PAPER

Evidence-Based Decision Making to Underpin the Thresholds in New Zealand's Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand

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ABSTRACT

Vessel biofouling is a significant pathway for the introduction of nonindigenous marine species (NIMS). New Zealand is the first nation to regulate the vessel biofouling pathway, with controls scheduled to come into force in May 2018. The *Craft Risk Management Standard (CRMS): Biofouling on Vessels Arriving to New Zealand* specifies the hull fouling thresholds that vessels must meet; and here, we present the evidence-based decisions that underpin these thresholds.

Under the CRMS, a vessel must arrive in New Zealand with a "clean hull," the thresholds for which are governed by the intended duration of a vessel's stay in New Zealand. For example, long-stay (≥21 days) vessels must meet a more stringent standard of hull cleanliness due to the increased likelihood of release and establishment of NIMS. While setting a clean hull threshold at "slime layer only" can be tractable when vessels operate within the specifications of antifouling coatings, incidental amounts of macrofouling can establish even under the best management practices. Because of such instances, the thresholds within the CRMS were designed to allow for the presence of some macrofouling species, albeit with restrictions to minimize biosecurity risk. These thresholds are intended to limit species richness and to prevent successful reproduction and settlement of the allowed taxonomic groups while considering the practicality and feasibility of implementation.

The difficulties of managing biofouling on different areas of the hull are acknowledged within these thresholds. For example, a greater tolerance of macrofouling has been allowed for niche areas due to the difficulties in preventing biofouling on these areas.
Keywords: biosecurity, biofouling, New Zealand, risk, regulation

Introduction

Biofouling is the process of accumulation of organisms on immersed surfaces. In the initial stages of biofouling, organic material sticks to a surface and is rapidly colonized by bacteria, microalgae, and cyanobacteria to form a biofilm (often referred to as a slime layer). Aside from continuous cleaning, there is currently no effective technology to prevent slime layer formation (Dobretsov, 2010).

The development of surface biofouling is a stochastic process based on the probability of biofouling organisms encountering a surface in a state that is suitable for attachment (Aldred & Clare, 2008). Complex interactions take place between abiotic and biotic factors. These interactions include the season of first submersion, length of submersion, surface type, presence of biofilm, biofilm type, and light availability (Aldred & Clare, 2008; Mieszkin et al., 2013; Terlizzi & Faimali, 2010). Despite the stochastic nature of the biofouling process, "pioneering" macrofoulers typically include green filamentous algae, barnacles, tube worms, and bryozoans (Hilliard et al., 2006; Lewis & Coutts, 2010).

An increasing amount of evidence indicates that vessel biofouling is an important means of transport of nonindigenous marine species (NIMS). For example, biofouling has been identified as a potential means of transfer for 87% of New Zealand's NIMS (Kospartov et al., 2008), and more than 85% of NIMS in the waters of Hawaii (United States; Eldredge & Carlton, 2002) and Port Phillip Bay (Australia; Hewitt et al., 1999) were likely transferred as biofouling.

Worldwide, nonindigenous species have had far ranging impacts on the marine environment and the people reliant upon it (e.g., Molnar et al., 2008; Ruiz et al., 1997; Sorte et al., 2010). The ongoing risks posed by vessel biofouling are of immediate concern to the Ministry for Primary Industries (MPI), given that the marine environment is a key part of many of New Zealand's economic, environmental, and social and cultural values:

- New Zealand's marine ecosystems and species are highly diverse, and it is estimated that as much as 80% of the country's native biodiversity occurs in the sea (New Zealand Government, 2000). Endemic species account for 51% of New Zealand's marine biodiversity, a very high number that distinguishes New Zealand as a global marine biodiversity hotspot (Costello et al., 2010). This large number of unique species is due to New Zealand's isolation from other landmasses for at least 83 million years (Gordon et al., 2010), and many species that have evolved in this context are especially vulnerable to introduced organisms.
- The commercial value of New Zealand's wild and farmed fisheries is $1.2–1.5 billion annually (Statistics New Zealand, 2015a).
- The majority of New Zealanders live within 50 km of the coastline (Statistics New Zealand, 2015b), and coastal waters provide a medium for many forms of recreational activities (Allen et al., 2009).
- Māori have a close relationship with the ocean, and it is regarded as a treasure that is integral to their culture, identity, spirituality, and mythology (Moon, 2015). The sea is important as a source of food, and the prestige of clans and tribes is still closely linked to their ability to provide hospitality to visitors through plentiful seafood (Morgan, 2006; Wehi et al., 2013).

To better understand and manage vessel biofouling risks in the New Zealand context, MPI commissioned a multiyear research survey of international vessels arriving in New Zealand.

The objectives of the study were to determine the identity (species), origin (native, nonindigenous, unknown), and extent of biofouling occurrence on vessels; the relationship between the presence of nonindigenous species and the amount/extent of biofouling

TABLE 1

Biofouling thresholds for short-stay vessels.

Vessel Surface	Allowable Biofouling
All surfaces	Slime layer; goose barnacles.
Wind/waterline	Green algal growth of no more than 50 mm in length
	Brown and red algal growth of no more than 4 mm in length
	Incidental (1%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans occurring as: ▪ isolated individuals or small clusters; and ▪ a single species or an organism type that appears to be the same species.
Hull area	Algal growth occurring as: ▪ no more than 4 mm in length; and ▪ continuous strips and/or patches of no more than 50 mm in width.
	Incidental (1%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as: ▪ isolated individuals or small clusters that have no algal overgrowth; and ▪ a single species or an organism type that appears to be the same species.
Niche areas	Algal growth occurring as: ▪ no more than 4 mm in length; and ▪ continuous strips and/or patches of no more than 50 mm in width.
	Scattered (5%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as: ▪ widely spaced individuals and/or infrequent, patchy clusters that have no algal overgrowth; and ▪ a single species or an organism type that appears to be the same species.
	Incidental (1%) coverage of a second nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as: ▪ isolated individuals or small clusters that have no algal overgrowth; and ▪ a single species or an organism type that appears to be the same species.

Short-stay vessels mean those vessels intending to remain in New Zealand for 20 days or less and to only visit places designated under Section 37 of the Biosecurity Act 1993 as places of first arrival (POFAs). These vessels generally remain under "biosecurity surveillance" while in New Zealand territory rather than becoming fully cleared of risk goods.

on a vessel; and the factors that influence the presence of nonindigenous species and the amount of biofouling on vessels (e.g., vessel maintenance regime, voyage history) (Inglis et al., 2010).

Findings from the vessel biofouling research program were used by MPI to underpin a risk analysis of vessel biofouling, which identified 12 broad taxonomic groups as posing a risk to New Zealand's core values (Bell et al., 2011). Although all species within these groups will not pose a biosecurity risk (e.g., species that are native, cosmopolitan, or already established), there are many NIMS within the groups identified that demonstrate characteristics likely to pose a biosecurity risk to New Zealand's core values (Bell et al., 2011).

The most effective option to manage the biosecurity risks associated with vessel biofouling is prevention (Bax et al., 2003). Reactive measures, such as containment and eradication of species, are labor-intensive, time-consuming, and expensive and often have limited success (Anderson, 2005; Davidson et al., 2008). As a consequence, risk management should seek to prevent the establishment of macrofouling on vessel hulls. However, it is noted that there are practical limitations to biofouling prevention, as any threshold set should achieve a biosecurity outcome while facilitating trade and other functions vital to the New Zealand economy.

In New Zealand, the Biosecurity Act 1993 is the legal framework that enables MPI to prevent the arrival and establishment of nonindigenous species (New Zealand Parliament, 1993). Under Section 24 of the Biosecurity Act 1993, New Zealand's MPI issued the *The Craft Risk Management Standard (CRMS): Biofouling on Vessels Arriving to New Zealand* on the 14th of May 2014. This standard applies to all types of seacraft entering New Zealand waters and is scheduled to come into force in 2018 to allow for industry to prepare biofouling management plans (MPI, 2014). The following options may be used to meet the "clean hull" thresholds within standard: continual maintenance using best practice (e.g., application or installation of appropriate antifouling coatings or marine growth prevention systems evidenced by a biofouling management plan and record book according to the International Maritime Organisation [IMO] guidelines; IMO, 2011), the implementation of an approved craft risk management plan, evidence of application of an approved treatment, or cleaning prior to or immediately upon arrival. This document presents the evidence that underpins the "clean hull" thresholds (Tables 1 and 2) through a stepwise series of decision points.

TABLE 2

Biofouling thresholds for long-stay vessels and/or vessels that intend to visit areas other those designated under the Biosecurity Act 1993 as POFAs.

Vessel Surface	Allowable Biofouling
All surfaces	Slime layer; goose barnacles.

Long-stay vessels mean those vessels intending to remain in New Zealand for 21 days or longer or those vessels intending to visit areas other than those designated under Section 37 of the Biosecurity Act 1993 as POFAs.

Presence or Absence of Hull Macrofouling

Allowance of Slime Layer Only

The IMO has adopted guidelines for the control and management of biofouling of vessels to minimize the transfer of aquatic invasive species (IMO, 2011). The intent of these guidelines is to maintain the submerged surfaces and internal cooling systems of the vessels "as free of biofouling, as is practical." Other than continuous cleaning, there appears to be no antifouling technology available to prevent slime layer fouling (Dobretsov, 2010). Applying a slime layer threshold would manage the biosecurity risks identified by Bell et al. (2011).

Allowance of Some Macrofouling

The best biosecurity management practice on a hull means no macrofouling species should be present (except for macroalgae on the wind and waterline[1]; Lewis, personal communication). However, a review of MPI's commissioned research on vessel biofouling has shown the presence of some macrofouling species on hull areas of newly antifouled and well-maintained vessels (Floerl et al., 2008; Inglis et al., 2010). The macrofouling found on these vessels was mainly located in niche areas that were not antifouled or were protected from hydrodynamic drag (Floerl et al., 2008; Inglis et al., 2010). Furthermore, macroalgae species richness on merchant vessels showed no differences between new coatings (2 months old) and those up to 30 months old (Mineur et al., 2007). However, it is

[1]The terms "wind and water line" and "boot top" can be used synonymously, but for the purposes of this article, the term "wind and water line" is preferred.

noted that antifouling age is not the only factor determining the likely presence of macrofouling species (IMO, 2011; Inglis et al., 2010).

Although the slime layer threshold would manage the biosecurity risks identified by Bell et al. (2011), the amount of vessels with incidental macrofouling may require significant resource effort at each New Zealand place of first arrival to make management decisions on vessels that pose an acceptable biosecurity risk. Some of the practical difficulties identified with respect to vessel compliance with a threshold set at "slime layer" include as follows: How often is incidental fouling present? What form does incidental fouling typically take? Does incidental fouling pose a biosecurity risk? What action should be taken on noncompliant vessels with incidental fouling?

To address these problems, the authors identified macrofouling levels that occur as incidental fouling under the best biosecurity management practices. From this baseline, the thresholds were designed taking into account organism biology, MPI-commissioned research, international research findings, and comments received from public submissions in response to consultation of the draft standard (MAF Biosecurity New Zealand, 2011).

Decision Point

"Pioneering" macrofouling species can be allowed as biofouling on vessels without compromising the overall management of biosecurity risk. However, depending on their characteristics, such as mode of reproduction or ability to facilitate the introduction of additional NIMS, restrictions on the amount of fouling allowed are required.

Types of Macrofouling Allowed

From analysis of the MPI-commissioned research and international literature, the authors identified the following taxonomic groups that are common as incidental fouling on well-maintained vessels.

Goose Barnacles

Goose barnacles (lepadomorphs) are ubiquitous foulers of tropical, subtropical, and temperate seas, with a pelagic life cycle that includes attachment to drift wood, floating plant debris, buoys, and vessel hulls, as well as turtles and some whales (Barnes et al., 2004; Lewis, 2004). Densities of 20–30 per square meter are common in areas of low flow, including entrances of irregularly used seawater intakes or outlets (Hilliard et al., 2006).

The presence of goose barnacles represents a low biosecurity risk because of their pelagic life cycle (Hilliard et al., 2006); however, species of *Lepas* may resemble bivalve molluscs to casual observers. Thus, goose barnacles can cause inspection concerns if misidentified as a potential bivalve pest resulting in wasted time and resource effort. A more serious biosecurity concern is the potential for small bivalves to be interpreted as goose barnacles (Hilliard et al., 2006). As most goose barnacles have a pelagic life history, these were not identified as a biosecurity hazard by Bell et al. (2011).

Macroalgae

Macroalgal fouling of hull surfaces of recreational, commercial, and naval vessels is a common phenomenon (Evans, 1981; Floerl et al., 2005; Godwin et al., 2004; Hay, 1990; Inglis et al., 2010; Lewis & Gillham, 2007; Mineur et al., 2007, 2008; Piola & Conwell, 2010; Schultz et al., 2011; Lewis, personal communication).

A primary factor determining the proportion of photosynthetic algae within biofouling communities is light availability (Cowie, 2010). Thus, macroalgae that require an appropriately lit environment are restricted in their potential zone of recruitment to conspicuous areas of the hull, just below the waterline (Lewis & Gillham, 2007; Mineur et al., 2007; Naval Sea Systems Command [NSSC], 2006).

Based on trends in macroalgal translocation and impacts, Bell et al.

TABLE 3

Fouling organism incidence by vessel type (percentage and number of vessels).

	Macroalgae	Bryozoans	Barnacles	Tube Worms
Commercial (*n* = 270)	28% (76)	2% (5)	58% (157)	9% (24)
Passenger (*n* = 49)	51% (25)	6% (3)	55% (27)	6% (3)
Fishing (*n* = 3)	100% (3)	33% (1)	100% (3)	67% (2)
Recreational (*n* = 182)	29% (52)	72% (131)	70% (127)	47% (86)
All vessels (*n* = 504)	31% (156)	28% (140)	62% (314)	23% (115)

(2011) assessed this taxonomic group as a biosecurity risk that requires management consideration. However, the MPI-commissioned research shows a relatively high incidence (%) of macroalgae on all vessel types (Inglis et al., 2010; Table 3).

Barnacles, Tube Worms, and Bryozoans

Bell et al. (2011) assessed the barnacle, tube worm, and bryozoan taxonomic groups as biosecurity risks that require management consideration, as these organisms have an extensive history of introductions and are capable of altering the structure and function of ecosystems.

However, it is recognized that macrofouling consisting of at least one of these organisms is common on all vessel types (Inglis et al., 2010; Table 3).

Decision Point

A threshold is required that manages the biosecurity risk but does not unnecessarily penalize vessels using a best practice approach. Therefore,

- goose barnacles on vessel hulls can be permitted without restrictions;
- macroalgae on vessel hulls can be permitted—with restrictions; and
- barnacles, tube worms, and bryozoans on vessel hulls can be permitted—with restrictions.

Practical Management of Macrofouling

From analysis of the MPI-commissioned research and international literature, the authors identified areas of well-maintained vessels that are prone to incidental fouling based on the vessel and fouling organism traits and considered if uniform or varied thresholds could be practically applied.

Varied Thresholds for Specific Areas of the Hull Surface

There are differences in the ability of management measures to prevent biofouling on different areas of the vessel hull including wind and waterline, hull areas, and niche areas (Institute of Marine Engineering, Science and Technology and International Paint and Printing Ink Council, 2016). The best biosecurity management practice on a hull means no macrofouling species should be present (except for macroalgae on the wind and waterline; Lewis, personal communication). However, a review of the MPI-commissioned research has shown the presence of some macrofouling species on hull areas of newly antifouled and well-maintained vessels (Floerl et al., 2008; Inglis et al., 2010). The macrofouling encountered on these vessels was mainly located in niche areas (Floerl et al., 2008; Inglis et al., 2010).

Niche areas are those areas on a vessel that may be more susceptible to biofouling because of different hydrodynamic forces, susceptibility to coating system wear or damage, or being inadequately, or not, painted at all, for example, sea chests, bow thrusters, propeller shafts, inlet gratings, and dry dock support strips. Niche areas pose a substantial biosecurity risk despite accounting for a relatively small proportion of the hull (Coutts et al., 2003; Coutts & Taylor, 2004; Floerl et al., 2008; Inglis et al., 2010; James & Hayden, 2000; Lewis, 2004). In the MPI-commissioned research, a large proportion of species collected were present in niche areas (84% from the combined sample of passenger and fishing vessels and 89% from recreational vessels). Although 98% of species collected from merchant vessels were present in niche areas, it is noted that a greater sampling effort was applied to niche areas (Inglis et al., 2010). Due to the susceptibility of niche areas to biofouling, a practical threshold that is less stringent than allowed for wind and waterline and hull areas was required that still manages the biosecurity risk.

Uniform Threshold for the Whole of the Hull Surface

Applying the niche area threshold to the hull area would result in the potential for an increase in propagule pressure of NIMS due to the relative surface area of the hull by comparison to niche areas. In the MPI-commissioned research on recreational vessels, hull area comprised approximately 93% of each recreational vessel's submerged surface area, about 14 times more than the area comprised by niche areas (Floerl et al., 2008). Applying the threshold for the hull area to niche areas may result in the noncompliance of a number of vessels that pose a minimal biosecurity risk and cause unnecessary delays at the border that may negatively impact New Zealand's economy.

Decision Point

The threshold for biofouling can be varied for specific areas of the hull surface.

Factors Affecting Macrofouling Thresholds

Macroalgae

Allowing macroalgae to enter New Zealand without restrictions represents a biosecurity risk (Bell et al., 2011). The morphologies of macroalgae associated with hull fouling are generally characterized as being small with flexible, filamentous or sheet-like vegetative structures and high growth rates (Lewis & Coutts, 2010; Ribera Siguan, 2003; Williams & Smith, 2007). The cosmopolitan distribution of many well-known fouling taxa such as members of the *Ceramiaceae, Ectocarpaceae, Ulvaceae,* and *Cladophoraceae* may be the result of biofouling and ballasting of wooden hulled ships of the past (Schaffelke et al., 2006). As a result of their now cosmopolitan distributions and incomplete records of origin, these taxa are now considered to be cryptogenic. Macroalgae with cosmopolitan distributions are common on vessel hulls; for example, Mineur et al. (2008) found that the majority (58%) of the macroalgae recorded on merchant vessels (n = 22) had a cosmopolitan distribution. It is noted that the use of antifouling paint on modern vessels does not provide full protection from macroalgal fouling (Lewis & Gillham, 2007; Schaffelke et al., 2006). Resistance to antifouling biocides has been shown to influence macroalgae distributions in the past, whereby the dominant copper-resistant *Enteromorpha* (*Ulva*) species were replaced by *Ectocarpus* as the major cosmopolitan fouling alga on ships following the introduction of tributyltin-based antifouling paints (Callow, 1986).

Wind and Waterline (Boot Top)

To manage the biosecurity risk posed by macroalgae, Hilliard et al. (2006) suggest that macroalgal fouling be restricted to "low levels of filamentous green macroalgae (i.e., small patches where the filament or blade growth is thin [i.e., <4-mm beard])." The rationale behind this limit is that thin patches with tufts less than 4 mm thick do not provide good nestling, flow sheltering, feeding, and hiding areas for amphipods or other mobile crustaceans in contrast to well-developed algal beards. Hilliard (personal communication) stated that he has "yet to see any grasping crustacean using simple waterline 'fur' as a successful shelter from turbulent flow." It is noted that brown and red algae were excluded from this allowance.

Application of such a standard to the wind and waterline may result in the exclusion of vessels likely to contain cosmopolitan species of green algae, such as *Cladophorales* and *Ulvales* (Mineur et al., 2007, 2008; Lewis, personal communication). Species within these taxa have an affinity for the wind and waterline because of the high light and high turbulence conditions, coupled with high biocide tolerance. Compromise of antifouling systems in this region due to turbulent water movement, paint degradation from wet and dry cycles, or ultraviolet exposure may further facilitate their establishment and growth (Lewis, personal communication).

The authors reviewed numerous images from the MPI-commissioned research for merchant vessels, passenger vessels, and recreational vessels and found no indication that wind and waterline algae ≤50 mm long were associated with increased incidence or abundance of other fouling organisms. It was therefore determined that a length of 50 mm for green macroalgae does not compromise the overall biosecurity risk of a vessel in terms of biofouling species present. Mineur et al. (2007) suggested that macroalgal fouling communities are short-lived and have a high turnover on parts of the hull exposed to emersion, especially under high sun exposure.

The tolerances for red and brown macroalgae can remain at <4-mm blade length as per Hilliard et al. (2006), as species within these taxa are not as ubiquitous as green macroalgae and so present a different biosecurity risk. These restrictions should adequately protect New Zealand given that reproductive capacity of the algae is limited by the size and restrictions based on vessel itinerary (Floerl et al., 2010; MPI, 2014).

Despite a suggested allowance of "small patches" of filamentous green macroalgae (Hilliard et al., 2006), the wind and waterline provide these macroalgae with a suitable environment for settlement until light becomes a limiting factor. Because of the high prevalence of macroalgal fouling of the wind and waterline, it is not practical to impose a limit on the extent of macroalgae occurring on this vessel surface. Preventing the overgrowth of macrofouling species by macroalgae on the wind and waterline may not be practically achievable due to the dynamic macroalgal growth conditions present on this section of the hull. Thus, macroalgal overgrowth of permitted macrofouling can be allowed on the wind and waterline section of the hull.

Hull and Niche Areas

The biosecurity risk posed by macroalgae in hull and niche areas is managed based on the advice of Hilliard et al. (2006). However, restrictions on algal morphology (e.g., coralline, bladed, foliose) or taxonomic group (e.g., red, brown, green algae) were omitted in these areas due to practical considerations at the border, such as the availability of taxonomic expertise. Restrictions can be based solely on the length of the growth and the extent of its coverage. These restrictions should adequately protect New Zealand given that reproductive capacity of the algae is limited by the size and timing restrictions based on vessel itinerary (Floerl et al., 2010; MPI, 2014).

Vessels coming into New Zealand with continuous algal turf on hull and niche areas represent a widespread failure of antifouling coating that is indicative of the presence of other macrofouling species. A large turf (area) of macroalgae increases the likelihood of the presence of blades >4 mm long, that is, the provision of habitat for other macrofouling species. Large algal turfs may impede the identification of macrofouling species on hull and niche areas, leading to the clearance of noncompliant vessels through New Zealand's border system. Furthermore, the successional nature of hull biofouling means that the longer a macrofouling species has been present, the more likely it is to be covered by overgrowth. Hence, a restriction is put in place to limit the overgrowth of allowed macrofouling organisms to help mitigate the presence of sexually mature individuals.

Strips of algae are not uncommon in niche areas, particularly along their outer edges. A threshold for allowable macroalgal growth needs to manage risk while facilitating trade. Following the advice of Hilliard et al. (2006) regarding the allowance of "small patches," the authors' review of hull images suggests that a 50-mm threshold allows for algal growth that is typically associated with well-maintained vessels. These findings are in agreement with those of Mineur et al. (2007), who found that small tufts (localized patches) of macroalgae (usually less than a few square centimeters in area) were a constant feature of the hulls of merchant vessels ($n = 22$), even when most of the surface was free of fouling organisms.

Barnacles, Tube Worms, and Bryozoans

Allowing species within these taxonomic groups to enter New Zealand without restrictions represents a biosecurity risk (Bell et al., 2011). Hilliard et al. (2006) noted that one of the disadvantages of listing balanomorph barnacles as a high-risk group is their common occurrence on most vessel types—particularly on anodes and where antifouling paint is absent, damaged, or colonized by bryozoans. These findings were consistent with the MPI commissioned research (Inglis et al., 2010).

The percentage cover and biomass of fouling organisms tend to be positively correlated with species abundance and richness; therefore, increases in the cover and biomass of biofouling are likely to increase biosecurity risk (Inglis et al., 2008). MPI's commissioned research attributed a higher level of biosecurity risk to vessels where any given hull or niche area had a level of fouling (LOF) rank of 4 or 5 (see Box 1) than to vessels where LOF was 2 or 3. Hull and niche areas with an LOF rank of 3 tend to have multispecies biofouling assemblages, whereas areas with an LOF rank of 2 typically have more of a limited biofouling species richness.

Analysis of the MPI commissioned research on recreational vessels shows that, when combinations of the barnacle, tube worm, or bryozoan groups are present as hull biofouling, it is likely that additional taxonomic groups will also be present (Table 4). For the wind and waterline and hull areas, it would therefore appear prudent to limit the taxonomic groups allowed and allow only single species—or species that appear to be the same—rather than combinations of organisms.

Vessel niche areas tend to be more susceptible to biofouling accumulation. MPI's review of niche area images from well-maintained vessels found that, when fouling was present, scattered individuals of a single species were often accompanied by incidental individuals of a second species. Because of the difficulties of preventing the occurrence of biofouling in niche areas, a tolerance level was set allowing

BOX 1

LOF ranks were developed to provide a measure of the amount and coverage of biofouling across a vessel hull (Floerl et al., 2005). The rank scale ranges from 0 (*no fouling*) to 5 (*very heavy fouling*).

LOF 0: No visible fouling. Hull entirely clean; no biofilm (slime) on any visible submerged parts of the hull.

LOF 1: Hull partially or completely covered in slime fouling. Absence of any macrofouling.

LOF 2: Light fouling. 1–5% of visible hull surface covered by macrofouling or filamentous algae. Usually remaining area covered in slime.

LOF 3: Considerable fouling. Macrofouling clearly visible but still patchy. 6–15% of visible hull surface covered by macrofouling or filamentous algae. Usually remaining area covered in slime. Authorities need to decide whether this is locally acceptable.

LOF 4: Extensive fouling. 16–40% of visible hull surface covered by macrofouling or filamentous algae. Usually remaining area covered in slime.

LOF 5: Very heavy fouling. 41–100% of visible hull surface covered by macrofouling or filamentous algae. Usually remaining area covered in slime.

TABLE 4

Incidence (percentage and number of vessels) of additional taxonomic groups occurring as hull fouling on recreational vessels in the presence of specific or combinations of macrofouling.

Group(s) Present	Incidence Among Vessels (*n* = 182)	Incidence of Additional Groups Present
Bryozoans × Barnacles × Tube worms	33.5% (*n* = 61)	83.6% (*n* = 51)
Bryozoans × Barnacles	23.1% (*n* = 42)	73.8% (*n* = 31)
Bryozoans × Tube worms	9.3% (*n* = 17)	76.5% (*n* = 13)
Barnacles × Tube worms	3.3% (*n* = 6)	50% (*n* = 3)
Bryozoans	6.0% (*n* = 11)	64% (*n* = 7)
Barnacles	9.9% (*n* = 18)	61% (*n* = 11)
Tube worms	1.1% (*n* = 2)	50% (*n* = 1)

Additional taxonomic groups include, but are not limited to, bivalves, ascidians, and mobile crustaceans (Inglis et al., 2010).

incidental coverage of a second nonalgal macrofouling organism (restricted to barnacles, tube worms, or bryozoans).

Based on the information reviewed, biofouling on wind and waterline and hull areas is not to exceed the low end of the LOF 2 coverage range (1%; Figure 1), and biofouling in niche areas should not exceed the maximum of this range (i.e., 5% of visible niche area surface; see Box 1 and Figure 2). It is noted that, for niche areas, this measure alone does not take into account the fouling complexity or species distribution.

The stringency of thresholds for fouling has been deliberately set to limit opportunities for organisms to accumulate in numbers that could facilitate successful reproduction, that is, reducing the propagule pressure by keeping the organisms too few in number and too far apart to allow successful spawning, settlement, and establishment. While barnacles are restricted in their reproduction by physical constraints, tube worms and bryozoans may be broadcast spawners, with some capable of asexual reproduction (Ruppert & Barnes, 2004).

The macrofouling thresholds set are based on preventing the potential for these organisms to facilitate the transport of other fouling species. Explicit consideration of "early-stage" macrofouling is a way of managing the risks posed by biofouling succession and organism maturity. The thresholds set for organism spacing (i.e., incidental or scattered individuals) are characteristic of early-stage fouling assemblages—these tend to have low species richness, which helps to mitigate against the presence of other risk organisms. The longer a macrofouling species has been present on a hull, the more likely it is to be mature.

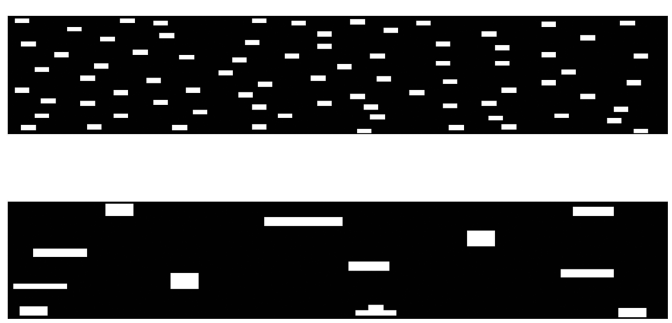
Under the best practice for hull maintenance, the presence of macrofouling species represents a failure of the antifouling system (except for

FIGURE 1

Examples of incidental (1%) macrofouling. These thresholds are intended to limit opportunities for organisms to occur in proximity and/or accumulate in numbers to a level that could facilitate successful reproduction.

FIGURE 2

Examples of scattered (5%) macrofouling. These thresholds are intended to limit opportunities for organisms to occur in proximity and/or accumulate in numbers to a level that could facilitate successful reproduction.



macroalgae on the wind and waterline; Lewis, personal communication). However, a review of the MPI commissioned research showed the presence of some macrofouling species on hull areas of newly antifouled and well-maintained vessels (Floerl et al., 2008; Inglis et al., 2010). As a result, the thresholds for wind and waterline and hull areas were set at a level of an early stage of antifouling failure to be able to warn vessels regarding the prevention of unacceptable biosecurity risk on subsequent visits. Therefore, vessels arriving in New Zealand with macrofouling on their hulls should receive a warning regarding the consequences of using an ineffective biofouling management plan.

Decision Point

Macroalgae

For wind and waterline, green algal growth can be no more than 50 mm in length; red and brown algal growth can be no more than 4 mm in length.

For hull and niche areas, any algal growth can be no more than 4 mm in length and in continuous strips or patches of no more than 50 mm in width; no algal overgrowth is permitted on the allowed macrofouling species.

Nonalgal Macrofouling

For wind and waterline areas, the tolerance set was incidental (1%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as isolated individuals or small clusters and as a single species or an organism type that appears to be the same species.

For hull areas, the tolerance set was incidental (1%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as isolated individuals or small clusters that have no algal overgrowth and as a single species or an organism type that appears to be the same species.

For niche areas, the tolerances set were the following:

- Scattered (5%) coverage of one nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as widely spaced individuals or infrequent, patchy clusters that have no algal overgrowth and as a single species or an organism type that appears to be the same species; and
- Incidental (1%) coverage of a second nonalgal macrofouling organism type of either barnacles, tube worms, or bryozoans, occurring as isolated individuals or small clusters that have no algal overgrowth and as a single species or an organism type that appears to be the same species.

Intended Vessel Itinerary

Varied Threshold Dependent on Intended Itinerary

The majority of species likely to be encountered on vessel hulls do not reach sexual maturity within 4 weeks of settlement (Floerl et al., 2010). The longer a vessel remains in New Zealand, the greater the likelihood that the species will spawn or escape from the biofouling and become established (Inglis et al., 2012). This will also depend on the season of arrival, the reproductive state of biofouling organisms, and their ability to spawn and produce viable offspring in New Zealand conditions. In general, establishment likelihood will increase with the amount of biofouling present on the vessel (Sylvester et al., 2011) and will vary by geographic origin and propagule pressure. Biofouling species from other temperate coastal environments are more likely to be able to establish self-sustaining populations in New Zealand waters than those with predominantly tropical distributions (Inglis et al., 2010; Sylvester et al., 2011).

Assuming that a vessel is deemed clean at the border according to the thresholds set, it should be able to remain in New Zealand for a period of 4 weeks without posing a biosecurity risk. It is noted that the 4-week period allowed is inclusive of traveling time to New Zealand, which is, on average, 11 days for international recreational vessels (Inglis et al., 2012). Taking this into account, a vessel remaining in New Zealand for a period of <3 weeks will be deemed "short stay." Exceeding the 3-week period would constitute a vessel being deemed "long stay."

Based on the data reviewed, the algal and nonalgal macrofouling thresholds described above are appropriate for short-stay vessels only. As a result, the period available for maturation, reproduction, and spawning is short enough to manage the likelihood of possible introductions (Floerl et al., 2010).

Long-stay vessels are subject to more stringent thresholds than short-stay vessels because the longer a vessel remains in New Zealand, the greater the likelihood that any species present will spawn or escape from the biofouling and become established (Inglis et al., 2012). Although there is evidence that wind and waterline is often fouled by cosmopolitan species (Mineur et al., 2007), a threshold of no macroalgae on the wind and waterline was set for long-stay vessels and vessels that visit non-POFA areas. Despite the ubiquity of some green macroalgae on the wind and waterline, there is the potential for some species to be nonindigenous to New Zealand and thus would be allowed to mature and reproduce once through the border. Furthermore, it is possible that the presence of these macroalgae could shelter other macrofouling species or obstruct detection of these species by border staff.

Decision Point

The threshold for long-stay vessels is set at "slime layer" fouling with allowance for goose barnacles. To ensure that the biosecurity risk is managed, long-stay vessels should ideally have an antifouling paint renewal or be cleaned within 4 weeks prior to entry to New Zealand. Cleaning before departure reduces the abundance and density of biofouling organisms on a vessel's hull, and if this is done within the 4-week time frame that includes traveling time, it can help reduce the likelihood, frequency, and success of spawning or dispersal events. Although the optimal approach would be to clean immediately before departure to New Zealand, this may not always be possible. While the 4-week window provides flexibility for vessel owners or operators and helps to mitigate against "spawning on arrival" events, a residual risk of postborder spawning remains. Vessel profiling will help MPI to identify vessels for further investigation where the approach to cleaning before arrival is questionable.

Vessels with itineraries that visit areas other than those designated under the Biosecurity Act 1993 as POFA are also subject to more stringent thresholds, that is, the threshold for long-stay vessels. The more stringent threshold was recommended for the protection and maintenance of those areas that do not typically receive high levels of vessel traffic. These areas can have national and international significance such as the Fiordland National Park, Kermadec Islands, and subantarctic islands.

Uniform Thresholds Regardless of the Intended Vessel Itinerary

From a regulatory perspective, having a uniform biofouling threshold for all vessels that enter into New Zealand represents the easiest situation to manage; however, the threshold set for short-stay vessels may not manage the biosecurity risk presented by long-stay vessels due to the period available for maturation, reproduction, and spawning. Furthermore, the threshold set for short-stay vessels was not designed for protecting high-value pristine areas and is unlikely to mitigate the biosecurity risks posed by vessels that visit non-POFA areas. Conversely, the more stringent threshold set for long-stay vessels or vessels that visit non-POFA areas may cause delays to short-stay vessels that actually present an acceptable biosecurity risk. This will also result in the misallocation of MPI resources to make management decisions, albeit unnecessary, regarding these vessels. For these reasons, a uniform threshold was not chosen.

Decision Point

The threshold for biofouling can differ depending on the intended vessel itinerary within New Zealand. Long-stay vessels are required to meet a more stringent threshold than short-stay vessels.

Long-stay vessels mean those vessels intending to remain in New Zealand for 21 days or longer or those vessels intending to visit areas other than those designated under Section 37 of the Biosecurity Act 1993 as POFAs.

Short-stay vessels mean those vessels intending to remain in New Zealand for 20 days or less and to only visit places designated under Section 37 of the Biosecurity Act 1993 as POFAs. These vessels generally remain under "biosecurity surveillance" while in New Zealand territory and are subject to further inspection rather than becoming fully cleared of risk goods.

Acknowledgments

The authors would like to thank the people who provided advice and peer review of this document, specifically T. Bates, Dr. A. Bell, Dr. S. Cobb, P. Hallett, Dr. S. Hathaway, L. Jones, C. Reed (MPI), John Lewis (ES Link Services Pty. Ltd.), and Dr. R. Hilliard (InterMarine Consulting Pty. Ltd.).

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References

Aldred, N., & Clare, A.S. 2008. The adhesive strategies of cyprids and development of barnacle-resistant marine coatings. Biofouling. 24(5):351-63. https://doi.org/10.1080/08927010802256117.

Allen, W., Elmetri, I., Clarke, S., Gibbons, J., Clark, K., Sinner, J., … Taylor, M. 2009. Mapping the Values of New Zealand's Coastal Waters: 3. Social Values (Biosecurity New Zealand Technical Paper No. 2010/05). Wellington, New Zealand: Ministry of Agriculture and Forestry. 39 pp.

Anderson, L.W.J. 2005. California's reaction to *Caulerpa taxifolia*: A model for invasive species rapid response. Biol Invasions. 7:1003-16. https://doi.org/10.1007/s10530-004-3123-z.

Barnes, D.K.A., Warren, N.L., Webb, K., Phalan, B., & Reid, K. 2004. Polar pedunculate barnacles piggy-back on pycnogona, penguins, pinniped seals and plastics. Mar Ecol-Prog Ser. 284:305-10. https://doi.org/10.3354/meps284305.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., & Geeves, W. 2003. Marine invasive alien species: A threat to global biodiversity. Mar Policy. 27:313-23. https://doi.org/10.1016/S0308-597X(03)00041-1.

Bell, A., Phillips, S., Denny, C., Georgiades, E., & Kluza, D. 2011. Risk analysis: Vessel biofouling. Wellington, NZ: Ministry of Agriculture and Forestry Biosecurity. 145 pp.

Callow, M.E. 1986. A world-wide survey of slime formation in antifouling paints. In: Studies of Environmental Science 28: Algal Biofouling, eds. Evans, L.V., & Hoagland, K.D., 1-20. Amsterdam, The Netherlands: Elsevier. https://doi.org/10.1016/S0166-1116(08)72167-8.

Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., & Miloslavich, P. 2010. A census of marine biodiversity knowledge, resources, and future challenges. PLoS One. 5(8):e12110. https://doi.org/10.1371/journal.pone.0012110.

Coutts, A.D.M., Moore, K.M., & Hewitt, C.L. 2003. Ships' sea-chests: An overlooked transfer mechanism for nonindigenous marine species? Mar Pollut Bull. 46:1510-3. https://doi.org/10.1016/S0025-326X(03)00292-3.

Coutts, A.D.M., & Taylor, M.D. 2004. A preliminary investigation of biosecurity risks associated with biofouling on merchant vessels in New Zealand. New Zeal J Mar Fresh. 38:215-29. https://doi.org/10.1080/00288330.2004.9517232.

Cowie, P.R. 2010. Biofouling patterns with depth. In: Biofouling, eds. Dűrr, S., & Thomasson, J.C., 87-99. Oxford, UK: Wiley-Blackwell.

Davidson, I.C., McCann, L.D., Sytsma, M.D., & Ruiz, G.M. 2008. Interrupting a multi-species bioinvasion vector: The efficacy of in-water cleaning for removing biofouling on obsolete vessels. Mar Pollut Bull. 56:1538-44. https://doi.org/10.1016/j.marpolbul.2008.05.024.

Dobretsov, S. 2010. Marine biofilms. In: Biofouling, eds. Dűrr, S., & Thomasson, J.C., 123-36. Oxford, UK: Wiley-Blackwell.

Eldredge, L.G., & Carlton, J.T. 2002. Hawaiian marine bioinvasions: A preliminary assessment. Pac Sci. 56:211-2. https://doi.org/10.1353/psc.2002.0012.

Evans, L.V. 1981. Marine algae and fouling: A review, with particular reference to ship fouling. Bot Mar. 24:167-71. https://doi.org/10.1515/botm.1981.24.4.167.

Floerl, O., Inglis, G.J., & Hayden, B.J. 2005. A risk-based predictive tool to prevent accidental introductions of nonindigenous marine species. Environ Manage. 35:765-78. https://doi.org/10.1007/s00267-004-0193-8.

Floerl, O., Smith, M., Inglis, G., Davey, N., Seaward, K., Johnston, O., … Coutts, A. 2008. Vessel Biofouling as a Vector for the Introduction of Nonindigenous Marine Species to New Zealand: Recreational Yachts (Biosecurity Research Project ZBS2004-3A). Wellington, NZ: Ministry of Agriculture and Forestry. 64 pp.

Floerl, O., Wilkens, S., & Inglis, G. 2010. Development of a template for vessel hull inspections and assessment of biosecurity risks to the Kermadec and sub-Antarctic Islands regions. Report prepared for Department of Conservation. Report no. CHC2010-086. 55 pp.

Godwin, L.S., Eldredge, L.G., & Gaut, K. 2004. The assessment of hull fouling as a mechanism for the introduction and dispersal of marine alien species in the main Hawaiian Islands. Bishop Museum Technical Report No. 28, Honolulu, Hawaii. 114 pp.

Gordon, D.P., Beaumont, J., MacDiarmid, A., Robertson, D.A., & Ahyong, S.T. 2010. Marine biodiversity of Aotearoa New Zealand. PLoS One. 5(8):e10905. https://doi.org/10.1371/journal.pone.0010905.

Hay, C.H. 1990. The dispersal of sporophytes of *Undaria pinnatifida* by coastal shipping in New Zealand, and implications for further dispersal of *Undaria* in France. Brit Phycol J. 25:301-13. https://doi.org/10.1080/00071619000650331.

Hewitt, C.L., Campbell, M.L., Thresher, R.E., & Martin, R.B. 1999. Marine biological invasions of Port Phillip Bay, Victoria. In: Centre for Research on Introduced Marine Pests Technical Report 20. Hobart, Australia: CSIRO Marine Research. 344 pp.

Hilliard, R., Polglaze, J., & Le Provost, I. 2006. Review and Evaluation of the Biofouling Protocol for Vessels Less Than 25 m in Length. Canberra, Australia: Australian Quarantine and Inspection Service. 149 pp.

Inglis, G.J., Floerl, O., Ahyong, S., Cox, S., Unwin, M., Ponder-Sutton, A., … Kluza, D. 2010. The biosecurity risks associated with biofouling on international vessels arriving in New Zealand: Summary of the patterns and predictors of fouling. Report prepared for Ministry of Agriculture and Forestry, Biosecurity New Zealand, 182 pp.

Inglis, G.J., Floerl, O., & Woods, C. 2012. Scenarios of Vessel Biofouling Risk and Their Management: An Evaluation of Options (Technical Paper No: 2012/07). Wellington, NZ: Ministry of Agriculture and Forestry. 122 pp.

Inglis, G.J., Ponder-Sutton, A., Unwin, M.J., & Floerl, O. 2008. Vessel biofouling as a vector for the introduction of nonindigenous marine species to New Zealand: Management tools. Report prepared for Ministry of Agriculture and Forestry, Biosecurity New Zealand, Project ZBS2004-04. 139 pp.

Institute of Marine Engineering, Science and Technology and International Paint and Printing Ink Council. 2016. A template for completion of a biofouling management plan. In: International Maritime Organization, Marine Environmental protection Committee, 70th session, Agenda Item 17. 15 pp.

International Maritime Organization. 2011. Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species. Annex 26, Resolution MEPC.207(62). Adopted on 15 July 2011. 25 pp.

James, P., & Hayden, B. 2000. The potential for the introduction of exotic species by vessel hull fouling: A preliminary study. NIWA Client Report No: WLG 00/51 No. 16. 57 pp.

Kospartov, M., Inglis, G., Seaward, K., van den Brink, A., D'Archino, R., & Ahyong, S. 2008. Nonindigenous and cryptogenic marine species in New Zealand – Current state of knowledge: Interim report. NIWA Report prepared for Ministry of Agriculture and Forestry, Biosecurity New Zealand, Project BNZ10740 + Tables + Appendices. 25 pp.

Lewis, J. 2004. Hull Fouling as a Vector for the Translocation of Marine Organisms (Report 1: Hull fouling research. Ballast Water Research Series Report No. 14). Canberra, Australia: Department of Agriculture, Fisheries and Forestry. 129 pp.

Lewis, J.A., & Coutts, A.D.M. 2010. Biofouling invasions. In: Biofouling, eds. Dűrr, S., & Thomasson, J.C., 348-65. Oxford, UK: Wiley-Blackwell.

Lewis, J.A., & Gillham, A.C. 2007. Antifouling paint patch trial project. Final report. Australian Government, Department of Defence. Defence Science and Technology Organisation. DSTO-CR-2007-0153. 17 pp.

MAF Biosecurity New Zealand. 2011. Import Health Standard: Vessel Biofouling. Review of submissions. Wellington, New Zealand: Ministry for Agriculture and Forestry Biosecurity, New Zealand. 20 pp.

Mieszkin, S., Callow, M.E., & Callow, J.A. 2013. Interactions between microbial biofilms and marine fouling algae: A mini review. Biofouling. 29(9):1097-113. https://doi.org/10.1080/08927014.2013.828712.

Mineur, F., Johnson, M.P., & Maggs, C.A. 2008. Macroalgal introductions by hull fouling on recreational vessels: Seaweeds and sailors. Environ Manage. 42:667-76. https://doi.org/10.1007/s00267-008-9185-4.

Mineur, F., Johnson, M.P., & Maggs, C.A., Stegenga, H. 2007. Hull fouling on commercial ships as a vector of macroalgal introduction. Mar Biol. 151:1299-307. https://doi.org/10.1007/s00227-006-0567-y.

Molnar, J.L., Gamboa, R.L., Revenga, C., & Spalding, M.D. 2008. Assessing the global threat of invasive species to marine biodiversity. Front Ecol Environ. 6:485-92.

Moon, P. 2015. Discovery myths of New Zealand: Some cultural, historical, and philosophical perspectives. Te Kaharoa. 8:1-44.

Morgan, T.K.K.B. 2006. An indigenous perspective on water recycling. Desalination. 187:127-36. https://doi.org/10.1016/j.desal.2005.04.073.

MPI. 2014. Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand. Wellington, New Zealand: CRMS-BIOFOUL. Ministry for Primary Industries. 8 pp.

New Zealand Government. 2000. New Zealand Biodiversity Strategy. Wellington, New Zealand: Department of Conservation. 144 pp.

New Zealand Parliament. 1993. Biosecurity Act 1993. Public Act 1993 No. 95. Date of assent: 26 August 1993. Reprinted on 18 October 2016. 300 pp.

NSSC. 2006. Naval ships' technical manual chapter 081. Waterborne underwater hull cleaning of navy ships, revision 5. Published by direction of Commander, Naval Sea Systems Command, USA. 68 pp.

Piola, R., & Conwell, C. 2010. Vessel Biofouling as a Vector for the Introduction of Nonindigenous Marine Species to New Zealand: Fishing Vessels (Technical Paper No: 2010/11). Wellington, NZ: Ministry for Agriculture and Forestry, Biosecurity. 57 pp.

Ribera Siguan, M.A. 2003. Pathways of biological invasions of marine plants. In: Invasive Species: Vectors and Management Strategies, eds. Ruiz, G.M., & Carlton, J.T., 183-226. Washington, DC: Island Press.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D., & Hines, A.H. 1997. Global invasions of marine and estuarine habitats by nonindigenous species: Mechanisms, extent, and consequences. Am Zool. 37:621-32. https://doi.org/10.1093/icb/37.6.621.

Ruppert, E.E., & Barnes, R.D. 2004. Invertebrate Zoology (6th edition). Orlando, FL: Saunders College Publishing. 1060 pp.

Schaffelke, B., Smith, J.E., & Hewitt, C. 2006. Introduced macroalgae: A growing concern. J Appl Phycol. 18:529-41. https://doi.org/10.1007/s10811-006-9074-2.

Schultz, M.P., Bendick, J.A., Holm, E.R., & Hertel, W.M. 2011. Economic impact of biofouling on a naval surface ship. Biofouling. 27(1):87-98. https://doi.org/10.1080/08927014.2010.542809.

Sorte, C.J., Williams, S.L., & Carlton, J.T. 2010. Marine range shifts and species introductions: Comparative spread rates and community impacts. Global Ecol Biogeogr. 19:303-16. https://doi.org/10.1111/j.1466-8238.2009.00519.x.

Statistics New Zealand. 2015a. Value of fisheries and aquaculture. Available at: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Marine/marine-economy/value-fisheries-aquaculture-archived-27-10-16.aspx.

Statistics New Zealand. 2015b. Are New Zealanders living closer to the coast? Available at: http://www.stats.govt.nz/browse_for_stats/population/migration/internal-migration/re-nzs-living-closer-to-coast.aspx.

Sylvester, F., Kalaci, O., Leung, B., Lacoursière-Roussel, A., Murray, C.C., Choi, F.M., … MacIsaac, H.J. 2011. Hull fouling as an invasion vector: Can simple models explain a complex problem? J Appl Ecol. 48(2):415-23. https://doi.org/10.1111/j.1365-2664.2011.01957.x.

Terlizzi, A., & Faimali, M. 2010. Fouling on artificial substrata. In: Biofouling, eds. Dűrr, S., & Thomasson, J.C., 170-84. Oxford, UK: Wiley-Blackwell.

Wehi, P., Cox, M., Roa, T., & Whaanga, H. 2013. Marine resources in Māori oral tradition: He kai moana, he kai mā te hinengaro. J Mar Island Cult. 2:59-68. https://doi.org/10.1016/j.imic.2013.11.006.

Williams, S.L., & Smith, J.E. 2007. A global review of distribution, taxonomy and impacts of introduced seaweeds. Annu Rev Ecol Evol S. 38:327-59. https://doi.org/10.1146/annurev.ecolsys.38.091206.095543.