Vessel Hard-stand Survey and Biofouling Risk Factors

Top of the South Marine Biosecurity Partnership

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Prepared for

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EXECUTIVE SUMMARY

The Top of the South (TOS) Marine Biosecurity Partnership has focused some of its activities on better understanding and managing biofouling risks from recreational vessel movements. Work over the last two summers has included biofouling assessments of recreational boats from across the TOS region, along with surveys of boaters to better understand their voyage habits and maintenance practices. Simultaneous with the summer work, biofouling assessments and boater surveys have been undertaken by appropriately-trained travel-lift operators at the Nelson and Waikawa hard-stands. The first part of this report describes the hard-stand survey work, and compares the results to previous summer survey findings. In the second part of the report, combined data from the summer surveys and hard-stand study are used to explore the extent to which levels of fouling (LOF[1]) on recreational vessels are related to boater practices with respect to antifouling, cleaning and boat usage, as these are all recognised risk factors.

Hard-stand survey

The analysis was based on 271 questionnaire returns from the Nelson and Waikawa hard-stands. Boat maintenance and use patterns were broadly similar to that reported from the 2015/16 summer survey, and can be summarised as follows:

- For 95% of boaters hauled out at the two hard-stands, the home port was in the TOS, with 11 boats coming from elsewhere in New Zealand and one being of international origin.
- Most boaters (92%) stated that they antifouled their vessel every 12-24 months (median 18 months). However, in practice the antifouling frequency appeared to be less than stated, reflecting that at the time of haul-out only 70% of boaters had antifouled within the previous 24 months.
- Vessel cleaning between antifouling events was reasonably common, with 43% of boaters having cleaned their hull at least once. Of this boater subset, 53% undertook in-water cleaning and 31% cleaned in locations outside the main vessel hubs, including in relatively pristine bays of the outer Sounds and Abel Tasman coast.
- Reported boat usage overall was typically quite low, with 9% of boats having remained unused since their last antifouling, while 50% had been active for 5% or less of available days, and 75% had been active for 10% or less of available days.
- Since last being antifouled, about 10% of boats domiciled in the TOS had travelled to other New Zealand locations (e.g. Fiordland, Auckland, Bay of Islands), with 2.4% (4 boats) having travelled internationally. Across all boats surveyed, a total of 1,459 days had been spent at New Zealand locations outside the TOS since last being antifouled.

[1] Level of fouling (LOF) assessment is based on a pre-defined scale ranging from LOF 1 (the absence of macrofouling) to LOF 5 (very heavy macrofouling, exceeding 40% cover of the submerged boat hull)

- When considered together with the summer survey data, it appears that about 75-80% of boats visiting the TOS region do not necessarily travel to a main hub (e.g. port, marina) during their visit.

Levels of fouling in relation to risk factors

The main dataset used for this second component of the study contained 339 records of LOF, for which there were corresponding data on some or all of the following risk factors: antifouling coating age (months), whether the boat had been cleaned (y/n) since last being antifouled, the percentage of days the boat had been idle since last being antifouled (percent idle), and vessel type (power/sail). The latter factor can to some extent be considered as a proxy variable for boat speed. While boat speed was also included as a potential predictor, missing records meant that analyses involving speed were based on only 178 observations. Note that the 339 records in the dataset were obtained after excluding 17 outliers, namely:

- Five records for boats whose home ports were in low salinity river-dominated environments (Havelock, Westport), and which were not considered to represent true marine biofouling.
- Twelve records for boats that had not been antifouled within ≤ 3 years (36 months). These primarily represented boaters with atypical habits who relied on cleaning more than antifouling as a management strategy.

Antifouling coating age was the most significant predictor of LOF, with higher LOF categories being associated with older antifouling coatings. Visual patterns between the other predictor variable and LOF were also evident, and were sometimes significantly correlated. For example, increasing LOF was generally associated with slower boats and boats that spent the majority of their time idle. Although cleaning 'reset' the LOF to low levels in specific instances, this was not always the outcome. In fact, the overall pattern was counter-intuitive, with LOF levels being greater overall on boats that had been cleaned than those that had not. Both the cleaning effort and method are likely to affect the outcome of cleaning; for example, it is conceivable that inappropriate cleaning (e.g. using an abrasive method on a 'soft' antifouling coating) leads to an exacerbation of fouling. Despite, the importance of a range of risk factors, the inclusion of multiple predictors (and their interactions) in regression models did not significantly improve on an optimum model that described LOF as a function of antifouling age alone.

Management implications

Management implications were considered from two perspectives. First, the antifouling frequency necessary to achieve management goals based on specified LOF outcomes was considered. For example, to limit heavily-fouled (LOF 4) boats to 5% or less of the boat population, the data suggested that an antifouling frequency of < 1 year would be necessary; in fact, 5% of LOF 4 boats had an antifouling coating that was 9.4 months old or less. One of the challenges in limiting fouling to low levels is that niche areas can become fouled quite quickly, despite effective antifouling on the main hull.

A second approach was to consider how the distribution of LOF scores might change if 'rules' were put in place with respect to the frequency of antifouling; i.e. specifying maximum intervals for the renewal of the antifouling coating. For example, ANZECC (2013) Anti-fouling and In-water Cleaning Guidelines recommended antifouling intervals of 12 months in the case of recreational boats with biocidal coatings (as used on most recreational vessels). In a scenario where all boaters conducted antifouling every 12 months compared with every 24 months, the expected reduction in the incidence of heavily-fouled (LOF 4 & 5) vessels was 64% and 62%, based on predictions from the regression model and raw LOF scores, respectively. However, even 12-monthly antifouling may not negate risk from heavily-fouled boats, with the incidence of LOF 4 and 5 vessels expected to be c. 10 - 14%. Nonetheless, while not a silver bullet, a 12-monthly antifouling regime would be expected to have a considerable benefit over the *status quo* in terms of reducing marine pest transport with recreational boats.

Conclusions

Achieving effective biofouling risk management is complex. Reducing hull fouling risk requires consideration of measures for recreational vessels from both within and outside the TOS. While there are clearly good biosecurity reasons for recreational boaters to undertake annual antifouling, for TOS boaters to adopt this approach would require a substantial change to current practices. Costs to boaters would be greater, and the availability of hard-stand resources (travel-lift, hard-stand space) would need to be carefully considered. Better antifouling outcomes might be achieved through development of 'best practice' measures for the selection and application of coatings, and for boat cleaning. As achieving a significant reduction in LOF is likely to require an increased frequency of cleaning, there is an immediate need for guidance on what is to be allowed in the TOS in terms of in-water cleaning. Related to this is a need to understand how different types of cleaning might affect the integrity and efficacy of different types of antifouling coating. In the absence of effective management of recreational vessels in the TOS and elsewhere, it is highly likely that new marine pests will be introduced to the region from other locations in New Zealand, while established pests will continue to be rapidly spread.

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1. INTRODUCTION

The Top of the South (TOS) Marine Biosecurity Partnership (the Partnership) has been focusing some of its activities on better understanding and managing biofouling risks from recreational vessel movements. There are several thousand recreational vessels at marina berths or on swing moorings in the TOS region (Floerl et al. 2015), as well as vessels that visit from other regions. Recreational boats are recognised as being important from a biofouling risk perspective, primarily because:

- They are prone to fouling, as they tend to spend long periods of time idle, which can reduce the efficacy of their antifouling coatings (Piola and Forrest 2009).
- Many recreational vessels travel at slow voyage speeds (< 10 knots), which enables associated fouling to survive transport from place to place (Coutts et al. 2010a; Coutts et al. 2010b).
- They often visit high-value coastal areas, providing a direct route for the spread of marine pests to such locations.

Initial studies conducted in the TOS focused on vessel biofouling in Nelson and Waikawa marinas and adjacent moorings (Forrest 2013; Forrest 2014). Over the last two summers, the focus has shifted to surveys of recreational boats in more remote parts of the TOS away from the main vessel hubs, to better understand the biofouling risks posed by boats that are active in the region (Forrest 2016; Forrest 2017). These surveys have revealed 'conspicuous' levels of fouling across about one third of boats present, and the presence of marine pests on some vessels. These pests have include long-established species like the Asian kelp *Undaria pinnatifida*, as well as high-profile species that have arrived more recently: the clubbed tunicate *Styela clava*, and Mediterranean fanworm *Sabella spallanzanii*.

The two recent regional surveys involved snorkel-based biofouling assessments, and also information-gathering from boaters to better understand their voyage habits and maintenance practices. The 2016 survey involved a reasonably comprehensive questionnaire that was given to boaters for return by post (Forrest 2016), whereas in 2017 boaters were directly asked a subset of key questions (Forrest 2017). Of particular interest to the TOS Partnership is whether levels of fouling on recreational boats can be related to boater practices with respect to antifouling, cleaning and boat usage, as these are all recognised risk factors (Inglis et al. 2010). An understanding of the relationship between biofouling and these risk factors raises the possibility that guidance can be development to determine best practice for recreational boats in the region.

The field surveys have provided a limited dataset that can be used to address such questions. In order to obtain more comprehensive information, the field survey work was undertaken alongside a simultaneous project involving delivery of boater questionnaires and assessment of vessel biofouling at the Nelson and Waikawa marina hard-stands. Together with the regional field surveys, this additional work provides a dataset of sufficient size to assess the relationship between biofouling and key risk factors, and also provides further information on boater habits that complements the questionnaire analysis undertaken in 2016 (Forrest 2016). This report describes the findings from that work. The first part evaluates boater habits based on the hard-stand questionnaires, while the second part involves an analysis of the biofouling data in relation to risk factors.

2. METHODS

2.1 Hard-stand data collection and analysis

2.1.1 Boater questionnaire

At the Nelson and Waikawa marina hard-stands, travel-lifts are used to remove boats from the water for cleaning, antifouling or other maintenance (Figure 1). The survey at each hard-stand location was undertaken by the travel-lift operators. At the time of boat haul-out, the lift operators asked the boat owner (when present and willing) to complete a one-page questionnaire (Appendix 1).

Figure 1. Boats on travel-lift at Nelson.

The questionnaire was the same as that used in the 2016 regional survey, which was itself based on a subset of the key questions asked during previous studies of vessel biofouling in New Zealand (Floerl and Inglis 2005; Inglis et al. 2010; Lacoursière-Roussel et al. 2012), with some specific questions customised to the information needs of the TOS Partnership. The questionnaire consisted of 11 questions designed to elicit key information from boat owners, including information on: boat type; home port; berthage (e.g. marina berth, mooring); typical voyage speed; antifouling practices (e.g. frequency, paint type); cleaning practices since last antifouling (e.g. cleaning method, location, frequency); extent of boat use since last antifouling; areas of boating activity (within and outside the TOS); and the voyage habits of visiting boats.

2.1.2 Vessel biofouling status

Following haul-out, travel-lift operators assessed the 'level of fouling' (LOF) on each boat, based on a semi-quantitative biofouling percentage cover scale described by Floerl et al. (2005) and shown in Table 1. The LOF approach has been used in many hull fouling studies in New Zealand, including in the TOS (Lacoursière-Roussel et al. 2012; Forrest 2013; Forrest 2014). It is generally recognised that marine pest risk, or the presence of non-indigenous species, typically increases with an increasing LOF (Inglis et al. 2010), and this pattern has been confirmed for marine pests in the TOS (Forrest 2016; Forrest 2017). The travel-lift operators were given prior training in applying the LOF method, including photographs and other visual aids to assist in assigning scores (Figure 2). Often there were two operators present for each vessel haul-out, such that the assigned LOF represents a consensus score. Note that only a subset of the vessels that were hauled out were assessed by the lift operators, usually during less-busy periods. In addition, as boaters were not always present when their vessel was hauled-out, not all of the LOF records have corresponding questionnaire data.

Table 1. Level of fouling (LOF) categories and descriptions based on Floerl et al. (2005). The Floerl et al. category of LOF 0 (no visible fouling) was not used in the present study; LOF 1 is taken to represent slime layer[2] fouling or less (i.e. absence of visible macrofouling).

LOF	Description	Macrofouling cover (%)
1	**Slime layer** fouling only. Submerged hull areas partially or entirely covered in biofilm, but absence of any macrofouling.	Nil
2	**Light fouling**. Hull covered in biofilm and 1-2 very small patches of macrofouling (only one taxon).	1 – 5
3	**Considerable fouling**. Presence of biofilm, and macrofouling still patchy but clearly visible and comprised of either one or several different taxa.	6 – 15
4	**Extensive fouling**. Presence of biofilm, and abundant fouling assemblages consisting of more than one taxon.	16 – 40
5	**Very heavy fouling**. Diverse assemblages covering most of visible hull surfaces.	41 – 100

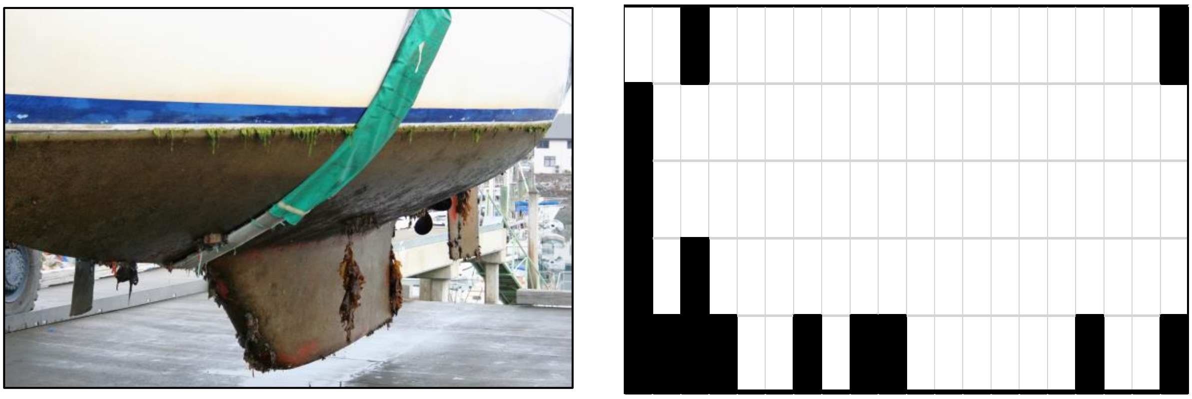

Figure 2. Example of visual aids provided to travel-lift operators for LOF assessment. These were used as examples of LOF 3, with the schematic representing the maximum cover (5%) for that category.

[2] Slime layer fouling described by LOF 1 contains no visible macrofouling, but may contain the microscopic or early life-stages of such organisms.

2.1.3 Analysis of questionnaires

The analysis of travel-lift data is based on 271 questionnaires completed at the two hard-stands from September 2015 to May 2017. Data from these questionnaires were entered into Excel and imported into the software R for analysis. Tabulated or graphical displays of the results are shown with respect to boater habits in terms of boat berthage, maintenance and use, and boater origin and areas of activity. As it was not always the case that questionnaire forms were completely filled out, for each of the results presented in the Figures and Tables below, the sample size (n) on which the summary data are based is indicated. In order to protect the commercial interests of the hard-stand facilities, only the aggregated data are presented.

2.2 Relationship between biofouling and risk factors

2.2.1 Data sources

To understand the relationship between biofouling and key risk factors, the travel-lift data were supplemented with data collected during the two previous regional field surveys. These regional surveys provided 198 additional LOF scores that had (to varying degrees) matching data on boater habitats. For the 2015/16 regional survey the boater data were derived from written questionnaire responses described by Forrest (2016), whereas in 2017 the data were derived from questions asked while on-the-water (Forrest 2017). As described in these previous reports, the LOF scores for the regional surveys were obtained by in-water snorkel diving assessment.

2.2.2 Fouling risk factors

The key risk factors considered in the analysis were as follows:

- The time (months) since last antifouling (antifouling age): antifouling (usually with a biocidal coating) is the main strategy to reduce the accumulation of biofouling on boat hulls, with antifouling age likely to be one of the most important predictors for recreational boats (Floerl et al. 2005; Clarke Murray et al. 2013; Floerl et al. 2016). Different coating types are recommended by manufacturers, depending on the operating profile (e.g. speed, level of activity) of the vessel.
- Whether the boat had been cleaned (y/n) in the intervening period since last being antifouled: cleaning of recreational boats would be expected to reduce fouling (Davidson et al. 2010), and could confound the relationship between antifouling age and LOF.
- The percentage of days boats surveyed had been idle (i.e. at berth or mooring) since last antifouling (percent idle): most of the commonly-used antifouling coatings perform more effectively when boats are used regularly, with boats that

remain idle for long periods (often referred to as the 'lay-up' period) being susceptible to fouling accumulation (Inglis et al. 2010).

- The type of vessel (sail, power) and its typical voyage speed: As speed increases, fouling can be physically dislodged. The threshold for fouling loss by dislodgement or damage is c. 10 knots (Coutts et al. 2010a; Coutts et al. 2010b); i.e. there tends to be high survival of fouling at voyage speeds of < 10 knots, with reduced survival as speed increases above that threshold. As power boats may travel at faster speeds than sail boats, their fouling levels tend to be less, especially when they are in active use (Forrest 2016, Forrest 2017).

2.2.3 Analysis of LOF vs risk factors

The total raw data set consisted of 356 records of LOF for which there were corresponding data on some or all of the risk factors. In order to focus the analyses on truly marine biofouling and 'typical' patterns of boater behaviour, 17 observations were omitted from the 356 records, as follows:

- Twelve observations were discarded representing boats that had not been antifouled within ≤ 3 years (36 months). These primarily represented boaters with atypical habits who relied on cleaning more than antifouling as a management strategy.
- Five additional observations were discarded that represented boats from home ports in low salinity river-dominated environments (Havelock, Westport). These vessels were not considered to represent true marine biofouling.

The final main data set used in the majority of analyses therefore consisted of 339 records, for which observations of LOF were matched with the predictor variables as follows: antifouling age (months), cleaned (y/n), percent idle, and vessel type (power/sail). The latter factor can to some extent be considered as a proxy variable for boat speed. While boat speed was also included as a potential predictor, missing records meant that analyses involving speed were based on only 178 observations.

Summary data for the above risk factors and their relationship with LOF are tabulated and shown graphically. Simple correlation analyses between LOF and individual predictors were undertaken, based on Spearman's rank correlation coefficients (rho values). To examine the relationship of LOF with the range of predictors and their interactions, ordinal regression analyses were used. Ordinal regression was based on cumulative link modelling methods, using the clm function in the 'ordinal' package of R. Cumulative link models are regarded as one of the best approaches for analysing data with ordinal responses (Christensen 2015). To prepare the data for ordinal regression, numeric LOF data were first converted to an ordered factor (5 > 4 > 3 > 2 > 1), and predictor variables were normalised and scaled using a Box-Cox transformation.

A range of regression models were tested, from a simple model of LOF as a function of antifouling age, progressing to more complex models that included all predictor variables as additive or interacting terms. Models were fitted using a logit link function, with a weighting factor applied to each LOF category as 1 – [n (lof)/ n (total)] in order to offset the effect of a disproportionate number of LOF 2 values (c. 64% of the data). The best models from the analyses were selected based on values of Cohen's kappa coefficient. As the selection process identified four models with similar kappa coefficients, likelihood ratio tests were applied to compare them, enabling selection of an optimum final regression model.

To provide management guidance in terms of appropriate antifouling intervals, some key summary statistics from the raw data were derived, and the optimum final regression model was used to predict the distribution of LOF scores (i.e. across LOF 1 – 5) at discrete antifouling paint ages (6, 12, 18, 24, 30 months). These predictions were compared to the distribution of LOF scores from raw data, based on intervals of 6-monthy antifouling paint ages centred around the same discrete paint ages. For example, the LOF distribution at 6 months as derived from the raw data, reflects boats whose antifouling ages ranged from 3 to 9 months, and so on. This approach provides for a reasonable comparison of raw data with regression model predictions, and is the best that can be achieved given that the LOF distribution for specific antifouling times cannot be determined from the raw data itself.

3. HARD-STAND QUESTIONNAIRES

3.1 General

A summary of the key statistics derived from the hard-stand boater questionnaires is given in Table 2, and compared to the previous analysis of regional questionnaires described by Forrest (2016). Of 271 returned hard-stand questionnaires, c. 54% came from the Waikawa hard-stand and the remainder were from Nelson. Of the total, 63% of vessels were sail boats and the remainder power boats. Of 262 respondents who reported on boat berthage, 77% usually kept their boats at marina berths, with the remainder on swing moorings.

3.2 Boat maintenance: antifouling and cleaning

3.2.1 Antifouling

Of 246 boaters who responded about antifouling practices, the average interval at which boaters reported that they applied an antifouling coating was c. 19 months (± SE 0.032), with a median interval of 18 months (Table 2). A total of 43% of boaters reported that they antifouled their vessel every 12 months, 56% within 18 months, and 92% within 24 months (Figure 3). Most of the remaining 8% of boaters reported antifouling within 36 months; however, six boaters undertook antifouling at longer intervals up to 60 months (5 years). Many of these were boats that tended to be regularly cleaned as an alternative to being more regularly antifouled. While boaters tended to antifoul using a wide range of paint types from a variety of manufacturers, the most-common category of coatings (83% prevalence) were ablative and semi-ablative biocidal paints that are designed to slowly erode away with water movement.

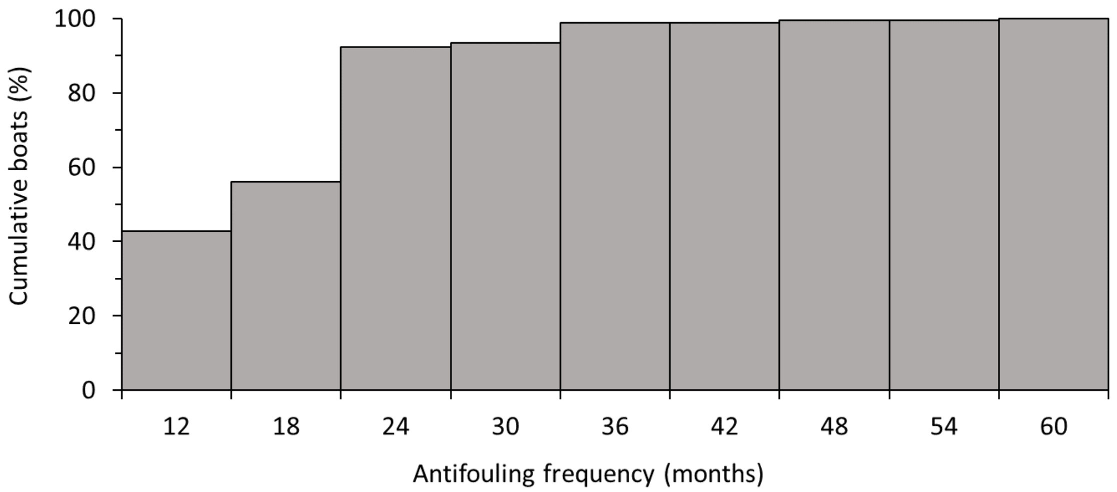

Figure 3. Antifouling frequencies reported by recreational boaters surveyed at Nelson and Waikawa hard-stands (n=246).

Table 2. Summary statistics from boater questionnaires conducted at Nelson and Waikawa hard-stands in the present study, compared to a regional questionnaire analysis from 2015/16 described by Forrest (2016). The 'n' value describes the number of survey responses from which each summary statistics is calculated.

	n	Hard-stand survey Number or percent	n	Regional survey 2015-16 Number or percent
Boats surveyed:	271	125 Nelson, (46.1%) 146 Waikawa (53.9%)	226	Boats from across entire TOS region
Boat type: sail, power	267	169 (63.3%), 98 (36.7%)	226	138 (61.1%), 88 (38.9%)
Boat berthage: marina, swing mooring	262	202 (77.1%), 60 (22.9%)	205	147 (71.7%), 58 (28.3%)
Home region:				
Nelson and bays	246	109 (44.3%)	192	105 (54.7%)
Marlborough Sounds	246	125 (50.8%)	192	67 (34.9%)
Elsewhere in NZ	246	11 (4.5%)	192	18 (9.4%)
International	246	1 (0.41%)	192	2(1.0%)
Typical voyage speed				
Sail boats: Median, mean +/- SE (min - max)	169	6.0, 6.05+/-0.007 (4 - 15)	146	6.0, 5.86+/-0.007 (4 - 12)
Power boats: Median, mean +/- SE (min - max)	98	12.0, 13.51+/-0.064 (6 - 30)	57	9.0, 10.88+/-0.088 (5 - 22)
Antifouling frequency (months)				
Median, mean +/- SE (min - max)	246	18.0, 19.07+/-0.032 (12 - 60)	198	18.0, 20.77+/-0.055 (6 - 120)
Cumulative number and % of boats antifouled				
12 months	246	105 (43%)	198	64 (32%)
18 months	246	138 (56%)	198	102 (52%)
24 months	246	227 (92%)	198	177 (89%)
30 months	246	230 (94%)	198	178 (90%)
36 months	246	243 (99%)	198	195 (98%)
Actual months since last antifouling at time surveyed				
Median, mean +/- SE (min - max)	213	15.4, 19.31+/-0.081 (< 1 - 205)	199	12, 12.94+/-0.058 (< 1 - 73)
Cleaning habits				
Boats that cleaned since last being antifouled	233	101 (43%)	206	73 (35.4%)
Boats cleaned in-water of those that cleaned	101	54 (53%)	73	41 (56.2%)
Percent of days boat used since last antifouling				
Median, mean +/- SE (min - max)	191	5.2, 14.19+/-0.129 (0 - 100)	187	7.4, 21.6+/-0.160 (0 - 100)
Activity of TOS boaters				
TOS boats unused (100% idle)	183	15 (8.2%)	164	10 (6.1%)
TOS boats active in TOS only	183	147 (87.5%)	164	154 (93.9%)
TOS boats active elsewhere in NZ	183	19 (10.4%)	164	16 (9.8%)
TOS boats active overseas	183	4 (2.4%)	164	4 (2.4%)
Habits of boaters visiting from outside TOS				
Percent that always visit hubs	5	20%	20	25%
Percent that sometimes visit hubs	5	80%	20	40%
Percent that rarely visit hubs	5	0%	20	35%

The general antifouling frequencies described above are similar to those reported in the 2015/16 TOS regional survey data (Table 2), and are reasonably consistent with the findings of other studies from New Zealand (Floerl et al. 2009; Lacoursière-Roussel et al. 2012) and overseas (Davidson et al. 2010; Clarke Murray et al. 2013). However, the antifouling frequencies reported by TOS boaters in the present study may in practice be slightly longer than suggested by Figure 3.

Figure 4 shows the actual time since last antifouling reported by boaters at the time of haul-out to hard-stand, from which the cumulative percentage of boats antifouled over time has been calculated. Of interest is that only 70% of boats hauled out had been antifouled in the previous 24 months, compared with the 92% of boaters (from Figure 3) that reported antifouling every 24 months or less. In fact, Figure 4 suggests that, in practice it is more like 32–33 months before > 90% of boaters have undertaken their antifouling renewal.

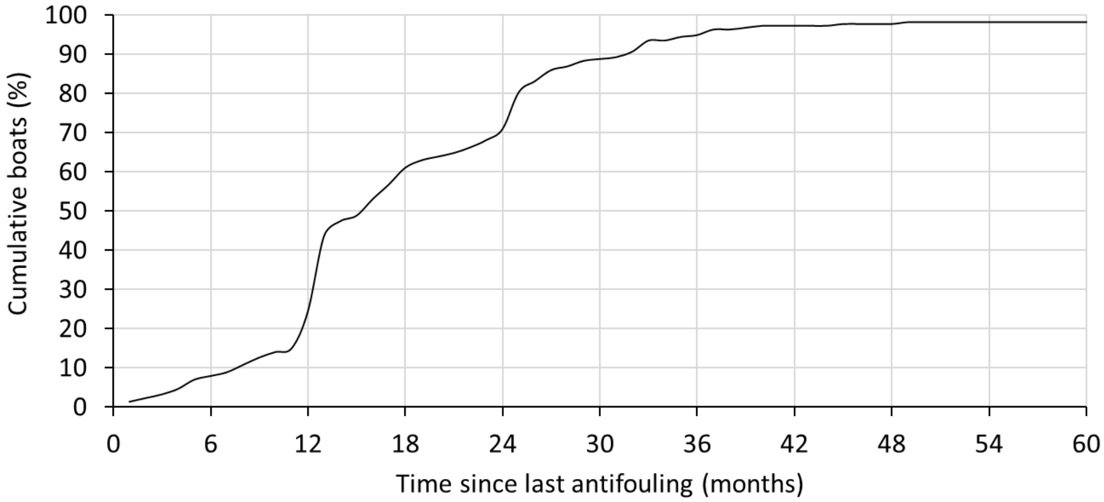

Figure 4. Actual time since last antifouling reported by boaters surveyed at Nelson and Waikawa hard-stands. Five outlier responses are not shown on graph, reflecting boaters reporting that they had not antifouled for between 5 and 17 years.

Unlike the regional survey analysis of Forrest (2016), which showed a peak in antifouling activity in the months leading up to the summer holiday period, no such seasonal pattern was evident in the hard-stand survey. This more recent finding is consistent with the results of an earlier study of 100 boats in TOS marinas, which found that antifouling occurred randomly throughout the year (Lacoursière-Roussel et al. 2012). In the present situation, it is also possible that the hard-stand survey under-represents any summer peak in antifouling activity, due to travel-lift operators being too busy to survey all boats hauled-out over that period.

3.2.2 Cleaning

Vessel cleaning between antifouling events was reasonably common. Of 233 boaters who provided information on their cleaning habits, 101 (43%) had cleaned their hull at least once since last being antifouled. This figure is comparable to or higher than previously reported TOS figures of 35% in the 2015/16 survey, and c. 20% reported by Lacoursière-Roussel et al. (2012). Of the 101 boaters that cleaned in the present study, 53% reported that they undertook in-water cleaning, which is close to the 56% reported in 2015/16 for the TOS (Table 2), but greater than figures reported from elsewhere in New Zealand and overseas (e.g. 24% in Auckland, Brine et al. 2013; 19.7% in British Columbia, Clarke-Murray et al. 2011).

Of interest is that 31% of TOS boats were cleaned in locations outside the main vessel hubs, including in relatively pristine bays of the outer Sounds and Abel Tasman coast. Although in-water cleaning is not currently permitted in the TOS, most boaters are unaware of this situation. The relatively high prevalence reflects that in-water cleaning is straightforward for boaters who are physically able, or otherwise willing to pay a diver. By contrast, haul-out and/or hard-stand costs are perceived by some boaters as being too expensive, especially in Nelson.

3.3 Boater origin and activity

A total of 246 respondents provided the name of their home port. Of these, the data reveal that 95% of boats hauled-out at the Nelson and Waikawa hard-stand facilities were domiciled in the TOS, split roughly between the Nelson bays region and the Marlborough Sounds (Table 2). A total of 11 of the boats originated from other New Zealand locations (3 Wellington, 4 Canterbury, 2 Auckland, 2 Greymouth), with one boat being from England.

Among the visitors from outside the TOS, only five responded on whether they would usually go to one of the main vessels hubs (e.g. Nelson, Picton, Waikawa) as part of their visit to the region. As such, it is difficult to draw meaningful conclusions from the hard-stand data. However, when considered together with the 2015/16 data (Table 2), it appears that about 75-80% of boats visiting the region do not always travel to a main hub. This result is consistent with impressions gained from wider conversations with boaters. For example, it appears common that Wellington boaters will cross Cook Strait to visit the outer Marlborough Sounds, thereafter returning back to Wellington without having travelled to any of the inner Sounds vessel hubs like Waikawa and Picton.

Information on boat usage since last antifouling was obtained for 191 respondents. As was the case for 2015/16, reported boat usage overall was typically quite low (Figure 5). A total of 17 boats (9%) had remained idle since their last antifouling, 95 (50%) had been active for 5% or less of available days, and 143 boats (75%) had been active for 10% or less of available days. In terms of only the boats domiciled in the TOS (n=183; see Table 2), the general boating activity since last being antifouled was as follows:

- 15 boats (8.2%) remained idle.
- 147 boats (87.5%) were active in the TOS for at least 1 day.
- 19 boats (10.4%) had travelled to locations in New Zealand outside the TOS (e.g. Fiordland, Auckland, Bay of Islands), with 4 boats (2.4%) travelling internationally (to Pacific Islands).

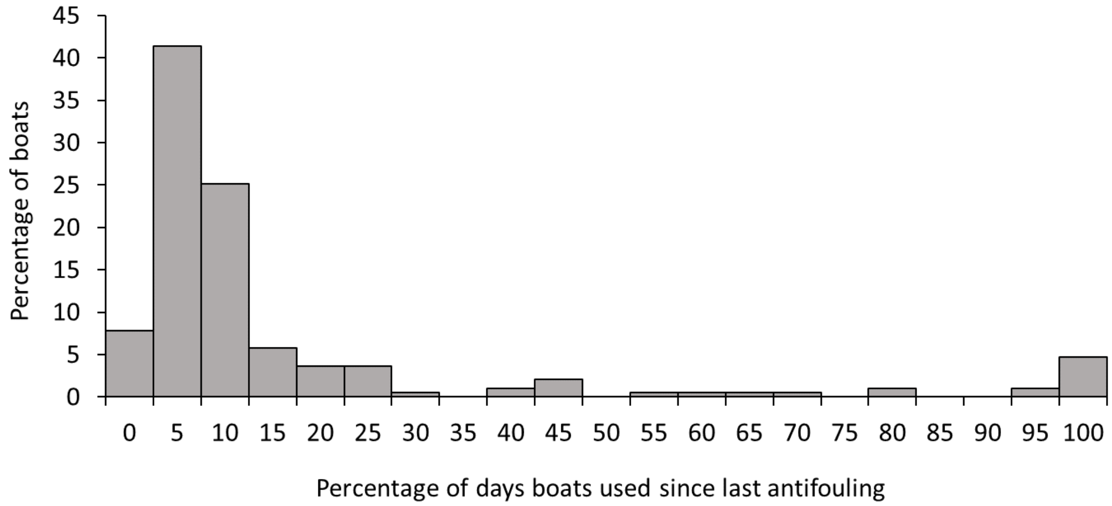

Figure 5. Percentage of days recreational boats reported to be in active use since last antifouling, and corresponding percentage of boats (n=191). Percentage of days recorded as: 0 = no active days, 5 = >0- 5% of days active, 10 = >5 - 10% of days active, etc.

Total days of boating activity across all sub-regions of the TOS, and further afield, is indicated in Table 3. This Table suggests that Queen Charlotte Sound experiences a disproportionate number of boating days relative to other sub-regions. This differs to the 2015/16 results, and reflects a small subset of Queen Charlotte boats that had very high usage days. It should be recognised that the activity statistics in Table 3 may not be regionally representative, given that they are derived from only two hard-stands. For example, if the Havelock or Tarakohe facilities had been included in the survey, a greater proportion of boats might be expected from Pelorus Sound and Golden Bay, respectively.

Despite this bias, the summary in Table 3 is of interest from a risk perspective, in that boats hauled out at Nelson and Waikawa have collectively spent an estimated 1,459 days active elsewhere in New Zealand since last being antifouled. This figure represents the activity of the 12 visitors to the TOS and the 19 TOS boats that travelled outside the region. In terms of new marine pest introductions to the TOS, this external activity is highly relevant. For example, there exists the potential for TOS vessels visiting external regions to be colonised by marine pests, which may subsequently grow to reproductive maturity if the vessel is not antifouled for many months after return to its home port in the region.

Table 3. Estimated total number of boating days since last antifouling (based on n=191 questionnaires).

Location	Boating days
Golden Bay	1,181
Tasman Bay	1,602
D'Urville Island	505
Pelorus Sound	1,145
Queen Charlotte Sound	7,795
Port Underwood	70
Elsewhere New Zealand	1,459
International	165

Based on reported areas of vessel activity, the origin of boats that visit the different TOS locations in Table 3 was derived (Figure 6). Bearing in mind the likely bias in the data as described above, results are consistent with 2015/16 in illustrating that most TOS sub-regions were characterised by a high proportion of vessels originating from the same sub-region. For example, 81% of boats active in Tasman Bay originated from Tasman Bay (mainly from Nelson marina), and 81% of boats active in Queen Charlotte Sound originated from that sub-region (mainly from Picton and Waikawa). Most sub-regions received a small proportion of visits from boats whose home ports were outside the TOS.

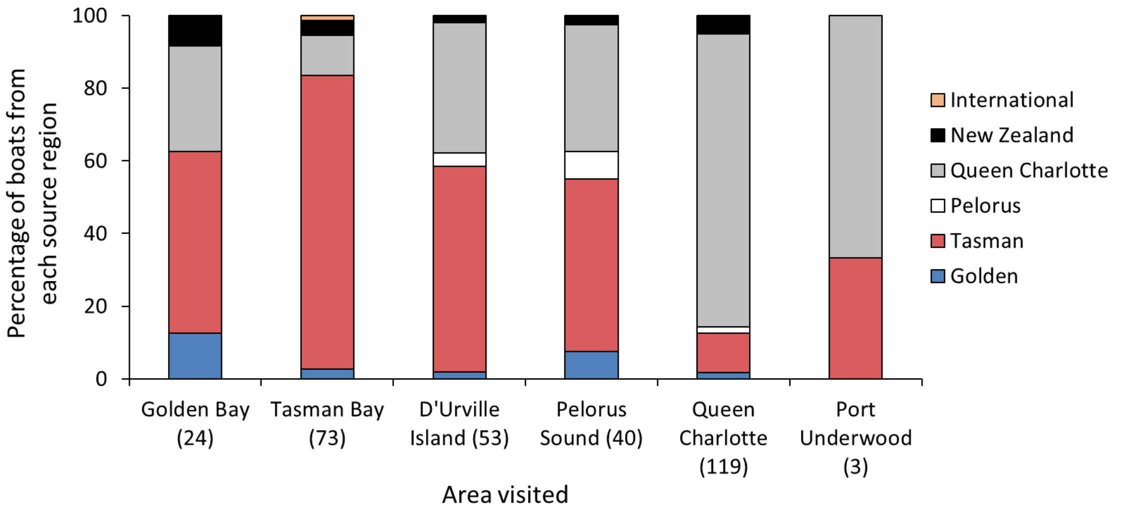

Figure 6. Origin of boats visiting different areas of the TOS. Boat origin is expressed as the percentage of boats from each of the source regions shown in the legend key. Percentages are based on numbers of boats indicated in brackets for each area visited. As such, data for places like Port Underwood (n=3 boats) may not be representative.

4. BOAT LEVEL OF FOULING IN RELATION TO RISK FACTORS

4.1 Patterns of LOF in relation to individual risk factors

Patterns of fouling (LOF) in relation to individual risk factors are shown in Figure 7. The correlation analysis revealed a statistically significant, moderate positive relationship between the age of the antifouling coating and LOF (Table 4). In Figure 7a, this is evident as a progression towards more heavily fouled boats as antifouling coating age increases. Similarly, Figure 7b shows the distribution of antifouling paint ages for boats within each LOF category, with increasing median LOF values associated with increasing paint age. For example, boats categorised as have light fouling (LOF 2) had a median paint age of c. 12 months, whereas heavily fouled boats of LOF 4 and 5 had median paint ages of c. 18 months and 22 months, respectively. However, for each LOF category there is a wide spread of values around the median.

Based on previous studies, cleaning is a factor that might be expected to reduce LOF, and contribute to variability in the relationship between LOF and antifouling age (Davidson et al. 2010). In the present study, the effect of cleaning is counterintuitive, in that the overall LOF on cleaned boats slightly exceeded that of boats that were not cleaned (Figure 7c). This difference becomes more evident as paint age increases, with a weak but significant increase in LOF due to cleaning relative to not cleaning (Table 4). A possible explanation is that the antifouling coating becomes damaged and less effective due to abrasive cleaning techniques that are increasingly required as fouling becomes more advanced (and/or as hard-encrusting fouling develops). Boats with relatively new coatings (or which are regularly cleaned, such as racing yachts) can be cleaned with gentle methods (e.g. a soft cloth) that probably cause little coating damage.

Table 4. Spearman's rank correlation coefficients (rho) for LOF in relation to potential predictor variables. Significance levels: ns = non-significant, * = significant, *** = highly significant.

Predictor	Spearman's rho	P-value & significance level
Antifouling paint age	0.441	$p < 0.001$ ***
Cleaned (y)	0.138	$p = 0.012$ *
Time since last cleaned	0.146	$p = 0.118$ ns
Percent idle	0.201	$p < 0.001$ ***
Voyage speed	-0.072	$p = 0.290$ ns

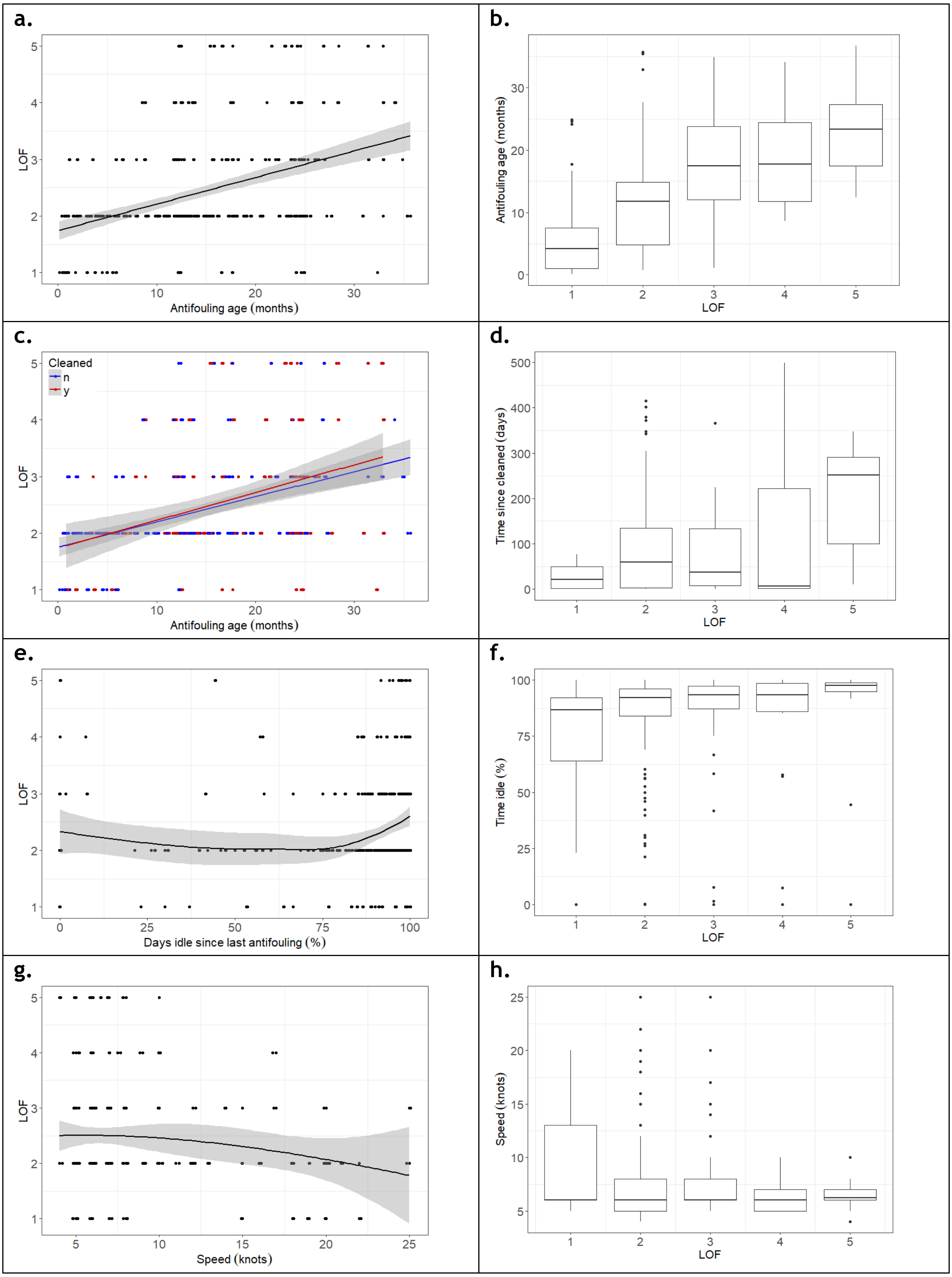

Figure 7. LOF patterns in relation to risk factors, with smoother functions (and 95% confidence bands) added to illustrate general trends. In the box plots, horizontal bars in the boxes represent medians, the top and bottom ends the upper (75th) and lower (25th) quartiles respectively, and extending lines (and dots) represent extremes.

By contrast, cleaning of more advanced fouling usually relies on scrubbing (e.g. with brushes and brooms), scraping, or high pressure water-blasting at hard-stand. These methods would be more likely to damage the coating, unless it has been specifically designed to be cleaned (e.g. long-life hard copper epoxy coatings). However, as noted in Section 3.2.1, the majority of boaters (83%) in the hard-stand survey used ‘soft’ ablative or semi-ablative coatings, which are not amenable to harsh cleaning.

When just the subset of cleaned boats is considered, the time since the boat was last cleaned appears to influence LOF scores to some extent (Figure 7d). However, although there is a positive relationship between LOF with time since last cleaning, the correlation was non-significant (Table 4). This result probably reflects the highly variable effect of cleaning on LOF. For example, the dataset included 42 boats that had been cleaned within a week of being surveyed, of which four were LOF 1 (slime-layer fouling or less) and seven were LOF 4 (16 – 40% fouling cover). Clearly, therefore, although cleaning can ‘reset’ fouling to low levels, it is not always the case that this occurs; the outcome is likely to depend on cleaning effort and the method used.

The correlation between LOF and boat activity was highly significant, although relatively weak (Table 4). The data included outliers represented by boats that spent little time idle, but became heavily fouled (Figure 7e). For the majority of boats, which were idle for 75% or more of days, an increase in LOF with increased time idle is more evident from Figure 7e. This situation is also illustrated in Figure 7f, which shows that boats that were heavily fouled (LOF 4 & 5) spent the most time idle. However, there is clearly considerable overall variability evident across the range of boating activity, which is consistent with the findings of Davidson et al. (2010). In the present study, the percentage of active boat days since last being antifouled is likely to be a fairly crude predictor of the effect of boat activity on fouling levels. For instance, it does not reflect the timing of boat activity relative to the survey, nor the subset of boats that had been primarily idle, but which had recently been antifouled.

Boat speed had a small negative effect on LOF (Table 4). The correlation was not statistically significant, despite the pattern that faster boats (power boats) tended to have reduced fouling levels compared with boats that travel only slowly (c. 10 knots or less; Figure 7g). The latter class of slow-moving vessels consisted of all sail boats and a subset of slower power boats. From Figure 7h, it is evident that boats exhibiting the highest levels of fouling were consistently those that also travelled at slow speeds. At the other end of the fouling spectrum, the upper quartile of LOF 1 boats (i.e. those with slime-layer fouling or less) were those with the fastest speeds (c. 13 knots or greater). Hence, although the trends in Figures 7g & 7h are not strong, the general patterns are consistent with experimental studies of the effect of vessel speed on hull biofouling cover (Coutts et al. 2010a; Coutts et al. 2010b). Note, however, that the physical effect of vessel speed on fouling cover may itself be highly variable, depending on factors such as voyage duration, and intrinsic attributes of the biofouling such as morphology (e.g. hard encrusting biofouling is better able to resist dislodgement than erect soft-bodied fouling).

4.2 Analysis of risk factors

The purpose of the ordinal regression analysis was to better understand how the individual risk factors described above acted in combination to influence LOF. Of the four 'best' models with similar kappa values, the most complex explained LOF as a function of several factors; namely, the interaction of antifouling paint age and boat cleaning, as well as the additive effects of boat type and level of boat activity (kappa statistic 0.275). By contrast, the simplest model consisted of antifouling paint age as the only predictor variable and had a similar kappa value (0.272).

A likelihood-ratio (LR) test revealed that the most complex model was not significantly better that the simple case (LR 0.969, df = 4, p = 0.914). Also, whereas the effect of antifouling paint age was highly significant in both the simple and complex models ($z \geq 5.773$, $P < 0.001$), the other predictor terms in the complex model were non-significant ($z \leq 0.389$, $p \geq 0.444$). Speed did not emerge as an important variable when compared (based on kappa coefficients) against models that used the full data set. However, as a predictor term in models with antifouling age that used the reduced data set, speed was only marginally non-significant ($z = -1.777$, $p = 0.0755$). Overall, therefore, despite boat cleaning, boat type, level of boat activity (percent idle), and speed having an influence on LOF, by far the most significant factor was antifouling paint age. This finding is consistent with the correlation analysis in Table 4. Accordingly, analyses presented below use as the optimum model the simple case of LOF as a function of antifouling age.

4.3 Implications for managing hull fouling

4.3.1 Overview

When the change in LOF with antifouling age alone is considered, relatively simple management guidance in relation to antifouling frequency can be developed, using raw survey data as well as predictions from the regression analysis. The two main approaches are to consider:

- The antifouling frequency that is likely to be necessary to achieve management goals that are based on specified fouling outcomes; e.g. limiting fouling to less than a certain target LOF.
- How the distribution of LOF scores would change if 'rules' were put in place with respect to the frequency of antifouling; i.e. specifying maximum intervals for the renewal of antifouling.

4.3.2 Management based on achieving LOF targets

Different regions around New Zealand are beginning to use, or consider, requirements (e.g. in pathway management plans) for recreational vessel fouling to be restricted to certain LOF targets. For example:

- Nelson City Council has in place a marina condition that prohibits berth-holders from having hull fouling of LOF ≥ 4 on berthed vessels.
- Auckland Council has developed permitted activity rules as part of its Unitary Plan that, among other things, aim to prevent movements of heavily-fouled recreational vessels (LOF ≥ 4) into and within the region.
- Northland Regional Council has proposed a pathway management plan that aims to prevent movements of moderately-to-heavily fouled recreational vessels (LOF ≥ 3) into and within the region.
- A 'clean hull' standard for Fiordland restricts fouling on all vessel types to a slime layer and goose barnacles, matching the most strict border standard for vessels arriving in New Zealand (CRMS 2014). The Fiordland approach requires vessels to have a 'Clean Vessel Pass', which is valid for 12 months. As no macrofouling is allowed other than goose barnacles, this standard will effectively mean that coastal vessels visiting Fiordland will need to achieve LOF 1 (slime-layer only).

Of immediate relevance to this report is the Nelson situation, but the implications of more onerous standards are also worth considering in the event that the TOS develops more restrictive approaches in the future. For present purposes, initial insight can be provided from the summary statistics that reflect the distribution of antifouling ages for each LOF category shown in Figure 7b. These summary statistics have been extracted from the raw data and are shown in Table 5.

In the case of standards that aimed to limit most boats to an LOF of not more than 3, say allowing 5% to reach LOF 4 (i.e. allowing only Q5, the fifth percentile of LOF 4), Table 5 suggests that antifouling at intervals of < 1 year would be necessary; i.e. 5% of LOF 4 boats had an antifouling coating that was 9.4 months old or less. Even the first quartile of LOF 4 boats (Q25) had paint ages of about one year (12.5 months) or less.

For a more ambitious goal that sought to limit most boats to a maximum LOF 2, again allowing 5% to reach the next LOF, Table 5 suggests that antifouling would need to be 3-monthly. One of the challenges in limiting fouling to LOF ≤ 3 is that niche areas can become fouled quite quickly. Additionally a small subset of the boating population will accumulate fouling on the general hull relatively quickly, possibly because of poor antifouling practices (see Section 5.2). In the case of the most ambitious Fiordland standard of zero macrofouling (except for goose barnacles), the LOF data in Table 5 suggests that the majority of boats obtaining a Clean Vessel Pass would not comply with the clean hull standard at the time of its 12-month renewal.

Table 5. Summary statistics (including quantiles, Q, from 1 – 99%) of the distribution of antifouling coating ages (months) for boats within each LOF category, reflecting the box and whisker plot of raw data in Figure 7b. The sample size (n) per LOF category is indicated.

Summary statistic	LOF 1	LOF 2	LOF 3	LOF 4	LOF 5
n	32	212	54	25	16
Minimum	0.1	0.4	1.1	8.6	12.2
Q1	0.2	0.7	1.6	8.6	12.3
Q5	0.6	1.8	3.0	9.4	12.4
Q25 (lower quartile)	1.0	4.9	12.0	12.5	16.5
Q50 (median)	3.4	11.8	17.4	17.7	22.3
Q75 (upper quartile)	7.5	15.0	23.9	24.4	25.1
Q95	24.7	25.0	28.5	32.0	31.8
Q99	30.0	32.7	33.8	33.8	32.7
Maximum	32.4	35.7	34.9	34.1	32.9

Of course, the dataset from which Table 5 was derived reflects a wide population of boats, some stationary and some in active use at the time of the survey. Hence, in cases like NRC where the LOF 2 standard applies to moving boats, the LOF vs antifouling age distribution profile may differ. For example, the last two summer surveys in the TOS (Forrest 2016, Forrest 2017) have shown that boats in active use when surveyed tend to have reduced fouling levels relative to other boats surveyed over the same time period. This situation likely reflects that: (i) boating activity can reduce fouling, particularly on the subset of faster moving boats (see Figure 7e-h); and (ii) a subset of boaters are likely to thoroughly clean or antifoul their vessels before planned periods of use (Forrest 2017).

4.3.3 Management based on antifouling frequency

Based on service lives of anti-fouling coatings indicated by paint manufacturers, ANZECC (2013) Anti-fouling and In-water Cleaning Guidelines recommended antifouling intervals for recreational boats of 12 months for biocidal coatings (as used on most recreational boats) and 24 months for biocide-free coatings. In support of a yearly antifouling interval, a recreational vessel modelling study by Floerl et al. (2009) indicated that the spread of a hypothetical invasive species within the New Zealand recreational boating network was c. 3.5 times slower when the threshold age for the antifouling coating was set at 12 months rather than 24 months. Related to this issue, many marinas in Northland have voluntarily adopted a ‘six or one’ rule, which requires visiting boaters to provide evidence that their vessel has been antifouled in the last six months or lifted and washed within one month.

Based on probabilities calculated from the optimum regression model, the predicted proportion of recreational vessels in each LOF category is shown in Figure 8, for discrete antifouling frequencies between 6 and 30 months. These predictions can be compared with those in Figure 9, which shows the actual (i.e. based on raw data) proportion of recreational vessels in each LOF category, for 6-month intervals of antifouling coating age centred around the same discrete antifouling frequencies as shown in Figure 8. As noted in the Methods (see Section 2.2.3) this is not a perfect comparison, but is the best that can be achieved given that the LOF distribution for specific antifouling times cannot be determined from the raw data.

Figures 8 and 9 both show the steady increase in the incidence of heavily fouled vessels as the antifouling frequency gets longer (i.e. as the paint ages). The model results in Figure 8 appear to slightly over-predict the incidence of moderate-to-heavily fouled vessels (LOF 3 - 5) and generally under-predict LOF 2. However, the results are not too dissimilar to the raw data. Both Figures suggest that at the current median antifouling age of 18 months for TOS boaters (see Table 2), c. 16 – 25% of boats are likely to be heavily fouled. By the time the majority of boaters have antifouled at c. 24 – 30 months (see Section 3.2.1), about a quarter to half of boats are likely to be heavily fouled.

Reducing the antifouling interval to 12 months would greatly reduce the incidence of heavily-fouled vessels. For example, in a scenario where all boaters conducted antifouling every 12 months compared with every 24 months:

- The expected reduction in the incidence of LOF 4 & 5 vessels would be 64% and 62%, based on predicted and raw LOF scores, respectively.
- The expected reduction in the incidence of LOF 3 - 5 vessels would be 45% and 64%, based on predicted and raw LOF scores, respectively.

However, even 12-monthly antifouling does not negate risk from heavily-fouled boats, with the incidence of LOF 4 and 5 vessels being 10.1% based on the raw data, and 14.1% based on model predictions. Similarly, a small proportion of heavily-fouled boats would be expected even for boats antifouled at 6-monthly intervals. As such, a 6-month antifouling rule in the case of Northland marinas (i.e. in the context of the 'six or one' rule described above) would not negate risk. In any case, biosecurity risk can arise from boats with even light overall fouling (LOF 2) due primarily to advanced fouling in niche areas. The bottom of boat keels, especially in the case of yachts, has been recognised as a particularly important niche area to address in the TOS (Forrest 2017), and this need has been similarly highlighted in other studies (Clarke Murray et al. 2013).

The adoption of a 12-monthly antifouling regime, such as advocated by ANZECC (2013), is clearly not a magic bullet. However, based on the relationships established in TOS vessel surveys between pest prevalence and increasing LOF (Forrest 2016, Forrest 2017), annual antifouling would have a considerable benefit in terms of reducing marine pest transport. While there are clearly good biosecurity reasons for recreational boaters to undertake annual antifouling, for TOS boaters to adopt this practice would require a substantial change to the current situation. Costs to boaters would be greater, and the availability of hard-stand resources (travel-lift, hard-stand space) would need to be carefully considered.

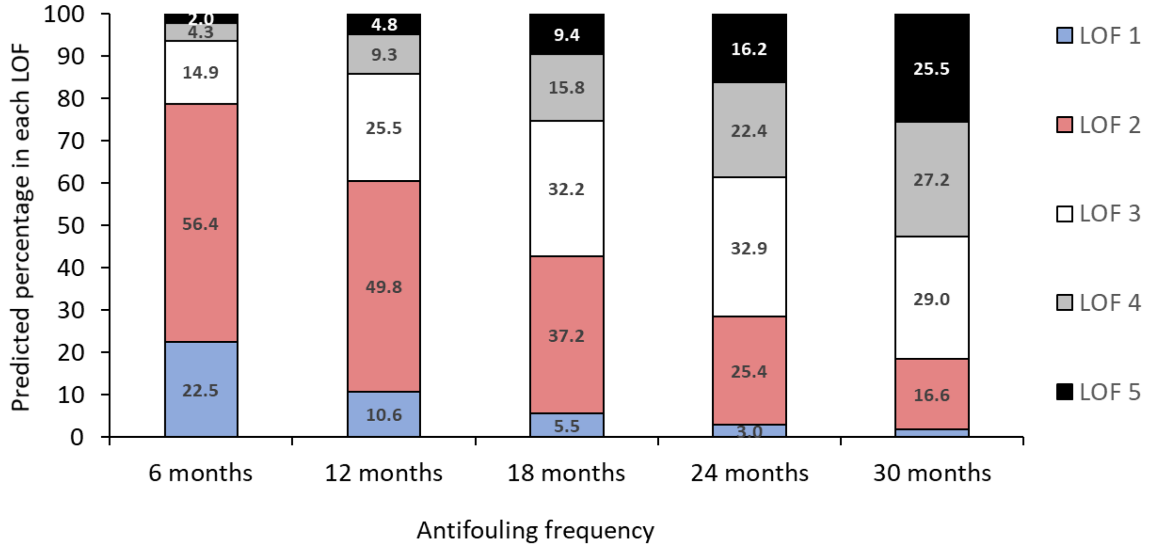

Figure 8. Distribution of LOF scores predicted from ordinal regression for antifouling frequencies between 6 and 30 months. The predicted percentage of scores in each LOF category is shown.

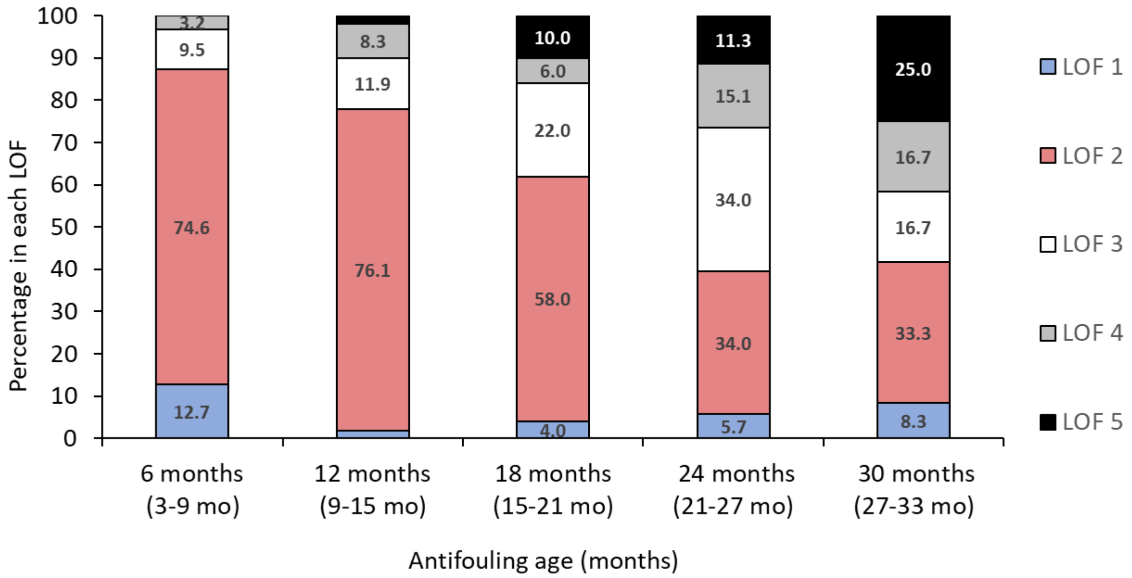

Figure 9. Distribution of LOF scores from the raw data for 6-monthly intervals centred around antifouling ages from 6 to 30 months. The percentage of scores in each LOF category is shown. See Methods Section 2.2.3 for details.

5. SYNTHESIS AND BROADER CONSIDERATIONS

5.1 Boater habits and recreational vessel risk

The present study reinforces the key findings of previous TOS surveys and boater questionnaire analyses. The TOS region is highly connected internally and externally by recreational vessel movements. Given the extent of fouling, and the associated occurrence of designated marine pests (Forrest 2016, Forrest 2017), it is clear that recreational vessel movements may represent a significant risk of spreading marine pests to many of the remote bays that characterise the TOS. Such areas may not otherwise necessarily be susceptible to the introduction of marine pests by natural dispersal or other anthropogenic pathways.

The hard-stand data highlighted that many boaters rely on in-water cleaning as a fouling control method, with almost a third of boaters conducting their cleaning in locations away from the main vessel hubs (sometimes in high value areas[3]). Such cleaning has the potential to transfer marine pests to remote areas directly, by dislodgement to the seabed, or by the stimulation of spawning as a result of cleaning disturbance (Hopkins and Forrest 2008; Hopkins et al. 2011). The actual risk depends on a range of factors specific to the fouling organisms (e.g. ability to reattach, reproductive state) and the cleaning environment (e.g. suitability of seabed habitat for dislodged organisms).

It is unclear from the present analysis whether cleaning has any net benefit within a boat's antifouling interval. Although cleaning was not a statistically significant predictor of LOF, the patterns relating antifouling age to LOF provided some indication that cleaning may in fact exacerbate hull fouling. It is critical to gain a greater understanding of this issue, particularly since moves towards stricter management regimes for hull fouling may mean that cleaning is more widely implemented. There is, therefore, an immediate need to develop clear guidance on appropriate cleaning in the TOS.

There are two dimensions to the cleaning issue. The first is a consideration of whether and under what circumstances in-water cleaning is acceptable. There are already very good guidelines that outline appropriate in-water cleaning (ANZECC 2013) and, while these guidelines have been informally endorsed by the Ministry for Primary Industries, they have not been formally adopted at a national or regional level in New Zealand. The ANZECC guidelines encourage the principle of cleaning before leaving home port, with biosecurity safeguards for cleaning practices that depend on the level of risk (e.g. high-risk cleaning requires waste capture).

However, as well as biosecurity issues, part of the concern over in-water cleaning relates to the potential release of antifouling contaminants such as copper (Morrisey et al. 2013). Auckland Council has addressed this issue in their Unitary Plan by specifying

[3] The survey of Forrest (2016) also revealed that some boaters conduct cleaning on remote beaches.

requirements for cleaning methods and waste capture that relate to levels of fouling. The Auckland Council approach is consistent with ANZECC in that it encourages regular in-water cleaning to ensure fouling doesn't accumulate, using gentle methods that minimise contaminant release. In simple terms, it could be argued that cleaning of locally-acquired fouling that leads to the local-scale deposition of antifouling contaminants into modified environments like ports and marinas, is a minor concern relative to the potential far-reaching and irreversible impacts of marine pests.

5.2 Predictors of fouling, and antifouling practices

This study found that antifouling coating age was a reasonable predictor of levels of recreational boat fouling, but this finding may not be true for other regions, and there may be other important fouling predictors that were not measured for the TOS. For example, a study in California by Davidson et al. (2010) did not find strong relationships between fouling percent cover and boat maintenance or boating practices. In addition, the TOS study by Lacoursière-Roussel et al. (2012) (which focused on sea squirt fouling), found that the type of voyage undertaken was the best predictor (voyages were categorised in that study as: racing, single day local trips, weekend trips, long haul trips). Nonetheless, that study found that non-cleaned boats with extensive stationary periods, and which had old antifouling paint, were also more likely to be fouled. Hence, although factors relating to cleaning, activity and speed were not statistically significant in the present study, it is important to keep in mind that they may be important in specific circumstances.

The present study would ideally have included a wider range of potential predictor variables than the few that were chosen. The approach used (i.e. both the questionnaire and on-water surveys) was designed to strike a balance between maximising information return without making it too onerous for boaters to complete the questionnaire. As it was, many survey forms were incompletely filled out. Nonetheless, it is important to recognise that unmeasured factors would undoubtedly have influenced LOF scores. For example, as noted in Section 4.1, the timing of boat activity relative to the survey may have been important, especially for fast vessels (i.e. assuming the potential for fouling dislodgement due to the physical effects of speed).

Given the importance of antifouling as a management measure, it is also important to recognise that paint age alone is not the only important attribute of the antifouling coating. The paint type used needs to be suited to the operational profile of the boat, and it is important to recognise that antifouling efficacy will depend greatly on the extent to which antifouling is conducted in line with instructions provided by paint manufacturers. These relate to a range of factors, including:

- Hull surface preparation.
- Recommended paint thinners.

- Application methods (e.g. brush, spray), target coating thickness and number of coats.
- Minimum coating drying times (for paint re-application and boat relaunch) under local conditions.
- Cleaning methods during recommended antifouling intervals.

The experience of the Coordination Team is that some boaters conduct practices that are not consistent with these types of recommendations, and which will only serve to undermine coating efficacy. For example, some operators/owners use inappropriate thinners (e.g. petrol), spread the coating as thinly as possible to save on paint and cost (which undermines paint effectiveness and operational life), and add herbicide or pesticide to try and enhance antifouling activity (but which will compromise efficacy).

6. CONCLUSIONS

Achieving effective biofouling risk management is complex. However, the relationship between LOF and predictors of fouling, while subject to variability, at least provides some basis for considering appropriate antifouling intervals for recreational boats. Adoption of an annual antifouling regime would be unlikely to remove all heavily-fouled vessels, but would significantly reduce marine pest transport risk. The development of standards based on maintaining boats beneath a target LOF mean the boater has to determine the best way to meet the target, which provides an alternative to prescribing 'rules' relating to antifouling or cleaning requirements. Whatever approach is taken, it is clear that achieving a significant risk reduction is likely to require an increased frequency of antifouling and/or hull cleaning. This situation raises the need for appropriate and affordable maintenance facilities, along with guidance on what is to be allowed in terms of in-water cleaning. Related to this is a need to understand how different types of cleaning might affect the integrity and efficacy of different types of antifouling coating. Further investigation and development of guidance in this respect is necessary so that cleaning does not lead to an exacerbation of risk.

As well as understanding appropriate cleaning methods and their effect on different coating types, better antifouling outcomes might also be achieved through development of 'best practice' measures for the selection and application of coatings. Clearly, current practices in the TOS, and the frequency at which most boats are antifouled, leads to a high proportion of heavily-fouled vessels in the boating population. While a subset of the boats surveyed were idle, and may in fact be maintained (cleaned or antifouled) before being used, it is apparent that heavily-fouled boats are nonetheless active in the region. For example, recent summer surveys have revealed that 8-9% of boats in active use were LOF 4 or 5 (Forrest 2016; Forrest 2017). Hence, heavy biofouling does not necessarily deter recreational boaters from using their vessels, especially in the case of slow-moving sail boats for which owners may not have a strong incentive (e.g. improved fuel efficiency or sailing speed) to maintain a clean hull.

The results of the present and previous TOS studies reiterate that reducing hull fouling risk requires consideration of measures for recreational vessels from both within and outside the TOS. For example, some TOS boats spend time in regions outside the TOS, while visitors to the region may voyage to remote areas without necessarily passing through a vessel hub. Ideally the risk from visiting vessels would be dealt with at their port of origin, such that vessels left their home ports with a 'clean' hull. The Coordination Team has already started working with Wellington marinas to achieve this outcome, but there is more that needs to be done nationally to be better ensure that effective (and ideally regionally consistent) management efforts are in place. In the absence of effective management of recreational vessels in the TOS and elsewhere, it is highly likely that new marine pests will be introduced to the region from other locations in New Zealand, while established pests will continue to be rapidly spread.

7. ACKNOWLEDGMENTS

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Appendix 1. Questionnaire used for boater survey at Nelson and Waikawa hard-stands.

HELP STOP MARINE PESTS SPREADING BY COMPLETING OUR BOATER SURVEY

This survey is part of research by the Top of the South Marine Biosecurity Partnership into hull biofouling in Marlborough, Tasman Bay & Golden Bay. Survey responses will be treated as CONFIDENTIAL, but aggregated research findings will be publicly available. For enquiries, contact **tosmarinebio@gmail.com**. Thanks for helping.

QUESTIONS FOR COMPLETION BY VESSEL OWNER/SKIPPER

1. Boat type: ☐ Sail ☐ Power **2. Where is your home port?**______________________

3. Where is your boat stored? ☐ Marina berth ☐ Mooring ☐ On land

4. What is your typical voyage speed? ___________ knots

5. How often do you apply antifouling paint: ____

6. When was the last anti-fouling paint applied (month/year)? ___________________________

7. Name or type of anti-fouling product: ____

8. Since last anti-fouling has the hull been cleaned (e.g. by scrubbing, brushing)?

☐ No ☐ Yes

9. Answer this question only if you answered YES to question 8:

- Was the vessel cleaned: ☐ On land/slip ☐ In-water ☐ Inter-tidal/beach
- How many times has it been cleaned? ________
- Geographic location(s) cleaning took place: ____
- Date most recently cleaned (month/year): ____

10. Since the last antifouling, approximately how many active boating days have you spent in (or near) each of the following locations?

Golden Bay: _____days Tasman Bay/Abel Tasman: _____days D'Urville area: _____days

Pelorus Sound: _____days Queen Charlotte Sound: _____days Port Underwood: _____days

Other regions of NZ: _____ days. List regions: ____

Other countries: _____ days. List countries: ____

11. If you are a visitor from outside Marlborough, Tasman Bay or Golden Bay, do you typically travel to a regional port or marina during your visit:

☐ Always ☐ Sometimes ☐ Rarely ☐ Never

FOR OFFICIAL USE ONLY

Date:

Fouling cover: ☐ Slime only (LOF1) ☐ 1 - 5% (LOF2) ☐ 6-15% (LOF3) ☐ 16-40% (LOF4) ☐ 41-100% (LOF5)