not.

1.4.1 Ecological impacts

The ecological impacts of an invasive species are complex and occur as a result of changes to the local biodiversity and/or alteration of ecological processes caused by that species. While the initial impacts may be minor and near-invisible, as the population increases over time, the impacts will increase in severity. They may include:

- competing with native species for space and food,
- preying upon native species,
- altering habitat of other species,
- altering environmental conditions (e.g. decreased water clarity),
- altering the food web,
- displacing native species, reducing native biodiversity and even causing local extinctions.

In relation to biodiversity, there have been losses of individual species at least in certain localities, and a general tendency towards homogenisation of species composition and loss of unique traits of particular communities (Lewis *et al*., 2003). The Mediterranean, for example, which has a high level of endemism and unique communities, has a high proportion of introduced species (Drake and Lodge, 2004; Galil, 2007).

A number of serpulid worms, which are also pioneer fouling species, have invaded harbour areas all over the Mediterranean (Galil *et al*., 2007). Some of these, such as *Ficopomatus* *enigmaticus,* build extensive biogenic reefs which can alter local physical features – even overgrowing soft substrates – and hydrodynamics. In a study in harbour in Turkey, alien serpulids made up more than 95% of the organisms on rocks and artificial substrates (Cinar *et al*., 2006). Also in the Mediterranean, the Asian date mussel *Musculista senhousia* has formed dense byssal mats over soft sediments, altering the hydrodynamics, sedimentology and microtopography of the bottom adversely affecting suspension-feeding infaunal bivalves, and favouring some surface-feeding species (Mistri, 2003; 2004, Mistri *et al*., 2004).

In North America, the zebra mussel invasion in the Hudson River led to sharp declines (65 – 100%) of all species of native bivalves between 1992 and 1999 as a result of competition for food, and fouling/smothering of the native species - although they have since stablised and even recovered to some extent (Strayer and Malcom, 2007).

Another important aspect is the synergistic interaction between invaders. In the North American Great Lakes, the zebra mussel has exacerbated the invasion by a Eurasion amphipod (*Echinogammarus ischnus)*, which is replacing a native amphipod, by colonising silty sediments and thereby expanding available habitat (Ricciardi, 2005). These two species are the prey of another introduced species – the round goby (*Neogobius melanostomus)* – a fish which feeds on amphipods as a juvenile, and zebra mussels as an adult. This gives the goby a competitive advantage over local fish species, the sculpin and logperch (Kuhns and Berg, 1999).

1.4.2 Economic Impacts

Economic impacts can occur both as a consequence of fouling on the vector itself (eg. hull-fouling) and fouling in the new location (e.g. fouling of water intake pipes and other infrastructure). It has serious implications for shipping, aquaculture and coastal industries in general. These include both the direct costs – for example, loss of productivity in aquaculture, or increased costs of fuel to shipping – as well as the costs associated with ongoing prevention, management and control.

Aquaculture

Biofouling, whether it comprises alien or native species, impacts on aquaculture by settling either on the infrastructure - net cages, ropes, platforms, buoys, etc. – or on the farmed species themselves. This can affect the viability of the operation in a number of ways:

- need for increased labour and other maintenance costs (Bourque *et al.*, 2003; Cohen *et al.*, 2001 – ex Minchin, 2007b);
- production losses as a consequence of reduced water flows through nets and trays resulting in reduced food supply and oxygen (CRAB, 2007; Willemsen, 2005);
- biofouling communities compete directly with cultured species for resources and may include predators; and
- production losses as a result of direct impacts on the stock species, including the introduction of diseases and parasites (CRAB, 2006). For example, in the case of caged fish, fouling leads to a need for more frequent net replacement and application of anti-fouling products. This increases stress on cultured fish, reducing growth rates and hence, productivity.

Current estimates based on figures from the industry and FAO suggest biofouling impacts on fish cages and shellfish costs the European industry between 5 and 10% of the industry value (up to €260 million/year).

The cost of changing nets for medium-sized salmon farmers is, for example, €60,000 per year. In some sectors the costs of manual cleaning of biofouled shellfish amounts to 20% of the product market value.

Fouling also reduces product value, currently tubeworm fouling of mussels downgrades them from Class A (1,300 Euros per tonne) to Class B (570 Euros per tonne). At a local level, periodic heavy fouling can be catastrophic reducing saleable products by 60-90% (CRAB, 2006).

Campbell and Kelly (2002) estimated the costs of fouling of cultured mussels for farmers in Scotland at between 450 – 470,000 Euros per year, while Cohen *et al*. (1995) reported losses to the North Pacific Ocean fisheries caused by the Green crab at $ 44 million annually.

Biofouling can also introduce parasites and pathogens which affect the health of the species being cultured, and therefore also the productivity of the operation (see below).

Coastal infrastructure

The zebra and quagga mussels are the most widely known examples of invaders which affect coastal infrastructure. In the North American Great Lakes they have had significant economic impacts on industries – especially the power industry which uses water for cooling purposes - as a result of the reduced water flows caused by the fouling. Maintenance of pipes clogged with zebra mussels costs the power industry up to $ 60 million per year while temporary shutdowns caused by reduced water flow can cost over $ 5,000 an hour. It is estimated that the cost of the zebra mussel invasion to the US will be $ 3.1 billion over the next ten years (US State Department website). The cumulative costs to industrial plants in the USA and Europe were estimated by Khalanski (1997) to be between US $ 3,000 – 5,000 million.

Shipping

Biofouling on a ship’s hull can increase the hydrodynamic drag and lower the manoeuverability of the vessel, leading to increased fuel consumption (Chambers *et al*., 2006). Fuel makes up about 50% of the operational costs of a ship, and it has been estimated that fouling increases the annual fuel consumption of the commercial shipping fleet by 40%, or 120 million tonnes of fuel at a cost of about $ 7.5 billion in 2000 (Shipyard Technology, Oct/Nov, 2000 – ex AMBIO website). A more recent estimate was $ 30 billion per year.

For a large container vessel this equates to additional fuel costs of $ 250,000 per year – compared to the $ 20,000 per year costs of a TBT SPC anti-fouling system. For trading vessels, the increased drag and associated fuel consumption as a result of biofouling alone make it worthwhile for shipping companies to invest in anti-fouling and/or cleaning measures. Other benefits include:

- improved manoeuverability – which can be impaired by propeller fouling
- better control of microbially induced corrosion (Chambers *et al*., 2006).

Microbiological fouling can also promote corrosion (microbially induced corrosion (MIC)) by, for example, the production of sulphides by sulphate reducing bacteria which cause the pitting of steel surfaces (Chambers *et al*., 2006).

Sales of anti-fouling coatings for commercial ships and recreational craft were estimated at $ 700 million per year (AMBIO website).

Costs of removal and control

Apart from the direct costs to various industries, once a species has been introduced, there are also major costs associated with eradication attempts and ongoing management and control. The eradication of the Black-striped mussel in Darwin Harbour, for example, cost approximately AUD$ 2 million, while the ongoing annual costs of control of zebra and quagga mussels in the North American Great Lakes are between US$ 100 million and US$ 400 million (BLG 12/11). The control of fouling in water intakes, piping systems and heat exchangers of desalinization and power plants, globally, costs over $ 15 billion per year, and of membranes used in wastewater and desalinization systems, over Euro 1 billion (AMBIO website).

1.4.3 Health

Relatively little attention has been paid to the role of biofouling in the spread of diseases. However, Minchin (2007b) reported a number of such studies:

- The spread of bonamiosis *via* oysters on barges in the UK (Howard, 1994);
- In the Indo-Pacific and Central America, the white spot virus – which affects shrimps - may have been spread by crustaceans inhabiting fouling on boat hulls (Chakraborty *et al.*, 2002; Minchin *et al.*, 2006);
- Amoebic gill disease – which affects cultured salmon (Tan *et al.*, 2002);
- Infectious salmon anaemia (Stagg *et al.*, 2001).

Minchin and Gollasch (2003) also discussed the possibility that commercial molluscs, which are frequently present on ship's hulls, might be responsible for transferring parasites or diseases between different cultured populations, particularly where these are close to ports.

Biofilms on the inside of ballast tanks – "termed interior hull fouling" – have also been implicated in the transmission of a variety of microorganisms and pathogens (Drake *et al.*, 2005; Drake *et al.*, 2007).

1.5 Case Studies

As mentioned previously, a number of species introduced by biofouling have had significant impacts. These include the Asian green mussel (*Perna viridis*); the Zebra mussel (*Dreissena polymorpha*); the Asian Rapa Whelk (*Rapana venosa*); the clubbed tunicate (*Styela clava);* the Giant Mediterranean Fanworm (*Sabella spallanzani);* the Caribbean Tube Worm (*Hydriodes sanctaecrucis*); the seaweeds *Hypnea musciformis* and *Undaria spp.*; the European Green Crab (*Carcinus maenas*) and the Black-striped mussel (Mytilopsis sallei).

Some of these are discussed in more detail in the case studies below.

1.5.1 Case study 1 – *Undaria pinnatifida*

Common names : Asian or Japanese kelp or 'wakame', Apron-ribbon vegetable..

This brown seaweed is native to Japan, where it is cultivated for human consumption. It is an opportunistic species and can rapidly colonise new areas. It was established accidentally in the Mediterranean when it was brought in with oyster shipments in 1971. It was subsequently deliberately introduced to the French north-west Atlantic coast for farming in 1983. This mariculture venture ultimately failed but the plant was not removed and began spreading. It was found on the United Kingdom's south coast in 2000, and has since arrived on the shores of other North European countries.

Undaria pinnatifida

Undaria has also been unintentionally introduced *via* hull fouling and/or ballast water to the coastal waters of Argentina, Australia, New Zealand and North America, where it was first discovered in California in the spring of 2000. By 2001 its fertile sporophytes were present in many Californian locations from San Francisco to Monterey Bay harbour (i.e. over a 500 km range and depths from the waterline to 25 m).

General Impacts: Undaria spreads rapidly, forming dense “forests” which compete for light and space with native algae. It becomes the dominant species, significantly altering the habitat and can lead to the exclusion or displacement of native plants and animals. It can become a nuisance to mariculture operations, increasing labour costs to remove the fouling.

Invasion pathways: multiple – including intentional and unintentional introductions associated with mariculture, as well as hull fouling and ballast water. Mature plants attached to a hull or other surfaces can release up to 100 million spores per season. These spores settle, grow into gametophytes – which in turn release sperm and eggs – and eventually develop into macroscopic plants.

Local dispersal methods: mariculture equipment such as salmon cages, and vessel fouling.

Extracted from: http://crimp.marine.csiro.au/nimpis http://www.issg.org/database

1.5.2 Case study 2 – *Carcinus maenas*

Common names: European shore crab, Green crab, Strandkrabbe

This crab is native to Europe and northern Africa. It has been introduced to the USA, Australia and South Africa. It is euryhaline, and a voracious predator which, in some of the locations where it has been introduced, has caused the decline of other crab and bivalve species. This species has been included among the 100 of the “World’s Worst” invaders (by IUCN ISSG).

General Impacts: A voracious predator. Able to crush mussels, and is a potential threat to mussel farms.

Geographical range: In its native range (north western Europe, including western Baltic Sea), it is abundant on any kind of seashore in shallow waters (upper intertidal to shallow subtidal), including estuaries.

Invasion pathways: Aquaculture, aquarium trade, live food trade, ships ballast water, hull fouling. Transfers can involve either larval stages (e.g. in ballast water), or adults, with the latter being part of the mobile component of a fouling community. In the new location, adults may either “jump ship”, or release larvae into the new environment.

Local dispersal methods: Boats, self-propelled, water currents.

Extracted from: http://www.issg.org/database

1.5.3 Case Study 3 - Dreissena polymorhpa

Common name: Zebra mussel

Zebra mussels are native to the Caspian and Black Seas. They are now established in the UK, Western Europe, Canada and the USA. They compete with zooplankton for food, thus affecting natural food webs. They also interfere with the ecological functions of native molluscs and cause great economic damage. This species has been nominated as among 100 of the "World's Worst" invaders.

General Impacts: Zebra mussels filter organic and inorganic particles between 7 and 400 microns, competing with native planktivores for food. The net result is a sedimentation of previously suspended organic matter in the form of faeces and pseudofaeces, shifting energy and nutrient balances from the pelagic to the benthic zone. Increases in water clarity favor increased photosynthesis by rooted aquatic macrophytes, and negatively effect fish species that prefer slightly turbid conditions, such as walleye. Removal of green algae gives cyanobacteria a competitive advantage, as zebra mussels will stop filtering in the presence of cyanobacteria. Zebra mussels settle in high numbers on native mussels (Unionidaceae), causing suffocation, starvation, and energetic stress leading to death. Loss of native mussel populations has increased dramatically where zebra mussels are present, particularly in the North American Great Lakes and Hudson and Mississippi rivers. Dense colonization of hard substrates is beneficial to benthic invertebrates; as habitat complexity increases so does availability of organic matter. Spawning reefs of fishes such as lake trout are negatively affected by zebra mussel colonies.

Geographical Range: Native range includes the Black, Caspian, and Azov seas; since the 1700's its range has expanded westward to most of western Europe and North America, where it is found in the Great Lakes and all of the major river drainages east of the Rocky Mountains.

Invasion pathways : Aquarium trade (possibly *via* aquarium waste dumping); Floating vegetation/debris; Ships ballast water (e.g. the Great Lakes); Ship/boat hull fouling (introduced to smaller lakes by overland transport on boat hulls and trailers); Translocation of machinery. In the case of hull fouling, clumps of mussels may break off during adverse weather or cleaning, and then re-attach to another hard substrate in the new location. Alternatively, environmental conditions in the new location may induce them to spawn.

Local dispersal methods: Aquaculture (larvae may be transported during fish stocking); boats (biofouling); on animals, people **(**on scuba diver's wetsuits or in scientific sampling equipment); and water currents (range expansion within North America has been very rapid due to downstream transport of planktonic larvae).

Extracted from: http://www.issg.org/database

1.5.4 Case study 4 – *Styela clava*

COMMON NAMES: Sea squirt, clubbed tunicate

Photo courtesy of Dr Keith Hiscock

Contact: Keith Hiscock, email: keith.hiscock@lineone.net

Styela clava is native to the Pacific Coast of Asia but has been reported from a wide range of countries, from Australia and New Zealand (2002), to the UK (1953) and other European countries, Canada and the USA (California and East Coast). It is tolerant of salinity and temperature fluctuations, the adults have no known predators, and grows rapidly, often becoming the dominant species in sessile communities on artificial structures including harbour and marina structures and equipment in aquaculture farms where it can cause serious problems.

General Impacts: It causes significant economic impacts as a consequence of the high density fouling of commercial structures and equipment, competition with cultured species for food and space, and overgrowth of shellfish. Its tendency to form dense stands – even monocultures – reduce biodiversity and affects aesthetic values reducing the appeal of an area for diving and other recreational activities.

Geographical range: Its native range is the Pacific Coasts of Asia (Japan, Korea and Russia), but there is limited available information on its biology and ecology in that region. It is a solitary, littoral species, but can occur to a depth of 40 metres and above low spring tide level under rocks.

Invasion pathways (primary and secondary): Hull fouling, aquaculture and ballast water (larvae), with hull fouling considered the most common. *Styela* is a sessile tunicate with a free-swimming larval stage. Introductions may therefore be as a result of the transfer of adults on hard surfaces (e.g. mariculture equipment), or as a consequence of the spawning of adults on a vessel visiting a new location.

Extracted from: Kluza, D., Ridgway, I., Kleeman, S. and Gould, B. (2006) Organism Impact Assessment: *Styela clava*. Report to Biosecurity New Zealand. 19 pp.
www.marlin.ac.uk/marine_aliens

2. BIOFOULING AS A PATHWAY

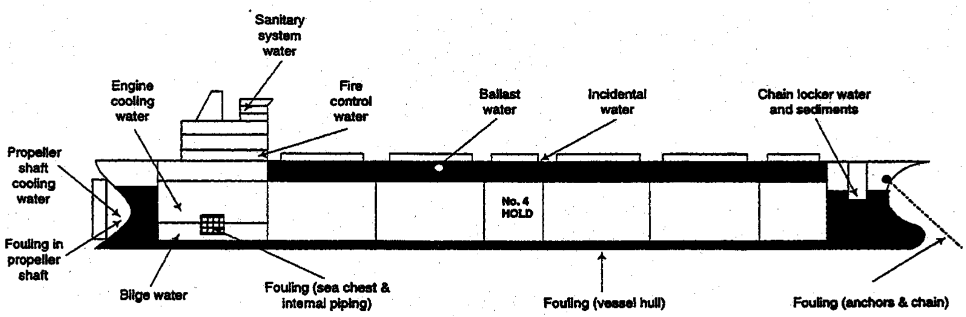
As indicated in the previous section, with a few exceptions, shipping is recognized across the world as the most important vector for marine invasive species. Over time, there have however, been varying perceptions about the relative importance of the two main sub-vectors – ballast water and hull fouling.

Historically hull fouling was a widely recognised and prominent vector, with descriptions of hull fouling in the literature going back to at least the early 1900's – prior to the initiation of the use of seawater as ballast – and when there was a predominance of wooden-hulled vessels. But, with the retirement of most wooden-hulled trading ships by the 1940s, the development of more efficient anti-fouling systems using toxins such as tributyltin (TBT), the faster speeds of modern ships, containerisation and their much shorter turn-around times in port, the perception emerged in the 1980's that hull fouling no longer posed a significant threat. More recently, it has become increasingly apparent that hull fouling is still a significant vector - particularly for certain categories of vessels. Thus, while many of the earlier studies focused on large ships, more recently there has been a growing recognition that other vessels, and especially small craft – private and commercial – could be even more significant, particularly in secondary spreading (Minchin *et al*., 2006). There are, however, also examples of primary inoculation *via* international yachts - for example, the introduction of *Mytilopsis sallei* to Darwin, Australia (Thresher, 1999).

Moreover, the recent adoption of the IMO Anti-fouling Convention (2004) which bans the use of the more toxic anti-fouling hull coatings, has given rise to concerns that the hull fouling problem will increase, at least in the short-term until other acceptable and effective anti-fouling systems are developed. At the same time, there is growing awareness of the role of other man-made substrates – such as equipment and marine debris - as vectors for the introduction of foreign marine species.

2.1 Hull-fouling and other ship components

Hull fouling studies generally consider all external wetted surfaces including sea chests, bilge keels, anode blocks, rudder pins, propellers, shaft protectors, echo sounder transducers and log probes to be part of the hull. They also include all internal surfaces and niches, including anchor wells, chain lockers, bilge spaces, fishing gear, bait lockers, cooling water intakes, strainers and pipework (e.g. AMOG 2002; Hutchings *et al.,* 2002; Rainer 1995).



Contemporary vessels are used for a variety of purposes, including trade, dredging, bridge construction, offshore oil and gas field development, fishing, cruising, recreational boating and military uses. According to their purposes, these vessels have not only a wide variety of structural characteristics (size, design etc.) but also differing operational patterns and requirements. For example, in contrast to trading ships, mobile drilling units may be laid up, moored or worked at a single site for several months or years, before being transferred to another harbour or work site where they again remain for another extended period. For such non-trading vessels, the increased drag and fuel consumption incurred from biofouling are not critical to operational profit-margins, and many such vessels undergo these types of movements without a thorough hull clean (e.g. dredgers, barges, drilling platforms, decommissioned warships).

Even when they have been applied, long stationary periods reduce the effectiveness of the self-ablating or 'self-polishing' action of modern anti-fouling coatings. This increases the opportunity for thick biofilms to develop, and for copper- and/or TBT-resistant taxa to colonise excessively leached or damaged areas in the coating. Biofilms 'pre-condition' TBT-based coatings for other species, while serpulid tube worms (particularly *Hydroides* spp.) can tolerate low copper levels, including unablated copper-based anti-fouling coatings and uncoated cupro-nickel surfaces of log probes, valves, intake apertures, rudder pins, propeller studs, etc (e.g. AMOG, 2002; GISP, 2004).

Once heavily fouled vessels arrive in a new port with already mature species, cues within enclosed harbour basins or estuaries can stimulate these adults to spawn within a few hours of arrival, with nearby wharf piles, jetties, breakwaters and other hard surfaces offering convenient settlement areas.

The threat of hull-fouling in relation to vessel type is discussed below, noting that there are a variety of other factors which influence the likelihood of any particular vessel carrying potentially harmful species, including the:

- presence or absence of an anti-fouling system;
- quality of its application;

- age, type, suitability and condition of the anti-fouling system;
- presence of niche areas and application of the anti-fouling to them;
- time spent in port or stationary;
- voyage speed, duration and route;
- geographic location and environmental conditions;
- defouling activities.

2.1.1 Trading Ships

This category includes chemical tankers, container ships, crude oil, gas and dry bulk carriers, general cargo ships, livestock carriers, product tankers, vehicle carriers, various ‘roll-on roll-off’ ferries and cargo ships (ro-ro vessels). Their commercial nature requires them to manage hull fouling so as to reduce the drag and increased fuel use caused by heavy fouling. Nevertheless, fouling may build up in sea chests and other crevices which are protected from turbulent flow (AMOG, 2002; Coutts *et al*., 2003; Dodgshun and Coutts, 2002). These have become known as “niche areas”.

2.1.2 Niche Areas

Niche areas include sea-chests, bow thrusters, rudders, propellers, bilge keels and anodes and have for some time been considered as contributing an important component to ship’s fouling (Coutts, 1999; Rainer, 1995). Sea-chests (recesses in ships’ hulls designed to facilitate the pumping of seawater on board a vessel) have received particular attention (Carlton *et al*., 1995; Coutts *et al*., 2003; Gollasch, 2002). In a study on a passenger ferry in Australia (a fairly active vessel) Coutts *et al.* (2003) found that the sea-chests harboured a number of species – including mobile species – not found on other parts of the hull. These included adult specimens of the European green crab (*Carcinus maena*) which were no longer able to escape through the grating covering the sea-chest, and of which the females were carrying eggs. They concluded that sea-chests – especially those on vessels such as cruise ships visiting sensitive areas - represent a serious biosecurity risk.

More recent quantitative research in New Zealand found that niche areas – including bow thrusters, sea chest gratings, rudders and shafts, keels and propellers and their shafts - had significantly higher biofouling levels on commercial and passenger vessels, as well as yachts. Even vessels with relatively clean hulls, sometimes had substantial fouling of niche areas. The incidence of fouling in niche areas was greatest on yachts (60%), with 50% for commercial and passenger vessels (BLG 12/INF.4).

2.1.3 Construction Barges

Barges are often used in port terminal developments and bridge construction projects across rivers, estuaries and embayments, either to move pre-assembled sections into place for lifting, or to support a heavy lift crane and other gear. They are often laid up for lengthy periods between projects, and their hulls are not usually cleaned or coated with anti-fouling as fuel efficiency is not a critical factor. A construction barge from Japan was the source of the Pacific oyster (*Crassostrea gigas)* introduction to New Zealand some 30 years ago during extension works to the Auckland Harbour bridge (Dinamani, 1971). Both construction and river trading barges have been implicated in the spread of *Dreissena polymorpha* and other mussels *via* inland waterways in Europe, North America and South America (the former provide connections to three different seas). Other examples of barge transfers include a ‘port hopping’ spread of the giant fan worm S*abella spallanzanii* between Western Australian ports (Clapin and Evans, 1995).

2.1.4 Drilling Platforms and Drilling Barges

Drilling units often spend extended periods in port or port anchorages before and after use on remote work sites, typically in shallow coastal waters. These stationary periods provide fouling species opportunities to settle, grow to maturity and spawn with nearby breakwaters and wharf piles providing convenient settlement areas. Even when they are being towed, the slow rates of tow, combined with the sheltered spaces on their underwater structures, means that fouling is not easily dislodged.

The increase in numbers of semi-submersible and jack-up drilling platforms since the 1950s has clearly provided more vectors for introductions of fouling species to and from oil and gas exploration regions in the Atlantic, Gulf of Mexico/Caribbean and Indo-Pacific. Drilling platforms have been reported to be inhabited by a wide range of species, including reef-building coral species and fish – for example, in the Gulf of Mexico and New Zealand (Bright *et al*., 1991; Cranfield *et al*., 1998). A drilling platform that arrived in New Zealand after a series of staged tows from Japan in 1975 was found to be heavily fouled by a range of biota, including green and red macroalgae, eight barnacle species representing three genera of north-west and west Pacific (*Tetraclita*, *Balanus* and *Megabalanus*), Japanese grapsid crabs (*Plagusia depressa tuberculata*) and sergeant-major fish (*Abudefduf saxatilis*) from the Solomon Islands (AMOG, 2002).

2.1.5 Dredges

Large cutter suction and trailer hopper dredges are typically used for major port developments where significant capital dredging is required. They are expensive to maintain and therefore tend to operate on a global basis, moving from one project to another at relatively slow speeds. Each contract will then require 2-6 months of work at one site. Their design provides many spaces and semi-enclosed compartments promoting the settlement of a wide range of hull fouling organisms, and, combined with their operational patterns, suggests that they pose a significant risk.

Smaller local dredges have been implicated in the secondary spread of the introduced fanworm, *Sabella spallanzanii*, in Western Australia (Clapin and Evans, 1995).

2.1.6 Military Shipping

In comparison with typical trading ships, military vessels have more structures on the hull which can provide sheltered areas for the settlements of fouling organisms. These include multiple sea chests (often 5-7), various emergency fire-fighting intakes, duplicated intakes and outlets for auxiliary units, and special sonar domes and underwater housings for auxiliary propulsion units. While the hulls of commissioned warships are generally well maintained, decommissioned warships are often laid up for lengthy periods (years) before eventually being towed at slow speed to new locations for various purposes, such as a major refit and recommissioning, target practice in deep sea locations, scuttling in coastal waters to provide an artificial fishing or diving reef, or to a mooring near a breakers yard (GISP, 2004).

Military vessels therefore also pose a significant threat and a number of incidents have been reported. For example, Godwin (2001) reported the arrival of a very heavily fouled military floating dock which had been towed from San Diego to Barber's Point harbour, Hawaii in 1999. A cleaning operation was, however, undertaken and the only apparent introduction was of the brown macroalga *Dictyota flabellata* which became established in the harbour itself.

In another case, the battleship USS *Missouri*, which was carrying a mature blue mussel community, caused the first reported example of a 'stepping stone' introduction pathway between vessels. In this instance, the temperature and salinity change experienced by the mussels on the ship's entry to Pearl Harbour is thought to have acted as a stimulus to spawning, which the mussels did within hours of arrival. A nearby submarine, which departed within a day of the *Missouri's* arrival, later reported a massive settlement of blue mussels in its open water compartments and pipework (Apte *et al.,* 2000).

2.1.7 Fishing Vessels

With the decline in fish catches in many parts of the world, many commercial fishing vessels are underutilized and poorly maintained with vessels being laid up and/or sold off for fisheries or other purposes in other areas. They therefore also represent a considerable risk in terms of hull-fouling, and there have been a number of reports supporting this. An 80 m Georgian trawler which was transferred to New Zealand following a two year lay up in the Black Sea provides one example. It arrived in Auckland in 1995 with massive hull fouling and a dry-docking operation yielded over 50 tonnes of fouling growth, much of it alive (Hay and Taylor, 1999). Hull fouling on fishing vessels has also been linked to the spread of *Undaria* between fishing harbours in New Zealand and of *Caulerpa taxifolia* fragments in the Mediterranean (Relini *et al*.,2000).

Artisanal fishing vessels in developing nations generally have no anti-fouling coatings and are instead usually scraped in-water or even on the shoreline (Russel *et al*., 2003). This, and the seasonal nature of their use, makes them important for the secondary spread of fouling organisms.

2.1.8 Non-Trading Commercial and Government Agency Vessels

These include a wide range of relatively small working vessels and patrol boats, from cable-layers, research ships and offshore supply vessels (with hull lengths in the 50-100 m range) and government agency patrol boats (Coastguard, Customs and Fisheries), port and harbour services craft (tugs, pilot launches and lifeboats), small passenger ferries, water taxis and fishing and dive charter boats (most of which are less than 50 m in length).

These vessels are usually relatively well maintained and, with the exception of the first group, typically have short-range operations from fixed bases. However for nations with large Exclusive Economic and Fishery Zones (including archipelagic and remote island states), their Coastguard, Customs and/or Fisheries patrol vessels may undertake long range operations to visit distant and isolated locations containing reefs and islands with high wild stock fishery and/or conservation values. These vessels are capable of transferring unwanted marine species if they have been infected by non-native fouling organisms when resting at home ports. Despite their smooth and polished hulls, mussel infestations have been found in the water strainer and pipework of a long distance Customs launch (Russell *et al.,* 2003).

2.1.9 Small craft (recreational and commercial)

This group includes offshore and inshore racing and cruising yachts and motor launches (kept in marinas or on moorings or boat racks due to their small size), and various trailered cabin-cruisers, runabouts, day-sailers and other craft which are typically in the 4-6 m length range.

Small craft have long been known to play an important role in the spread of invertebrates and plants in freshwater environments, with trailered boats playing a central role in the spread of the Zebra mussel *Dreissena polymorpha* and several macrophytes between rivers and lakes in Ireland, New Zealand, and the US. However, in such cases, this is mainly due to their entanglement in fishing gear, anchor chains and boat trailers (Minchin *et al*., 2006).

Despite the large – and growing - numbers of small craft in coastal environments, and the fact that in many countries the use of organotin-based antifouling paints on vessels less than 20 m has been banned since the mid-1980's, their role in the spread of invasives *via* hull fouling has only been investigated in depth more recently. The emerging picture suggests that these vessels in fact pose a significant threat for various reasons:

- many are stationary for long periods of time,
- they are often poorly maintained,
- most are moored in marinas or in sheltered bays or estuaries which provide ideal conditions for the establishment and spread of fouling organisms (Minchin *et al*., 2006).

At the same time, the threat is different for different categories of small craft. International/offshore racing yachts, for example, are usually kept clean of biofouling to maximise their speed. On the other hand, international cruising yachts typically undertake long, slow voyages containing several legs, each interspersed with stopovers in various anchorages, marinas or harbours. Compared to racing yachts they are generally operated on a less rigorous basis, some on a shoestring budget, where hull cleaning and maintenance is carried out *ad hoc* when a safe careening or snorkelling opportunity arises. The majority of international cruising yachts follow favourable seasonal trade wind routes within the sub-tropical and tropical belts of the Pacific, Indian and Atlantic Oceans, and across basins such as the Mediterranean and parts of the Caribbean. They can cover considerable distances on a single cruise and typically visit areas with significant environmental and conservation values such as remote atolls and pristine bays, in between visits to trading ports, fishing harbours or marinas for revictualling and/or temporary lay-up. Cruising yachts therefore have the potential to become infected and inoculate several locations on a single cruise (Kinloch *et al.,* 2003; Russell *et al.,* 2003).

In response to this, New Zealand – which is visited by between 400-500 international cruising yachts each year – instituted a hull inspection program in Auckland in 2002, and some 100 of these vessels were inspected as part of program to develop a video 'HullCam' to save diver costs (NIWA ,2003). Yachts have also been inspected by divers before entering the marinas at Darwin since 1999, following the detection there of the Black-striped mussel, *Mytilopsis sallei* (Bax, 2000).

Many domestic yachts and other recreational craft are also operated on a very casual basis, with owners failing to follow the advised cleaning and re-coating dates (Floerl and Inglis, 2001; Hutchings *et al.,* 2002). Both motor launches and cruising yachts may remain for extended periods within marinas before moving elsewhere, either for cruising purposes or following sale. Domestic cruising yachts and motor launches are therefore a significant secondary pathway for the spread of marine pests, and have been implicated in spreading the Japanese seaweed *Undaria pinnatifida* in both southern Tasmania and New Zealand (Floerl and Inglis ,2001; Kinloch *et al*., 2003; Russell *et al*., 2003).

The age of the anti-fouling paint on yacht hulls in New Zealand was found to be the most important risk factor since most paints only prevent fouling for 9 – 18 months. (Floerl *et al*., 2005). This was also found to be an important factor in a similar study in Scotland, during which 100 yachts from the 10 largest marinas were sampled, although travel history was also significant (Ashton *et al*., 2006). Predictably, another factor was that those yachts which had been relatively stationary over the preceding twelve months had the most macro-fouling.

2.1.10 Derelicts and Shipwrecks

Derelict and abandoned vessels are often found in the backwaters and peripheries of ports, marinas, bays, lagoons and estuaries, where they may act as ‘reservoirs’ of alien fouling species, providing a significant source of spawn every breeding season. Most derelicts are privately-owned non-trading craft, as trading vessels are rarely abandoned if only because of their value to salvage companies.

Stranded or wrecked vessels which have been poorly maintained clearly pose a significant risk, especially since they may come to rest in areas other than ports – including pristine marine protected areas not normally exposed to such threats. Moreover, it is not often easy to mount successful response operations to such incidents. In 2000 in New Zealand, for example, the Ministry of Fisheries initially ordered a fishing boat which had sunk at the remote and relatively pristine Chatham Islands to be removed using its powers under the *Biosecurity Act* 1993 but bad weather prevented salvage attempts (Wotton *et al*., 2004).

It was then decided to use heat-treatment to remove the Japanese kelp (*Undaria*) which was attached to its hull. This was achieved using plywood boxes with foam seals which were attached to the hull by magnets. Electric elements inside the boxes (powered by a diesel generator on the surface support vessel) 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, and a monthly monitoring programme over the following three years indicated that the operation had been successful. The island shorelines were also surveyed regularly for *Undaria* and no traces of it were found.

Removing Japanese kelp (*Undaria pinnatifida*) by heat treatment from a fishing vessel wrecked in the Chatham Islands, New Zealand

More recently a salvage and disposal operation costing in the order of $ 20 million was undertaken in response to the stranding in 2006 of a decommissioned oil rig on the remote oceanic island of Tristan da Cunha while under tow from Brazil to Singapore (Enviro-Fish Africa, 2007; Wanless *et al*., in prep.) The rig was more than 40 years old and the operation was initiated after a survey found a “virtually intact subtropical reef community” comprising 14 phyla, 40 families and 62 non-native taxa, and which was considered to pose a major threat to the Tristan economy which is largely based on a lobster fishery and subsistence fishing.

2.2 Ports, harbours and marinas

Many authors have noted that the majority of established marine invasive species occur in or around ports and harbours (Carlton, 1987, 1996a,b, 1999; Cohen and Carlton, 1998; Hewitt *et al*., 1999; Minchin and Gollasch, 2003; Occhipinti-Ambrogi, 2000). This is clearly linked, in the first instance to the fact that shipping in one form or another is responsible for the majority of transfers. However, it is exacerbated by a number of other factors. For example:

- Many sessile species coordinate spawning by using temperature cues. Thus, the environmental conditions in ports, where temperatures are often higher than in the adjacent sea – or just the change of conditions in comparison to those experienced during the voyage – may induce spawning in mature fouling communities. Apte *et al*. (2000), for example, reported a spawning event involving the mussel *Mytilus galloprovincialis* on the hull of a naval vessel two hours after its arrival in Pearl Harbour, Hawaii;

- The presence of extensive areas of artificial surfaces in ports then provides a ready-made substrate for the larvae of introduced species to settle;
- Vessels from various parts of the world – and domestic vessels – are often berthed in close proximity facilitating the transfer of fouling species between vessels, especially in the case of species with short planktonic phases (Minchin and Gollasch, 2003);
- The presence of aquaculture operations in ports (due to the shelter and facilities which ports provide);
- Small craft marinas are often situated within or in close proximity to larger commercial ports;
- In-water cleaning of fouling or on-land cleaning facilities may result in the deposition (intentional or otherwise) of fouling material, including live specimens, into or near port environs.

Similar factors apply to yachts and other recreational vessels which are frequently berthed in marinas, where they are not only in close proximity to other vessels from diverse parts of the world, but where the marina itself provides a substrate on which introduced species can establish. There has also been a proliferation of marinas around the world in recent decades (Minchin *et al*., 2006), including many which are not associated with ports, but may be situated in sensitive estuarine environments. Marinas can therefore be the first entry point for invasive species – *via* international yachts - but they also provide an extensive network of widespread suitable habitats for secondary spread *via* domestic boats. Moreover, pontoons in marinas are not generally painted with anti-foulants.

In summary, ports, harbours and marinas are sites where there is an overlapping of a number of vectors and activities which play a role on biofouling.

2.3 Mariculture, fisheries/fishing and diving equipment

Mariculture is a significant pathway for the introduction of alien species in some areas – for example, the western Mediterranean. For the most part, though, this is a result of deliberate introductions of the stock species themselves. Non-intentional introductions can, however, also occur as parasites, pathogens, commensals or even fouling species on the stock, as well as through the movement of fouled aquaculture equipment such as settlement lines, grow out lines, shellfish trays and fish pens from one area to another – although the latter would be primarily secondary transfers. The movement of salmon cages contaminated with *Undaria* is believed, for example, to have been responsible for the spread of this seaweed into New Zealand's Marlborough Sounds (White *et al*., 2004), as well as for the translocation of the sea squirt *Didemnum vexillum* from Shakespeare Bay to East Bay, some 35 kilometres away (Pannell and Coutts, 2007).

The sale and/or transfer of uncleaned fishing equipment has also been implicated in the introduction of a number of species, although it is likely that in the majority of cases this is a result of entanglement of organisms or fragments of seaweed in the equipment rather than actual fouling. A number of agencies have developed codes and guidelines to promote more rigorous cleaning of such equipment.

Similarly, diving equipment has many places where pieces of seaweed can easily become entangled and lodged. Many algal pests have the ability to survive without emersion for several days if conditions remain damp, and can regenerate from small fragments. Dive tourism often involves visits to several divergent locations within 2-4 days, and thus diving gear can act as vectors in secondary pathways that enhance the spread of algae. This has been reported the case for the spread of Japanese kelp (*Undaria pinnatifida*) on the east coast Tasmania (Kinloch *et al* 2003) and for invasive macroalgae in Hawaiian eutrophic bays. Codes for inspecting and cleaning diving gear, particularly straps of fins, buoyancy vests, knife sheaths and regulator stages are being applied in the Hawaiian tourism industry (GISP, 2004).

2.4 Marine debris

Marine species have always used marine debris in the form of natural flotsam and jetsam, and even other species, as a means of dispersal from one area to another. However, in the past few decades, the volume of marine debris has grown exponentially as a result, in particular, of the introduction of persistent plastics. Floating plastic, packing cases, containers and other artificial debris can, in the same way as natural debris (seaweed rafts, mats of terrestrial vegetation, logs and slow moving whales, turtles and whale sharks), provide a substrate for fouling species – and there is now a substantial body of evidence to this effect.

For example, fishing nets which have drifted ashore after being abandoned or lost in the Pacific Ocean have been found covered with many marine organisms (Cranfield *et al.,* 1998). A survey of marine debris in northern New Zealand waters revealed 28 bryozoan species that had not previously been recorded, while other studies have confirmed that plastics and other persistent materials can support various encrusting fouling organisms and associated epibiota, as well as a relatively diverse mobile fauna (Barnes 2002a,b, Barnes and Fraser 2003, Gregory 1998, Jokiel 1990, Minchin 1996, Russell *et al.,* 2003, Winston *et al.,* 1997).

A study of stranded shoreline litter on 30 remote islands found substantial amounts of plastic even in areas not regularly visited by shipping. The study also found that plastic is typically colonized more than other debris material and carries heavier fouling in the tropics rather than at higher latitudes (Barnes, 2002). Barnes and Fraser (2003) also found plastic debris carrying fouling species in the Antarctic.

The contribution of lost containers to this problem has not yet been thoroughly assessed. The Through Transport Club (which insures the majority of container lines) estimates that some 2,000 containers are lost overboard annually. However, they are rarely watertight and it is likely that the majority sink (www.veromarine.co.nz).

2.5 Primary and secondary pathways

Biofouling is important as both a primary and secondary vector. While international shipping has been responsible for the introduction of numerous species from one corner of the globe to another, domestic or regional shipping is equally important in spreading those species which have been introduced by ships themselves, or other vectors, within a country or region. The golden mussel (*Limnoperna fortunei)*, for example, which was introduced to Brazil in 19991 – probably through ballast water – is considered to have spread approximately 240 km/year up-river as a result of biofouling on local boats (BLG 12/11; Darrigran and Escurra de Drago, 2000; Oliviera *et al*., 2006).

Other examples include *Caulerpa taxifolia* - which is thought to have been originally introduced to the Mediterranean *via* the Monaco aquarium, and then spread by small craft and fishing vessels (Ribera Siguan, 2003; Sant *et al*., 1996) – and *Sargassum muticum*, where secondary spread occurred *via* oyster movements and small craft (Wallentinus, 1999).

3. MANAGEMENT PRACTICES

3.1 The hierarchical approach to invasive species management

The first step in a biological invasion is the introduction of the species concerned into the new environment. Once there, it must be able to survive in the ambient conditions (temperature, salinity, etc.), and the survivors must persist and reproduce successfully until they establish a self-sustaining ‘founder population’. Once established, the species begins to multiply and spread, sometimes after a substantial time lag – maybe a few years, or even decades. The period of spreading – sometimes known as the explosion phase – is when the species/population becomes invasive.

Management measures may be applied at various points in the process of invasion, starting from prevention of introductions, to early detection of introduced species or founder populations and rapid response thereto – in the form of eradication or containment - and long-term control of invasive populations. The further along in the process of invasion that the measure is applied the more costly and less effective it generally is. In other words, although prevention measures may be costly, an analysis of the long-term costs and benefits (environmental, economic and social) will invariably show that they are less than the losses and costs which are incurred if the invasives are allowed to establish, and then require ongoing control.

The starting point for the management of invasive species – as for most environmental problems - is that “prevention is better than cure.” In other words, prevention is the most cost-effective and environmentally desirable option, and should be given priority in any invasive species management strategy. This is commonly known as the hierarchical approach to management of biological invasions. Prevention is especially important for marine environments given the difficulties of detecting introductions in marine habitats, of eradicating species that have become established, and of functional control and mitigation programmes.

Preventing the introduction of marine species and spread *via* fouling requires adherence to effective anti-fouling and/or cleaning programmes aimed at:

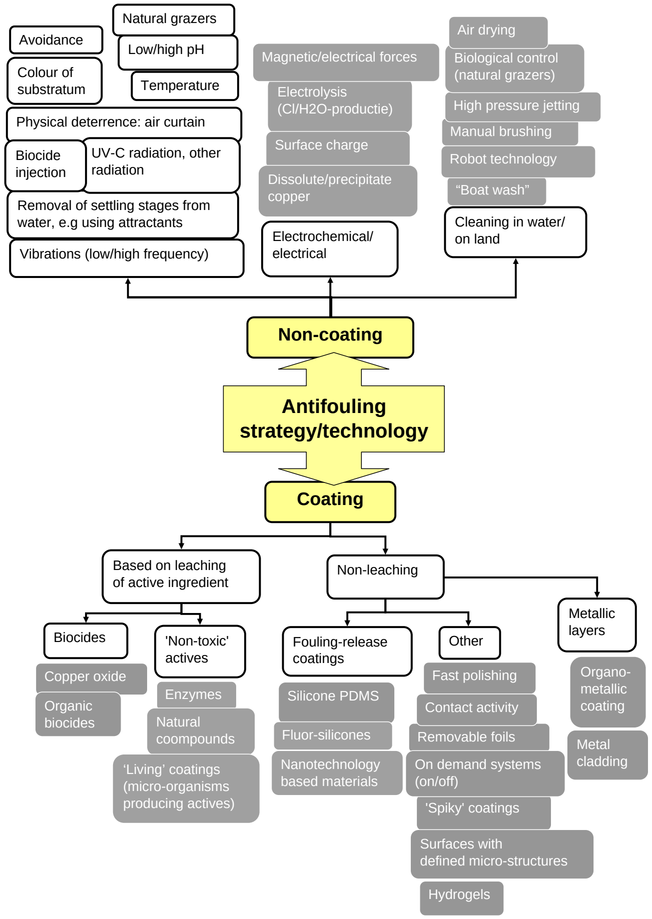
- preventing settlement of fouling organisms,
- preventing growth of settled organisms,
- removing and disposing of biofouling organisms that have established.

Education programmes are also required to make the owners/operators/users of boats, ships, marinas, mariculture facilities and diving equipment, aware of the role which they play in the transport of unwanted fouling species and the steps they should take to reduce introductions *via* this vector.

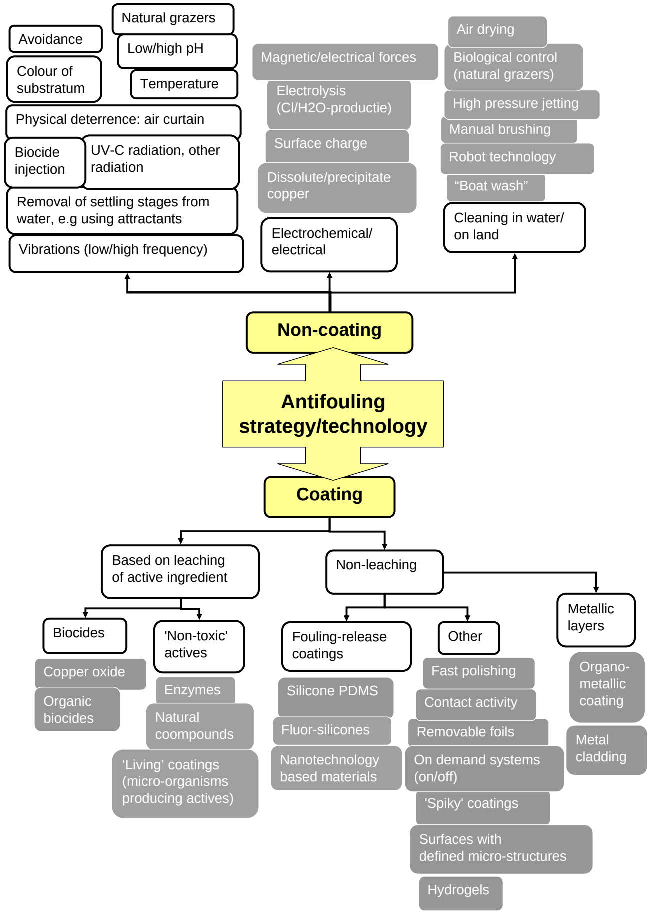
3.2 Anti-fouling strategies

There are three main approaches to anti-fouling: i) preventing the initial settlement of fouling species by repelling or killing them; ii) preventing the development of settled organisms by killing them, inhibiting their growth or reducing their adhesion ability; and iii) removing the fouling through cleaning.

The technologies can be subdivided into those based on the application of a coating, and those which do not. These have been summarized by Willemsen (2005) in a paper on biofouling in European aquaculture. Some of these technologies – most of which have been developed with the shipping industry in mind - are discussed in more detail below.



Reference: Willemsen PR (2005). Biofouling in Aquaculture: is there an easy solution? European Aquaculture Society Special Publications No.35, June 2005.



3.2.1 Anti-fouling systems

An anti-fouling system is defined in the International Convention on the Control of Harmful Anti-fouling Systems on Ships, 2001 (AFS Convention) as “a coating, paint, surface treatment, or device that is used on a ship to control or prevent attachment of unwanted organisms”. In fact, such coatings generally protect the structures concerned not only from fouling species, but also from saltwater corrosion and temperature fluctuations (Chambers *et al*., 2006). As far as fouling is concerned, they function in one of two ways:

i) The coating contains biocides or non-toxic active agents which gradually leach from the coating, thereby inhibiting the settlement of marine organisms;
ii) The coating prevents successful attachment of marine organisms – mainly fouling-release or metallic coatings.

The first coating to be patented goes back to 1625, and consisted of copper sheathing with heavy metal based coatings. In the early days, lead, arsenic and mercury and their organic derivatives were used as biocides, but were eventually banned because of the environmental risks they posed. However, copper-based coatings, often containing booster biocides, have continued to be used – although restrictions have subsequently been placed on the use of certain booster biocides (Thomas *et al*., 2005).

Tributyltin (TBT) was first used as a biocide in a self-polishing copolymer patented in 1976, and became widely used because of its effectiveness, being toxic at extremely low (parts per trillion) levels. This high toxicity however, soon started causing significant problems in a wide range of marine biota in the marine environment – particularly along shipping routes (Ten Hallers-Tjabbes *et al*., 2003). This led during the 1980’s to a fairly widespread ban by individual countries on its use on vessels less than 25 metres in length, and later to the development of the IMO Anti-fouling Convention, and a global ban on the application of TBT containing paints from 2003.

Self-polishing copolymers - which allow a gradual release of the biocide from the polymer - using copper and zinc as biocides - are still in use, but there has been increasing emphasis on the development of environmentally acceptable, biocide-free, alternatives.

These include:

- Foul release coatings (FRCs), or non-stick coatings (often using silicone or Teflon), which provide a very smooth surface to which organisms find it difficult to adhere. Those that do begin to adhere are quite easily washed off by, for example, the movement of a vessel through the water. However, these are clearly unlikely to be very effective for stationary vessels and other submerged structures. Moreover, they are not effective against biofilms, and those which are silicone-based contain some toxic components (Chambers *et al*., 2006).
- Biomimetics: there is a considerable amount of research into anti-fouling technologies based on the natural properties of biological systems themselves. Such initiatives can be sub-divided into two categories based on the anti-fouling properties of marine organisms themselves:
    - chemical methods - through the use of secondary metabolites and
    - physical properties of the surface of the organism – also known as microtopography.

Many of these are very promising, but none is currently being used commercially.

While the aquaculture industry continues to use some of the above technologies – including biocidal and fouling release coatings - there has recently been a more concerted effort to develop strategies more suited to their needs. These include (after Willemsen):

- biological control using grazers such as sea urchins (Hidu *et al*., 1981);
- farming practices such as avoidance – by removing or repositioning cultures during periods of known heavy settlement (Rikard *et al*., 1996);
- new cage designs (Menton and Allen, 1991);
- spraying with anti-fouling solutions such as acetic acid.

However, many of these are still under development, and cleaning programmes remain a necessity.

3.2.2 Cleaning programmes in the shipping industry

Physical cleaning of vessel hulls and niches normally takes place during scheduled dry-docking. However, depending on the effectiveness of the anti-fouling system, and the regularity of dry-docking, cleaning may be required more frequently. This may take place in-water, or, in the case of smaller vessels, on a slipway or haul-out facility – or even on the beach, although this is not longer considered acceptable.

In-water cleaning

In-water cleaning techniques generally vary depending on the size of the vessel as well as the composition of the hull, and the type of anti-fouling paint. Small vessels (i.e., less than 25 m) are typically cleaned by divers using hand-held scrapers, while commercial vessels generally require diver-operated devices with rotating brushes. In-water cleaning seldom cleans the entire hull – especially niche areas – and the dislodged material is, in most cases, just allowed to settle onto the seabed. Hopkins and Forrest (2008) found that even where brushes were combined with a suction system to collect the material, up to 12% was still lost.

In-water cleaning has historically been widely used for defouling small and large vessels, especially between scheduled dry-dockings. However, many countries have now introduced restrictions on this practice in light of invasive-species related concerns. These include the fact that whole organisms – or even communities of organisms – especially mobile organisms, byssal mussels and other molluscs, dislodged during cleaning can be transported by currents to nearby substrates such as pilings, rocks, or rubble and sand patches where they can settle and re-attach (AMOG 2002, Walters 1996). Moreover, crushing of invertebrate species can release eggs and sperm, while fragments of some macroalgae - such as *Caulerpa* - bryozoans, ascideans, sponges and worms such as *Sabella* can regenerate (AMOG, 2002; ANZECC, 1996; Rainer 1995).

Another aspect of in-water cleaning is that it is likely to remove at least part of the existing anti-fouling, and since no new paint is applied, it therefore increases the chance of the surface being recolonised. Boats that had been cleaned in Australia, for example, were found to have up to six times more recruitment than those that had been sterilized or left uncleaned (Floerl *et al*., 2005; Hopkins and Forrest, 2008).

In-water cleaning may therefore, increase the risk of introductions.

In New Zealand, a new approach to reducing the risk of hull-fouling by encapsulating the vessel in plastic has recently been tested. The targets in this case were ascidians and the objective was to kill them by creating anoxic conditions within the plastic wrapping (Coutts and Forrest, 2005; Denny, 2007).

On-land cleaning or dry docking and cleaning facilities

Cleaning during dry docking or at haul-out facilities or on slipways is usually accomplished using water blasters and scrapers. This produces both solid material and a liquid effluent. While the solid material is then generally collected and removed from the slipway or dry dock and disposed of at a landfill site, the liquid effluent can pose a problem in as much as it can carry eggs and larvae and even adults of smaller species. Cleaning facilities should, therefore, include treatment systems for this effluent – for example, filters and/or containment or settlement tanks. Facilities in New Zealand appear to rely on a combination of freshwater and residence time in the settlement tanks to reduce the risk of the effluent, although in some cases the effluent is then discharged to the municipal sewer, or stored and recycled for use in water blasting (Woods *et al*., 2007).

A study with detailed recommendations on hull cleaning and the removal of anti-fouling systems has recently been completed by Ten Hallers-Tjabbes (2007) under the project: EUROMED Cooperation on Maritime Safety and Prevention of Pollution from Ships. Although the focus of the study was to promote appropriate methods to deal with biocides such as TBT, many of the recommendations would also be relevant to concerns around the fate of the biological material removed during hull cleaning procedures.

In-water vs on land cleaning

Woods *et al*. (2007) concluded that the debris produced during cleaning carried out at dry dock or haul-out facilities (using water-blasting) generally contained fewer viable organisms than in-water cleaning.

3.2.3 Cleaning programmes in the aquaculture industry

The aquaculture industry utilizes a variety of cleaning methods depending, in part, on the species being cultured and, therefore the equipment. Those described on the CRAB website and the in CRAB Best Practice manual include:

- manual cleaning – scrubbing or brushing (used for shellfish stock and infrastructure);
- mechanical cleaning - using machines (used for shellfish stock and infrastructure and finfish infrastructure);
- hot water immersion (used for shellfish stock and infrastructure);
- high pressure washing – using water jets (used for shellfish stock and infrastructure and finfish infrastructure);
- dipping in freshwater – up to 2 days (used for shellfish stock and infrastructure);
- dipping in chemical solution – for example, acetic acid, hydrated lime, saturated brine, hypochlorite solution (used for shellfish stock and infrastructure);
- air drying prior to cleaning (used for shellfish stock and infrastructure and finfish infrastructure).

The advantages and disadvantages of these are summarized in a series of Strategy Factsheets available on the website (www.crabproject.com).

3.2.4 Current practice

Vessels

The predominant technical approach to managing biofouling is a combination of the application of an appropriate anti-fouling system in combination with regular maintenance and cleaning. A variety of codes and guidelines has been developed for the application of anti-fouling coatings as well as the cleaning of commercial and recreational vessels with a view to limiting the introduction of both biological material and contaminants into the marine environment. As can be seen from the following examples, these include materials which could provide the basis for regulations as well as outreach/educational material:

- Code of Practice for antifouling and in-water hull cleaning and maintenance (1996) – developed as part of the ANZECC strategy to protect the marine environment (a joint Australian/New Zealand initiative).
- Clean Boats – Living Seas: A Boatie's Guide to Marine Biosecurity – developed by Biosecurity New Zealand for recreational boaters which covers anti-fouling as well as cleaning practices.
- Guidelines for the Prevention of Biofouling on Commercial Vessels – developed by the Australian Shipping Association and Australian Government.
- Guidelines for Clean Boats, Clean Waters (2006). Michigan's Aquatic Invasive Species Programme.
- Guidelines for Trailer Boats in the State of Wisconsin. (www.seagrant.wisc.edu/outreach/nis/Prevent.html).
- Ministry of Environment and Natural Resources in Seychelles published draft Antifouling and Hull Cleaning Guidelines (2004).
- US EPA Boat Cleaning Management Measures.
- International Sailing Federation (ISAF): Draft Guidelines for Recreational and Similar Small Craft to Minimise the Translocation of Alien Species *via* Bio-fouling, Bilge Water and Ballast Water, and Guidance on the Protection of the Marine Environment (submitted to recent MEPC and BLG meetings).
- Environmentally Sound and Safe Removal of Harmful Anti-Fouling Systems and of Cleaning of Ships' Hulls (Ten Hallers-Tjabbes, 2007) – developed under EUROMED Cooperation on Maritime Safety and Prevention of Pollution from Ships.

While some codes are out of date in certain aspects, and others are focused on the toxicity of the anti-fouling, together they can be considered to represent emerging best practice. This includes the following points:

1. Anti-fouling coatings should not contain organotins.
2. Anti-fouling products should be registered with a regulatory authority.
3. There should be a labeling system for registered anti-fouling products.
4. The selection of an anti-fouling system should be based on the vessel type, operations (speed and frequency of movement, etc.), and composition of the hull.
5. It may be necessary to use a different coating in niche areas.
6. The frequency of re-application of the coating should be based on the manufacturers recommendations, provided that:
    - i) As a general rule, recreational boats should be recoated annually, and more frequently if damaged.
    - ii) Recreational vessels planning to sail internationally – or even to another domestic region – should have been recoated less than a year prior to departure.
    - iii) International law requires vessels > 500 tonnes to be dry docked twice every five years. This can be used for cleaning and re-application of the AFS.

7. Accurate documentation of coating applications and maintenance should be kept for verification purposes.
8. Application and removal of coatings should be done at facilities above the tidal zone, and with appropriate infrastructure and resources. Beaching or encapsulation of boats in plastic for in-water cleaning are NOT recommended.
9. Sale of anti-fouling products should be limited to approved facilities.
10. Spraying should not be done in high winds, and sheeting should be used to prevent spray drift.
11. Surfaces should be thoroughly cleaned before the coating is repaired or re-applied.
12. The angles and corners of sea chests should be beveled, and grates rounded to minimize fouling. Grates should be hinged to facilitate access. Steam blow-out pipes can also be used to minimize growth in sea chests.
13. Vessels coated with paints containing biocides should NOT be cleaned in-water, and those with biocide-free coatings only in exceptional circumstances.
14. Where in-water cleaning is permitted, all material removed (biological and coating) should be collected for disposal on shore.
15. In-water repair of minor damage can be considered for commercial vessels.
16. Propeller polishing is permissible and should be combined with the inspection of other niche areas.
17. Water blasting or vacuum blasting are preferred cleaning methods to the use of chemicals or dry abrasion. Burning should be prohibited.
18. Dry dock facilities and on-land cleaning areas for small boats (slipways, haul-outs, etc.) should be bunded and/or have sumps to ensure that all solid and liquid paint residues and fouling material can be contained and/or collected.
19. Such facilities should be required to meet specific standards.
20. Appropriate facilities should be required at all marinas.
21. All material > 1mm must be collected and disposed to landfill.
22. Liquid effluent should be collected, coarse pre-screened, treated and discharged to municipal sewer, or recycled for water blasting.
23. The treatment of liquid effluents should include multiple settlement tanks – ensuring a residence time of 24 – 48 hours – and should have a salinity of 0 ppt to ensure that none of the fouling species survive.
24. Where liquid effluent has to be discharged to sea, it should be fine-screened.
25. New facilities should be designed to allow for the treatment of waste water and disposal to sewer, and existing facilities upgraded for the same purpose.

Given the limitations of current antifouling measures, and the poor maintenance history of many vessels, some port States have started to look at other management options. These include inspection of hulls – initially of high risk vessels only - prior to port entry followed by denial of entry, or mandatory hull cleaning.

Aquaculture

Both biocidal coatings – mainly based on copper oxide – and manual cleaning are widely used, although there is considerable variation depending on the species being cultured, the location, the size of the facility, etc.

In the finfish sector, for example, the most widely used strategy for controlling biofouling is net cleaning (Durr and Fowler, 2006).This includes in-water cleaning or drying of the nets ashore, followed by cleaning. The more rigid cages, being introduced in some areas to address other problems such as predators, are more difficult to move, and are cleaned *in situ.*

However, nets may also be treated with copper-oxide based anti-foulants especially in countries where there are high levels of fouling due to the environmental conditions – for example Chile. The levels of copper permitted vary, with Canada, for example, allowing 20% higher levels than European countries (Durr and Fowler, 2006).

In shellfish farms, anti-fouling methods are primarily based on cleaning – manual or mechanical – in combination with dipping in, e.g., hot water, and air drying. However, the placement of grazers such as sea urchins and sea snails in shellfish trays is also being assessed, as is the use of special shellfish coatings (Watson and Icely, 2006).

Other options include biological control (using natural grazers), non-toxic antifouling coatings, electrical methods, poly-culture, and shellfish handling and immersion techniques (CRAB, 2006).

The European Best Practice in Aquaculture Biofouling (CRAB, 2007) can probably be regarded as reflecting current best practice globally. However, of importance to this review, is that it does not deal directly with the question of invasive species. Nevertheless, any strategy which reduces biofouling in aquaculture, will also contribute to reducing the risk of such biofouling translocating invasive species.

3.3 Current research

3.3.1 Natural and/or non-toxic anti-foulants

Given the serious economic implications of biofouling – including those resulting from the introduction of invasive species – and the imminent restrictions on the use of biocides in anti-fouling systems, there is a substantial amount of research being undertaken in this field in some cases involving collaborative efforts between government and industry.

Biofouling on the surface of a living organism – or epibiosis – is a non-symbiotic, often facultative, association between the fouling organism and that surface. The presence of fouling organisms on an individual may have beneficial or detrimental effects. Beneficial impacts include protection from predation, provision of ammonium, or protection from dessication (e.g. in seagrasses). On the other hand, they can reduce photosynthesis and growth, interfere with reproductive output, affect shell condition of molluscs, reduce mobility, impair the functioning of appendages and gills, and make them more susceptible to predation (De Nys *et al*., in press).

As a result of these negative impacts, many marine species have developed mechanisms to prevent or reduce fouling. These include behavioural, mechanical, physical and chemical mechanisms and may be used in combination, potentially synergistically. An overview of these mechanisms, together with examples and case studies is provided in De Nys *et al*. (in press).

Amongst the natural chemicals which have been shown to act as anti-foulants – using laboratory and field assays - are halogenated furanones from the Australian red alga *Delisea pulchra* (De Nys and Steinberg, 2002). The positive results of the initial work on furanones have now been picked up in a commercial development programme.

Dahlstrom *et al*. (2000) have also identified natural products which inhibit the settlement of barnacle larvae, and biofilms themselves – and especially some bacteria found in biofilms – can also inhibit settlement, and have given rise to the concept of “living paint” (De Nys and Steinberg, 2002).

One of the natural physical defence mechanisms which is being investigated with a view to commercial application is the small-sale surface structure of the organism – microtopography. Research has focused on species that carry only limited fouling, including pilot whales (Baum *et al*., 2002), *Mytilus* spp. (Bers *et al*., 2006; Bers and Wahl, 2004; Scardino *et al*., 2003; Scardino and de Nys, 2004), the brittle star *Ophiura texturata* and the crab *Cancer pagurus* (Bers and Wahl, 2004), and tropical sea stars (Guenther *et al*., 2007; Guenther and de Nys, 2007).

The AMBIO project – Advanced Nanostructured Surfaces for the |Control of Biofouling - is using nanotechnology in an attempt to produce a nanostructured surface where properties such as surface energy, charge, conductivity, porosity, roughness, wettability, friction, physical and chemical reactivity and compatibility with biological organisms is controlled (see www.ambio.bham.ac.uk/).

Alternative strategies for controlling biofouling are particularly important in the context of the aquaculture/mariculture industry given the potential for biocides to accumulate in seafood products. Fouling control techniques and technologies have recently been investigated through the EU-funded CRAB project (Collective Research in Aquaculture Biofouling – www.crabproject.com) with a view to developing sustainable, non-toxic anti-fouling management strategies for the European Aquaculture Industry. Strategies investigated included biological controls (using natural grazers); non-toxic anti-fouling; electrical techniques; and shellfish handling and immersion techniques (Willemsen, 2005). The project culminated in the publication of *"European Best Practice in Aquaculture Biofouling"* in 2007.

3.3.2 Risk analysis

New Zealand is undertaking research to understand the relative risks posed by different types of international vessels visiting their ports, including recreational yachts, fishing boats, passenger vessels and commercial vessels. The research is also looking at seasonal and geographic (i.e. last port of call) variations in the level of biofouling in an effort to determine the primary factors influencing levels and composition of biofouling.

The level of fouling on yachts is being measured using a HullCam – a specially designed sampling system using a remote video lens attached to a frame which can be rolled across the yacht hull (www.niwa.co.nz/ncabb/abb/2003-05/filming).

The risk posed by biofouling comes not only from the introduction and establishment of adult organisms in the new location, as a result of, for example, dislodgement from the vector, but also as a consequence of the fact that most biofouling species have planktonic life stages, and that spawning can be induced by the altered environmental conditions in a port or marina (Minchin and Gollasch, 2003). The level of risk will thus depend on various factors, including species composition, dispersal mechanisms of the species, reproductive status (seasonal), and the level of fouling (cf. "propagule pressure"), and the period of residence time of the vessel (Floerl *et al*., 2005; Hopkins and Forrest, 2008).

3.4 Education and training needs

The management of biofouling involves a wide range of stakeholders and, as is true when new requirements and responsibilities are introduced in any field, they need to be educated to have an understanding of the issue, and trained in management techniques. Target groups should include:

- recreational boat owners
- commercial ship owners and operators
- port and marina operators
- dockyard and ship scrapyard operators

In the face of the enormous numbers of recreational boats – and therefore boaters – many countries have already put considerable emphasis on outreach programmes. The Department of Fisheries and Oceans in Canada, for example, partnered with the Ministry of Natural Resources to produce a sticker and brochures which were then distributed at marinas, trade shows, etc. Similar campaigns have been conducted in the US and New Zealand.

Once regulations have been adopted, more formal training may need to be introduced.

4. REGULATORY FRAMEWORK

The inadequacy of existing regulatory measures for biofouling has been pointed out in a number of international fora. The Convention on Biological Diversity (CBD) Conference of Parties decision VI/23(7) in 2002, urged the International Maritime Organisation (IMO) and other relevant organizations to take up as a matter of urgency the development of mechanisms to minimize hull-fouling as an invasion pathway. The lack of a regulatory framework for biofouling was again identified as a major, and high priority, gap in the regulation of invasive species at a meeting of a CBD Ad Hoc Technical Expert Group meeting in Auckland, New Zealand in May, 2005 (UNEP/CBD/SBSTTA/11/16). Biofouling was also included as a priority in the Joint Work Programme on Marine and Coastal Invasive Alien Species developed at a workshop in Montreal in June, 2005, and co-hosted by the CBD, GISP and the UNEP Regional Seas Programme (UNEP/CBD/SBSTTA/INF10).

Since then, hull-fouling has been formally placed onto the IMO agenda. Moreover, there are a number of national-level initiatives which could not only provide the basis for the development of guidelines on biofouling as a whole, but which could also serve as the starting point for the development of an international regulatory framework.

4.1 National

4.1.1 Australia

Marine biosecurity in Australia is currently regulated by the Quarantine Act, 1906 in combination with the Biological Control Act, 1984. However, neither of these acts adequately covers unintentional introductions – such as those from biofouling. The incident involving the invasion of the black-striped mussel in Darwin, in 1999, led the Northern Territory Government to introduce interim measures such as hull inspection programmes for international yachts. Those vessels which have not been adequately anti-fouled, are then cleaned at appropriate facilities (Hewitt and Campbell, 2007).

The incident in Darwin also led to the development of a National System for the Prevention and Management of Marine Pest Incursions which was endorsed through an intergovernmental agreement (between the federal government and states of Australia) in April, 2005. It comprises three main components: Prevention; Emergency management; and Ongoing management and control, as well as supporting components on research and development, communications, monitoring, and evaluation and review. With respect to biofouling, the agreement states that:

- The Australian Government, through legislation, will ensure that vessels entering Australia are subject to agreed measures to minimize the risk of introducing marine pests through biofouling;
- The states and the Northern Territory will ensure that vessels traveling between Australian locations are subject to agreed measures to minimize the risk of translocating marine pests through biofouling;

- The Parties, through agreed best practice management guidelines and protocols, will within their jurisdictions promote the uptake of measures for aquaculture operations to minimize the risk of translocating marine pests that may be associated with stock, equipment and infrastructure;
- The Parties, through agreed best practice management guidelines and protocols, will within their jurisdictions promote the uptake of measures to minimize the risk of areas becoming reservoirs for marine pests and to minimize the risk of translocating marine pests that are associated with equipment, infrastructure or any other submerged equipment or structures associated with these areas.

Guidelines, voluntary protocols or regulations on biofouling will be introduced for aquaculture; the aquarium trade; commercial and recreational fishing; commercial shipping; ports, marinas, slipways, shipyards and dry docks; non-trading commercial vessels; the petroleum industry; and recreational vessels. Treatment systems for biofouling of a vessel's internal water systems will be investigated, and standards for antifouling systems developed.

The agreement is being implemented by the National Introduced Marine Pests Coordinating Group, with activities including the development of policy instructions for a proposed Biosecurity and Agriculture Management Bill. In addition, vessel fouling has now been included as part of the regular quarantine inspection for incoming vessels, and new biofouling protocols have been introduced by the Australian Quarantine and Inspection Service (AQIS) – the lead agency for preventing the introduction of marine pests in Australia - starting with voluntary guidelines in October, 2005. The voluntary protocols, which will eventually be replaced by mandatory controls, are currently only being applied to international vessels less than 25 m in length and vessels apprehended for illegal activities (Western Australia State of the Environment Report, 2007). A copy of the protocol and guidelines can be found in Annex 7.2.1. The Government of Australia, in collaboration with the Australian Shipping Association has also produced Guidelines for the Prevention of Biofouling on Commercial Vessels – see Annex 7.2.2.

Australia became a Contracting Party to the AFS Convention in January, 2007. The Convention is implemented locally through the Protection of the Sea (Harmful Anti-fouling Systems) Act 2006.

4.1.2 Canada

The Canadian Government adopted an Invasive Alien Species Strategy in 2004. This recognizes the Ministers of Agriculture and Agri-Food, Fisheries and Oceans, Natural Resources and Environment as lead federal Ministers on invasive species. The strategy also points to the need for the development of an Action Plan to Address the Threat of Aquatic Invasive Species.

There are, however, currently no regulations regarding biofouling although some research is underway through the Canadian Aquatic Invasive Species Network with a view to determining the need (e-mail from Department of Fisheries and Oceans (DFO)).

In terms of recreational boating, emphasis has been put on outreach programmes, and stickers and brochures have been distributed at various marinas, trade shows etc. In addition, a number of guides to Best Management Practices for boats and boatyards have been developed (www.pyr.ec.gc.ca/boatyards/index_e.html). However, these are largely focused on the potential toxicity of wastewater from cleaning operations rather than the invasive species issue. In support of this concern, the Georgia Strait Alliance has recently produced a publication entitled Alternative Fouling Control Systems (2008).

4.1.3 New Zealand

New Zealand has two laws which are pertinent to the management of marine invasives: the Biosecurity Act, 1993 and the Hazardous Substances and New Organisms Act, 1996, with the former covering unintentional introductions. A policy – "Ballast Water and Ship's Hull Defouling: A Government Strategy – was published in 1998, setting out possible options.

Using powers under the Biosecurity Act, 1993, hull inspection programmes for yachts were established in New Zealand in 2002, and hull-cleaning guidelines for "boaties" - specifically aimed at protecting remote conservation areas such as the Chatham Islands – have been developed (Hewitt and Campbell, 2007) (See Annex 7.2.3). Hull fouling regulations as such, are however, still under development pending the final outcome of a survey of vessels arriving in New Zealand ports, which will include a risk analysis (Liz Jones, pers. comm.). In the meanwhile, arriving commercial vessels are required to complete a vessel clearance procedure which includes submission of a Master's Declaration, a copy of which can be found at Annex 7.3. The vessel clearance procedure is also currently being reviewed, and the new, more comprehensive, standard which will apply to all inbound vessels will likely be put into effect in mid-2008 for commercial vessels, and at the start of the 2008/09 season for cruise vessels and pleasure craft. The draft "Requirements for Vessels Arriving in New Zealand" includes the following text on hull-fouling:

"*Although New Zealand has no specific regulations on hull fouling as a risk for transferring marine pest organisms, good hull maintenance is encouraged. Vessel hulls, including recesses around rudders and water intake/outlets (sea-chests), should be kept free from excessive growth of seaweed, barnacles, shellfish and other encrusting marine life. Antifouling coatings should be in good condition and renewed before the expiry date of the paint manufacturers' recommended replacement period.*

An inspector may direct specific action be taken for a vessel that is considered to pose a severe biosecurity risk due to the marine life carried on its hull."

The new system incorporates a biosecurity risk assessment based on the information in the Master's Declaration which has to be provided 48 hours prior to arrival. This will result in a risk rating which will determine whether or not an inspection is required – although an audit system will also be in place (www.biosecurity.govt.nz/commercial-transport-and-border-management).

4.1.4 Seychelles

In May, 2004, the Ministry of Environment and Natural Resources in Seychelles published draft Antifouling and Hull Cleaning Guidelines based on those of New Zealand, Australia and the US. The main aim of the guidelines was to provide guidance on the setup and operation of hull-cleaning services in Seychelles. The guidelines cover:

- Application, Maintenance, Removal and Disposal of Antifouling Paints.
- General Requirements (labeling, application sites, etc.)
- Procedural issues.

4.1.5 United Kingdom

The introduction of non-native species into the United Kingdom is regulated through the provisions of the Wildlife and Countryside Act 1981 (www.mceu.gov.uk/MCEU_LOCAL/fepa/FEPA-hull-maint.HTM). Under Section 14(1) of this Act it is an offence to release or allow to escape into the wild any animal which:

> a) is of a kind which is not ordinarily resident in and is not a regular visitor to Great Britain; or
>
> b) is included in Schedule 9 Part I (this includes established invasive non-native species of birds and other animals).

Under Section 14(2) of the Act, it is an offence to plant or otherwise cause to grow in the wild any plant listed on Schedule 9 Part II (which includes some species of established invasive non-native plants, including some marine seaweeds).

There is, therefore, a general prohibition on the introduction of **all** non-native animal species, but only specified plant species. Moreover, releases do not have to be intentional to be prohibited, although Section 14(3) provides a defence if the defendant can show that all reasonable steps were taken and all due diligence exercised to avoid committing an offence.

Deliberately scraping non-native marine organisms off a ship's hull and effectively releasing them into the water would therefore constitute an offence under the Wildlife and Countryside Act 1981, especially if no measures were taken to prevent their release into the sea.

It is also likely that some restrictions (including complete bans) on ship maintenance activities may be imposed in some waters by harbour authorities, local authorities and similar bodies under local bylaws.

4.1.6 United States of America

Invasive species management in the USA is coordinated through the National Invasive Species Council which was established by an Executive Order in 1999. The Council comprises representatives from 10 governmental agencies, and in 2001 adopted a National Management Plan which identified priorities, programmes and other initiatives. The plan is currently being updated for the period 2008 – 2012. The draft document does not make any mention of biofouling. However, the Coast Guard – which has been regarded as the primary agency for hull fouling in as much as it already has a legal mandate for ballast water management and vessel inspections – has recently been mandated by the Ballast Water Management Act of 2007 (S. 1578) to develop a strategy for other ship-related vectors (Bryant, 2008). Moreover, the mandatory ballast water program already requires vessel owners to remove fouling organisms (Showalter and Savarese, 2004/5).

> *“Masters, owners, operators, or persons-in-charge of all vessels equipped with ballast water tanks that operate in the waters of the US must:*
>
> *(5) Rinse anchors and anchor chains when you retrieve the anchor to remove organisms and sediments at their place of origin.*
> *(6) Remove fouling organisms from hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, State and Federal regulations.” (33 Code of Federal Regulations : 151.2035(a)(5)-(6) (2005)* after Showalter and Savarese, 2004/5*).*

The Coast Guard has also developed *Voluntary Guidelines on Recreational Activities to Control the Spread of Zebra Mussels and Other Aquatic Nuisance Species*, which are promoted through boater training and education campaigns. (Showalter and Savarese, 2004/5).

In addition, a number of States have introduced laws and/or outreach programmes. The California ballast water management program, for example, is based on the federal guidelines and therefore includes the provisions on hull fouling as outlined above (CSLC, 2003). Maryland has taken a similar approach. Hawaii has designated the Department of Land and Natural Resources as the lead agency for ballast water and hull fouling (Hawaii Revised Statutes: 187A-32(a) (2004)). They have established the Hawaii Alien Aquatic Organism Task Force and have a projected date of 2007/2008 for completion of a hull fouling prevention plan. Minnesota, Wisconsin, and Vermont also have regulations in place, although these are more focused on particular species – such as zebra mussels. Virginia has voluntary guidelines based on the federal guidelines (Showalter and Savarese, 2004/5).

Voluntary guidelines tend to be implemented through volunteer outreach programmes – for example, the Clean Boat, Clean Water Programme in Michigan.

From the perspective of anti-fouling, the US banned the use of TBT in 1988 (Showalter and Savarese, 2004/5).

4.2 Regional

4.2.1 ICES Code of Practice

In 2005, the International Council for the Exploration of the Sea (ICES) produced an updated version of its Code of Practice on the Introduction and Transfer of Marine Organisms. This code has become widely used, and has been formally endorsed by FAO. However, this code deals with the intentional introduction of species for aquaculture, restocking and stock enhancement, and does not address unintentional introductions through biofouling.

In 2006, the ICES/IOC/IMO Working Group on Ballast and Other Ship Vectors recommended the preparation of an ICES Code of Best Practice for the Management of Ships Full Fouling, but this is yet to be published.

4.2.2 European Union

The European Union first introduced restrictions on the use of some biocides in anti-fouling paints through the EU Biocides Products Directive; 98/8/EC http://europa.eu.int/eu-lex/pri/en/oj/dat/1998/l_12319980424en00010063.pdf. The use of organotins was then completely prohibited by a Commission regulation (782/2003). This regulation bans the application of TBT antifouling paints on all ships flying the flags of EU States from 1 January, 2003; prohibits vessels entering EU ports from having a TBT-based paint (unless sealed by another coating) from 1st January, 2008; and requires survey and certification for EU flagged vessels coated after 1st January, 2003, and for foreign vessels once the AFS Convention enters into force.

4.2.3 Barcelona Convention/ Mediterranean Action Plan

The Barcelona Convention provides the regulatory framework for the UNEP Regional Seas Programme for the Mediterranean. The Biodiversity Protocol to the Convention calls on Contracting Parties to take “all appropriate measures to regulate the intentional or unintentional introduction of non-indigenous or genetically modified species into the wild and prohibit those that may have harmful impacts on the ecosystems or species”. To this end, the Parties adopted an “Action Plan Concerning Species Introductions and Invasive Species in the Mediterranean”. In turn, this led to the development of “Guidelines for Controlling the Vectors of Introduction into the Mediterranean of Non-Indigenous and Invasive Marine Species” (undated). The guidelines cover ballast water, hull fouling and aquaculture. With respect to hull fouling, they cover three main issues: enhancing knowledge and research; improving understanding and awareness; and providing appropriate prevention measures, with the last section including some brief technical recommendations. These can be found at Annex 7.3.1.

4.2.4 ANZECC: Code of practice

The ANZECC Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance was officially endorsed by Australia and New Zealand in 1995, and, although it is now outdated in certain respects, it was the first significant step towards regulating biofouling. Many of its recommendations have been taken up by subsequent codes, not only in these two countries, but around the world.

4.2.5 North America

In 1993, Canada, Mexico and the US signed a side agreement to the North American Free Trade Agreement (NAFTA) – the North American Agreement on Environmental Cooperation. This established a Commission on Environmental Cooperation (CEC), one of whose projects is “Closing the Pathways of Aquatic Invasive Species across North America” (Showalter and Savarese, 2004/5; http://www.cec.org).

4.2.6 SPREP (Secretariat of the Pacific Regional Environment Programme)

In 2006, the Pacific Islands endorsed a Regional Strategy on Shipping-related Introduced Marine Pests. The strategy includes specific pre-border and border measures on vessel fouling. The pre-border measures are premised on all ports in the region implementing inspection and cleaning requirements for vessels prior to departure. Inspections should include not only hulls, but niche areas and, in the case of fishing boats, fishing gear.

Border measures for hull fouling include:

- inspection of high risk vessels and floating facilities;
- inspection of international yachts and other pleasure craft at first port of call, and mandatory cleaning as necessary;
- promotion of good maintenance and anti-fouling practices;
- a ban on in-water scraping and cleaning;
- organisms removed during on-shore cleaning to be disposed of at appropriate land disposal facilities.

4.3 International Regime

While there is at present no international agreement dealing specifically with biofouling as a pathway for the introduction of invasive species, there are a number of conventions with provisions relating to invasive species more generally, as well as a convention on anti-fouling systems. These are outlined briefly below:

4.3.1 The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) provides a comprehensive basis for measures to protect all components of biodiversity against invasive alien species. The Convention is administered by the United Nations Environment Programme (UNEP), with its Convention Secretariat based in Montreal.

Article 8(h) of the Convention requires Parties: *“As far as possible and as appropriate, (to) prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.”*

Conference Of Parties # 2 of the CBD in 1995 adopted a programme of action for implementing the Convention in marine and coastal environments. Known as the “Jakarta Mandate on Marine and Coastal Biological Diversity”, it identified five thematic issues, one of which was alien species. The goal of the programme of work under the Jakarta Mandate is: “to prevent the introduction of invasive alien species into the marine and coastal environment, and to eradicate to the extent possible those invasive alien species that have already been introduced.” To a large extent, this is being implemented through the UNEP Regional Seas Programme.

4.3.2 UNCLOS

The United Nations Convention on the Law of the Sea (UNCLOS) provides a comprehensive legal regime governing all uses of the oceans and their resources.

Article 196 of UNCLOS provides that “States shall take all measures necessary to prevent, reduce and control … the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto”.

4.3.3 International Convention on the Control of Harmful Anti-fouling Systems on Ships – the AFS Convention

As early as 1989, in response to the growing evidence of harmful impacts to marine species of biocides associated with anti-fouling systems – in particular organotins - an MEPC Resolution called on Governments to adopt measures to ban the use of tributyltin (TBT) containing anti-fouling paints on vessels less than 25 metres, and of paints with a leaching rate of more than 4 microgrammes of TBT per day. Following several further resolutions, the MEPC initiated the development of a binding international instrument. The International Convention on the Control of Harmful Anti-fouling Systems on Ships was adopted on the 5th October, 2001, and, following its ratification by the required 25 States (representing about 38.1% of global shipping) will enter into force on the 17th September, 2008.

Annex 1 of the Convention stipulates that as of 1st January, 2003, no ship shall apply, or re-apply, organotin compounds. Further, that as of 1st January, 2008, all ships (with some specific exceptions), either:

- Shall not bear such compounds on their hulls or external parts or surfaces; or
- Shall bear a coating that forms a barrier to such compounds leaching from the underlying non-compliant anti-fouling systems.

The effective date of these provisions will now be the entry into force date, namely 17th September, 2008.

The Convention also provides for the addition of other substances and control measures to Annex 1, as well as the establishment of a survey and certification system for the anti-fouling systems of all ships of 400 tonnes or more (with the exception of certain platforms and floating storage units). Smaller vessels are required to carry documentation to prove their compliance with Annex 1.

Unfortunately, while the Convention acknowledges the role of anti-fouling systems in controlling invasive species, it does not establish any criteria or standards in this regard. The focus is on ensuring anti-fouling systems which are effective from the standpoint of the ship’s performance, while not being toxic or otherwise harmful to the marine environment.

4.3.4 Hull-fouling on the IMO agenda

In March, 2006, Australia presented an Information paper to the 54th meeting of the Marine Environment Protection Committee (MEPC 54) of IMO pointing out the importance of biofouling as a pathway for the introduction of marine pests in Australian waters, and reporting on a project being undertaken jointly by the Australian Government and the shipping industry to investigate management options for commercial vessels (MEPC54/INF.5). This stimulated the development of a "Proposed Code of Practice for minimizing the transfer of invasive aquatic species *via* biofouling on recreational and similar small boats" which was submitted to MEPC 55 by Friends of the Earth International (MEPC 55/13/1). This latter initiative was picked up by the International Sailing Federation (ISAF), who have now produced several versions of "Draft Guidelines for recreational and similar small craft" (and which have now been broadened to cover other environmental concerns) (MEPC 56/13; BLG 12/11/1).

At MEPC 56 in April 2007, New Zealand, Australia, the UK, FOEI and the IUCN formally proposed the addition of a new agenda item – Development of international measures for minimizing the transfer of invasive aquatic species through biofouling of ships – onto the agenda of the Sub-Committees on Bulk Liquids and Gases (BLG) (MEPC 56/19/3). The authors identified the following critical areas which would need to be investigated in the process of developing international measures:

- Anti-fouling paint application and use – addressing appropriate paints for different vessel types and activities;
- Approaches to minimizing biofouling in niche areas – anti-fouling use, cleaning or design solutions;
- In-water cleaning – appropriate methods that minimize the risk of introductions;
- Documentation/certification standards for maintenance regimes; and
- Design of dry dock and other vessel cleaning facilities to minimize the risk of release of biological materials into the environment.

The authors also pointed out, that different approaches would probably be required for different vessel types, and listed a number of options for the implementation of international measures. These included:

- development of Guidelines for adoption as an MEPC or IMO Assembly resolution;
- linking measures to the AFS Convention;
- linking measures to the BWM Convention;
- development of a new Convention.

This item was first discussed at BLG 12 in February, 2008. The papers submitted included proposals on potential management measures for niche areas (adapted from the Australian Guidelines for the Prevention of Biofouling on Commercial Vessels) (BLG 12/11). These are reproduced at Annex 7.2.4. In addition, New Zealand and the United Kingdom submitted a paper summarizing the advantages and disadvantages of the various implementation options outlined above (BLG 12/11/2). While this paper itself did not suggest any particular option, it seems likely that the introduction of measures would consist of two phases: i) the adoption of Voluntary Guidelines; and ii) in the longer term the introduction of mandatory measures to ensure greater consistency, to support survey and certification measures, and to stimulate the further development of effective technologies (BLG 12/11).

The development of international measures for biofouling of ships is considered as a high priority and has a completion date of 2010. To this end, a Correspondence Group under the Chairmanship of New Zealand has been established.

1. 5. CONCLUSIONS AND RECOMMENDATIONS

Biofouling is a complex problem irrespective of the species. It occurs on a variety of structures and materials, and has serious economic implications for a number of industries, including shipping, aquaculture (including mariculture), and power and other industries which use seawater (and freshwater) for cooling or other purposes. At the same time, biofouling is a major pathway for the introduction of invasive species, with all the additional problems inherent to that issue. Moreover, the anti-fouling systems which have been developed have largely been based on the use of biocides, which has implications for the broader marine (aquatic) environment, and which concerns have led to the imminent ban of the most effective of those biocides, namely TBT. Even cleaning measures for fouling – and anti-fouling systems - can create problems if the material removed is not properly disposed of. Management of biofouling therefore needs to be approached from a holistic perspective rather than being focused on just one aspect of the problem.

Nevertheless, the purpose of this review is to look at biofouling as a pathway for the introduction of invasive species. And the goal of management efforts from this perspective should be to prevent – or minimize as far as possible – such introductions. This would involve:

- Ensuring the correct selection, application, re-application and maintenance of an anti-fouling system – depending, in the case of vessels, on the type and composition of vessel, part of the vessel, frequency of voyages, etc;
- Given the fallibility of anti-fouling systems – and perhaps a lack of awareness of the extent of the problem - the establishment of:
  i) border control measures;
  ii) environmentally compatible cleaning programmes and facilities;
  iii) appropriate disposal facilities.
- Management regimes for mariculture facilities, ports, harbours and marinas;
- Education and training programmes.

In a number of these areas best practice is emerging in the form of guidelines at national, regional and international levels. In others, the issue is yet to be adequately addressed. Moreover, given the international nature of shipping and the invasive species problem, there is a need for an international approach.

5.1 Anti-fouling systems

Anti-fouling systems have primarily been developed to deal with the economic costs incurred by the respective industries, rather than as a result of concerns over invasive species. Nevertheless, anything which reduces fouling, will contribute to reducing the risk of invasive species introductions. General recommendations regarding anti-fouling systems include the following:

- Anti-fouling coatings must comply with international standards. In the case of shipping this implies those set by the AFS Convention, which currently states that they should not contain organotins. This may be extended to other biocides or controls at a later stage;
- At the national and/or regional level, anti-fouling products should be registered with a regulatory authority and there should be a labeling system for registered anti-fouling products. In Europe for example, anti-fouling products containing biocides are already regulated under the Biocides Products Directive EC 98/8/EC;
- The selection of an anti-fouling system should be based on the vessel type, operations (speed and frequency of movement, etc.), and composition of the hull;

- It may be necessary to use a different coating in niche areas;
- The frequency of re-application of the coating should be based on the manufacturers recommendations, provided that:
    - As a general rule, recreational boats should be recoated annually, and more frequently if damaged;
    - Recreational vessels planning to sail internationally – or even to another domestic region – should have been recoated less than a year prior to departure;
    - International law requires vessels > 500 tonnes to be dry docked twice every five years. These can be used for cleaning and re-application of the AFS;
- Application and removal of coatings for all vessels should be done at facilities above the tidal zone, and with appropriate infrastructure and resources;
- There should be a system for approving facilities, and sale of anti-fouling products should be limited to approved facilities;
- Spraying should not be done in high winds, and sheeting should be used to prevent spray drift;
- Surfaces should be thoroughly cleaned before the coating is repaired or re-applied.

Additional recommendations on niche areas are:

- The angles and corners of sea chests should be beveled, and grates rounded to minimize fouling;
- Grates should be hinged to facilitate access;
- Steam blow-out pipes can also be used to minimize growth in sea chests.

Current guidelines generally suggest using anti-fouling coatings according to the manufacturers' recommendations, but do not provide clear guidance on product selection. What would be useful is an independent system of certification of anti-fouling systems at the international level, or at least a set of standards or criteria for such systems which could then be used as a basis for the development of registers of acceptable products at the national level. This should distinguish between products which are acceptable for use on vessels, and those for aquaculture, for which lower levels of biocide may be required.

The CRAB project evaluated various anti-fouling systems for use in aquaculture, and the European Best Practice in Aquaculture Biofouling – which was an outcome of that project - outlines the advantages and disadvantages of some categories of anti-fouling coatings (biocidal and silicone based foul-release coatings), and reviews other anti-fouling systems. It would be a useful starting point for international guidance in this field.

5.2 Border control measures

A number of countries have recently introduced measures which allow the inspection of international vessels at their first port of call for evidence of hull-fouling. Vessels carrying unacceptable levels of fouling may then be required to undergo cleaning within a specified time period at the port concerned. However, most countries would be unable to inspect all incoming vessels, and it has therefore been suggested that a system of risk assessment be used to assist border officials to target high risk vessels. This could be based on the vessel's:

- maintenance history
- compliance history
- travel history. (Hewitt and Campbell, 2007).

A risk assessment matrix for biofouling is discussed in Godwin (2004). This suggests a series of decisions based on the type of vessel and its history. High priority vessels are in the first instance, those that are slow-moving and which have long port residence times (barges, drilling platforms, pontoons and floating drydocks). Floating drydocks are also subject to frequent change of ownership, and are moved around the world, thus making them an even greater risk. Another category of potentially high risk vessels are those that enter the port on unscheduled visits as a consequence of a medical, mechanical or other emergency. These would then be further assessed on the basis of compliance history, and periods of inactivity.

This information can be provided to the relevant authorities prior to the vessel's arrival, so that they can assess the need for inspection. Where vessels are inspected, the inspection itself could target particular priority species, depending on the port of origin and travel history of the vessel concerned, noting that this would require a database of relevant information to support implementation.

Godwin (2004) also provides some insight into inspection techniques with the initial step being a visual inspection from the pier-side or a boat to rank the level of fouling according to an agreed system – for example, that developed by Floerl *et al*. (2005). A similar inspection of underwater fouling can be made using a remotely operated underwater camera. This initial ranking can be used as a basis for determining further steps – either a more rigorous inspection using divers, or, if significant fouling is already evident, the vessel could be required to undergo cleaning, or leave port.

It is also noted that if a system of inspection and mandatory cleaning is adopted, the country must ensure that it has appropriate cleaning facilities available. Hopkins and Forrest (2008) noted, for example, that in-water cleaning could actually increase the risk of introductions either by failing to remove the fouling material from the water, or by triggering spawning of organisms still on the vessel. Investigations in this regard are ongoing.

Regulations should also require vessels to keep accurate documentation of coating applications and maintenance for verification purposes.

Given that this is a field which is still emerging, guidelines on border control measures – including risk assessment – would be very beneficial.

5.3 Cleaning programmes and facilities and disposal

Historically the cleaning of biofouling has largely taken place in-water for large vessels, and on the beach or quayside for smaller craft. With the heightened concerns over the possible introduction of invasive species from biofouling, these are generally no longer considered acceptable, and the following recommendations have emerged:

- Beaching or encapsulation of boats in plastic for in-water cleaning are NOT recommended;
- Vessels coated with paints containing biocides should NOT be cleaned in-water, and those with biocide-free coatings only in exceptional circumstances;
- Where in-water cleaning is permitted, all material removed (biological and coating) should be collected for disposal on shore;
- In-water repair of minor damage can be considered for commercial vessels;
- Propeller polishing is permissible and should be combined with the inspection of other niche areas.

Regarding on-shore cleaning facilities, the following points have been made:

- Water blasting or vacuum blasting are preferred cleaning methods to the use of chemicals or dry abrasion. Burning should be prohibited;
- Dry dock facilities and on-land cleaning areas for small boats (slipways, haul-outs, etc.) should be bunded and/or have sumps to ensure that all solid and liquid paint residues and fouling material can be contained and/or collected;
- Such facilities should be required to meet specific standards;
- Appropriate facilities should be required at all marinas;
- All material > 1mm must be collected and disposed to landfill;
- Liquid effluent should be collected, coarse pre-screened, treated and discharged to municipal sewer, or recycled for water blasting;
- The treatment of liquid effluents should include multiple settlement tanks – ensuring a residence time of 24 – 48 hours – and should have a salinity of 0 ppt to ensure that none of the fouling species survive;
- Where liquid effluent has to be discharged to sea, it should be fine-screened;
- New facilities should be designed to allow for the treatment of waste water and disposal to sewer, and existing facilities upgraded for the same purpose.

It is noted that the SAFEMED Project Report (Ten Hallers-Tjabbes, 2007), provides very detailed recommendations for cleaning procedures at facilities of four different levels:

i) Fully equipped facilities;
ii) Incompletely-equipped facilities;
iii) Improvised facilities;
iv) Beach cleaning.

While these recommendations have been developed primarily with the toxicity of biocide-based anti-foulings in mind, they could with minor modifications, provide a sound basis for managing invasive species concerns. Indeed, guidelines addressing both aspects are preferable.

5.4 Management of mariculture facilities

While biofouling is a serious, and ongoing, economic problem for the aquaculture industry, it is suggested that the role of aquaculture equipment in translocating invasives could be managed by placing restrictions on the movement of such equipment. A number of observers noted that the movement of equipment from one area to another is in any event, not a common practice and when it is moved, it must be cleaned and dried (E.Black, pers com.). A second option might be to introduce standards for cleaning of equipment prior to it being moved.

5.5 Ports, harbours and marinas

While considerable work has been done on the development of anti-fouling systems and cleaning methodologies for the shipping and aquaculture industries, relatively little attention seems to have been paid to the fact that ports, harbours and marinas facilitate invasive species introductions, or how this could be managed. Floerl and Inglis (2003) have suggested that harbour design can exacerbate hull fouling by influencing the rate of recruitment of fouling organisms. Apart from looking at design features, there could be a case for requiring a separation of berths for domestic and foreign vessels.

Certainly commercial ports and harbours play an important role in keeping records of vessel movements. They would be aware of impending arrivals, and would normally be required to notify the authority responsible for vessel inspections. This is not necessarily true for marinas and, with the proliferation of recreational craft, and the growing evidence of the risk they pose in terms of species introductions, the regulation and management of marinas seems to be an area requiring further investigation.

5.6 Other coastal areas

While most commercial vessels, if they are not just passing, are likely to stop over in ports or in their vicinity, smaller vessels, and yachts in particular, may just anchor off the coast, especially around small islands and in more remote areas. Although there would be difficulty in enforcing regulations in such situations, guidelines for vessels visiting sensitive areas should be considered in combination with an outreach and education campaign.

5.7 Marine debris

While marine debris is a potentially significant vector for invasive species, the management thereof lies in trying to prevent the debris in the first place, rather than in trying to prevent fouling thereof. There are a number of initiatives in this regard, and it is therefore not addressed further here.

In conclusion, the recognition in recent years that, regardless of advances in anti-fouling systems, biofouling remains a significant pathway for the introduction of invasive species, has given rise to a number of initiatives to develop guidelines and regulations. Nevertheless, there are some gaps which should be addressed. Moreover, the existing initiatives could be immeasurably strengthened if a) they are brought together with those initiatives looking at biofouling from other perspectives; and b) there is global cooperation on the matter. While the IMO has initiated discussions, they are limited to the (mainly marine) shipping industry.

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7. ANNEXES

7.1 Summary of Definitions

Many terms used in marine bioinvasion management are straightforward. Together with those addressed above, they can be summarily defined as follows:

Advection	Horizontal and vertical dispersal of organisms, propagules, particles, heat, etc., by the movement of oceanic, coastal, estuary or riverine water currents.
Alien species	A species which has been introduced into a new geographic area (or ecosystem) outside of its natural distribution range (non-native, non-indigenous).
Anthropogenic	Directly or indirectly caused by any type of human activity.
Aquaculture	Farming of aquatic organisms - typically involving interventions in the rearing process to enhance production and growth, such as stocking, feeding, disease/predator protection, etc. Implies individual or corporate ownership of the farmed stock (www.fao.org/docrep/t8582e/t8582e03.htm).
Aquatic species	Any organism which spends all or significant parts of its lifecycle in fresh, brackish or marine waters.
Aquatic nuisance species	Defined in the US NANSPC Act 1990 as: "…a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters". Has same meaning as *Harmful marine species* and *Marine pest*.
Ballast water	Any water and associated sediment used to manipulate the trim and stability of any vessel (including modern ocean racing yachts).
Baseline port survey	A biological survey aimed at finding and identifying all introduced marine species that may be present in a port (see Targeted port survey).
Benthic	Relating to, or inhabiting, the seabed.
Bilges, bilge spaces	The lowest internal portions of a vessel's hull.
Bilge water	Any water and other liquids that accumulate in the bilge spaces.
Biofouling	Aquatic organisms attached or nestling on or in man-made hard substrates which are then immersed in water, such as ship's hulls and associated structures including the internal seawater pipe work, anchor well, cable locker, bilges, etc.
Biological control	Control of pests and weeds by another organism (insect, bacteria, virus, predator, etc.), by a biological product (hormone), or by genetic or sterility manipulations. Classic biological control uses a host-specific pathogen, parasite or predator obtained from the native range of the targeted pest.
Bow or stern thruster	A propeller or water jet device set into the hull to improve manoeuvring or assist accurate positioning.
Commensal organism	Any plant or animal that lives as a 'tenant' of other organisms but not at their expense (see *Parasite*). Commensals providing mild or essential benefits to their 'partner' organism form a *Symbiotic relationship*.
Cosmopolitan species	A wide-ranging species found in at least two ocean basins, often displaying a broad temperature tolerance. Often *Cryptogenic* in parts of its range.

Cryptogenic species	A species which is neither demonstratively native nor introduced in one or more regions. Includes many *Cosmopolitan* species.
Endemic species	A species with a native distribution restricted to the bioregion/s of interest as a result of one of several biogeographical speciation mechanisms.
Endophyte	An organism growing inside a plant, such as an internal fungus.
Eradicate	To remove entirely, completely destroy, extirpate, get rid of.
Escapee	Any organism inadvertently allowed to pass through barriers designed to prevent their escape or release of propagules, such as escapees from public or private aquaria or research laboratories
Established introduction (see *Introduced species*)	An alien or Non-native species that has established at least one self-sustaining viable population in the region of its introduction.
Exotic species	Ambiguous term for describing an alien or Non-native species. Can invoke misunderstanding by implying a tropical origin and rareness. Originally used for spices, foods and plants with a striking smell, taste or coloration of tropical/subtropical origin (Exotica: excitingly different). See *Ornamental*.
Feral species	Any aquatic or terrestrial species which has established a population in the wild from previously domesticated or cultured populations .
Fouling organism	Any plant or animal that attaches to natural and artificial substrates such as piers, navigation buoys, pilings or hulls. Includes crawling and nestling forms as well as seaweeds, hydroids, barnacles, mussels, bryozoans etc.
Harmful marine species	Defined in the IMO *Ballast Water Convention* as: “Aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into fresh water courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas”.
Incursion	Unauthorised entrance or movement of a non-native species into a region or country where it is not already established. See *Interception*.
Indigenous (native) species	Naturally distributed within the region of interest, with a longterm presence extending into the pre-historic record.
Inoculation	Any *ballast water* discharge or transfer of biofouled material containing organisms not native to the receiving environment.
Integrated pest management	Long term application of a combination of chemical, physical, biological and/or habitat interventions to control the density or distribution of a pest.
Intentional introduction	Purposeful transfer or deliberate release of a non-indigenous species into a natural or semi-natural habitat located beyond its native range.
Introduced species	Any species whose movement into a region beyond its native range was directly or indirectly assisted by human activity, intentionally or otherwise. (includes species which make a self-mediated range expansion because of a new canal, waterway or anthropogenic climate change).
Invasive species	Any *introduced species* which establishes and spreads in the geographic area to which it has been introduced causing damage to the ecology, economy and/or health.
Mariculture	A type of *Aquaculture* involving estuarine or coastal water farming of any brackish or marine species.
Marine pest	Used frequently in Australian and NZ government publications and other literature to describe a noxious invasive marine species that threatens environmental, economic or social values (see *Aquatic*

	Nuisance Species; *Harmful Marine Species*).
Non-invasive species	An *Introduced species* that remains localised within a new environment and shows little propensity to spread despite several decades of opportunity.
Noxious species	Another term used in government legislation for listing unwanted species which are subject to regulations attempting to control their import or spread.
Ornamental species	Decorative plants and animals with unusual or eye-catching features that are selectively bred, imported or genetically modified for display in gardens, parks, ponds or aquaria.
Parasite	Any fungus, plant, protozoan or metazoan animal that lives within (endoparasite) or on (ectoparasite) a living organism (host) and draws its nutriments directly from it. Typically reduces its host's fitness, growth, fertility and/or survivorship (c.f. *Commensal organism*).
Pathogen	Any protozoan, bacteria, virus, particle or other aetiological agent causing illness or *Disease*.
Pathway	Mechanism or route by which an organism disperses with the aid of human activities
Pelagic	Relating to, or inhabiting, the water column of open coastal waters or seas.
Pest	Any troublesome, noxious or destructive organism; a bane, 'curse' or 'plague' species (see *Aquatic Nuisance Species; Harmful marine species; Marine Pest; Noxious species*).
Pesticide	Any substance or preparation used for destroying a pest (typically associated with insects and rodents, with *herbicides* used for weed killers).
Primary invasion	Initial establishment of an invasive marine species in a disjunct region (i.e. located beyond a land, ocean or temperature/salinity barrier).
Propagules	Dispersal agents of organisms, including spores, zygotes, cysts, seeds, larvae and self-regenerative tissue fragments.
Quarantined species/ organism	Any organism held in a confined or enclosed system designed to prevent its escape or release of associated disease agents or *Commensal organisms.*
Reservoir	An epidemiological term for invasive spcies population/s which breed in uncontrolled locations to provide propagules or recruits that can spread to other areas.
Risk	The likelihood and magnitude of a harmful event
Risk analysis	Evaluating a risk to determine what type and level of actions are worth taking to reduce the risk (often termed the '*Risk assessment*' in the US).
Risk assessment	Undertaking the various tasks required to determine the level of risk (often termed the '*Risk analysis*' in the US).
Risk management	The culture, organisational framework and activities which are directed towards identifying, evaluating and reducing risks.
Risk species	A species known or suspected to become a harmful species if introduced, based on documented outcomes or inductive evaluation of available evidence respectively.
Sea chest	A substantial recess built into a vessel's hull covered by a grill, containing seawater intakes and designed to avoid cavitation and increase pumping efficiency to the cooling circuits. Located well below the waterline and typically near the engine room. Paired and multiple sea chests are common in commercial and fighting ships.
Secondary invasion	Subsequent spread within a new region by the progeny of the initial

	founder population (see *Primary Invasion*).
Stowaway/Hitchhiker	Informal terms for any unobtrusive organism which is hidden from casual view by its location in niches, tanks, pipework, shells of dead animals, anchor wells, lockers, cargo or bilge spaces, containers, freight, luggage, etc.
Symbiotic relationship	When a *Commensal organism* provides mild or essential benefits to its 'partner' organism (Mutualism; e.g. zooxanthellae in reef-building corals).
Target species pathogen	A pathogen typically selected from the native range of a pest species that has been targeted by a biological control or eradication programme.
Targeted port survey	A port survey with sampling regime that is aimed at detecting the presence of one or more specific pest species (see Baseline port survey).
Taxon/Taxa	Any taxonomic group/s (class, family, genus, species, sub-species, etc.).
Topsides	All parts of a vessel's hull above the water line.
Translocate/Translocation	Any deliberate or unintentional transfer of an organism or its propagules between disjunct sites. The ICES 1994 *Code of Practice on the Introductions and Transfers of Species* restricts 'Transfer' and 'Transplant' to a species translocation "*within its present range*" (i.e. both native and introduced ranges). This distinction is not followed in this review.
Unintentional introduction	An accidental, unwitting and often unknowing introduction, directly or indirectly caused by a human activity.
Vector	The physical means, agent or mechanism which facilitates the transfer of organisms or their *propagules* from one place to another .
Vessel	Includes all types of ship, barge, mobile drilling unit, work boat, fishing vessel, yacht, launch, recreational boat, submersible and other craft.

7.2 Examples of existing protocols/guidelines

7.2.1 Protocol for recreational vessels in Australia (adapted)

Background

The Australian Government has directed the Australian Quarantine and Inspection Service (AQIS) to implement protocols to minimise the introduction of exotic marine species into Australian waters.

AQIS will phase in the new biofouling protocols starting with voluntary guidelines from 1st October 2005. The terms of the protocol will be reviewed after about six months and any required modifications will be made before management requirements become mandatory - this will not be before 1st October 2006.

During the voluntary guidelines phase, AQIS will seek to inform vessel operators about marine pest issues and ask vessel operators to share their practical knowledge about hull maintenance methodologies. Information gathered during the voluntary phase will be used to inform the review process.

In this manner, by the time mandatory requirements are ready for implementation, the protocol will stipulate standards for vessel cleanliness that are achievable for operators and effective in protecting the marine environment

Initially, AQIS will regulate only those vessels that have been identified as presenting the highest risk of introducing marine pests through biofouling although proposed legislative changes will enable AQIS to regulate any internationally plying vessel for biofouling. The first group of vessels to be regulated includes:

- Internationally plying vessels less than 25m in length
- Vessels of any size apprehended for illegal activities or rescued in line with Australia's obligations under international treaties.

The Protocol

The requirements of the new biofouling protocol are designed to encourage best practices for yacht maintenance. AQIS recognises that yachtspersons are environmentally conscious and do not wish to be responsible for marine pest translocations.

To meet Australia's biofouling requirements, vessels' hulls and ancillary gear must be clean on arrival in Australian waters. Documentary evidence of cleaning or maintenance performed will be requested by AQIS to assist in the assessing the condition of each vessel.

To achieve the required standards of cleanliness all ancillary gear and internal seawater systems on board should be cleaned to remove biofouling organisms before leaving your last port of call prior to coming to Australia.

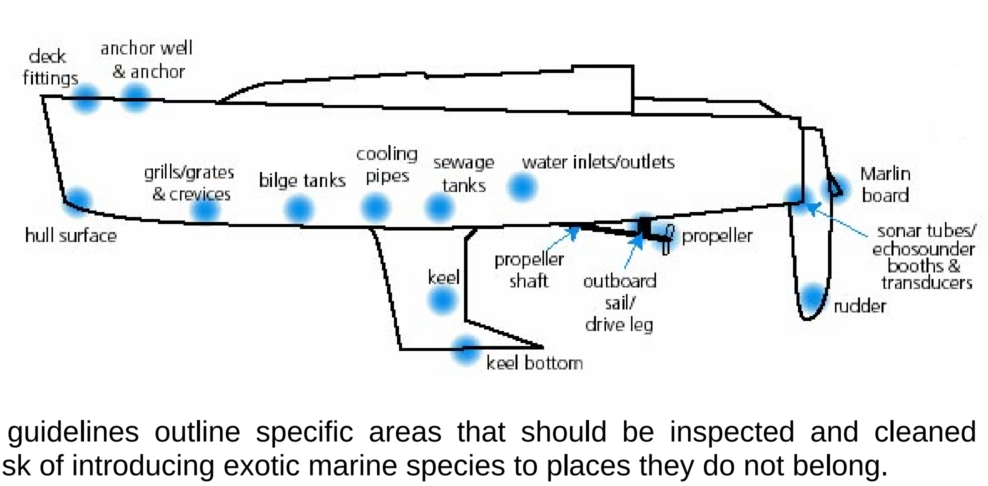
Recommended cleaning practices include:

1. Cleaning the vessel's hull within one month prior to arrival; or
2. Applying antifouling paint within one year prior to arrival; or
3. Booking the vessel to be hauled out and cleaned within one week after arrival.

Note: In-water cleaning of internationally plying vessels in Australian waters is not permitted.

Biofouling Maintenance Guidelines

High risk areas to target on your vessel



The following guidelines outline specific areas that should be inspected and cleaned to minimise the risk of introducing exotic marine species to places they do not belong.

Ancillary gear
In port, ancillary gear may routinely be in contact with salt water and the sea or river bed. Port environments present the best opportunities for biofouling organisms to attach to ancillary gear.

Before departing from your last port of call to come to Australia, ensure that all ancillary gear is scraped, cleaned and washed to remove mud and marine growth – pay particular attention to the following areas:

- tenders;
- outboard motors;
- fenders;
- anchor well;
- anchor, rope and chain; and
- deck fittings.

Internal water systems

Seawater is drawn into yachts for various uses including engine cooling, toilet flushing and for galley requirements. Experience tells us that regular use in port makes internal water systems susceptible to marine biofouling.

Regular treatment to remove marine organisms inside a vessel's internal seawater systems is desirable but, as yet, no effective and suitable universal method has been devised. Research in this area continues under the auspices of the Northern Territory Government and, when an acceptable methodology has been devised, AQIS is likely to adopt it and recommend it to yachtspersons.

In the meantime, there are certain internal piping systems on vessels that are easily accessible – such as sea strainers. These should be regularly cleaned and care must be taken that no live marine organisms that are removed are put back into the sea.

Other internal seawater systems include:

- engine cooling systems
- refrigeration systems
- deck wash systems
- fire systems
- toilet/shower
- desalination plants
- galley sinks

If you are able to gain access to any of these areas safely, you should clean them out regularly ensuring that live organisms cannot re-enter the sea. Care must also be taken not to pollute the sea with chemicals or biocidal agents.

Clean pipes make for efficient machinery as well as protecting the marine environment.

Underwater hull

Most of a vessels' hull is in constant contact with the sea. These areas are at the greatest risk of having marine biofouling organisms attach.

The application of an antifouling coating to a vessel's hull discourages the attachment of biofouling species.

There is a range of different brands and types of antifouling on the market. The application of paints containing tributyltin (TBT) to vessels' hulls has been banned in Australia since

January 2004. After December 2006, vessels with a TBT product on their hulls will be obliged to remove it or entirely seal it in using some other coating. After December 2008, all antifouling paints containing TBT products will be totally banned.

AQIS is interested in learning about the effectiveness of different types of antifouling under different conditions of use and we ask yachtspersons to assist us by sharing their knowledge of such matters during the data collection / voluntary guidelines phase of regulation.

Most antifouling paints these days are “ablative” which is also known as “self polishing”. As a vessel’s hull passes through the water, the surface of the paint slowly erodes, hopefully dislodging any organisms that may have attached. These paints also release tiny quantities of biocidal agents as they erode and these are intended to discourage further organisms from attaching.

Even the best types of antifouling are less effective when a vessel spends a long time in port as a walk around any marina will demonstrate. After a protracted stay in port, it is common for all areas of an underwater hull to have accumulated some level of marine growth. On smooth parts of the hull – especially if a vessel is coated with antifouling – much of this growth will fall off as the vessel moves along. “Niche areas” that are protected from a vessel’s slipstream underway are the most likely to retain fouling organisms as the vessel sails along. These areas include:

- rudder, rudder stock and post;
- propellers, shaft, bosses and skeg;
- seawater inlets and outlets;
- stern frame, stern seal and rope guard;
- sacrificial anode and earthing plate; and
- sounder / speed log fairings.

What to do about hull biofouling?

As discussed above, even vessels whose hulls are coated with antifouling are likely to pick up some fouling organisms if they stay in port for a while. Some of those organisms are likely to remain attached during a sea passage especially in niches around the hull that are protected from the vessel’s slipstream as it sails along.

The best way to ensure that a vessel’s hull will be clean on arrival in Australian waters is to inspect and if necessary clean it before heading this way. The most effective way to inspect and clean a vessel’s hull is by hauling it out of the water so that all areas are accessible for inspection / cleaning. This is not always possible and other methods of inspection/cleaning may have to be used such as snorkelling or using a hookah to examine and, if necessary, clean off any marine growth.

Care of the marine environment outside Australia’s territorial sea

Australia seems likely to be the first nation to introduce requirements for vessels’ hulls to be clean when arriving from overseas. Those requirements will not be brought in until AQIS has gathered sufficient data to enable properly informed policy to be made.

AQIS jurisdiction generally extends to the outer edge of the territorial sea (12nm offshore) although there are some exceptions to this. It is our intention to improve the protection of Australia’s marine environment. We do not wish to do this at the expense of other nations.

Mariners should give due consideration to the marine environments of other nations regardless of any legislative requirement to do so when deciding how to clean their vessels' hulls. If a vessel arrives in any port with a clean hull, any fouling that attaches in that port will be indigenous (or already introduced) to that port. Removing such biofouling should therefore present no threat to the port's environment. Indeed, we understand that many ports provide facilities in intertidal areas for local vessels to careen their hulls.

If a vessel arrives in port with a fouled hull, then the fouling organisms on that hull may well pose a threat to the port's marine environment. Mariners in this situation should clean their vessels' hulls at a proper slipway where material removed can be collected and disposed of away from the sea.

It will always be an acceptable management option for vessel operators to arrange to slip their vessels soon after arrival in Australia - usually within one week for lightly fouled vessels but immediate slipping may be required for heavily fouled vessels arriving from overseas.

Documentation

If you clean or apply antifouling paint to your vessel, keep a record of where, when and by whom the work was done (including paint details). Also retain any receipts from marinas, haul out facilities or chandlers to assist AQIS to verify when the work was done. If you do the work yourself, keep records of what was done, where and when in your vessel's logbook or journal.

AQIS has produced a logbook in which you can record all biofouling maintenance. The use of this document will assist AQIS to assess the condition of a hull during the routine vessel inspection that is carried out on all internationally plying vessels at their first port of call.

Benefits of clean hulls

Regular hull maintenance benefits vessel owners as well as the Australian environment. Boats sail better and faster, resale values are maintained and hulls last longer when they're kept clean. In addition, vessel operators who arrive in Australia with a clean hull won't face the cost of an unscheduled haul out of their vessel.

Why do the new protocols target specific categories of vessels?

AQIS is phasing in the new protocol with high-risk vessel categories first and other categories to follow when addressed through the International Maritime Organization (IMO).

Smaller vessel operators have no legal requirement to maintain their hulls and currently present a high risk of spreading marine pests because:

- Smaller vessels, especially recreational craft, may spend months at a time in port, increasing the potential for biofouling;
- Many smaller vessels proceed under sail at relatively slow speeds; and
- Fuel costs are less of an issue for sailing vessel operators than for larger vessel operators. The reduction of fuel consumption is not so great a motivational factor for operators of smaller vessels to keep hulls clean.

A large number of **foreign vessels engaged in illegal operations** (e.g. people smuggling or unlicensed fishing in Australian waters) are apprehended by Australian authorities annually. Most of these vessels are very poorly maintained and therefore pose a higher risk of introducing exotic marine organisms via biofouling. The risks posed by these vessels will be managed in cooperation with the Royal Australian Navy and the Australian Customs Service.

Larger commercial vessels present a major risk of introducing exotic marine organisms *via* ballast water taken up from foreign ports. For this reason strict laws on ballast water management were introduced in Australia in 2001 to govern these vessels. However, as far as hull fouling is concerned, larger commercial vessels are considered to be less of a risk than other types of vessels, because of the following factors:

- Under international maritime law all vessels over 500 gross tons must be removed from the water twice in every five-year period so their hulls may be inspected for seaworthiness. Operators make use of these opportunities to clean and apply anti-corrosive and anti-fouling coatings to those areas of the hull that are only accessible when out of the water.
- Due to the commercial interests in minimising drag caused by hull fouling (fuel is the biggest expense of operating a commercial vessel) hulls have the highest quality antifouling coatings applied by professional contactors.
- Commercial vessels typically travel between ports at relatively high speeds and port stays are kept as short as possible – often less than 24 hours. This minimises the opportunity for biofouling.

More information

For more information about the new protocol to regulate biofouling please visit the AQIS website: http://www.aqis.gov.au/yachts

7.2.2 Guidelines for recreational vessels in New Zealand

The points listed below are paraphrased from the ***Boaties Guide to Marine Biosecurity***:

i) Vessels should be slipped for cleaning and re-application of anti-fouling paint before sailing from their home ports to another region. As a minimum, the boat should be clear of obvious growth of seaweeds, barnacles, mussels and oysters.
ii) As a general rule, vessels should be cleaned and repainted with anti-fouling annually. Some paints may last longer but, as a rule of thumb, the vessel should never be carrying more than a light slime layer.
iii) As a minimum, the anti-fouling paint should be replaced as per the manufacturer's recommendation, or if the paint has been scraped or damaged.
iv) Vessels should be cleaned out of the water – preferably in a boat maintenance facility - and all biological material removed should be disposed of in a bin which will go to a land-based disposal site.
v) All areas of the vessel normally below the waterline should be hosed and brushed down. Apart from the hull, particular attention should be paid to keels and stabilizers, intakes and outlets, propellers, shafts, rudders, rudder shafts and casings, rudder recesses, anchors, anchor chains, and anchor wells.
vi) The choice of anti-fouling paint should depend on the type of boat and its pattern of use. Factors to be considered include the usual speed of travel, the length of periods of inactivity, and the material composition of the hull.

NOTE: apart from protecting the marine environment, proper maintenance will extend the life of the boat and gear, and reduce running and maintenance costs.

7.2.3 Guidelines for cleaning

The recommendations below are extracted from Woods *et al.*, 2007.

i) Cleaning of vessels should be conducted out-of-water and in a facility where **all** fouling organisms removed are quarantined from the marine environment (i.e., no material removed from vessel hulls should be allowed to aerosol-drift, drain or otherwise move back into the nearby marine environment). Where out-of-water cleaning is not practicable, in-water cleaning should be conducted in such a manner that **all** fouling material removed is collected (ideally down to a particle size of 50-60 micrometres) and disposed of in landfill as appropriate.

ii) **All** macro (> 1 mm) material from vessels cleaned out-of-water should be collected and disposed of in landfill as appropriate.

iii) **All** liquid effluent (runoff) from out-of-water vessel water blasting/cleaning should be collected and treated in a liquid effluent treatment system prior to discharge or recycling for water blaster use.

iv) This effluent should be coarse pre-screeened (e.g. to 1 mm) before entry into the liquid treatment system. This will reduce inorganic and organic build-up within the treatment system and thus maintain system effectiveness (e.g. removal of boundary layer acceleration of suspended particles caused by sediment bed build-up) and extend the period between maintenance sediment removals. Material caught on the pre-screen should be disposed of in landfill as appropriate.

v) **All** liquid effluent should be processed through multiple settlement tanks to facilitate settling out of any marine organisms and particles (i.e. vessel hull paint flakes). Where practicable, settlement tanks should be of large volume (hydraulic capacity) and of appropriate physical design (e.g. use of weirs and baffles) to maximize settlement and allow as long as possible a residency time/exposure time of marine organisms to freshwater before progression to a discharge or fine filtering/screening stage. Residence time of effluent water within the treatment system should be a minimum of 24 hours, but preferably > 48 h. Salinity should be as close as possible to 0 ppt to achieve 100% mortality of most marine organisms. Sedimented material should be regularly removed from the settlement tanks and disposed of in landfill as appropriate. Flocculating and precipitating agents which facilitate separation and removal of positively and negatively buoyant particles can be used if they improve the efficiency of the system. The use of diesel/oil absorbing mats may also be appropriate.

vi) Following coarse screening and passage through settlement tanks, treated effluent may be wasted to a municipal sewage/wastewater system or similar extensive freshwater treatment system for additional treatment rather than direct discharge to sea. This wasting to a municipal sewage/wastewater treatment system (dependant on relevant council restrictions) should further reduce marine organism viability by increasing residence time within freshwater as well as exposing any organisms to other biological and physical treatment processes and contaminants which may kill them (depending upon the nature of the waste treatment system in question).

vii) Where discharge of treated effluent will be directly to the sea, following processing in settlement tanks, **all** liquid effluent should be fine filtered/screened, preferably to a size range of 10 – 20 micrometres, but 50-60 micrometres is an acceptable minimum to remove the smallest of most types of marine organisms before discharge.

viii) As an alternative to discharge of treated effluent to the sea or sewage system, treated liquid effluent could be stored and then recycled for water blasting other vessels rather than discharged. This theoretically increases the residence time of any remaining organisms in freshwater (and thereby reduces their chances of survival) and reduces total freshwater usage by the cleaning facility.

7.3 Masters Declaration for arriving vessels: New Zealand

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NEW ZEALAND MINISTRY OF AGRICULTURE AND FORESTRY
Section 19, BIOSECURITY ACT 1993

MASTER'S DECLARATION

I of the hereby certify that:
(Given Name) (Family Name) (Full Name of Vessel)

1. The origin of all meat on board the said vessel is as follows (attach extra page if required) -

Type of Meat on board (including Poultry and Fresh-water Fish)	Country of Origin

2. The origin of all fresh produce including fruit and vegetables on board the said vessel is as follows (attach extra page if required) -

Type of Fresh Produce on board	Country of Origin	Port and Country of Loading

3. *Garbage* - Do you have a garbage management plan for the vessel Yes

Indicate the garbage control on board the vessel:

Incinerator ☐ Drums ☐ Holding Room ☐ Holding tanks ☐

Galley Shute ☐

Shute discharges into: Sea ☐ Tank ☐

4. The following live animals (including insects, fish, reptiles and birds) are on board the said vessel -

Type of Animals (identifying features)	Number of Animals	MAF Permit or Prior approval details

5. The following pest management programmes are adhered to on board the said vessel -

Pest Management Programme (e.g. baiting or treatment)	Control measures in place (treatment type and application method)

6. To the best of my knowledge and belief the foregoing statements are true and correct in every particular and I am fully aware of the provisions of the Biosecurity Act 1993, section 19.

Dated this day of 20 Time:

Master’s Signature:

NZ Biosecurity Act 1993

Section 19.

Persons in charge of certain craft to obey directions of inspector or authorised person –

(1) This section applies to a craft, and place in New Zealand, if-

(a) The craft arrives in New Zealand there; or

(b) The craft is carrying risk goods that it was carrying when it arrived in New Zealand at some other place.

(2) Where this section applies to a craft and place, the person in charge of the craft shall-

(a) Obey every reasonable direction given by an inspector as to-

  (i) The movement of the craft in the place; or

  (ii) The unloading or discharge of risk goods or the disembarkation of crew or passenger from the craft; or

  (iii) Measures (including any bond required under section 18 (2) of this Act) to ensure that any risk goods not intended to be unloaded or discharged from the craft are maintained in a secure place under the control of that person; and

(b) Within the required time or times, deliver to an inspector a report, in such manner and form, and containing such particulars verified by declaration, and with such supporting documents, as may be required; and

(c) Answer all questions relating to the craft or its cargo, crew, passengers, stores, or voyage, asked by an inspector;-

and every person disembarking from the craft shall, on request by an inspector, make his or her baggage available for inspection by the inspector.

Section 18.

(1) The person in charge of any craft that arrives at a place in New Zealand-

(b) Shall prevent risk goods from leaving the craft without the permission of an inspector.

(2) The person in charge of any such craft shall, if so required by an inspector, pay a bond for such amount not exceeding $10,000 as the inspector may require to secure due compliance with subsection (1) (b) of this section.

Privacy Statement

Information sought on the New Zealand Master's Declaration and associated crew and passenger lists for arriving vessels is required to administer the Biosecurity Act 1993 (the Act) . Collection of this information is authorised by s 19 of the Biosecurity Act and failure to provide information may be an offence under the Act. The Ministry of Agriculture and Forestry will not disclose any personal information unless it is in accordance with New Zealand law.

The Privacy Act 1993 provides rights of access to, and correction of, personal information held in readily retrievable form. Should you wish to exercise these rights please contact MAFBNZ at vra@maf.govt.nz

7.4 Regional Guidelines

7.4.1 Hull fouling guidelines for the Mediterranean region (an extract)

Encourage the development of national strategies and plans for responding to actual or potential threats from alien invasive species introduced in the hull fouling of vessels, within the context of national strategies and plans for the conservation of biodiversity and the sustainable use of its components. These strategies may include:

- Routine vessel monitoring to document the risk of species invasions in hull fouling.
- Identification of vessels which are likely to carry high risk species in their hull fouling (risk assessment).
- Identify ports which receive a large number of "critical" vessels.
- Evaluate hull treatment methods for "critical" vessels.
- Make all dockyards and scrapyards operators aware that organisms removed from ship hulls should be collected and discharged safely on land.
- Strongly encourage marina operators to apply the proposed guidelines.