CHAPTER 6: SMALL CRAFT AND THE SPREAD OF EXOTIC SPECIES

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1. Introduction

Over the past centuries, an increasing number of marine non-indigenous species (NIS) have been recorded from urban and port environments worldwide (Cohen & Carlton 1988; Cranfield *et al.* 1998; Hewitt *et al.* 1999; Coles *et al.* 1999; Godwin 2003). This spread has for many species been attributed to shipping. Ships are capable of spreading exotic species in ballast water (taken on board to provide stability at sea) or attached to submerged hull surfaces (hull fouling). Worldwide, more than 2,000 different species have been identified from hull-fouling assemblages (Visscher 1927; Allen 1953; Skerman 1960; Gollasch 2002). Despite a likely decline in the rate of species transfers on ship hulls through the development of modern toxic 'antifouling paints', NIS continue to be transported on the hulls of domestic and international vessels (Rainer 1995; Ruiz *et al.* 1997; Coutts 1999).

Despite the large numbers of private and commercial small craft in coastal locations worldwide, managers so far have focused almost exclusively on large ships as vectors. The role of small craft in the transport of NIS has only recently become acknowledged and has only been investigated in a few studies (James & Hayden 2000; Floerl 2002; Floerl *et al.* in press a). In freshwater environments, private small craft are known to facilitate the spread of both aquatic invertebrates and plants. Trailered overland boat traffic between rivers and lakes is the main means by which recreational vessels spread the zebra mussel (*Dreissena polymorpha*) and some exotic macrophytes through New Zealand, the US and Ireland (Johnstone *et al.* 1985; Johnson *et al.* 2001; Minchin *et al.* 2003). Transport of these taxa occurs primarily by entanglement of fragments or individuals snagged in fishing gear, anchor chains and boat trailers. In contrast, transport of marine organisms on small craft is mainly by attachment (fouling) to submerged parts of the hull. In many countries, organotin-based, highly effective antifouling paints have not been permitted on vessels <25m in length since the mid-1980s due to impacts of tributyl tin (TBT) on aquaculture production (Champ & Lowenstein 1987). Small craft owners have had to rely on the less effective copper based products.

Yachts, motorised craft and small commercial vessels are normally held at marinas or on moorings in sheltered bays, estuaries, lakes and rivers. These environments have suitable conditions for establishment and the subsequent spread of fouling organisms. Marinas provide a wide and extensive range of hard surfaces for attachment that include breakwaters, pontoons and pilings. A typical marina holds 100-1,000 small craft and many are idle for extensive periods (weeks to months) and some are poorly maintained (Floerl 2002). This contrasts with large ships normally in port for hours to days (Coutts 1999). Many common fouling organisms can survive transport on vessel hulls for considerable distances (Allen 1953; Crisp 1958; Carlton & Hodder 1995; Gollasch & Riemann-Zuerneck 1996; Apte *et al.* 2000).

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In this chapter, we examine hull fouling on small craft as a transportation vector for NIS in widely dispersed regions including temperate and tropical environments. We provide summaries of NIS incursions associated with small craft movements, outline the factors that make small craft susceptible to fouling, document a recent general increase in the abundance of small craft and associated industries, discuss the likely dispersal routes of NIS by small craft and make recommendations for managing the risks of small craft fouling and NIS transportation.

2. Incursions of non-indigenous species associated with small craft movements

Over the past three decades, private and commercial small craft have been implicated in the spread of a number of aquatic NIS that includes both animals and plants (Table 1). Spread of these species has occurred in marine, brackish and freshwater environments, with transportation of organisms by hull fouling, entanglement on projecting equipment or from fragmentation or drop-off of individuals.

Fouling of hulls is the principal mode of transmission for many marine and freshwater animal and plant NIS, and this includes the movements of small craft with examples from most world regions (Table 1). Founder populations have become established within commercial shipping ports and marinas. These species may subsequently spread along coastlines or to remote embayments as a result of natural dispersal, aquaculture stock movements, shipping and small craft. Occasionally as in the case of the *Mytilopsis sallei* invasion to Darwin, Australia, the introduction will have been as a result of a primary inoculation, in this case by overseas yachts in March 1999 (Thresher 1999).

Small craft are also likely to have also contributed to the spread of NIS having become entangled in fishing gear or on anchor chains. The mutant form of the green alga (*Caulerpa taxifolia*) was first observed in the Mediterranean Sea near a public aquarium in 1984. By 2003, the species was found on the coasts of six Mediterranean countries: spreading from Monaco to France, Italy, Spain and Croatia and Tunisia (Ribera Siguan 2003). *C. taxifolia* is often retrieved with anchors and so could have been carried in this way from the Ligurian Sea to the Balearic Islands, a known leisure craft route (Cornell 2002). Even releases of small algal fragments, tolerant of being held within anchor lockers, can result in new populations (Sant *et al.* 1996). Fragments entangled in commercial fishing nets, often cleaned while in harbour, could also create new populations (Ceccherelli & Cinelli 1999; Relini *et al.* 2000; Meinesz *et al.* 2001).

It is indeed possible that diseases may be spread with small craft. At present the evidence for this is inconclusive but requires further investigation and this aspect should be included in risk assessments in the management of living resources. The viral disease, infectious salmon anaemia (ISA), can be transmitted without direct contact by wild and reared salmonids (Jones & Groman 2001) and well-boats (boats with slatted openings to cargo holds allowing a continuous water exchange) used to carry salmon smolts may be responsible for this virus transmission between fish-farms (Stagg *et al.* 2001). A further example is from barge movements that may have transmitted a disease of oysters to neighbouring bays on the southwest coast of Britain (Howard 1994). The spread of the white spot syndrome virus (WSSV) in the Indo-Pacific and Central America may also be spread to neighbouring areas by crustaceans acting as carriers fouling boat hulls.

Table 1. Documented cases of NIS introductions where small craft have been recorded or implicated in their spread.

Species	*Native range*	*Introduced to*	*Spreading pattern*	*Impacts*	*References*
Caulerpa taxifolia	Strain evolved from aquarium industry	Mediterranean Sea	Secondary spread with small craft and fishing vessels.	Forms dominant stands and excludes other biota.	Ribera Siguan 2003; Sant *et al.* 1996; Meinesz *et al.* 2001.
Sargassum muticum	Japan, Korea, China, SE Russia	NE Atlantic, NE Pacific,	Secondary spread with oyster movements and small craft.	Forms dominant stands, exclusion and hydrography changes.	Wallentinus 1999.
Undaria pinnatifida	Japan Sea, Korea, China, SE Russia	New Zealand, Australia, Northern Europe, Argentina	Port, marina and natural environments. Natural, boat and shipping mediated dispersal. Local spread with small craft and aquaculture stock movements.	Possible displacement of native algal species.	Hay & Luckens 1987; Fletcher & Farrell 1998; Curiel *et al.* 1999; Talman *et al.* 1999; Forrest *et al.* 2000, Wallentinus 1999.
Mytilopsis sallei	Central America and Caribbean	Australia, India	Invasive within enclosed environments and estuaries.	Nuisance fouling, displacement of native species.	Ganapati *et al.* 1971; Rao *et al.* 1989 ; Thresher 1999; NIMPIS 2002a.
Perna viridis	Indo-Pacific	Australia, Gulf of Mexico and Carribbean	Alongshore dispersal and with craft.	Nuisance fouling, displacement of native species.	NIMPIS 2002b; Neil *et al.* 2002.
Dreissena polymorpha	Ponto-Caspian river basins	Northern Europe and North America	Secondary spread via waterways or overland transport of small craft, downstream dispersal.	Nuisance fouling, displacement of native species.	Kinzelbach 1992; Minchin *et al.* 2003; Pollux *et al.* 2003.
Caprella scaura	Australia	Northern Adriatic Sea	Local spread by small craft fouling.	Unknown.	Hale 1929; Sconfietti & Danesi 1996; Sconfietti *et al.* (in press)
Tricellaria inopinata	Probably Pacific origin	Northern Europe	Secondary spread by fouling of naval and recreational vessels.	Nuisance fouling, displacement of native bryozoans.	d'Hondt & Occhipinti Ambrogi 1985; Occhipinti Ambrogi 1990; Dyrynda *et al.* 2000; De Blauwe & Faasse 2001; Fernández Pulpeiro *et al.* 2001.
Watersipora subtorquata	Largely unknown	Australasia	Fouling of commercial and recreational vessels. Provides a non-toxic substrate for other species.	Increased drag, enhanced fouling.	Allen 1953; Banta 1969; Gordon & Mawatari 1992; Hewitt *et al.* 1999; Floerl 2002; Wisely 1962; Ng & Keough 2003.
Elminius modestus	Australasia	Northern Europe	Secondary spread to harbours and remote bays by commercial and recreational vessels.	Increased drag.	Beard 1957; O'Riordan 1996.
Ficopomatus enigmaticus	Indo-Pacific	Europe, New Zealand, Australia	Secondary spread to estuaries and lagoons by ships and small craft.	Nuisance growths on hulls and navigational structures.	Kilty & Guiry 1973; Read & Gordon 1992.

3. Hull fouling on small craft: influencing factors and prevalence in locations worldwide

3.1 SMALL CRAFT MARINAS – SOURCES OF FOULING

Generally, private and commercial small craft are moored within designated small craft harbours ('marinas') or on pile or buoy moorings within or near commercial ports (Richardson & Ridge 1999; Floerl 2002). Most modern marinas consist of floating pontoons held in place by arrays of vertical piles or chains. Marinas are often surrounded by protective breakwaters or other wave-dampening devices (Floerl & Inglis 2003). These structures of concrete, wood and metal provide horizontal, vertical, subtidal and intertidal habitats for sessile organisms, under varying conditions of shelter. Most marinas give berthing for 100-1,000 vessels that supply an extensive surface area of artificial hard-substrate habitat; in some localities this may exceed the area for attachment granted naturally. A marina with 250 berths can have ~3,600 m^2 of pontoon and piling surfaces. The largest marina in the southern hemisphere, New Zealand's Westhaven Marina, has 1832 berths and supplies ~31,000m^2 of settlement space (Richardson & Ridge 1999). Pontoon and piling surfaces in most marinas are usually fully occupied by fouling assemblages (Floerl 2002).

3.2 HUMAN FACTORS INFLUENCING HULL FOULING

Any vessel used in the sea requires some means of reducing the growth of fouling or of damage to the hull by boring organisms. A frequent method for many small craft is to remove them from the water after each short period of use. However, for many craft this approach is not practical. Therefore, virtually all vessels that are permanently kept in seawater use toxic antifouling paints that are applied to submerged parts of the hull and that temporarily prevent the accumulation of fouling assemblages. Depending on the type of antifouling used, these paints can usually prevent hull fouling for periods of 9-18 months given regular use of the vessel (Floerl 2002). Data on antifouling paint ages on yachts sampled in New Zealand and Australia indicate that the potential for hull fouling is considerable. Of 920 yachts surveyed, 51% had an antifouling paint aged >9 months, and on 25% of these yachts the paint was older than 18 months.

Once fouling assemblages have developed on vessel hulls, they are normally removed via a combination of manual scraping or scrubbing with wire brushes, and using high-pressure water jets. Following fouling removal, new antifouling paint is usually applied to the hulls. However, this process is costly and generally amounts to US$~1,000 per boat annually. This is because vessels must be removed from the water and because good quality paints are expensive. The cleaning of hulls alone by using snorkellers/divers or by careening (tidal dry-out) is cheaper. However, there are only short-term benefits if the hull is not also painted. This is because the hull is seldom entirely cleaned using these methods. Commonly, traces of barnacle and oyster cement, byssal threads and soft tissues of sponges, hydroids or ascidians may remain and act as positive settlement cues and non-toxic platforms for a range of larvae (Burke 1986; Pawlik 1992). In an experiment conducted in Queensland, Australia, yacht hull surfaces that had been cleaned by scraping and brushing attracted six times more fouling organisms (recruits/cm^2) over a 14-day period than surfaces that had been cleaned using the same method but subsequently sterilised (Floerl *et al.* in press a). Small craft that periodically have their hulls cleaned manually in the water thus have an enhanced potential to transport fouling species between places. In Australia and New Zealand, 53% of 920 yachts sampled had their hull manually cleaned by divers in the past (Floerl 2002).

3.3 ENVIRONMENTAL FACTORS INFLUENCING HULL FOULING

The protection of many marina basins by continuous breakwalls can cause a local entrainment of water and propagules during periods of rising tides, resulting in a localised concentration of larvae and enhanced rates of recruitment (Floerl & Inglis 2003). Craft residing in such marinas tend to develop fouling assemblages that reflect the surrounding populations on pontoon and piling surfaces. Floerl and Inglis (2005) found a positive relationship between (i) the age of the antifouling paint on the vessels' hulls and the time they have resided in a marina, and (ii) the number of sessile species occurring on marina surfaces that had colonised the hulls of these vessels. However, this relationship may be altered by severe disturbance events. Severe freshwater flooding, such as that associated with the monsoonal season in the tropics, can kill off a substantial proportion of the fouling assemblages on marina surfaces and resident vessel hulls, overriding the influence of antifouling paint age on fouling abundance.

3.4 PREVALENCE OF HULL-FOULING ORGANISMS ON SMALL CRAFT IN LOCATIONS WORLDWIDE

Since it is difficult and expensive to prevent the colonisation of small craft hulls by sessile marine animals and plants, it is not surprising that the prevalence of hull fouling on these vessels is quite high (Table 2).

Table 2. Sessile marine taxa encountered on small craft hulls in Italy (five marinas), Ireland (four marinas), Spain (two marinas), Hawaii (two marinas) New Zealand (five marinas) and Australia (three marinas).

	Italy[1]	*Ireland*[2]	*Spain*[2]	*Australia*[4]	*Hawaii*[2,5]	*New Zealand*[4]
Number of craft sampled	15	132	96	70	139 & 12	783
Number of species	n/a	n/a	n/a	45	n/a	n/a
Macroalgae	+	+			+	+
Sponges	+	+	+	+	+	+
Hydroids		+	+	+	+	+
Anthozoans		+				
Serpulids	+	+	+	+	+	+
Other polychaetes				+	+	+
Barnacles	+	+	+	+	+	+
Amphipods	+	+		+		+
Isopods	+					
Tunicates	+	+	+	+	+	+
Bryozoans	+	+	+	+	+	+
Bivalves	+	+	+	+	+	+
Fish eggs	+					

[1] Savini and Occhipinti-Ambrogi, unpubl. Data, [2] Minchin, unpubl. Data, [3] Floerl *et al.* 2005; Floerl unpubl. Data, [4] Floerl 2002, [5] Godwin *et al.* 2004.

In Italy, 40% of 623 small craft sampled in marinas on the North Adriatic coast had fouling assemblages on their hulls (Savini & Occhipinti Ambrogi unpubl. data) (Figure 1). In Ireland, yachts used in competition were found devoid of noticeable fouling whereas those that were not used for racing could carry extensive fouling assemblages (Dan Minchin pers. obs.). All of the seventy domestic and international yachts surveyed by Floerl (2002) in Queensland

(Australia) were fouled. During 2002 and 2003, a total of 783 international yachts were surveyed upon their arrival in New Zealand; 14.5% of these vessels were found to have fouling organisms on their hulls (Floerl *et al.* 2005). In all six international locations, representative species of most sessile marine taxa were sampled from small craft hulls, and the area occupied by fouling assemblages ranged from 1% up to 97% of submerged hull surfaces (Floerl 2002; Table 2).

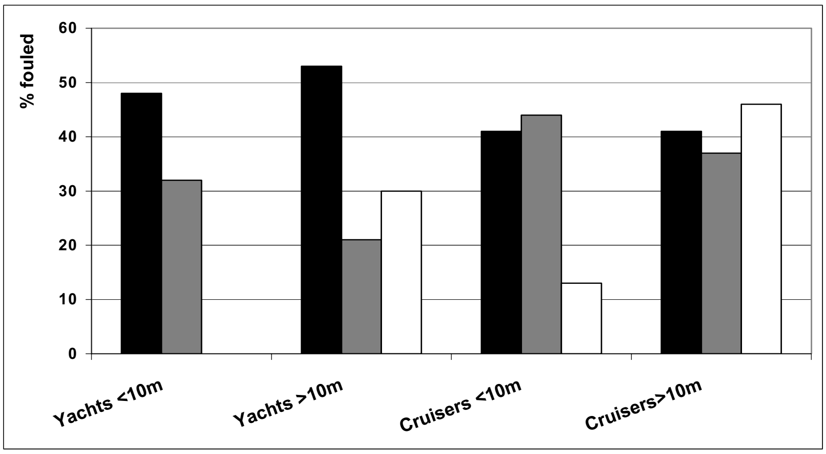
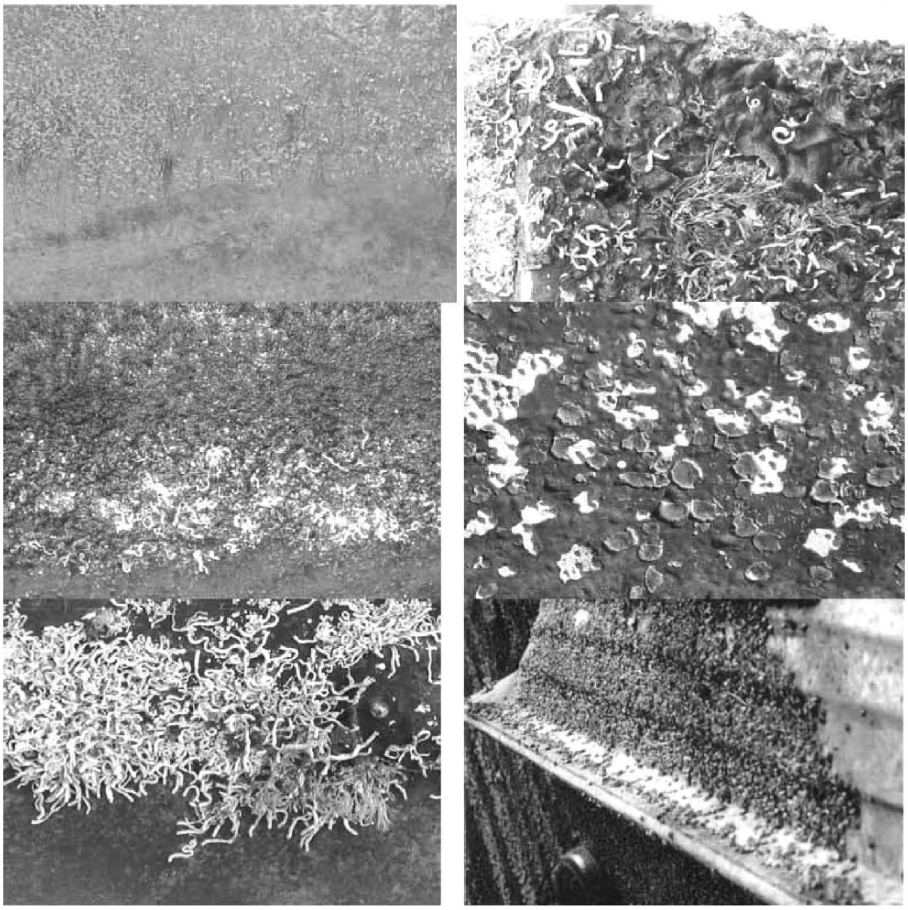


Figure 1. Percentage of craft (to 30 m) found fouled at three marinas in the Northern Adriatic Sea. Total boats examined: Aprilia (black) – 111, Cesenatico (grey) – 292 and Fano (white) – 220.

3.4.1. *Fouling of hulls*

Yachts within marinas in Ireland, Spain and Hawaii were examined under calm and good light conditions from pontoons. Levels of fouling were arbitrarily defined on a four-point scale from no noticeable fouling to heavy incrustation (Plate 1). These surveys were followed up with boatyard studies to score the principal fouling taxa.

Plate 1. Hull fouling of small craft showing relative fouling levels used in surveys. Left-top: no noticeable fouling, some diatomaceaous films some occasional algal filaments. Left-middle: some fouling – invertebrates and/or algae clearly visible with <33% cover. Left-bottom: moderate fouling with protrusion from the surface with <66% cover. Right-top: heavy fouling – extensive protrusion from the hull surface normally composed of several species and with up to 100% cover. Right-middle: fibre-glass hull demonstrating damaged gel-coat and osmosis blistering and basal plaques of barnacles which if untreated would provide a suitable surface for the development of heavy fouling over a short time-period. Right-bottom: Angling boat with zebra mussel attachment after two summers and a winter in water.



Greatest fouling occurred in the warmest water. There was an accretion of fouling on heavily fouled craft in Hawaii sufficient for pufferfish to feed on (Figure 2). Crusts of barnacles, molluscs and tube-worms were common and of red algae to 60 cm in length. Whereas in the Mediterranean Sea yachts had less fouling protruding from the hull but had algal films and fine filamentous green algae on which mullet appeared to feed. In Irish waters at Crosshaven, an estuary, the levels of fouling were less using the observation method used (Figure 2). However, on occasion, algae and tunicate fouling can be extensive on idle craft at sheltered marine sites. Thus, it would appear that the level of fouling on yachts in different world regions varies, with less in cooler regions. Reasons for this variation could be due to the influence of temperature on the generation time of the principal biota and paints becoming less effective sooner in warmer seas. There are some other contributory factors. Fibre-glass hulls should contain <0.5% water under the outer gel coat. This level can increase with prolonged immersion and can be prevented with periodic removal from the water. Where this is not done blisters can form (osmosis) and break away to leave roughened pits on the hull surface that can enhance opportunities for fouling biota attachment (Plate 1)

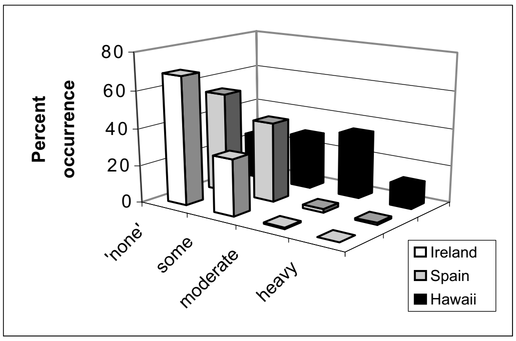


Figure 2. Relative levels of fouling at marinas in Crosshaven, Ireland (132 craft); Mallorca, Spain (139) and Honolulu, Hawaii (36) (Minchin unpub.).

3.4.2. *Seasonal movements*

Compilation of data from yachts visiting Hawaii during a 2-year period show that, from all source regions, there are trends by season. The main feature for craft is the avoidance of periods with tropical storms.

In Mallorca, berthing charges are high due to local congestion. In advance of the winter period many small craft overwinter at marinas in the south of Spain or in Turkey.

There are specially constructed ships for the transport of dozens of small craft at one time. These behave like floating dry-docks and, following changes in the water ballasting, enable small craft to 'swim-on' and 'swim-off'. Craft may be transported between north and south Europe, to either side of the Atlantic and between the Atlantic and Pacific Oceans in this way. These services are provided throughout the year and are popular for cruisers that otherwise would require large amounts of fuel for such journeys and in the smaller cruisers fuel space would compromise the living space aboard. It is not known what potential for NIS transmission such craft movements have. Movements from the Mediterranean to the Caribbean are favoured following the hurricane season.

4. Long distance routes and global patterns of small craft movements

4.1 VOYAGES

The majority of small craft long distance voyages are undertaken by sailing yachts. Yachts travel at comparatively low speeds compared with large engine powered commercial ships, and fouling assemblages acquired in coastal environments are generally not dislodged by drag when the vessels are under way. There are some specific patterns and situations that determine the passage of yachts across oceans:

- Yachts follow specific routes to take advantage of wind speed and direction and ocean current patterns to reduce the number of travelling days. The most practical overall route on world cruises is to sail westwards. Sailing craft generally follow the trading routes of former sailing ships that are likely to have regularly carried particular suites of fouling species (Cornell 2002).

- Tropical storms such as cyclones of hurricanes develop in tropical latitudes during parts of the year (the monsoonal period generally ranges from December to March). The tracks of these storms tend to be from east to west and veering northwards in the Northern Hemisphere and southwards in the Southern Hemisphere. Cruising in such areas at these times is unwise and normally avoided.

- A world trip will take two or more years. This requires extensive planning.

Given the popularity of established routes for intercontinental sailing trips, and the need for having to avoid certain regions on account of tropical storms, yachtsmen plan their routes to reduce the risks that can arise in poor sea states (Figure 3). For example, in New Zealand, visiting yachts move south from abroad to arrive between October and December to avoid the austral tropical cyclone season. The number of international yacht arrivals to New Zealand has increased considerably from <10 to over 450-550 over the past 30 years (Grant &Hyde 1991). Most (~ 95%) international yachts arrive at Opua, in the Bay of Islands. The previous destinations of 783 international arrivals sampled in 2002-2004 included 31 tropical South Pacific regions, notably Fiji (34.5% of all arrivals), Tonga (32%), a range of tropical Pacific island nations (20%), Australia (8.2%) and Vanuatu (2.8%). Prior to sailing to New Zealand, these yachts spent from 1 day to 6 years in these locations (median: 21 days; Floerl unpubl. data), and 14.3% arrived with visible fouling on their hulls (Floerl *et al.* 2005). Many of the fouling organisms on these yachts, acquired in tropical environments, are unlikely to survive in the colder New Zealand waters. However, some (~ 7% of total) yachts arrived from the similar temperate and sub-tropical Australian ports of Hobart, Sydney and Melbourne. These locations contain known invasive species that include the European crab (*Carcinus maenas*), the Japanese seastar (*Asterias amurensis*), the Mediterranean fanworm (*Sabella spallanzanii*) and the alga (*Caulerpa taxifolia*) (Hewitt *et al.* 1999). If imported to New Zealand on vessel hulls, these species may be able to survive in coastal waters.

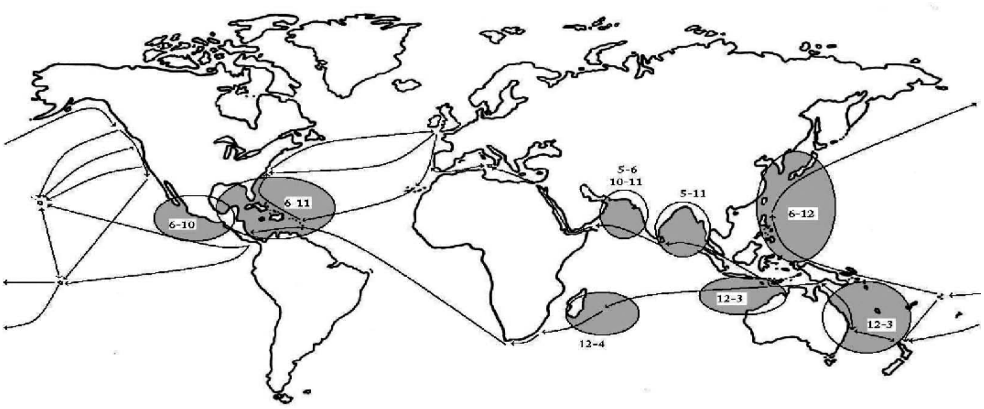


Figure 3. Principal world yachting routes (arrows) and storm regions (shaded areas). Months of storms arranged numerically. (Data from Cornell 2002)

Small craft arrive at the Big Island or Oahu in the Hawaiian Islands at all times of year. A study of a sample of yachts over a two-year period showed the majority arrived during the months from May to July (Godwin *et al.* 2004) (Figure 4). Arrivals at this time avoid the tropical storm periods on either side of the Pacific Ocean. The smaller numbers arriving during August to October may be due to planning to avoid the storm periods and will have arrived earlier. Interviews with five boat skippers living aboard in Waikiki Marina confirmed this view. The storm periods in Australasian waters covers a period from December to March. The majority of vessels (50%) arrive from the east (the main around-the-world route) and 33% from the south (Figure 5) (Godwin *et al.* 2004).

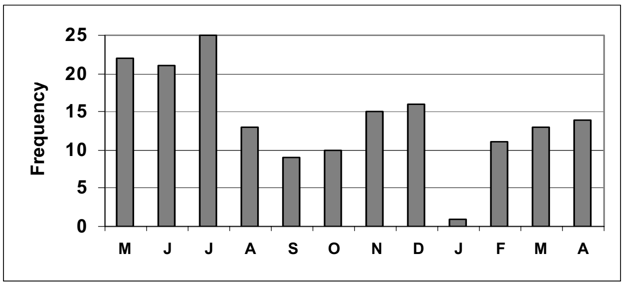


Figure 4. Arrivals of yachts by month to the Hawaiian Islands, May 2001 to May 2003 (data from Godwin *et al.* 2004). Tropical storm periods: East Pacific – June to October; Pacific – June to December; Australasian region – December to March

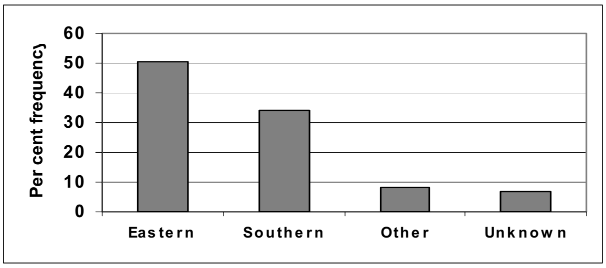


Figure 5. Frequency of likely routes used by yachtsmen to arrive in Hawaii (data from Godwin *et al.* 2004)

Ireland tends to receive international yachts predominantly from the Caribbean, the east-coast of America and from other northern European destinations. The majority arrive in Cork Harbour, Kilmore Quay or Waterford Harbour (Cornell 2002). In a sample of fourteen marinas on all Irish coasts there was a 100% prevalence of visiting boats from the British Isles, Northern Europe and Scandinavia, an 86% prevalence from North America, 64% from the Mediterranean, 28% from the Baltic Sea and 14% from South America. Six marinas had members who in the last three years had embarked on world tours. Vessels arriving from northern Europe tend to sail to the southwest coast of Ireland. Few vessels range to the northwest and north coasts as these areas have large expanses of unprotected coastline. Within the Irish Sea there are general movements to either side that often include the Isle of Man.
Italy receives world-trip traffic *en route* through the Mediterranean Sea (Cornell 2002). There are two principal gateways to the Mediterranean: Gibraltar, for craft arriving from Northern Europe and the Americas, and Port Said on the Suez Canal for vessels arriving from the Indo-Pacific. Yachts on world cruises will most usually enter the Mediterranean Sea *via* the Suez Canal where they remain for at least a season, usually the spring and/or summer. Yachts entering *via* the Strait of Gibraltar planning to reach the eastern Mediterranean Sea do so from late spring. The preferred routes include the Balearics, French Riviera, Sicily, Malta, Greece, Cyprus, Israel and then Port Said. Yachts sailing westwards from the Suez Canal also prefer the same destinations. Yachts entering the eastern Mediterranean from the Red Sea usually arrive in the early spring, almost 2-3 months before those arriving from the western Mediterranean.

4.2. DOMESTIC CRAFT

In many coastal locations around the world, domestic small craft are frequently moored within or in the vicinity of centres of international shipping activity. They are thus able to become colonised by NIS established in these locations or present on the hulls of international craft moored in their vicinity (Apte *et al.* 2000). However, there is strong variation in the potential of domestic craft to assist in the spread of marine NIS. This is principally because a large proportion of domestic small craft are seldom used and/or tend to remain locally rather than travel for long distances. In New Zealand, for example, 692 (=75%) of 923 domestic yachts sampled remained within 100 km of their homeports during a 12-month period, and 125 of these remained in their homeport without moving at all. Only 10% of the 923 yachts had undertaken 50 or more trips away from their homeport within 12 months. However, these boats in total visited 72 coastal locations around New Zealand, and they remained in these places for periods ranging from 1 day to 11 months. Generally, in New Zealand domestic yachts can be divided into three groups that differ in their potential to act as carriers of NIS: A first group (approximately 20% of 923 New Zealand yachts sampled) consists of yachts that are exclusively used in competition and are regularly cleaned to reduce drag and maximise speed and manoeuvrability (Yachting New Zealand pers. comm.; Floerl unpubl. data) and so are unlikely to pose a significant risk, especially since the great majority race only locally. A second group consists of yachts that are occasionally used for primarily short (<100km from homeport) day-trips but spend most of the time inactively moored in coastal marinas. Such craft are often likely to carry fouling assemblages on their hulls, and these may contain NIS occurring around their homeport, but these boats are unlikely to significantly spread them along the coastline. Amongst New Zealand yachts, this second group comprises approximately 75%. A third, small group of yachts are primarily used to travel between widely separated destinations (>100km to nationwide). During these trips, the yachts may spend days to months in foreign marinas. Maintenance of some of these craft is irregular and such boats could act as efficient dispersal vectors for NIS. In New Zealand, 5% of 923 yachts sampled fell into this category.

5. The increase in the private boating industry

In recent years, especially the 1980s, there has been a worldwide increase in the number of small craft and their associated marinas and moorings. In Queensland, Australia, for example, the number of coastal marinas has increased eleven-fold, from five in 1960 to 54 in 2000 (Floerl 2002). In Italy, small craft marinas and ports have increased in number by 73% between 1985 (403 marinas) and 2002 (716 marinas), and currently provide mooring space for approximately 116,000 small craft (Pagine Azzurre 1986, 2003). In Ireland, no marinas existed in the mid-1970s and coastal moorings were used for small craft. Today, there are 29 marinas along the coast and four further marinas planned. This increase in marina development was concomitant with an increase in the numbers of small craft. In Queensland (Australia), for example, the number of registered seaworthy yachts (>8m length) doubled between 1985 and 2000, from ~8,000 to ~16,000 boats (Floerl 2002).

Generally, small craft moorings are not uniformly distributed around the coastline but are instead characterised by regions of higher and lower densities. This can be described using the Index of Recreational Port Capability (RPCI). This index refers to the number of moorings/marina berths available within a given region of coastline in kilometres (Occhipinti-Ambrogi 2002). Concentrations of marinas and berthing space (high RPCI) are likely to be associated with high frequencies of small craft movements. Since the probability for establishment of NIS is a function of propagule supply (Ruiz *et al.* 2000), regions with a high RPCI may have a higher chance of harbouring or aiding in the spread of NIS compared with those regions with lower RPCI index. The average RPCI for Italy is 16, with the highest concentrations of berths occurring on the coasts of Veneto and Friuli (northwestern Adriatic) with a RPCI of 90 or higher. Occhipinti-Ambrogi and Savini (2003) identified the Northern Adriatic as one of the Mediterranean regions prone to invasion. RPCI values in this region have recently increased by 10-20%, which may lead to an increase in inoculation by NIS or their propagules. In this region the number of marina ports has almost doubled since 1985 (Figure 6).

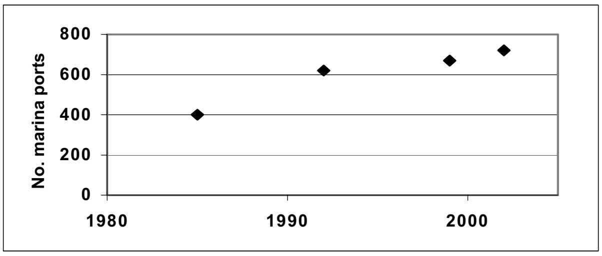


Figure 6. The number of marina ports on Italian coasts 1985-2003.

6. Risk assessment of leisure boat fouling

The Failure Modes and Effects Analysis (FMEA) is a system employed by industry to reveal risk areas that could lead to health and safety problems. Each identified component in the analysis develops a level of risk which accumulates a progressively higher risk level each time the same component is identified by an experienced operator. This approach has been used to find faults in equipment design, processing methods and where human behaviour may elevate risk. The first approach in using FMEA analysis for managing aquatic species transmissions was developed by Hayes (2002). He examined fishing vessels as vectors. The analysis consisted of in-depth discussion of each component of a boat that could act as a potential risk of carrying an organism, and included any carried water. These discussions were repeated in different ports and all opinions were reasoned into a series of levels of risk and mathematically arranged.

Here we have used the FMEA approach by examining the fouling of a single species, the zebra mussel (*Dreissena polymorpha*) on different leisure craft in Ireland. Each part of a boat was examined and scored according to the presence and relative number of zebra mussels present at a time when boats were lifted from the water for winter servicing. Study of bilge and toilet water was confined to a small number of craft because of difficulty of access. Areas examined included features found only on some boats (i.e. bow thrusters, rudder spaces) and spaces that developed over time with boat use (e.g. spaces that form between the keel-band and keel, especially of wooden lake-boats) (Table 3).

A further analysis was based on boat behaviour; different craft have different usage patterns according to their design, size and environment. For example, yachts are normally removed from the water each year and cleaned, generally remain faithful to lakes and seldom pass beneath bridges, so do not normally travel far and are unlikely to be significant vectors (Table 4). These two sets of gathered information were combined in the risk assessment to evaluate which craft and where the greatest relative risk of transporting zebra mussels took place. The analysis clearly shows that small open boat hull fouling poses the greatest risk of transmission (Plate 1). This analysis agrees well with the risks perceived as bearing the highest risk of transmissions by management. Hayes (2002) discussed the movement of zebra mussels in North America. There boat behaviour is different and different modes of transmission are perceived to be acting as vectors. In North America boats are regularly moved by trailer, so hull fouling does not create the greatest risk. This is because many boats are kept at home, or trailer parks, and do not remain in the water over long periods. The main transmission method is probably by plants with attached zebra mussels collecting on outboard motors and snagging on trailers when boats are removed from the water, later being transferred to a different water body. Johnson and Padilla (1996) claim that zebra mussels attached to a hull that is removed from the water will not survive more than five days' aerial exposure. In Ireland, however, under cooler and damper conditions, survival can occur for up to 18 days (Pollox *et al*. 2003). There was a further risk that larvae carried in live bait wells were being transmitted between water bodies (Johnson *et al.* 2001). In Ireland bait wells or buckets are not in general use because fishing using live fish as bait is illegal. Further factors that may be considered in risk assessments include distance of dispersal of trailered craft (Buchan & Padilla 1999) and lake size, landscape and facilities (Reed-Anderson *et al.* 2000).

Table 3. Relative hazard of transmissions based on field observations by examining sub-components of vessels as vectors, an approach modified from Hayes (2002). It is assumed that the inoculation capability is low where numbers transmitted are low. Normal font = samples from 1997/98, bold = 2004. 2004 data include 5 vessels imported from marine areas. Hazard levels: + – present unlikely to form an inoculum, ++ – inoculum size may be sufficient for an inoculum, +++ – inoculum likely to be effective. (See also text).

Vector	*Boats examined Infested/ boat number*	*Life stage present*	*Principal risk*	*Potential numbers transmitted*	*Comment*	*Relative overall hazard*
Hull surface	3/56 **7/79**	Juveniles, adults	Waterways international overland	10,000's	Frequent movements	+++
Beneath keel-bands	2/56 **3/79**	Juveniles, adults	Waterways international overland	1,000's	Movements noted, such fouling on old craft	+++
Rudder spaces and pinions	**2/79**	Juveniles, adults	Waterways international	1,000's	Movements noted	+++
Mooring buoy and chain	14/14	Juveniles adults	Waterways	10,000's	Movements unknown	++
Dinghy, tender	3/32	Juveniles adults	Waterways overland	1,000's	Some moved over winter	++
Bow-thruster tunnel	**5/14**	Juveniles, adults	Waterways, international	1,000's	Occurring on cleaned vessels	++
Outside of engine casing	**5/79**	Juveniles adults	Waterways overland	1,000's	On idle craft	++
Water intake ports	**4/79**	Juveniles, adults	Waterways international	100's	Vessels in water 1+ years	++
Propeller shaft	**1/79**	Juveniles adults	Waterways overland	1,000's	On idle craft	++
Propeller	**1/79**	Juveniles adults	Waterways overland	1,000's	On idle craft	++
Projecting instruments, anodes	**1/79**	Juveniles adults	Waterways international	100's	Normally on hull fouled vessels	++
Tyre fenders	4/5	Juveniles adults	Waterways overland	100's	Seldom moved	++
In submerged engine housing	**3/79**	Juveniles adults	waterways	100's	On idle craft	+
Anchors and chain lockers	1/1	adults	waterways	100's	Attached to debris, plants	+
Toilet water	2/3	larvae	Waterways international	10's	<5 litres capacity	+
Bilge water	0/1	larvae	Waterways overland	10's?	Bilge water quality varies	+
Bait bucket	Not sampled	larvae	Waterways overland	10's?	Bait buckets <10 litres	+

Table 4. Nature of craft in inland waters and potential for zebra mussel transmissions. In 1997/98 distinction between small and large cruisers was not made. Normal font = 1997-1998 data, bold = 2004 data. Hazard levels: + – present unlikely to form an inoculum, ++ – inoculum size may be sufficient for an inoculum, +++ – inoculum likely to be effective. (See also text).

Craft type	*Boat no.*	*Maxi-mum fouling burden*	*Normal range*	*Comment*	*Usage pattern*	*Berthage pattern*	*Relative hazard*
open craft <6m length	12/73	10,000+	Waterways, overland, Imports for special events	Used for angling and wildfowl hunting	Seasonal, Ranging brief to long immersions	Widely spread	+++
Small cruisers <10m length	(8/77) **2/15**	10,000+	Waterways, overland, regular imports	Sometimes trailered	Seasonal, removed in winter	Faithful to marinas, winter berths	+++
Large cruisers >10m length	(8/77) **6/15**	500,000+	Waterways, regular imports	Confined to waterways	Seasonal removed in winter	Faithful to marinas, winter berths	+++
Barges to 30m length	**23/33**	*ca* 20 million	Waterways, some imported from Britain, Netherlands, Germany	Remain in water for years accumulating large fouling burdens	seasonal	Not normally at marinas	+++
Narrow boats to 15m length	3/5	10,000+	Waterways, imported from Britain	Normally in canals generally lower fouling burdens	seasonal	Canal harbours, not usually marinas	+++
Yachts to15m length	**4/20**	100,000+	Waterways, overland, some imports	Confined to lakes on account of bridges	Seasonal, removed in winter	Adjacent to yacht clubs, marinas	++
Powerboats <6m	**2/28**	100's	Overland, waterways	Usually moved by trailer	Highly seasonal	variable	++
Sailing dinghies	34	None noted	Overland	Sailing events	Seasonal, brief immersions	Yacht clubs, public slipways	+
Hire cruisers	4/21	1,000+	Waterways	Well maintained	Seasonal, annual servicing	Special marinas	++

7. Discussion

Small craft worldwide are involved in the spread of a wide range of non-indigenous species of aquatic animals and plants. As we have shown, transport of marine species occurs predominantly via hull fouling on yachts or cruisers undergoing coastal or oceanic voyages. Hull fouling can also facilitate the spread of freshwater species, such as has occurred in the case of the zebra mussel (*Dreissena polymorpha*), in Ireland (Minchin *et al*. 2002). At the level of countries or biogeographic regions, small craft can facilitate the spread of NIS in two different ways: (1) by introducing new, previously absent species, and (2) by facilitating the secondary spread of already established NIS. New introductions can only be facilitated by craft arriving from overseas or from locations within the species introduced range. Secondary dispersal of established NIS can be accomplished by both domestic and foreign vessels (Inglis & Floerl 2002). In Italy and Ireland, small craft are likely to contribute primarily to the secondary spread of established NIS. It is likely that centres of shipping and boating activity, such as commercial ports, popular yachting destinations and international points of entry are at highest risk of containing or becoming inoculated with NIS or their propagules (Hewitt *et al.* 1999; Ruiz *et al.* 2000). During transfers a large proportion of hull fouling assemblages may partially or fully perish en-route following changes in water temperature or salinity (Minchin & Gollasch 2003). However, frequently a proportion of organisms survive coastal or inter-oceanic voyages of long duration and between different physical environments (Bertelsen & Ussing 1936; Allen 1953; Crisp 1958; Foster & Willian 1979; Gollasch & Riemann-Zuerneck 1996; Apte *et al.* 2000).

A global trend of increase in tourism and trade has been matched by a concomitant increase in private and commercial small craft and associated berthing infrastructure. The resulting increase in coastal artificial hard-substrate habitat and frequencies of vessel movements between coastal locations provides increased opportunities for the transfer and establishment of marine NIS (Carlton 1996). In some locations this has already been observed. For example, the sedimentary coastlines of the Northern Adriatic Sea are today protected by an almost continuous belt of stone breakwaters; many of these are associated with small craft marinas. These breakwaters have a total length of approximately 80.6km, offering >800,000m^2 of attachment surface to sessile marine biota. The alien predatory snail (*Rapana venosa*) and the alga *Codium bursa* have increased in abundance while progressively expanding their range along the breakwater series (Airoldi *et al.* 2004; Savini *et al.* 2004). *R. venosa* is dependent on hard surfaces on which to lay its eggs (Savini & Occhipinti Ambrogi 2004), and the provision of such habitat through breakwater systems has facilitated the regional spread of the species, which today occurs at a biomass of up to 7 kg/100 m^2 on breakwaters (Occhipinti Ambrogi & Savini, unpublished data). The shell of *R. venosa* provides a biogenic habitat for native epibiota, dominated by bryozoans, serpulids and barnacles (Savini & Occhipinti Ambrogi 2004).

There are several approaches to limiting the introduction and spread of NIS aquatic species by hull fouling on small craft. One would require an increase in hull maintenance by vessel owners and operators. However, this is difficult to achieve because more frequent dry-docking and antifouling paint renewal is likely to be unaffordable or impracticable to a large proportion of the boating population. A second approach would be the introduction of quarantine protocols for hull fouling on international vessel arrivals. With the exception of the port and marinas around Darwin, Australia, there are no existing quarantine procedures for arriving yachts to prevent the importation of non-indigenous fouling organisms into coastal countries worldwide. In both New Zealand and Australia, quarantine officials check arriving vessels for insects, plant seeds and pets (and their diseases) to limit quarantine risks to human health, agriculture and terrestrial environments (Grant & Hyde 1991; New Zealand and Australian Customs Services, pers. comm. 2001-2003). However, upon entry into Darwin's four marinas, internationally travelled vessels are required to go through another inspection by the Northern Territory Fisheries Department. Any vessel that has not renewed its antifouling paint since its arrival in (or return to) Australia is slipped and the hull inspected. If either the stage of the tide or the boat structure does not allow this method of inspection, then the hull is inspected by divers. In addition, the internal plumbing systems of internationally travelled vessels are subjected to a 5% detergent treatment held in by seacocks for a 14-hour period. In early 2003, approximately 30 potential pest introductions had been intercepted by the

inspection of over 700 yachts (Marshall, pers. comm.). In all other Australian and New Zealand ports of entry, submerged hull surfaces of yachts are occasionally checked for illegal objects or attachments, but never for potential problem species they may carry.
Screening systems and risk assessment models have been developed for ballast water (e.g. the Australian Ballast Water Decision Support System) and imports of terrestrial plants and animals (Ruesink *et al.* 1995; Daehler & Carino 2000). Similar tools are required for managing the risk of introducing and spreading NIS on the hulls of ocean-going vessels. The development of predictive tools that allow quarantine officials to efficiently discriminate low-risk vessels from those that may pose a risk (i.e. those that are likely to carry NIS) would help reduce the number of propagules that reach native environments and, therefore, the number of NIS that may establish and (become) spread. Such tools are currently in development (Floerl *et al.* 2004) but have not been fully developed and verified.
In the absence of border quarantine protocols and/or resources to increase hull maintenance on small craft, outreach and education programmes for small craft users, port and marina operators and local and regional management authorities are required to increase their knowledge and awareness of invasive species and their potential impacts on ecosystems and industries, and to provide them with an incentive for reducing the frequency of transport of such organisms on the hulls of small craft worldwide.

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