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Science underpinning the thresholds proposed in the CRMS: Biofouling on vessels arriving to New Zealand

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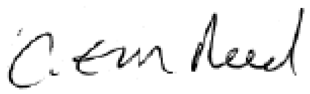

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1 Summary of proposed biofouling thresholds

This document presents the science that underpins the thresholds proposed in the Craft Risk Management Standard (CRMS): Biofouling on Vessels Arriving to New Zealand.

Biofouling is recognised as a significant pathway for introduction of non-indigenous marine species into New Zealand. The risk analysis of vessel biofouling notes that the biosecurity risk can be mitigated by restricting the fouling on vessels entering New Zealand to the level of slime layer (microfouling) or less (Bell et al. 2011).

The setting of a level of clean at "slime layer" for the CRMS is tractable when vessels operate within the specifications of antifouling coatings. However, there are instances within "normal" vessel operation that may result in the establishment of macrofouling. For example, the waiting periods for the loading/unloading of cargo can be up to 3 months in Australia. Because of such instances, the thresholds proposed in the CRMS allow for the presence of some macrofouling species, albeit with restrictions to minimise biosecurity risk. The thresholds proposed are designed to limit species richness, and to prevent successful reproduction and settlement of the allowed macrofouling species whilst considering the practicality/feasibility of implementation.

The proposed thresholds specifically focus on four taxonomic groups of organisms common to early-stage macrofouling – macroalgae, barnacles, tubeworms and bryozoans. Macroalgae are found on hull surfaces of many otherwise clean vessels. They are usually found on the wind/water line area where antifouling systems are less effective and the light availability is high. Barnacles, tubeworms and bryozoans are typically the first macro-organisms to colonise hull surfaces, thus they may provide habitat for other fouling species. The presence of early-stage fouling by these species within the proposed thresholds serves as a warning to vessel owners that their biofouling management plan is failing. These vessels may pose a potential biosecurity risk to New Zealand on subsequent visits.

The practical difficulties in managing biofouling on different areas of the hull are acknowledged within the thresholds proposed. For example, a greater tolerance of macrofouling species has been proposed for niche areas due to the specific difficulties in preventing biofouling on these areas. Further, tolerance for a green macroalgae on the wind/water line has also been proposed due to the challenge of preventing these organisms from fouling this area.

The proposed thresholds are also governed by the intended duration of a vessel's stay in New Zealand. For example, long-stay vessels must meet a higher standard of hull cleanliness due to the increased likelihood of release and establishment of non-indigenous species.

Tables 1 and 2 summarise the recommendations for the proposed thresholds in the CRMS: Biofouling on Vessels Arriving to New Zealand.

Table 1: Recommended biofouling thresholds for short-stay vessels.

Vessel surface	Allowable biofouling
All surfaces	Slime layer; Goose barnacles.
Wind/water line	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 non-algal macrofouling organism type of either barnacles, tubeworms 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 non-algal macrofouling organism type of either barnacles, tubeworms 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 non-algal macrofouling organism type of either barnacles, tubeworms 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 non-algal macrofouling organism type of either barnacles, tubeworms 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.

Table 2: Recommended biofouling thresholds for long-stay vessels and/or vessels that intend to visit areas other those designated under the Act as Places of First Arrival.

Vessel surface	Allowable biofouling
All surfaces	Slime layer; Goose barnacles.

Short-stay vessels
For those vessels intending to remain in New Zealand for less than 3 weeks, the threshold for short-stay vessels applies.

Long-stay vessels
For those vessels intending to remain in New Zealand for more than 3 weeks and/or visit areas other those designated under the Act as Places of First Arrival, the threshold for long-stay vessels applies.

2 Background

Biofouling is the process of accumulation of organisms on immersed surfaces. In the initial stages of the biofouling process, organic material sticks to a surface and is rapidly colonised by bacteria, microalgae and cyanobacteria forming a microfouling layer (slime layer). The creation of a slime layer occurs rapidly on submerged surfaces. Aside from continuous cleaning, there is currently no effective technology to prevent slime layer formation, including biocidal or foul release coatings (Dobretsov et al. 2010).

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 and 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 and Clare 2008; Terlizzi and Faimali 2010). Despite the stochastic nature of the biofouling process, 'pioneering' macrofoulers typically include green filamentous algae, barnacles, tubeworms and bryozoans (Hilliard et al. 2006; Lewis and Coutts 2010).

Where antifouling coatings are absent, worn, old, or damaged, Hilliard et al. (2006) suggested the following common successional pattern in port and coastal waters:

- Primary slime layer with grey and green tinges that vary with diatom content and light;
- Gossamer-like amphipod tubes (dependent on season and level of water movement);
- Filamentous green algae that can develop into waterline or transom beards providing shelter to amphipods and other clinging biota;
- Encrusting bryozoans;
- Tubeworms, barnacles, turfing red algae, hydroids, erect bryozoans, ectocarpoid brown algae;
- Mussels, oysters, encrusting sponges, sea anemones and sea squirts; and
- Larger mobile forms, including errant polychaetes, crabs, whelks, nudibranchs, crinoids and territorial fishes.

The MPI risk analysis of vessel biofouling identified twelve taxonomic groups as posing non-negligible risks to New Zealand's core values. The taxonomic groups identified were:

- Amphipods and Isopods;
- Barnacles;
- Bivalves;
- Bristleworms (including Tubeworms);
- Bryozoans;
- Crabs;
- Echinoderms;
- Flatworms;
- Gastropods;
- Hydroids;
- Macroalgae; and
- Sea squirts.

Not all species within these groups will pose a biosecurity risk as they may be native, cosmopolitan, or already established. However, there are many non-indigenous species within these groups that demonstrate characteristics likely to pose biosecurity risks to New Zealand's core values (Bell et al. 2011).

It is noted that research is required to confirm the presence and translocation potential of potentially hazardous bacteria, viruses and microalgae before the development and implementation of biofilm control measures can be justified. As already noted, preventing the entry of non-indigenous bacteria, viruses and microalgae via vessel hull fouling cannot be practically achieved (Dobretsov et al. 2010).

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 labour intensive, time consuming, 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 the vessel hulls. However, it is noted that there are practical limitations to biofouling prevention requiring that thresholds be set that achieve a biosecurity outcome whilst facilitating trade.

3 Evaluation of thresholds

3.1 Presence or absence of macrofouling on the hull

3.1.1 Allowance of slime layer only

Other than continuous cleaning, there appears to be no effective antifouling technology available to prevent slime layer fouling (Dobretsov et al. 2010). Applying a slime layer threshold would manage the biosecurity risks presented by the groups of macrofouling taxa identified in the risk analysis of vessel biofouling (Bell et al. 2011).

The IMO has recently adopted guidelines for the control and management of biofouling of vessels to minimize the transfer of aquatic 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."

3.1.2 Allowance of some macrofouling

Best antifouling practice on a hull means no macrofouling species should be present (except for macroalgae on the wind/water line[1]; Lewis *pers. comm.*). However a review of the MPI commissioned research on vessel biofouling has shown the presence of some macrofouling species on hull areas of newly antifouled/well-maintained vessels (Floerl et al. 2010; Inglis et al. 2010). The macrofouling found on these vessels were mainly located in niche areas that were not antifouled and/or were protected from hydrodynamic drag (Floerl et al. 2010; Inglis et al. 2010). Further, Mineur et al. (2007) showed no differences between new coatings (2 months old) and those up to 30 months old in terms of macroalgae species richness on merchant vessels. However, it is noted that antifouling age is not the only factor determining the likely presence of macrofouling species (Inglis et al. 2010; IMO 2011).

Although the slime layer threshold would manage the biosecurity risks identified from the vessel biofouling risk analysis (Bell et al. 2011), the amount of vessels with incidental macrofouling may require significant resource effort at each Place of First Arrival (POFA) 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" are:

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

- 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 non-compliant vessels with incidental fouling?

To solve these problems the Risk Analysis Team identified macrofouling levels that occur as incidental fouling under best antifouling management practices. From this baseline, thresholds have been proposed taking into account organism biology, MPI commissioned research and international research findings, and comments received from public submissions.

3.1.3 Recommendations

The Risk Analysis Team considers that some "early-stage" macrofouling species be allowed as biofouling 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 non-indigenous species, some restrictions on the amount of fouling allowed would be required.

3.2 Types of macrofouling that should be allowed

Analysis of the MPI commissioned research on vessel biofouling and international literature has allowed the Risk Analysis Team to identify species that are common as incidental fouling on well-maintained vessels.

3.2.1 Goose barnacles

Goose barnacles (lepadomorphs) are ubiquitous foulers of tropical, subtropical and temperate seas, with a pelagic lifecycle that includes attachment to drift wood, floating plant debris and hulls of slow moving vessels, as well as turtles and some whales (Barnes et al. 2004; Lewis 2004). Densities of 20-30 m^{-2} are not uncommon in areas of low flow, including entrances of irregularly used seawater intakes or outlets (Hilliard et al. 2006). Stalked or goose barnacles, such as *Lepas* spp., often foul submerged surfaces in open oceans, including buoys, but are also sometimes found on vessel hulls (Lewis 2004).

The presence of goose barnacles does not represent an unacceptable level of fouling risk (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). Goose barnacles were not considered a hazard species and not included in the vessel biofouling risk analysis (Bell et al. 2011).

3.2.2 Macroalgae

Macroalgal fouling of hull surfaces of recreational, commercial and naval vessels is a common phenomena (Evans 1981; Hay 1990; Godwin et al. 2004; Floerl et al. 2005; URS 2002, 2006 in Hilliard et al. 2006; Lewis and Gillham 2007; Mineur et al. 2007; Mineur et al. 2008; Piola and Conwell 2010; Schultz et al. 2011; Inglis et al. in prep.; Lewis *pers. comm.*).

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

The risk analysis of vessel biofouling (Bell et al. 2011) identified the macroalgal taxonomic group as a non-negligible biosecurity risk. However, the MPI commissioned research on vessel biofouling has shown a relatively high incidence (%) of macroalgae on all vessel types (Inglis et al. 2010; Table 3). Therefore, a threshold that manages the biosecurity risk but does not unnecessarily penalise low risk vessels is proposed (see section 3.4.1 Macroalgae).

3.2.3 Barnacles, tubeworms and bryozoans

The risk analysis of vessel biofouling (Bell et al. 2011) identified the barnacle, tubeworm and bryozoan taxonomic groups as non-negligible biosecurity risks. However, it is recognised that macrofouling consisting of at least one of these organisms is common on all vessel types (Inglis et al. 2010; Table 3). Therefore, a threshold that manages the biosecurity risk but does not unnecessarily penalise low risk vessels is proposed (see section 3.4.2 Barnacles, tubeworms and bryozoans).

Table 3: Fouling organism incidence by vessel type (percentage and number of vessels).

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

3.2.4 Recommendations

From the above findings it is recommended that the presence of:

- Goose barnacles on vessel hulls are permitted without restrictions. The presence of goose barnacles may be used by Quarantine Inspectors as an indicator of the presence of restricted macrofouling;
- Macroalgae on vessel hulls are permitted – with restrictions (see section 3.4.1 Macroalgae); and
- Barnacles, tubeworms and bryozoans on vessel hulls are permitted - with restrictions (see section 3.4.2 Barnacles, tubeworms and bryozoans).

3.3 Practical management of macrofouling

Analysis of the MPI commissioned research on vessel biofouling and international literature has allowed the Risk Analysis Team to identify areas of well-maintained vessels that are prone to incidental fouling based on vessel and fouling organism traits.

3.3.1 Varied thresholds for specific areas of the hull surface

There exist intrinsic differences in the ability to prevent biofouling on different areas of the vessel hull including wind/water line, hull areas and niche areas. Best antifouling practice on a hull means no macrofouling species should be present (except for macroalgae on the wind/water line; Lewis *pers. comm.*). However, a review of the MPI commissioned research has shown the presence of some macrofouling species on hull areas of newly antifouled/well-maintained vessels (Floerl et al. 2010; Inglis et al. 2010). The macrofouling encountered on these vessels were mainly located in niche areas that were not antifouled and/or protected from hydrodynamic drag (Floerl et al. 2010; Inglis et al. 2010).

Niche areas are those areas on a vessel that may be more susceptible to biofouling due to different hydrodynamic forces, susceptibility to coating system wear or damage, or being inadequately, or not, painted, e.g., sea chests, bow thrusters, propeller shafts, inlet gratings, dry-dock support strips, etc. Niche areas therefore pose a substantial biosecurity risk despite accounting for a relatively small proportion of the hull (James and Hayden 2000; AMOG

Consulting 2002; Coutts et al. 2003; Coutts and Taylor 2004; Floerl et al. 2010; Inglis et al. 2010). In the MPI commissioned research on vessel biofouling, 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 on the latter vessels (Inglis et al. 2010). Due to the susceptibility of niche areas to biofouling, a practical threshold is proposed that is above that allowed for wind/water line and hull areas.

3.3.2 Uniform threshold for the whole of the hull surface

Applying the proposed niche area threshold to the hull area would result in the potential for an increase in propagule pressure of non-indigenous species due to the relative surface area of the hull by comparison to niche areas. In the MPI commissioned research on the hull fouling of recreational vessels, hull area comprised approximately 93.2% of each recreational vessel's submerged surface area, about 14 times more than the area comprised by niche areas (Floerl et al. 2008). Applying a higher niche area threshold to the wind/water line and hull areas also belies industry best practice and therefore cannot be justified. Applying the threshold proposed for the hull area to the niche areas may result in the non-compliance of a number of vessels that pose a minimal biosecurity risk causing unnecessary delays at the border and may negatively impact New Zealand's economic interests.

3.3.3 Recommendation

From the above findings it is recommended that the threshold for biofouling should be varied for specific areas of the hull surface.

3.4 Factors affecting macrofouling thresholds

3.4.1 Macroalgae

Allowing species within this taxonomic group to enter New Zealand without restrictions represents a non-negligible biosecurity risk (Bell et al. 2011).

The morphologies of macroalgal species associated with hull fouling are characterised as being small with flexible, filamentous or sheet like vegetative structures and high growth rates (Ribera-Siguan 2003; Williams and Smith 2007; Lewis and Coutts 2010). 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 (i.e., of unknown origin). Macroalgae with cosmopolitan distributions are common on vessel hulls; for example, Mineur et al. (2008) found that the majority (58%) of the macroalgal species 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 (Schaffelke et al. 2006; Lewis and Gillian 2007). 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 tributyl-tin containing antifouling paints (Callow 1986).

Wind/water line (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. Note that brown and red algae were excluded from this allowance. Further, Hilliard (pers comm.) states that he has “yet to see any grasping crustacean using simple waterline ‘fur’ as a successful shelter from turbulent flow.”

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

Considering the above, the Risk Analysis Team has reviewed images from the MPI commissioned research on vessel biofouling for merchant vessels, passenger vessels and recreational vessels and 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 should remain at < 4 mm blade length as suggested by Hilliard et al. (2006) as species within these taxa are not as ubiquitous as green macroalgae and thus present a different biosecurity risk. These restrictions should adequately protect New Zealand given that reproductive capacity of the algae should be limited by the size and timing restrictions in place (Floerl et al. 2010; see section 3.5).

Despite a suggested allowance of “small patches” of filamentous green algae (Hilliard et al. 2006), the wind/water line provides 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/water line, it is not practical to propose a limit on the extent of macroalgae occurring on this vessel surface.

Preventing the overgrowth of macrofouling species by macroalgae on the wind/water line may not be practically achievable due to the dynamic macroalgal growth conditions present on this section of the hull. Thus it is proposed that macroalgal overgrowth of permitted macrofouling be allowed on the wind/water line section of the hull.

Hull and niche areas

To manage the biosecurity risk posed by macroalgae in hull and niche areas, it is proposed that MPI follows the advice of Hilliard et al. (2006). However, due to practical considerations at the border, such as the availability of taxonomic expertise, there should be no restrictions on algal morphology (e.g., coralline, bladed, foliose) or taxonomic group (e.g., red, brown, green algae) in these areas. Restrictions should 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 should be limited by the size and timing restrictions in place (Floerl et al. 2010; see section 3.5).

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, i.e., 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 non-compliant vessels through New Zealand's border system. Further, the successional nature of hull biofouling means that the longer a macrofouling species has been present on a hull, the more likely it is to be covered by overgrowth. Hence, it is proposed that a restriction be put in place to limit the overgrowth of allowed macrofouling organisms to help mitigate the presence of sexually mature macrofouling individuals.

Strips of algae are not uncommon in niche areas, particularly along their outer edges. A threshold for allowable macroalgal growth needs to balance between risk mitigation and vessel clearance. Following the advice of Hilliard et al. (2006) regarding the allowance of "small patches", our review of the vessel biofouling 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 (localised patches) of macroalgae (usually less than a few cm^2 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.

Recommendations
For wind/water line, green algal growth should be no more than 50 mm in length; red and brown algal growth should be no more than 4 mm in length.

For hull areas and niche areas, any algal growth should be no more than 4 mm in length and in continuous strips and/or patches of no more than 50 mm in width; no algal overgrowth should be permitted on the allowed macrofouling species (see section 3.4.2).

3.4.2 Barnacles, tubeworms and bryozoans
Allowing species within these taxonomic groups to enter New Zealand without restrictions represents a non-negligible biosecurity risk (Bell et al. 2011).

In terms of previous proposed thresholds for macrofouling, the following levels of fouling were deemed by Hilliard et al. (2006) as low risk:

- Minor growth of green algae (as green slime, individual filaments or small patches < 4 mm thick with no obvious projecting wads of thicker tufts);
- Goose barnacles; and
- Flat solitary calcareous discs, i.e., encrusting bryozoa or pink coralline algae.

The following levels of fouling were deemed by Hilliard et al. (2006) as high risk:

- Macroalgae beards (> 4 mm thick with numerous projecting tufts);
- Balanomorph barnacles (i.e., acorn, star and giant barnacles);
- Tubeworm infestations;
- Mussels and oysters; and
- Complex growths containing multiple spongy, filamentous, encrusting or foliose plants and animals.

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 colonised by bryozoans. These findings were consistent with the MPI commissioned research on vessel biofouling (Inglis et al. 2010).

The percentage cover and biomass of fouling organisms tend to be positively correlated with species abundance and richness, and increases in the extent and amount of biofouling are therefore likely to increase biosecurity risk as well (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 an 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 multi-species biofouling assemblages, whereas areas with an LOF rank of 2 typically have more limited biofouling species richness.

Box 1: Level of fouling (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.

Analysis of the results of the MPI commissioned research on biofouling of recreational vessels has shown that when combinations of the barnacle, tubeworm and/or bryozoan groups are present as hull biofouling, it is likely that additional taxonomic groups will also be present (Table 4). For the wind/water line and hull areas, it would appear prudent to allow only single species, or species that appears to be the same, rather than combinations of organisms from these broad taxonomic groups.

Table 4: Incidence of additional hull fouling groups occurring on recreational vessels in the presence of specific or combinations of macrofouling (percentage and number of vessels).

Group combination (Total vessels *n* = 182)	Percentage Incidence	Percentage incidence of additional groups present
Bryozoans x Barnacles x Tubeworms	33.5% (*n* = 61)	83.6% (*n* = 51)
Bryozoans x Barnacles	23.1% (*n* = 42)	73.8% (*n* = 31)
Bryozoans x Tubeworms	9.3% (*n* = 17)	76.5% (*n* = 13)
Barnacles x Tubeworms	3.3% (*n* = 6)	50% (*n* = 3)
Bryozoans	6.0% (*n* = 11)	64% (*n* = 7)
Barnacles	9.9% (*n* = 18)	61% (*n* = 11)
Tubeworms	1.1% (*n* = 2)	50% (*n* = 1)

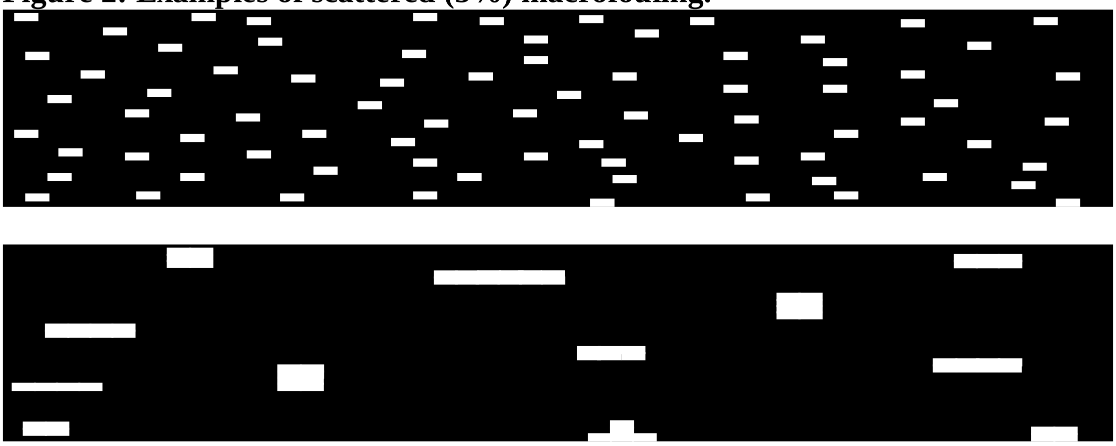
Vessel niche areas tend to be more susceptible to biofouling accumulation (see 3.3.1). MPI's review of niche area images from well-maintained vessels found that when fouling was present, scattered individuals of a single species were often accompanied by incidental individuals of a second species. Because of the difficulties of preventing the occurrence of biofouling in niche areas, a tolerance level allowing incidental coverage of a second non-algal macrofouling organism (restricted to barnacles, tubeworms or bryozoans) is proposed.

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

Figure 1: Examples of incidental (1%) macrofouling.

Low thresholds of fouling have been deliberately proposed to limit opportunities for organisms to occur in proximity and/or accumulate in numbers to a level that could facilitate successful reproduction, i.e., reducing the propagule pressure by keeping the organisms too few in number and too far apart allow successful spawning, settling and establishment. It is noted that barnacles are restricted in their reproduction by physical constraints and that species such as tubeworms and bryozoans may be broadcast spawners (Ruppert and Barnes 2004).

Figure 2: Examples of scattered (5%) macrofouling.



Further, the macrofouling thresholds proposed 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 proposed for organism spacing (i.e., incidental/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 reproductive.

Under best practice for hull maintenance, the presence of macrofouling species on a vessel hull represents a failure of the antifouling system (except for macroalgae on the wind/water line; Lewis pers. comm.). However, a review of the MPI commissioned research has shown the presence of some macrofouling species on hull areas of newly antifouled/well-maintained vessels (Floerl et al. 2010; Inglis et al. 2010). As a result, the thresholds for wind/water line and hull areas have been proposed 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, any vessel that arrives in New Zealand with any macrofouling on its hull should receive a warning regarding the consequences of using an ineffective biofouling management plan.

Recommendations
For wind/water line (Boot-top) areas: the tolerance should be for incidental (1%) coverage of one non-algal macrofouling organism type of either barnacles, tubeworms 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 should be for incidental (1%) coverage of one non-algal macrofouling organism type of either barnacles, tubeworms 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 tolerance should be:
- Scattered (5%) coverage of one non-algal macrofouling organism type of either barnacles, tubeworms or bryozoans, occurring as widely spaced individuals and/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 non-algal macrofouling organism type of either barnacles, tubeworms 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.

3.5 Intended vessel itinerary

3.5.1 Varied threshold dependent on the intended vessel 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 risk that the species will spawn or escape from the biofouling and become established (Inglis et al. 2012). The magnitude of this risk is uncertain, as it will 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, the risk is likely to increase with the amount of biofouling present on the vessel (Sylvester et al. 2011) and will vary with its geographic origin. 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 proposed thresholds, it should be able to remain in New Zealand for a period of 4 weeks, less the travelling time (from the last point of likely infestation), without posing a significant biosecurity risk. It is noted that the 4-week period allowed is inclusive of travelling 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 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 macrofouling thresholds recommended in Section 3.4 are for short-stay vessels only (i.e., a vessel that remains in New Zealand for a period of less than 3 weeks). 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 should be 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/water line is often fouled by cosmopolitan species (Mineur et al. 2007), allowance of no macroalgae on the wind/water line of long-stay vessels or those vessels that visit non-POFA areas is proposed because the CRMS must cover all sea craft entering New Zealand, including those vessels that stay indefinitely and those that routinely visit for long periods, such as recreational vessels, fishing vessels and barges (Inglis et al. 2012). Despite the ubiquity of some green macroalgae on the wind/water line, there is the potential for some species to be non-indigenous to New Zealand and thus would be allowed to mature and reproduce once through the New Zealand border. Further, it is possible that the presence of this macroalgae could shelter other macrofouling species or obstruct detection of these species by border staff. Also, from a risk perspective it would be inconsistent to disallow macroalgae fouling on hull and niche areas whilst allowing it on the wind and waterline.

Recommendations

As a result of the assessment conducted by the Risk Analysis Team, the threshold for long-stay vessels is recommended to be 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 before entering 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 timeframe that includes travelling time, it can help reduce the likelihood, frequency and success of spawning/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/operators and helps to mitigate against "spawning on arrival" events, a residual risk of post-border spawning remains. Border Clearance Procedures will help MPI to flag vessels for further investigation where the approach to cleaning before arrival may not have been effective.

Vessels with itineraries that visit areas other those designated under the Act as Places of First Arrival (POFA) should also be subject to more stringent thresholds i.e., the threshold for long-stay vessels. The higher threshold is recommended for the protection and maintenance of those areas that do not typically receive high vessel traffic. These areas can have national and international significance such as Fiordland National Park, and the Kermadec Islands and sub-Antarctic Islands. It is in the interests of both the regulator and vessel owner/operator to maintain these areas by preventing the introduction of non-indigenous species through vessel biofouling.

3.5.2 Uniform thresholds regardless of the intended vessel itinerary

Having all vessels meet the same threshold for entry into New Zealand represents an ideal situation from the regulatory perspective, however:

- The threshold proposed for short-stay vessels may not manage the biosecurity risk presented by long-stay vessels due to the period available for reproduction and spawning;
- The threshold proposed for short-stay vessels may not manage the biosecurity risk presented by vessels that visit non-POFA areas as it was not designed for the protection of high value pristine areas; and
- The higher threshold proposed for long-stay vessels and/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.

Recommendations

From the above findings it is recommended that the threshold for biofouling should differ dependent on the intended vessel itinerary within New Zealand. Long-stay vessels should be required to meet a more stringent threshold than short-stay vessels.

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