An investigation of hull cleaning and associated waste treatment options for preventing the spread of non-indigenous marine species

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Report Title	An investigation of hull cleaning and associated treatment options for preventing the spread of non-indigenous marine species
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8. Executive Summary

In January 2003 the Ministry of Fisheries (MFish) contracted NIWA to assess the risk posed to marine biosecurity by New Zealand's commercial hull cleaning facilities.

The specific objectives of this project were:

1. To investigate for a variety of hull cleaning situations the types, amounts and viability of fouling organisms discharged and assess whether the effluent control methodology used is successful in reducing the amount of viable material reaching the coastal marine area.

2. To discuss and make recommendations on control methodologies that would be most effective in minimizing the release of viable organisms from hull cleaning situations taking into account the efficacy, practicality and cost of using effective methodologies in an existing or new hull cleaning situation.

Between May and August 2003, NIWA staff visited hull cleaning facilities in Lyttelton, Auckland, Whangaparaoa and Tauranga, where vessels are removed from the water for cleaning (dry-dock and haul-out facilities) or where fouling organisms are removed *in situ* by divers. In Objective 1, 19 vessels were sampled, ranging from 10 – 105 m in length. Sampling of fouling organisms and liquid effluent was done at all stages of the hull

cleaning and waste treatment process. Macrofouling was sampled before, and immediately following its removal from vessel hulls by freshwater blasting or manual scraping (in-water cleaning). Liquid fouling waste was examined before it entered settlement tanks and filters, and following treatment prior to discharge into the sea.

In all cleaning operations examined, physical removal of fouling assemblages from vessel hulls did not result in mortality of all organisms. The overall viability of organisms removed from hulls was lowest in haul-out (16 %) and dry-dock (43 %) facilities, where fouling organisms were often exposed to air, high-pressure freshwater blasting and trampling. However, viability was high for (1) hard-bodied organisms not directly attached to hull surfaces (epibiota), and (2) organisms associated with clumps of mussels in the protected sea chests of large ships. Survival and viability of organisms following in-water cleaning by divers, which did not involve exposure to air or high-pressure water blasting, was significantly higher (72 %) than in shore-based operations.

The multi-chamber settlement tanks used by the facilities examined to remove solid particles from liquids (water blast effluent) were effective at killing and removing biota suspended in the liquid effluent. Concentrations of intact animals, propagules and unicellular organisms in the first settlement tank chamber were 39 – 100 % lower than those in the cleaning run-off. Liquids sampled in the last chamber of the settlement tanks had 99 – 100 % of all animal and unicellular biota removed, and it is likely that few or none of the remaining organisms were viable. In some cases, freshwater taxa were encountered in the tanks. No biological material occurred in the final effluent of facilities that subject settlement tank contents to filtration (sandfilter) prior to discharge into the sea.

The results of Objective 1 suggest that:

(1) In-water hull cleaning without collection of fouling waste poses the highest risk to marine biosecurity. This excludes operations that collect and contain fouling organisms following their removal from vessel hull, as such operations were not included in this study.

(2) Operations that clean vessels in shore-based facilities and discharge solid and liquid fouling waste into the sea without any treatment pose a more than minor risk to marine biosecurity.

(3) Operations that clean vessels out of the water and employ settling tanks to separate fine particulates from liquid waste prior to discharge into the sea pose a relatively low risk to marine biosecurity, providing there is an adequate residency time of liquid waste in the tanks.

(4) Operations that clean vessels out of the water and employ settling tanks and filters (e.g. sandfilters) to separate fine particulates from liquid waste prior to discharge into the sea pose negligible risk to marine biosecurity.

The residency period of water blasting effluent in settlement tanks is likely to vary between seasons because far more vessels are cleaned per day during summer months than during winter. Actual residency time will be a function of the capacity of the settlement tanks and the number of vessels cleaned per day (and, therefore, the volume of water entering the tanks). We recommend that a repetition of settlement tank sampling be carried out during summer months when far more boats are cleaned per day and the residency period of cleaning effluent in settlement tanks is likely to be shorter.

A review of existing legislation and waste treatment methods used at existing cleaning facilities in New Zealand and elsewhere was conducted as part of Objective 2. Our review suggests that although few of New Zealand's Regional Coastal Plans deal explicitly with managing risks to marine biosecurity, concerns about the release of toxic contaminants from cleaning facilities and their effects on the coastal marine environment have meant that many of the larger Regional Authorities have moved to discourage return of untreated solid and liquid wastes to the marine environment.

We recommend fouling waste treatment systems described in (3) above are a desirable standard for hull cleaning facilities where there is a risk of contamination by unwanted marine organisms. For operators that already have some form of collection and settling tank treatment system, the most cost-effective option is likely to be retain and/or modify the existing system to achieve the characteristics listed in (3) above. For operators that do not currently have treatment systems, the simplest and most cost-effective option is likely to be that described in (3) above. This recommendation is based simply on the fact that currently this is the most commonly used system in New Zealand and it is a system that has been shown to be effective at reducing biosecurity risk (Objective 1). This recommendation does not preclude the use of other, possibly more sophisticated systems.

There are likely to be significant benefits of including additional filtration steps or other more sophisticated treatment technologies as 'add-ons' to the treatment process. First, such steps will offer an additional buffer of confidence in reducing risks to marine biosecurity, for example by providing a final 'catch all' removal of particles greater in size than the 'particle standard' of 60 μm proposed by McClary and Nelligan (2001). Second, they will improve the removal of fine particulates and associated antifouling chemicals. This is important for operators who not only need to manage marine biosecurity risk, but who also may need consents for discharges to the sea under the Resource Management Act, or may need permission to divert hull-cleaning waste to local community wastewater treatment plants.

OBJECTIVE 1:

Introduction

Hull fouling is an important pathway for the introduction and spread of non-indigenous marine species in New Zealand and worldwide (AMOG Consulting 2002; Minchin and Gollasch 2003). Local establishment of non-indigenous species (NIS) can occur following release of reproductive propagules from intact fouling assemblages on vessels' hulls, or by survival of viable organisms removed during vessel cleaning (Environment and Natural Resources Committee 1997; Minchin and Gollasch 2003). Around 30,000 vessels are removed from the sea each year in New Zealand for cleaning, resulting in approximately 140 tonnes of biogenic fouling residues (McClary and Nelligan 2001). In addition, an unknown number of vessels are cleaned each year in tidal grids, careening bays, or by divers. Treatment and disposal of fouling waste varies widely among facilities and cleaning situations. Some facilities dispose of fouling waste as landfill. Others discharge solid waste and/or filtered or unfiltered liquid effluent into the sea. Because of the variation in treatment and disposal methods it is unclear what risk hull cleaning facilities pose to New Zealand's marine biosecurity.

In March 2002, MFish released a public consultation paper on proposals to regulate hull-cleaning activities under the Biosecurity Act 1993 to reduce the risk of harmful marine species being introduced to, and being spread throughout New Zealand coastal waters. The proposed regulations sought to prohibit the cleaning of vessels if fouling material removed from them was discharged directly into the coastal marine area without containment, collection, treatment of liquid effluents and disposal to land of all collected material. Cleaning vessels by careening, in-water cleaning by swimmer or diver, hosing or water blasting on a hardstand or slip where contaminated water drains into the sea without treatment would, therefore, contravene the proposed regulations. Public submissions to the consultation paper noted that there was no evidence that fouling organisms survive the cleaning process, where they may be subjected to scrubbing, water-blasting, drying out on a hardstand, being stored in freshwater sumps and filtration. Also, because of the range of cleaning and treatment procedures used in hull-cleaning facilities within New Zealand, survival of organisms is likely to vary widely from operation to operation.

In response to the concerns raised by submitters, MFish commissioned NIWA to undertake surveys of hull-cleaning facilities in New Zealand to:

1. Quantify the relative survival of organisms removed under different types of cleaning and treatment,
2. Improve our understanding of the types of hull fouling organisms that are likely to survive the various cleaning procedures and
3. Identify the methods of cleaning, collecting, treatment or disposal of fouling that offer the most effective means of killing NIS should they be present.

The project was divided into two specific objectives:

1. To investigate for a variety of hull cleaning situations the types, amounts and viability of fouling organisms discharged and assess whether the effluent control methodology used is successful in reducing the amount of viable material reaching the coastal marine area.

2. To discuss and make recommendations on control methodologies that would be most effective in minimizing the release of viable organisms from hull cleaning situations taking into account the efficacy, practicality and cost of using effective methodologies in an existing or new hull cleaning situation.

9. Methods

Cleaning facilities visited

In consultation with MFish, eight hull cleaning facilities were chosen from the list of operations visited by McClary and Nelligan (2001) as part of MFish Research Project ZBS2000-03. The operations comprised three types of cleaning situations:

(1) tidal grids (intertidal facilities)
(2) hard-stand cleaning operations, and
(3) in-water hull cleaning,

and three methods for treating fouling waste:

(4) no containment of fouling waste and discharge of all material into the sea (this includes in-water hull cleaning),
(5) separation of solid and liquid waste and discharge of unfiltered liquids into the sea, and
(6) separation of solid and liquid waste and discharge of filtered liquids into the sea.

The facilities chosen for sampling were located in Lyttelton, Tauranga, Whangarei, Whangaparaoa and Auckland (Table 1.1). In each facility, fouling waste arising from hull cleaning may be subject to one, two or three successive treatment stages. Treatment stage 1 consists of the actual physical removal of fouling material from vessel hulls using water blast (vessels removed from the water) or hand-held scrapers (in-water cleaning). No containment of fouling material occurs in the in-water cleaning operations investigated in this study; all material thus remains in the sea (Fig. 1.1). In facilities where vessels are removed from the water for cleaning, solid waste is collected and disposed of as landfill. Liquid fouling waste is collected in multi-chamber settlement tanks, where finer solids are separated from the liquid (Treatment Stage 2). After the liquid has passed through all chambers of the settlement tanks it either passes through a filter (Treatment Stage 3) prior to discharge into the marine environment or is discharged without filtration (Fig. 1.1). A detailed account on the treatment of solid and liquid fouling waste in each of the facilities that remove vessels from the water for cleaning is provided below:

Lyttelton dry-dock

The Lyttelton dry-dock is operated by the Lyttelton Port Company. It is the only dry-dock in NZ's South Island and can accommodate vessels of up to 120 m in length. Ships are manoeuvred into the dock basin and the dock is then closed using sealed lock gates. The dock water is usually drained overnight. During draining, wooden beams are wedged between the dock walls and the vessels to keep the ships in an upright position. Services offered by the dry-dock include: mechanical repairs, removal of fouling and application of antifouling paint. Cleaning of vessels is carried out using up to four water blasters (freshwater; 4,000 psi).

Treatment of fouling waste: Solid fouling waste is collected and disposed of as landfill. The liquid runoff from the water blast is collected in a settling tank, where magnesium sulphate is added and coarse solids settle out. The liquid stage then passes into a second settling tank, where the flocculating agent Magnafloc® is added, and where finer particulates are allowed to settle. Water then passes into a final settling tank equipped with settlement shakers that remove further material from suspension. Liquid contents of the final tank are discharged back into the marine environment without physical screening or filtration. Solid waste is removed from the tanks on average every three months.

Westpark Marina

In the Westpark Marina, vessels up to 18.5 m in length are removed from the water using a travel lift. Services offered include mechanical repairs, removal of fouling and application of antifouling paint. Cleaning of vessels is carried out using a water blaster (freshwater; 3,000 psi).

Treatment of fouling waste: Solid fouling waste is collected and disposed of as landfill. The liquid runoff from the water blast is collected in a triple-chamber, in-ground 'grit separator' (settling tank). Coarse solids settle out in the first chamber. The liquid stage then passes through another two chambers, separated by a weir that allows fine particulates to settle out and oils to separate (through addition of 'Matasorb cushions'). The final tank has an overflow outlet from where the water is discharged into the marine environment (via the stormwater system) without physical screening or filtration. No flocculation agents are added to the settling tanks at any stage. Solid waste is removed from the tanks on average every three months or more frequently if required to maintain efficiency of the system.

Tauranga Marina

The Tauranga Marina offers a travel lift and tidal grids for vessel maintenance. The travel lift can remove vessels up to 20 m in length from the water. Services offered include mechanical repairs, removal of fouling and application of antifouling paint. Cleaning of vessels is carried out using a water blaster (freshwater; 3,000 psi).

Treatment of fouling waste: Solid fouling waste is collected and disposed of as landfill. The liquid runoff from the water blast is collected in a settling tank, where coarse solids settle out. The liquid stage then passes into another two settling tanks, which are separated by a weir allowing fine particulates to settle. The final tank has an overflow outlet from where the water is discharged into a 'sand trap' (a nearby beach). This sand trap euphemism acts as a sandfilter, and the top "few inches" of sand are periodically removed by a bobcat and disposed of as landfill. No flocculation agents are added to the settling tanks at any stage. Solid waste is removed from the tanks on average every three months.

Orams Marine Maintenance

Orams Marine offers two travel lifts and two slipways to remove vessels up to 49 m in length from the water. Services offered include mechanical repairs, removal of fouling and application of antifouling paint. Cleaning of vessels is carried out using a water blaster (freshwater; 8,000 psi).

Treatment of fouling waste: Solid fouling waste is collected and disposed of as landfill. The liquid runoff from the water blast is collected in a settling tank, where coarse solids settle out. This tank has an overflow outlet that leads into a second tank, where fine particulates are allowed to settle. Overflow from the second tank passes through a sandfilter and is then discharged into the sea. No flocculation agents are added to the settling tanks at any stage. Solid waste is removed from the tanks on average every three months.

Changes to the selection of operations visited

Contact with all facilities was established in February 2003 to outline the purpose of the research and to negotiate an appropriate time for sampling. During conversation with the Whangarei Cruising Club it became apparent that, while seeking resource consent, this facility had recently closed one of its two tidal grids and allowed use of the other grid exclusively for mechanical checks and repairs but not for cleaning. As the Whangarei Cruising Club's grids were unavailable for sampling, NIWA suggested choosing the Westhaven Marina's (Auckland) tidal grids as a replacement, which was endorsed by MFish (letter dated 27 May 2003).

Between 10 June and 16 July 2003, NIWA personnel were in regular (daily or bi-daily) contact with the Tauranga and Westhaven marinas to arrange sampling dates for vessel cleaning on tidal grids. Between June and August, two separate trips (each with a duration of two days) were undertaken to the Tauranga Marina, and five trips to the Westhaven Marina. Fifteen vessels were inspected that used the available tidal grids. All of these boats were clean of fouling and removed from the water for either mechanical repairs (e.g. change of sacrificial anodes or checking of propeller shaft) or removal of slime. Communication with the marina operators suggests that tidal grids are usually not used for de-fouling because of convenient and inexpensive haul-out facilities nearby. Consequently, no de-fouling of vessels on tidal grids was sampled in this study (communicated to Mfish in the July 2003 Progress Report).

Sampling of vessels removed from the sea for cleaning

Between May 16 and August 28 2003 surveys were done of the viability of organisms removed from vessel hulls in haul-out and dry-dock operations in Lyttelton (Lyttelton Dry-dock), Auckland (Orams Marine Maintenance, Westpark Marina), and Tauranga (Tauranga Marina Society). A total of 19 vessels were sampled. Sampling of fouling organisms and liquid effluent was done at all stages of the hull cleaning and waste treatment process (Fig. 1.1). Macrofouling was sampled before, and immediately following its removal from vessel hulls. Liquid fouling waste was examined before it entered settlement tanks and filters, and following treatment prior to discharge into the sea.

Definition of a viable organism

For a fouling organism removed from a boat hull to establish a self-sustaining population in New Zealand waters, it must:

1. survive the cleaning process and be returned to the sea, and
2. be able to grow and produce offspring which are themselves capable of surviving and reproducing in New Zealand conditions.

In this project we defined a viable organism (adult or propagule) as being one that is "potentially capable of living and developing normally in the marine environment". This simply means that the plant or animal has survived the cleaning process (Stage 1) and is in a condition that would *potentially* allow it to grow and produce offspring. The likelihood of successful establishment of populations in New Zealand waters involves interactions between the organism, its local environment and native enemies (competitors, predators and parasites) and cannot be addressed without complex field experimentation and testing.

Even our simple definition of viability has some difficulties, as many marine species (particularly macroalgae and clonal invertebrates) are able to regenerate from very small fragments. The likely survival of these fragments can only be determined definitively by culturing them in the laboratory. In this study, we took a pragmatic approach that used field assessments of physiological condition and best available knowledge as surrogates for more complex tests of viability.

Sampling of hull-fouling assemblages before and after removal from hulls

To obtain an estimate of the proportion of organisms that survive the de-fouling process and/or the subsequent treatment methods, the amount of fouling on a hull (expressed as wet weight) was determined before cleaning commenced. For each vessel, the "total wetted surface area (TWSA)" was determined using formulae developed by the antifouling paint industry (Akzo Nobel, pers. comm. 2003). Separate formulae were used for different classes of vessel:

Regular yachts:
TWSA = 2 x Length x Draft

Superyachts and trawlers:
TWSA = (2 x Length x Draft) + (beam x draft)

Large ships (> 100 m length):
TWSA = (Length between perpendiculars x (Beam + (2 x light load draft))) x 0.72

Calculation of TWSA for each vessel used measurements provided from either the vessel owners or from technical plans provided by the operators of the cleaning facilities. An estimate of the proportion of the TWSA that was covered by fouling organisms was obtained by taking digital images (image size 20 x 20 cm; Olympus C4400 Zoom) of random areas around each hull (including main hull area, rudder and keel), and superimposing 60 random dots to calculate the average fouling cover per image. Ten randomly placed replicate images were taken for boats of 30 m length or less, while 18 images were taken of larger ships (Lyttelton dry-dock). Because of access restrictions, only 10 images could be taken of the hull of the *Hebe* (76.4 m). The total biomass (weight) of fouling organisms on each hull was then determined by measuring the average fouling weight in three 400 cm^2 areas around the hull, and extrapolating the derived value to the estimated total hull area covered by fouling organisms. Fouling assemblages on vessel hulls are usually not distributed randomly (Coutts 1999; James and Hayden 2000). However, we did not use a stratified sampling approach to determine fouling cover in this study as this would have necessitated individual area calculations for the various strata, which was beyond the scope of this project. Instead, we used a randomised approach to obtain a broad estimate of fouling intensity on vessels cleaned in New Zealand maintenance facilities.

After a vessel's hull had been cleaned of fouling organisms by water-blasting and/or scraping, samples of the removed biota were collected from the surrounding area by filling four replicate 1-L containers with fouling material collected haphazardly from the ground below and around the vessel. For each vessel, the time between its removal from the water, and the time between completion of the cleaning process and the collection of samples were recorded. Fouling cover and biomass varied among the vessels examined in this study. While in some cases enough fouling material was available to fill four 1-L jars, only one jar could be filled following the cleaning of other boats.

Following collection, each container was emptied into a sorting dish (45cm L x 28cm W x 12cm H), and the types of organisms or fragments, their size and their degree of structural damage and dryness (desiccation) were recorded. Organisms and fragments were separated by phylum or major taxonomic group (e.g. barnacles, bivalves, colonial ascidians) into additional sorting dishes. These dishes were then flooded with clean seawater and left undisturbed for 20-30 minutes to allow the organisms to recover. The organisms and fragments in each sorting dish were then examined under magnification using either a handheld magnifying glass (5 x magnification) or a Wild M-7A dissecting miscroscope (31 x magnification) for signs of active feeding and movement. Decisions as to whether an organism or fragment was viable were based on criteria developed with guidance from NIWA taxonomists (see Appendix Table A1 for detail). This sequence of activities was continued until all four 1-L containers had been emptied and examined.

Sampling of liquid effluent prior to discharge into the sea

In the haul-out facilities four 10-L samples of liquid effluent were taken at each of four separate stages in the treatment process. The number of these stages sampled varied according to the set-up of the cleaning facility. Samples of liquid effluent were collected (1) from the waterblast runoff before it entered the settlement tanks (Lyttelton, Orams and Westpark: two vessels per facility; Tauranga: three vessels), (2) from the first chamber of the settlement tanks (all four facilities), (3) from the final chamber of the settlement tank prior to passing through a sandfilter (Tauranga), or (4) from the discharge pipe following settlement and filtration (sandfilter) (Orams). In the Tauranga Marina, sampling at (4) was attempted on various occasions but could not be achieved as, at the time of our visits, the settlement tanks were not sufficiently full to cause overflow of tank contents into the sand trap following cleaning of vessels.

All samples of effluent were filtered through a 60 μm mesh to retain the biological material within them. A combination of visual observations and vital staining analysis was performed on three replicate small samples (2 ml) from each 10-L sample to determine the viability of small organisms or propagules. The samples were added to fresh seawater and left undisturbed for 20-30 minutes before examination under the microscope for movement and damage (magnification ranged from x40 to x100 as appropriate). The material was then filtered again and one drop of filtrate was added to a cover slide together with one drop of the vital stain Janus Green B (made up from distilled water at 1:10,000). The solution was then examined under a compound micoscope within 36 hours. Janus Green stains mitochondria in eukaryotic tissue samples (Clark 1973). Like all other available stains, Janus Green does not provide information on mitochondrial or cellular *activity*. However, as eukayotic cells degenerate soon after they die the colour and intensity of the stain can provide an indication of whether the contents of a sample are in their original state (staining visible within the superstructure (e.g. exoskeleton)) or whether mortality has occurred a considerable time ago (staining dispersed throughout the sample due to tissue degeneration). In this study, the combined use of visual observations (movement) and vital stains is useful for rapid assessment of viability of small organisms or propagules in liquid samples.

The remaining filtrate from each 10-L sample was made up to 50 ml of 5% formaldehyde/seawater and transported to the laboratory for further analysis. Two subsamples (2 ml each) were taken from each 50-ml filtrate sample and organisms, propagules and their fragments presented within them were identified and enumerated using a Leitz Fluovert FS microscope (100 x magnification). The abundance of all organisms and propagules was estimated using direct counts, with the exception of filamentous algae, for which a rank scale of abundance was used (0 – absent; 1 – very low abundance; 2 – low abundance; 3 – moderate abundance; 4 – high abundance; 5 – very high abundance).

Sampling of vessels cleaned in the water

An assessment of the viability of fouling organisms removed from vessel hulls during in-water cleaning operations was made in Gulf Harbour Marina and Orams Marine Maintenance facility. Three vessels were sampled in each. Before the cleaning, the amount of fouling on each vessel hull was determined using the techniques described above. NIWA divers then mimicked in-water cleaning by removed fouling organisms from randomly-chosen locations on the hull of each vessel using the same method (a paint scraper) used by many hull cleaning facilities and private individuals. Fouling organisms removed from hulls were collected using catch bags made from fine nylon mesh (0.2 mm). The quantity of fouling organisms collected was standardised to the same volume used for vessels cleaned in haul-out facilities by transferring the contents of the mesh bags into four (or fewer, depending on the material available) replicate 1-L containers. Immediately after collection, all material was placed in sorting trays filled with clean seawater, and the viability of organisms was assessed using the procedures described above (Section 'Sampling of hull-fouling assemblages before and after removal from hulls'). Our approach did not include an assessment of propagule (eggs & larvae) release from adult organisms during in-water hull cleaning, as it was not possible to distinguish these from other sources of propagules in the water column or to tell if material removed from the hull had recently released gametes.

10. Results

Sampling of solid fouling material

The vessels cleaned during the study included private yachts, harbour tugs, tankers and fishing trawlers of 10.0 - 104.5 m in length (Table 1.2). Fouling cover on the hulls ranged from 2.8 ± 1.2 % (mean ± standard error) to 46.9 ± 7.6 % of the submerged surfaces, and from 0.05 ± 0.006 kg to 614 ± 285 kg in wet weight (Table 1.2; Plate 1.1). The average wetted surface area of vessel hulls cleaned in the dry-dock (897.3 ± 456.2 m^2) was greater than of those cleaned in haul-out facilities (37.2 ± 4.1 m^2) and, as a consequence, the cleaning process generally took much longer (dry-dock: 69 ± 54 h; haul-out facilities: 39 ± 8 min; t-test, $t_{11} = 2.59$, $P = 0.024$). All of the vessels sampled were cleaned by water blasting (freshwater, 3,000 – 8,000 psi).

A total of 10,317 organisms or fragments from solid fouling material were examined during the study. These included species of barnacles, bivalves, bryozoans, ascidians, hydroids, polychaetes, sponges, algae, motile crustaceans and molluscs, flatworms, nemertean worms and anemones (Table 1.3; Appendix Table A2). The numerically most abundant taxa were tubiculous polychaetes (serpulids, sabellids and spirorbids), erect and encrusting bryozoans, and barnacles (acorn barnacles: 99 %; goose barnacles: 1 %) (Table 1.3).

Degree of desiccation and types of damage to organisms examined

Because of the relatively short period between the removal of vessels from the water and the onset of cleaning in haul-out facilities (25 ± 11 min), most fouling organisms were still wet when fouling cover was examined. In the dry-dock, however, the time between removal from water and cleaning was significantly longer (13 h 42 min ± 2 h 19 min; t-test, $t_{11} = 11.27$, $P < 0.001$) and most soft-bodied organisms (especially ascidians, sponges and hydroids) had considerably dried out by the time water-blasting commenced. When the solid waste samples were collected all material from haul-out and dry-docking facilities was re-hydrated and moist or wet from the freshwater used in the cleaning process.

The type and severity of physical damage to organisms removed from the hulls varied among vessels and operations. In haul-out and dry-dock operations the pressure associated with the water blast and trampling by cleaning staff had fragmented and crushed a large proportion of soft-bodied (haul-out operations, 59.7 ± 10.9 %; dry-dock operations, 40.5 ± 21 %) and hard-bodied organisms (77.0 ± 6.9 % and 33.7 ± 3.6 %) (Fig. 1.2 a; Plate 1.2). In-water removal of organisms from boat hulls with a paint scraper caused similar damage to fragile or brittle hard-bodied organisms such as tubeworms and barnacles (66.4 ± 10.6 % damaged), but considerably less to soft-bodied taxa such as sponges, ascidians, flatworms and nudibranchs (10.0 ± 4.4 % damaged; Fig. 1.2 a). Following prolonged exposure to air (dry-dock) or high-pressure blasting with freshwater (dry-dock and haul-out operations), patterns of mortality varied among operations. Survival of unprotected soft-bodies organisms tended to be lower in haul-out and dry-dock operations (20.5 ± 7.2 % and 31.9 ± 39.1 %, respectively) than following in-water cleaning (88.35 ± 5.9 %). Rates of survival of hard-bodied organisms were generally low in all three facilities and ranged from 16.5 % (haul-out operations) to 47.6 % (dry-dock) (Fig. 1.2 b).

Viability of organisms

The proportion of organisms that remained viable following removal from vessel hulls varied considerably among broad taxonomic groups and cleaning operations. In all three types of operations, more than 18 % of the total number of organisms and fragments examined were viable, with no apparent differences among operation type (Fig. 1.3 a). Tubiculous polychaetes comprised 71.2 % of all organisms investigated in in-water cleaning operations, but only 0.8 % and 38.7 % of those examined in dry-dock and haul-out operations, respectively. When they were excluded from the data, the mean proportion of organisms that was alive and viable following in-water hull cleaning increased to 72.3 ± 8.6 % (Fig. 1.3 b).

Much greater average proportions of bivalves (82 ± 18.1 %; N=45 specimens examined), ascidians (75.1 ± 7.8 %; N=359), bryozoans (57.6 ± 14.4 %; N=413), errant polychaetes (100 %; N=37) and sponges (88.9 ± 10.2 %; N=16) remained viable after in-water hull cleaning than after cleaning in dry-dock or haul-out operations (Fig. 1.3). In addition, very large proportions (93-100%) of motile molluscs (N=10, not encountered in other operations), motile crustaceans (N=39), nemerteans and flatworms (N=122, not encountered in other operations) and anemones (N=34) were viable following in-water removal. In contrast, none of the bryozoans (N=28), ascidians (N=21), hydroids (N=9), tubiculous polychaetes (N=4) and sponges (N=10) examined in the dry-dock facilities were viable following their removal from vessel hulls (Fig. 1.3).

There was considerable variability in the rates of survival of different organisms associated with differing amounts of fouling on individual vessels and variation in the cleaning process. For example, few tubeworms living on the hull surfaces survived the cleaning process in any of the operations sampled. Of the more than 5000 serpulids, sabellids and spirorbids that were examined, <12 % remained viable after cleaning (Fig. 1.3 h). The most common forms of damage observed in this group were fragmentation of the tube and/or the worm inside it, and/or loss of the tentacular crown and feeding structure. In nearly all cases, the only living and viable individuals were growing epibiotically on other organisms such as barnacles and bivalves. Similarly, most barnacles growing directly on hull surfaces were also killed by cleaning, as their shell plates were detached from the basal plate and the animal inside from its test. However, in some cases – particularly the *Hebe* and *Godley* sampled in the Lyttelton dry-dock – barnacles also occurred as epibionts on bivalves or formed large clumps by growing on top of one another. When these vessels were cleaned, between 61 % and 78 % of the barnacles examined were alive, compared with 0.2 – 28 % survival per vessel in other operations (Fig. 1.3 c). The viability of bivalves varied among operation types and vessels (Fig. 1.3 d). During the cleaning of the *Alexander Slobodchikov* in Lyttelton, a large quantity of bivalves was removed from the vessel's sea chests, 61 % of which remained viable (Plate 1.3). Sea chests are recesses for ballast water intake of large ships (Dodgshun and Coutts 2002), whose interior is protected from significant drag during movement of the vessel. These recesses allow bivalves to persist in large clumps and also shield the organisms from the main force of water blasting during cleaning. The errant polychaetes and two motile crustaceans (all viable) that were collected following cleaning of this ship were encountered inside the clump of mussels removed from the sea chests. Most motile crustaceans (amphipods and isopods) examined in haul-out and in-water cleaning operations were viable (Fig. 1.3). They were generally encountered in protected micro-habitats such as empty barnacle tests or the internal cavities of sponges or solitary ascidians.

Macroalgae

We were not able to reliably determine mortality or viability in marine macroalgae following their removal from vessel hulls. In total, 86 samples of algae were examined, all of which were *Enteromorpha* sp. These algae grow as a double layer of cells, each of which, under certain conditions, could fragment from the main body of the alga and act as a colonising propagule (Adams 1994; Nelson, pers. comm. 2003). Sixty-seven percent of algae collected were damaged and fragmented to varying degrees, and often faded due to a loss of pigment. More detail on this group is provided below (Sampling of liquid effluent).

Sampling of liquid effluent

Abundance of organisms

A total of 64 samples of liquid effluent (10 L per sample) were taken in the four facilities from different stages of treatment. Intact specimens or fragments of nematodes, crustaceans (mainly copepods), gastropods, bivalves, rotifers, ciliates, diatoms, tintinnids, filamentous algae, spores, eggs and pollen (terrestrial plants) were encountered in these samples, at total concentrations of up to 63,113 individuals 10 L^{-1} (Table 1.4).

In all of the facilities, average concentrations (N=4 10-L samples) of intact animals (up to 36,650 ± 6196 10 L^{-1}), intact propagules (up to 835 ± 328 10 L^{-1}, including eggs, spores and larvae) and intact unicellular organisms (up to 2880 ± 1425 10 L^{-1}) were greatest in the initial run-off from the water blasting (Fig. 1.4). Settlement and filtration progressively reduced the mean concentrations of organisms in the liquid effluent. In samples taken from the first chamber of the multi-chamber settlement tanks, concentrations of intact animals, propagules and unicellular organisms were reduced by between 40% to 100 %, and the rank abundance of filamentous algae decreased by 10 to 80 % (Table 1.4, Fig. 1.4).

The final treatment stage that was sampled varied among operations. In the Westpark Marina, the final samples of effluent were taken from the first chamber of the settlement tanks. In Tauranga, the final samples of effluent were taken from the last chamber of the settlement tanks, since the tanks were not full enough for overflow to be discharged. In Lyttelton the effluent sampled was the unfiltered discharge that was piped from the settlement tanks into the sea, and at Orams Marine the effluent from the tanks passed through a sand filter before being sampled. In each of the facilities sampled, concentrations of intact animals, propagules and unicellular organisms in the first chamber of the settlement tanks were between 39.7 % and 99.9 % lower than those encountered in the cleaning run-off, and varied from 1.7 – 98.5 individuals 10 L^{-1} (Table 1.4; Fig. 1.4 a - d). In the Tauranga Marina, the number of intact animals, propagules and unicellular organisms had been further reduced during their passing from the first to the final chamber of the settlement tanks, where their final concentrations were ~ 1 % of those observed in the first chamber (animals and unicellular organisms) or nil (propagules). Orams Marine was the only facility where liquid waste was sampled following its passing through a settlement tank and a sandfilter. No animal matter (dead or viable) was encountered in the final discharge. In each facility, the abundance of filamentous algae at the final stage of sampling had decreased by 10 – 85 % compared to their concentrations in the cleaning run-off (Fig. 1.4 e). However, it was not possible to ascertain whether the filamentous algae encountered in the settlement tanks were marine or freshwater species. Rainwater falling onto the cleaning area during the study washed pollen grains into the settlement tanks, and may have also added freshwater algae.

Viability of organisms

Vital staining for mitochondria (Janus Green) returned positive results within liquid samples collected from the water-blast run-off in all facilities (Table 1.5). Wherever staining was observed, it was clearly contained within the organisms, such as the exoskeleton of crustaceans, the bodies of nemertean worms or the cells of filamentous algae. In all run-off samples analysed, visible movement (only observed in nemerteans) occurred only in those from three vessels: the *Alexander Slobodchikov*, cleaned in the Lyttelton dry-dock, and the *Chancellor* and *Lady Crossley*, cleaned at Orams Marine in Auckland. No movement of organisms was observed at any other stage of treatment. Positive mitochondrial stains were also obtained in samples from in the first settlement tank chamber of the Lyttelton dry-dock and the Tauranga Marina (Table 1.5). However, only in filamentous algae was the stain clearly retained within intact cell walls. For most other biota the staining was observed within fragments (e.g. body parts) of organisms. Complete exoskeletons of crustaceans and bryozoans (and other taxa) were in most cases found to be empty and did not stain properly. No mitochondrial staining was observed in samples taken from the final settlement tank chamber or discharge liquid of any of the facilities visited.

11. Discussion

The viability of organisms and efficiency of effluent control methods was investigated at a variety of treatment stages: (1) Following physical removal of fouling organisms from vessel hulls (solid and liquid fouling waste arising during cleaning in dry-dock, haul-out and in-water cleaning operations), (2) following collection of liquid effluent in settlement tanks, and (3) following physical screening and filtration of settlement tank discharge (Fig. 1.1). Our results show that each stage in the treatment process kills or removes different types of organisms, resulting in a final discharge that contains little or no viable biological material. The proportion and types of organisms killed, however, varied among facilities and depended on the range of treatment options that was incorporated.

Stage 1: removal of fouling from vessel hulls

(a) Solid fouling waste

Dry-dock and haul-out operations

Physical removal of fouling organisms from hulls in operations that remove vessels from the sea for cleaning damaged or killed 40 - 60 % of soft-bodied organisms, and 36 - 77 % of hard-bodied organisms examined, depending on operation type. Mortality was caused by a combination of exposure to air for extended periods, high-pressure (3,000 – 8,000 psi) blasting with freshwater and trampling by cleaning staff. Nevertheless, significant proportions (> 5 % of samples examined) of barnacles, bivalves, ascidians, bryozoans, tubiculous polychaetes, errant polychaetes, sponges and motile crustaceans removed from vessel hulls in dry-dock and haul-out operations were still viable and potentially capable of living and reproducing if they had been returned to the sea at this stage. The overall viability was 43 % and 16 % of all organisms removed in dry-dock and haul-out facilities, respectively. Our results suggest that the prolonged exposure to air that precedes vessel cleaning in dry-docks (between 10 to 18 hours in this study) is sufficient to kill a variety of soft-bodied taxa including ascidians, sponges and some bryozoans (M. Kelly-Shanks, pers. comm. 2003). In both dry-dock and haul-out operations, cleaning by high-pressure water blast caused further damage and mortality of all taxonomic groups observed growing on the exterior of the vessels. However, rates of survival appear to be greater for organisms living in the sea chests or other recesses of larger vessels. Because sea chests are built into the hulls of ships (often extending 2 m into the body of the vessels) and are covered by steel grids, organisms living inside them are more protected from desiccation stress than those attached to exterior hull surfaces (Dodgshun and Coutts 2002). Diverse and "thick" fouling assemblages are commonly observed in sea chests and, in New Zealand and Australia, some have been found to contain non-indigenous species (Dodgshun and Coutts 2002; Coutts *et al.* 2003; Dodgshun and Coutts 2003). The application of high-pressure water blast to large clumps of mussels - such as those observed in the sea chests of the *Alexander Slobodchikov* - is likely to damage and kill organisms living on the periphery of these clumps, but many of the cryptic organisms living in the centre of the clumps were unaffected. We expect that rates of survival will also be relatively high in solid material removed from the exterior of very heavily fouled vessels, since some degree of protection is provided by interstices in the large volumes of material removed. Dense aggregations of mussels often contain a large number of epibiotic and motile species (Lohse 1993), and many of these - such as the crabs, shrimps, isopods, amphipods and errant polychaetes associated with clumps of *Perna canaliculus* in the *Alexander Slobodchikov*'s sea chests – are able to survive physical removal from hulls.

All of the dry-dock and haul-out operations visited in this study collect and contain solid waste removed from the vessels and dispose of it as landfill. Despite the relatively high rates of survival of organisms following cleaning, therefore, the risk to marine biosecurity is comparatively small, since none of the solid waste is returned to the sea. However, of the 37 hull-cleaning operations reviewed in MFish Research Project ZBS2000-03 (McClary and Nelligan 2001) 13 operations discharged solids back into the sea without further treatment. These operations clean mainly domestic vessels (30 – 2,200 per annum) and, in total, service about 21 overseas vessels per annum (McClary & Nelligan 2001). In these operations, there is a more than minor chance that any non-indigenous species cleaned from the vessels that are returned to the sea as part of the solid waste will survive. We found that a significant proportion of the fouling organisms removed from vessels hulls in dry-dock and haul-out operations remain in a viable state.

In-water hull cleaning

We also assessed survival and viability of fouling organisms removed from vessels by in-water cleaning using a paint scraper. More sophisticated technology is available, including manned underwater vehicles (e.g. "mini-pamper" by UMC International) or rotating brushes operated from the surface (e.g. JIMIK International's "Hull Super Scrub"; see Jones (2000) and Objective 2 of this report). However, according to marina operators (Westhaven and Gulf Harbour Marina Management, pers. comm.) and recent research (Floerl unpubl. data 2002-2003) paint scrapers or stiff brushes are most commonly used to remove fouling from small vessels (e.g. yachts) in New Zealand and other locations.

During in-water cleaning, fouling assemblages are not subject to prolonged exposure to air, to high-pressure water blasting, to immersion in freshwater or to trampling. Rates of damage and mortality of organisms removed from the vessels *in situ* were, therefore, much lower than of those of organisms removed by shore-based cleaning facilities. A significant proportion (> 5 %) of the individuals in all of the taxa examined remained viable after in-water cleaning. Scraping caused consistent physical damage (and mortality) only in brittle and calcareous organisms, especially barnacles (~ 32 % of individuals remaining viable) and tubiculous polychaetes (8 % of individuals). With the exception of tubeworms (the most abundant, but most fragile group of organisms in this study) rates of survival were between 29 % and 56 % higher for organisms removed during in-water cleaning than for dry-dock and haul-out operations, respectively. In total, around 72% of the organisms removed during in-water cleaning remained viable in the solid waste.

In-water hull cleaning by commercial operators is available in a range of facilities New Zealand wide. Some commercial operators contain fouling waste using vacuum systems and/or filtration (McClary and Nelligan 2001). However, when this material is not contained (as may occur when private yacht owners clean their boats on snorkel or SCUBA), organisms removed from the hulls sink onto the sea floor close to where the vessels are moored. During the process of scraping, damaged organisms (e.g. tubeworms) may release gametes or brooded larvae (Bureau of Rural Sciences 1999; G. Read, pers. comm. 2003; see below). Ports and marinas usually contain a large abundance of hard substrata available for colonisation – e.g. breakwalls, pontoons and pilings – and propagules originating from fouling waste may be able to establish on these surfaces. Because of the large proportion of these organisms that remain viable after the cleaning process, in water cleaning is likely to pose a more than minor risk to marine biosecurity if material removed from hulls is not contained and disposed of on land.

(b) Water blast runoff during cleaning of vessel

The high-pressure water blast used to clean hulls in shore-based cleaning operations removed fouling assemblages and often the top layer of antifouling paint. In most cases examined, liquid run-off from the water-blast was coloured by the antifouling paint on the hull, and contained a diverse assemblage of intact animals, propagules and unicellular organisms or fragments of organisms (Plate 1.4). Our data show that the propagules and brooded larvae of organisms removed during the water blasting were contained in the liquid effluent at concentrations of up to 850 per 10 L. Four of the 36 samples examined contained actively moving animals (all nemertean worms), and all samples stained positive for mitochondria. During the cleaning of the *Alexander Slobodchikov* in the Lyttelton dry-dock, two live crabs with carapace widths of ~ 15 mm were encountered in the water blast run-off. The liquid samples were taken approximately 5 - 15 m from where the vessels were being cleaned and, at that time, the organisms collected had been exposed to freshwater (and osmotic stress) for only 1 – 2 minutes. Our results and consultation with NIWA specialists indicate that most of the animals observed in the cleaning run-off were likely to be dead (M. Kelly-Shanks, G. Read and W. Nelson, pers. comm. 2003), as a result of physical damage and exposure to freshwater and toxic antifoulant residues. However, a number of estuarine species are extremely tolerant to low salinities. One example is the serpulid worm *Ficopomatus enigmaticus* (formerly *Mercierella enigmatica*) that is non-indigenous to New Zealand and is known for its nuisance growths on submerged artificial structures (Read and Gordon 1991). *F. enigmaticus* can tolerate salinities of < 1 ppt and cleaning run-off that reaches the marine environment without prior filtration or screening may contain viable propagules of this and other euryhaline species (Table 1.6; Straughan 1972).

Thirteen of the cleaning facilities (not including tidal grids) sampled by McClary and Nelligan (2001) did not collect liquid waste in settling tanks. Our observations suggest that facilities that discharge liquid effluent directly into the marine environment present a more than minor risk of discharging viable organisms or propagules into the surrounding waters.

Stage 2: Collection of liquid fouling waste in settlement tanks

In each facility, samples of liquid waste were taken from the first chamber of the settlement tanks immediately following the cleaning of a vessel. In all facilities, the concentrations of animals, propagules, unicellular organisms and algae were considerably (10 – 100 %) lower than in the liquid run-off captured from water blasting of vessel hulls. The "age" of the tank contents varied at the time of sampling. In the Westpark Marina the tanks had been emptied two weeks earlier. At Orams Marine, the contents were at least one month old. At the Lyttelton dry-dock the liquid had been in the tanks for three months, and in the Tauranga Marina effluent had been in the tanks for six months. As a result, the tanks contained liquid waste that had originated from a varying number of vessels. This variation was reflected in the number of organisms and propagules encountered in the tank contents. The difference in relative abundance of organisms in the water blast run-off and tank contents was generally greatest (77 – 100 %) in facilities whose tanks had been cleaned within the last month and smallest (39 – 87 %) in facilities where tanks had been cleaned three to six months ago. This could reflect the greater overall amount of fouling waste that has accumulated in the tanks, from a greater number of vessels, over the longer retention period. However, there are also other explanations. For example, in the Tauranga Marina, which had the longest retention time of all the tanks that were sampled, filamentous algae occurred in greater abundance within the tanks than in the water-blast run-off. Other predominantly freshwater taxa, such as rotifers, were more common or occurred exclusively in tanks that had not been cleaned for extended periods. These data suggest active growth of freshwater organisms within the settlement tanks. In all of the tanks examined, terrestrial plant seeds and pollen grains were encountered, and it is likely that wind and rain also transport filamentous freshwater algae into them. A large proportion of the organisms detected in effluent discharged from the settlement tanks, therefore, is likely to consist of freshwater organisms that pose no risk to marine biosecurity.

The effectiveness of multi-chamber settlement tanks in removing biological material from liquid waste in the hull-cleaning facilities is illustrated by our samples taken from the final chamber of the Tauranga Marina settlement tank, and the unfiltered tank discharge of the Lyttelton dry-dock. In both facilities, nearly all (99 – 100 %) intact animals, larvae and unicellular organisms had been removed from the liquid stage of the tank contents. The maximum concentration of intact organisms and propagules recorded at this stage was 98 10 L^{-1}. We believe that most of these were likely to be dead: firstly because no active movement of organisms was observed in any samples examined from this stage of the treatment process, and secondly, because of the prolonged exposure of organisms to freshwater. The volume of the settlement tanks examined varied among facilities - approximately 25 m^3 in Lyttelton and at Orams Marine, and 3.5 m^3 in the Westpark Marina. Given an average discharge of 20 L min^{-1} per water blaster (McClary

& Nelligan 2001; R. Mathieson pers. comm. 2003) and an average cleaning duration of 39 minutes (data from this study), the settlement tanks in haul-out facilities would be full following the cleaning of between five (Westpark) and 32 vessels (Orams). In the Lyttelton dry-dock, where on average three water blasters operate at one time (average effective blasting time is approximately four hours), the tanks would fill up following the cleaning of approximately two vessels. Depending on season and facility, the liquid waste arising from hull cleaning may be able to fill from empty the settlement tanks examined in this study within < 2 d (summer: up to 20 vessels cleaned per day) and approximately 15 days (winter: approximately two boats cleaned per day; pers. comm. with operators of the various facilities). Many species of marine invertebrates and plants are unlikely to survive such prolonged exposure to freshwater (Andrews 1973; Coates and Byron 1991; Anil *et al.* 1995). This is also the case for a selection of well-known NIS that occur around New Zealand. For example, even short exposure to freshwater has detrimental effects on larvae and small colonies of the bryozoan *Bugula neritina*, and 100 % mortality will occur in the serpulid *Hydroides elegans* following exposure to salinities of 5 ppt. for 9.5 hours. Also *Sabella spallanzanii*, a tubiculous polychaete that is currently not established in NZ but has invaded parts of Australia and that could possibly be transported on the hulls of ships and boats will not survive exposure to freshwater for more than 2-12 hours (Table 1.6; Mak and Huang 1982). However, the introduced euryhaline tubeworm *F. enigmaticus* and the Pacific oyster *Crassostrea gigas* are able to survive exposure to very low salinities for extended periods - 11 weeks in the case of *F. enigmaticus* (Table 1.6).

Our results suggest that, to keep risk to biosecurity at a minimum, it is important to ensure a 'safe' residency period of settlement tank contents (liquids) in facilities where liquid waste is treated in multi-chambered settlement tanks but not subsequently filtered. Because of the variation in the salinity tolerance between marine sessile species (Table 1.6) it is not possible to recommend a 'silver bullet' residency time. However, the literature available for a range of animal species suggests that exposure to freshwater for approximately three days is sufficient to cause high or total mortality (but see Apte *et al.* 2000). Longer periods may be required for intertidal animal and plant species, which are often adapted to freshwater exposure in the form of rain and runoff (W. Nelson, pers. comm. 2003).

Stage 3: Physical screening and filtration of settlement tank discharge

Only one facility used in the study (Orams Marine Maintenance) filtered the effluent from the settlement tanks prior to its discharge into the sea. All four replicate 10-L samples of the filtered discharge were entirely free of marine animals or their larvae, eggs, spores or unicellular organisms. Filamentous algae were present in very low abundance and, as discussed above, are likely to have been freshwater species that reached the tanks through rainwater run-off.

Conclusions

There are differences in the degree of biosecurity risk posed by waste material discharged at different stages of the treatment process at hull cleaning operations within New Zealand. The results of Objective 1 results suggest that:

(1) *In-water hull cleaning without collection of fouling waste poses the highest risk to marine biosecurity.* This excludes operations that collect and contain fouling organisms following their removal from vessel hull, as such operations were not included in this study.

(2) *Operations that clean vessels in shore-based facilities and discharge solid and liquid fouling waste into the sea without any treatment pose a more than minor risk to marine biosecurity,* as both solid and liquid phases are likely to contain a large number of viable organisms and propagules. This excludes tidal grid operations, as these could not be included in this study. However, we expect viability of organisms removed from vessels in tidal grids to be considerable, as they are not subject to water blasting with freshwater. Thirteen of the 37 facilities sampled during MFish Research Project ZBS2000/03 discharge solid and liquid fouling waste into the sea without any treatment, and approximately 2,950 vessels are cleaned in these facilities per annum (McClary and Nelligan 2001).

(3) *Operations that clean vessels out of the water and employ settling tanks to separate fine particulates from liquid waste prior to discharge into the sea pose a relatively low risk to marine biosecurity.* Because the residence time of water in the settling tanks is usually several days, or even weeks (depending on tank size and frequency of cleaning), only organisms that are highly tolerant to very low salinities are able to reach the sea in a viable state. Twelve of the 37 facilities sampled during MFish Research Project ZBS2000/03 fall into this category, and approximately 7,650 vessels are cleaned in these facilities per annum (McClary and Nelligan 2001).

(4) *Operations that clean vessels out of the water and employ settling tanks and filters (e.g. sandfilters) to separate fine particulates from liquid waste prior to discharge into the sea pose negligible risk to marine biosecurity.* In this study, no intact organisms or propagules were encountered in the final discharge, and all biological material in these samples had a size of 80 µm or less. Three of the 37 facilities sampled during MFish Research Project ZBS2000/03 fall into this category, and approximately 4,600 vessels are cleaned in these facilities per annum (McClary and Nelligan 2001).

Likely influences of time of year (season) on the results of this study

This study did not include a comparison of the viability of organisms removed from vessel hulls during winter and summer months. However, for shore-based cleaning facilities we believe that patterns of post-cleaning survival and viability would not differ profoundly between seasons, as most mortalities appeared to have been caused by physical damage (blasting, freshwater exposure and trampling) rather than temperature and exposure to air. We also do not anticipate any differences in viability patterns following in-water cleaning during summer or winter, as organisms will not be exposed to air, and therefore to changes in ambient temperature, at any time.

However, as outlined above (section "Stage 2: Collection of liquid fouling waste in settlement tanks", paragraph 2), the residency period of water blasting effluent in settlement tanks is likely to vary between seasons because far more vessels are cleaned per day during summer months than during winter (pers. comm. with all facility operators of this study). It is likely, therefore, that organisms and propagules contained within the cleaning effluent are subject to freshwater exposure (settlement tanks) for shorter periods during summer than during winter (this study). In addition, rainfall is likely to vary between seasons. Rainwater falling onto the cleaning area for vessels will lead to faster filling of the settlement tanks. The influence of 'seasonality' (number of boats cleaned and amount of rainfall) on risk to biosecurity is likely to be greater for facilities that do not filter settlement tank contents prior to discharge into the marine environment than for facilities that do have filters in place. We recommend that a repetition of settlement tank sampling be carried out during summer months when far more boats are cleaned per day and the residency period of cleaning effluent in settlement tanks is likely to be shorter.

OBJECTIVE 2:

Introduction

To address this objective we reviewed existing national and international guidelines for containment and treatment of wastes from boat yards and cleaning facilities. We also considered a wider suite of treatment options based on technologies that are used elsewhere for other industrial or marine biosecurity applications. A quantitative evaluation of existing system performance (from Objective 1) and the qualitative consideration of alternative technologies were used as a basis for making recommendations on the relative merits of different treatment options for New Zealand hull-cleaning facilities.

It is important to note that the focus of Objective 2 is on the efficacy and practicality of the various treatment options for minimising risks to marine biosecurity. Most treatment systems for hull cleaning residues have been designed to minimise the discharge of organic biomass, particulates (e.g., paint flakes), hydrocarbons and soluble, toxic anti-foulant chemicals that arise from the boat cleaning and maintenance. Both functions of treatment are relevant for the overall management of vessel hull-cleaning operations but the Ministry of Fisheries (MFish) is primarily responsible for the biosecurity function, while regional councils and the Ministry for the Environment (MfE) are responsible for managing other environmental effects of the waste from these facilities (see below).

12. Review of existing regulations and guidelines for hull-cleaning

New Zealand regulations & guidelines

There are currently no national regulations or standards for hull-cleaning practices in New Zealand. At present, discharges from boat-cleaning facilities are regulated by Regional Authorities under the Resource Management Act 1991. Although most facilities are required to obtain a resource consent to discharge waste arising from cleaning activities into the marine environment, the way in which these discharges are regulated and the conditions that are placed upon them vary somewhat among regional authorities.

The New Zealand Coastal Policy Statement (NZCPS) provides national guidance to Regional Authorities on the issues to be covered by Regional Coastal Plans (DoC 1994), the documents that provide the planning framework for environmental decision-making for non-fisheries coastal resources. Policy 5.2.1 of the NZCPS deals with the disposal of waste from vessel cleaning facilities. It states that:

"Provision should be made to require adequate and convenient rubbish disposal facilities in ports, marinas and other such busy areas, and for the provision of facilities for the collection and appropriate disposal of the residues from vessel maintenance."

Some Regional Authorities (e.g. Environment Waikato) have interpreted this to mean that discharges of most wastes from ports, marinas and boat maintenance areas should be disposed of on land at appropriate facilities (Environment Waikato 2001). Others, however, have taken this to mean that discharges to the marine environment from cleaning facilities are acceptable, provided they meet certain conditions of quality. Below, we provide a short summary of how selected Regional Authorities manage waste disposal from vessel maintenance facilities in their Regional Coastal Plans.

Auckland Regional Council
Under section 20.5.1 of the Proposed Auckland Regional Coastal Plan (ARC 2002), discharge of any contaminant resulting from the cleaning, anti-fouling or painting of vessels is a **permitted activity** subject to the following conditions:

a the discharge or escape of contaminant materials or debris onto the foreshore, seabed or into the water shall be collected as far as practicable and removed from the coastal marine area; and
b any discharge will not, after reasonable mixing, give rise to any or all of the following effects:
    i the production of any conspicuous oil or grease films, scums or foams, or floatable or suspended materials; or
    ii any conspicuous change in the colour or visual clarity of water in the coastal marine area; or
    iii any emission of objectionable odour; or
    iv any significant adverse effects on aquatic life, and
c no discharge of contaminants from this activity shall occur into Coastal Protection Areas 1, other than those in Rule 20.5.108, and Tangata Whenua Management Areas.

(NB: the installation of collection devices such as ground covers, netting or other devices to ensure the collection of any contaminant or debris from the operation may be necessary to comply with this rule.)

In addition, under Section 20.6.1 of the plan, the Auckland Regional Council has undertaken to:

a develop in consultation with the boating community and boating industry representatives, a comprehensive and practical approach to dealing with sewage and other contaminant discharges from commercial and recreational vessels to the coastal marine area once Government Regulations have been introduced to control the discharge of contaminants from vessels; and
b encourage practices involving boat maintenance which prevent significant quantities of toxic or otherwise harmful substances from entering the coastal marine area; and

c encourage practices which will prevent vessels from discharging significant quantities of contaminated bilge water or other contaminants to the coastal marine area; and

d in conjunction with territorial authorities, promote or otherwise ensure that adequate provision is made in port developments, at slipways and hardstand or haulout areas for the collection, treatment and appropriate disposal of vessel maintenance and cleaning residues, sewage and other contaminants from vessels, and in marinas sewage and other contaminants from recreational vessels; and

e in conjunction with local network operators, promote a comprehensive and practical approach for dealing with the discharge of stormwater, wastewater and other contaminants from the existing, and any future upgraded, public network system.

Environment Waikato

Discharges from Ports, Marinas and Boat Maintenance Areas are managed as a **discretionary activity** under Section 16.3.7 of the Waikato Regional Coastal Plan. Section 16.3.7 specifies that:

Any discharge resulting from activities occurring on the hard stand areas of ports, marinas or boat maintenance areas, is a discretionary activity provided it complies with the standards and terms stated in this Rule.

Standards and Terms

I. The discharge shall not contain any solid wastes or hazardous substances.
II. The discharge shall not contain any substance which will cause the production of conspicuous oil, or grease films, scums or foams, or floatable suspended materials outside a 5 metre radius of the point of discharge.
III. Boat maintenance residues shall be collected and disposed of in appropriate land-based facilities.

Assessment Criteria

In assessing any application for Discharges from Ports, Marinas and Boat Maintenance Areas, regard shall be had to:

IV. the extent to which the activity will adversely affect any conservation value within the ASCV areas as marked on maps in Appendix III and described in Appendix IV of this Plan; and
V. the Decision-Making Criteria and Considerations which are set out in Appendix II of this Plan, and which are relevant to this activity; and
VI. the extent to which the siting and location of the discharge will result in cumulative adverse effects on water quality and natural character; and
VII. the extent to which the discharge will emit any objectionable odour; and
VIII. the extent to which, after reasonable mixing, the discharge (either by itself, or in combination with other discharges) will give rise to any adverse effects on flora or fauna.

Explanation. *"ACSV areas" are Areas of significant Conservation Value identified in the Coastal Plan*

Environment Waikato recently released a proposed variation to the Regional Coastal Plan for public consultation that deals with construction and operation of marinas (Environment Waikato 2003). Rule 16.2 of the variation states that:

"There shall be no discharge of water and/or contaminants into water from boat maintenance, ballast, boat careening, or hull cleaning within the marina basin."

Wellington Regional Council
The Wellington Regional Coastal Plan encourages boat-servicing facilities to dispose of waste through land-based municipal treatment facilities. Relevant sections include:

10.2.6 To require all new marinas and/or boat servicing sites to contain facilities to accept sewage and other contaminants from vessels for disposal through municipal (or other approved) treatment processes.

10.2.7 To encourage existing marinas and/or boat servicing sites to contain facilities to accept sewage and other contaminants from vessels for disposal through municipal (or other approved) treatment processes.

Explanation. *"Other contaminants from vessels" includes offal, food wastes and vessel cleaning residues.*

Environment Bay of Plenty
The Regional Coastal Plan for the Bay of Plenty treats the:

"discharge of any contaminant from cleaning of the exterior of the hulls of ships or offshore installations below the load line, or parts of a ship used for carrying cargo, as a **discretionary activity**" (Section 9.2.4(f)).

Discharges are managed under consent to comply with water quality standards and to minimise adverse effects on the surrounding environment. Section 9.2.3 (k) of the plan:

"promote(s) or otherwise require(s) that facilities are available for the appropriate shore based disposal of contaminants associated with the operation or maintenance of vessels."

In addition, Environment Bay of Plenty has undertaken to:

9.2.8(a) Encourage the use of non-toxic or less toxic antifoulants on vessels.
9.2.8(b) Encourage practices for boat maintenance which will prevent significant quantities of toxic or harmful substances from entering the sea.
9.2.8(c) Encourage practices which will prevent vessels from discharging significant quantities of contaminated bilge water and other contaminants into the sea.
9.2.8(e) In conjunction with district councils, promote or otherwise ensure adequate provision is made for the collection, treatment and appropriate disposal of vessel maintenance and cleaning residues, as well as sewage from vessel holding tanks and contaminated bilge water."

Summary

Although few of the Regional Coastal Plans deal explicitly with management of marine pests or risks to marine biosecurity, concerns about the release of toxic contaminants from boatyards and cleaning facilities and their effects on the coastal marine environment have meant that many of the larger Regional Authorities are prohibiting or discouraging return of untreated solid and liquid wastes to the marine environment.

International regulations and guidelines

During the preparation of this report we found no evidence of any country that has implemented mandatory national standards or regulations for hull-cleaning methods to reduce the risk of discharge of marine pests. Reference to the literature (e.g., Raaymakers, ed. 2001) and personal communication with the US Navy (E. Holm, US

Navy Surface Warfare Centre, pers. comm.) suggests that some other countries have produced guidelines (e.g., US Naval Ships' Technical Manual – Waterborne Underwater Hull Cleaning of Navy Ships [US Navy, 2002]) and are also pursuing similar types of regulatory development, but none appear to be further advanced than Australia and New Zealand. Below, we summarise some of the regulations and guidelines that have been implemented in Australia and the USA to manage waste from boat cleaning and maintenance facilities.

AUSTRALIA

In Australia the state environmental protection agencies administer a Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance (ANZECC 2000), prepared by the Australian and New Zealand Environment and Conservation Council Maritime Accidents and Pollution Implementation Group. The guidelines provide direction for decision-making implemented through state environmental laws that regulate discharges to coastal waters.

The ANZECC guidelines encourage general maintenance of small and large vessels to be conducted at an appropriate facility, either above the tidal zone or in a dry dock, and prohibit any in-water cleaning of vessel hulls in Australian waters without a permit from the Harbour Master, local government or state environmental protection agency. All antifouling waste removed during cleaning and repainting is to be treated as controlled wastes and should be collected for disposal at an appropriate facility, in accordance with local environmental and/or waste disposal authorities. Recommendations for the containment and treatment of liquid wastes from cleaning and painting facilities are as follows:

- Use of water during removal should be minimised by moving towards ultra high pressure water blasting, vacuum or containment blasting.
- Use of high pressure blasting should be minimised and coloured run off should be avoided.
- Where practical, water should be recollected for either recycling or for release to sewer (with the approval of local sewerage authorities) so that the water can be treated.
- Release to sewer, where approved by local authorities, should be controlled to allow maximum dilution in the sewerage system.

The State of Victoria, Environment Protection Agency has released a series of recommended practices, based on the ANZECC guidelines, that are intended to minimise impacts on the marine environment. These are:

- All cleaning should be performed in a way to ensure no marine organisms or harmful paints fall into marina waters.
- To minimise the carriage of waterborne contaminants, washing hulls on land by mechanical scraping is preferable to pressure washers.
- High pressure wash guns produce a wastewater contaminated with marine organisms, hull paint and fragments of hull material They must be used only where proper collection, treatment and disposal facilities are provided.
- Solid waste from boat maintenance and cleaning areas should be contained in watertight covered bins for disposal into a licensed landfill.
- Bio-degradable cleaning products are preferred. The use of cleaning compounds should be minimised and discharges into the sea prevented.

- Bilge water from distant ports or marinas should not be discharged to the local environment. It should be disposed of in the open sea or to sewer. This will reduce the risk of transferring unwanted species.

Between 1996 and 2001, the Australian government funded a Marine Waste Reception Facilities Program that established best practice facilities for the management and treatment of marine wastes at port and marinas around the country. The programme assisted with up to 50% of the cost of installing upgraded facilities in a number of demonstration sites throughout the country. A summary of these upgrades is provided in Appendix Table A3. Movement toward best practice in these facilities generally involved developing procedures for the containment and treatment of all liquid and solid wastes generated on site, with minimal discharge back into the marine environment. Most facilities sought to treat wastewater to a level sufficient for safe re-use or disposal in municipal sewerage facilities. The proposed upgrades involved a variety of treatment facilities, with the most common being settlement tanks and sand traps to capture suspended particulates in the liquid wastewater.

USA

In the USA, boatyards and other facilities that include outdoor boat cleaning or repair operations must obtain a federal National Pollutant Discharge Elimination System (NPDES) stormwater permit from the Environmental Protection Agency (EPA). A minimum requirement of the permit is the implementation of a stormwater pollution prevention plan. In addition, the EPA has implemented a "Management Measure for Marinas and Recreational Boating" that covers the containment and treatment of waste from boat cleaning and maintenance facilities. "Management Measures" are defined in section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) as "*economically achievable measures to control the addition of pollutants to coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives*". They are intended to be applied by the States to new and expanding facilities to achieve best environmental practice.

"*Recommended design features* (for boat cleaning facilities) *include the designation of discrete impervious areas (e.g., cement areas) for hull maintenance activities; the use of roofed areas that prevent rain from contacting pollutants; and the creation of diversions and drainage of off-site runoff away from the hull maintenance area for separate treatment. Technologies capable of treating runoff that has been collected (e.g., wastewater treatment systems and holding tanks) may be used in situations where other practices are not appropriate or pretreatment is necessary. The primary disadvantages of using such systems are relatively high costs and high maintenance requirements. Some marinas are required to pretreat storm water runoff before discharge to the local sewer system. Washington State strongly recommends that marinas pretreat hull-cleaning wastewater and then discharge it to the local sewer system.*" (EPA 1993)

EPA recommends removal of 80% of Total Suspended Solids (TSS) in wastewater runoff from hull maintenance areas before it is discharged, preferably to municipal wastewater treatment facilities. A summary table of the treatment methods contained in the EPA Management Measure for Marinas and Recreational Boating is provided in Appendix Table A4. Some of these are discussed

13. Review of hull-cleaning methods and waste containment, treatment and disposal systems currently used in New Zealand

McClary and Nelligan (2001) reviewed hull cleaning methods and waste treatment and disposal systems currently used in New Zealand. They surveyed a range of existing operational practices at 37 hull-cleaning sites around the country and presented detailed site observations and findings in MFish Report ZBS 2000/03. A simplified summary of the various types of systems described in that report is shown in Table 2.1.

In addition to the operations described in MFish Report ZBS 2000/03, two other methods have been identified during the preparation of this report and are also included in Table 2.1. First is the practice of mooring small vessels within containment bags and adding herbicides and/or biocides to the waters between the hull and the containment bag, a practice that is not encouraged in the ANZECC (2000) Code of Practice document. The second method was developed by New Zealand Diving and Salvage Ltd (2002) for divers using an underwater vacuum scraper head to remove bio-fouling from vessels while still in the water. Development of this method is described in a report prepared for the Ministry of Fisheries titled Development of Incursion Response Tools – Underwater Vacuum Trials (NZ Diving and Salvage Ltd, 2002).

Table 2.1 divides the various systems into types based on the nature of the hull-cleaning operation site (e.g., in-water, tidal grid, dry dock etc), the hull cleaning method (e.g., scrubbing, water blasting, vacuuming etc), the waste collection and waste treatment methods (e.g., settling tanks, filtration etc), and the final destination of the solid and liquid fractions of the waste (i.e., land, sea or local sewage treatment plant). The key points to note from Table 2.1 are:

- All types of cleaning operations that occur in-water, or out-of-water but below high tide (e.g., diver cleaning, tidal grids and careening bays), inevitably discharge some or all of the solid and liquid wastes to sea.
- Only operations that are out-of-water can effectively contain and treat all wastes and dispose of liquid and solid effluent in a controlled manner. In-water vacuuming and enclosed-bag herbicide treatment do provide some treatment and containment, but in both these cases some solid and liquid wastes are inevitably discharged to sea.
- Operations that do effectively contain waste out-of-water have a number of treatment options and can dispose of solids to land and divert treated liquid waste to any of several discharge options (i.e., back to the sea, re-use for water blasting, treatment on site and/or via local sewer system to wastewater treatment plant).

In summary a variety of hull-cleaning methods are currently used in New Zealand with waste management systems that range in complexity from no management at all (i.e., bio-fouling debris falls directly into the sea), to wholly contained collection, treatment and disposal systems.

Evaluation of performance of existing systems in New Zealand

Performance of treatment systems tested in this project

The performance of several existing treatment systems was analysed in Objective 1 of this report. Conclusions on the survival of marine organisms at different stages of the tested treatment processes were provided in Section 12. These conclusions are briefly summarised in Table 2.2. Briefly, we found that large proportions (16%-72%) of the marine organisms removed from vessel hulls remained viable after they had been cleaned from the boat. Collection of solid wastes (with disposal to landfill) and containment and treatment of liquid wastewater by settlement removed > 99% of all macrobiota, with the remaining organisms being mostly of terrestrial or freshwater origin. The latter were effectively removed by filtration of the discharge following settle

Performance of underwater hull-cleaning systems

The performance of the underwater vacuum cutter head method (NZ Diving and Salvage Ltd, 2002) was assessed by the Cawthron Institute (Nelson) and the detailed findings presented by Coutts (2002). The report concluded that, although the first version of vacuum cutting head was not effective or practical for divers to use, the diver-operated vacuuming nozzle that was subsequently trialled proved to be a more effective and selective method. Overall the report recommended that *"Current technology is moving closer towards capturing de-fouled material from the more uniform areas of the hull (flat sides), but the challenge now lies with cleaning the areas protected from strong laminar flows (APSLF) such as the gratings, pipes, sea chests, rope guards, rudders, bow thrusters and bilge keels on the hulls of vessels. It is recommended, therefore, that the diver-operated vacuuming nozzle be tested during a merchant ship's hull de-fouling operation to determine whether or not it is a practical tool for removing, collecting and filtering de-fouled material from these APSLF."* (Coutts, 2002).

Coutts (2002) also concluded that the filtering system used by NZ Diving and Salvage (2002) could successfully filter material to 50 µm, although some particulate matter between 200 µm and 250 µm was detected in effluent samples after filtration. They noted that it was *"...not yet known if the filtering plant can be utilised for de-fouling the hulls of other vessels including merchant ships."* They therefore recommended that the system be further tested for performance with different filter bag sizes and flow rates.

Similar underwater hull cleaning methods have been used in the United States and are still under development by the US Navy (E. Holm, US Navy Surface Warfare Centre, pers. comm.). Examples are the Submerged Cleaning and Maintenance Platform (SCAMP) or the similar SeaKlean multi-brush systems. These mechanical devices are held next to the hull from the thrust and suction generated by a large impellor. The brushes of the device rotate and sweep biofouling off the hull and up a vacuum pipe to collection tanks. While these methods are reported to be effective at removing biofouling from vessels still in the water, the efficiency of the methods at capturing and containing all potentially viable biological material is reported to be variable depending on the extent of bio-fouling, conditions in the water and skill of the diver operators (US Navy Uniform National Discharge Standards (UNDS) website http://unds.bah.com).

It is also worth noting that a large proportion of private yachts are cleaned in NZ using simple underwater brushing and scraping techniques that have no residue containment or treatment method at all. For example it has been estimated that around 42% of international yachts are currently cleaned using these in-water hull-cleaning methods between one and four times during their stay in NZ (Floerl, unpubl. data). The performance of these methods is likely to be at best comparable with Treatment Stage 1 in Table 2.2.

14. Consideration of alternative treatment technologies

There have been many different treatment technologies designed to remove specific types of contaminants from water. International literature on the topic is vast. For removing viable marine organisms from an effluent, the most relevant technologies to consider in addition to those already discussed, are those that focus on separating fine suspended solid particles for other applications (e.g., stormwater treatment devices) and those relating to the treatment of ship ballast water. Both of these are considered in the discussion below.

Many other technologies are also available for treating community wastewater (i.e., sewage) but these technologies tend to focus on removing organic contaminants, dissolved nutrients and pathogenic micro-organisms, usually by using relatively expensive processes (e.g., oxidation ponds, activated sludge processes etc). In addition, these technologies usually rely on biological treatment processes that require a continuous influent stream organic load (such as community wastewater) to 'feed' and maintain the treatment micro-organisms. Hull-cleaning waste loads are generally variable, depending on the frequency with which boats are cleaned at the facility and would not, on their own, be suited to these kinds of treatment processes. Biological treatment processes could remove contaminants from hull-cleaning wastes that have other effects on the environment (e.g., soluble anti-fouling chemicals), but the most cost effective way to achieve this is likely to be discharging into an existing community sewerage system, having first removed a proportion of the gross and suspended solids.

Suspended-particle removal technologies commonly used for stormwater

The USEPA Management Measure for Marinas and Recreational Boating (USEPA 1993) lists a number of particle removal technologies that can be used to treat stormwater run-off from marinas and hull maintenance sites (see Appendix Table A4). These technologies (and/or slight variations of them) are common options for treating urban stormwater in New Zealand and the Auckland Regional Council has recently reviewed their use (ARC 2003). Several of these treatment options could potentially be applied to hull-cleaning situations, depending on site-specific characteristics and space limitations. These are:

- Holding (settling) tanks
- Sand (or other media) filters

- Infiltration trenches or basins
- Vegetative swales or filter strips
- Ponds and/or wetlands
- Oil and grit separators
- Coarse contaminant traps (or swirl concentrators)
- Absorbant booms or pillows

These options are compared in Table 2.3(A), with comments on cost considerations, performance reliability, and practical advantages and disadvantages. A brief summary of each is provided below.

Settling tanks

Settling tanks are basically large containers designed to hold volumes of waste for prolonged retention periods. These can be steel concrete, fibreglass or polymer tanks that are used for above-ground storage, or subsurface constructed tanks. Contaminant removal is essentially by "settling out" of suspended particles that are denser than water. In the context of treatment to reduce risks to marine biosecurity, treatment in these systems is also afforded by the prolonged exposure of marine organisms to fresh water in the tank. Settling tanks are currently the most common method of primary treatment for hull-cleaning wastes in New Zealand and have been shown in this study (Objective 1) to be reasonably effective at removing viable marine organisms. They are relatively cheap to install (~NZ$5,000-10,000) and on-going maintenance and operation involves simple removal and disposal of accumulated waste to landfill. The key issue for successful implementation is sufficient storage volume to allow a satisfactory time for retention of liquid effluent and effective baffling for serial flow and low turbulence. The longer the retention time the more effective treatment for viable organisms is likely to be. Depending on the retention time, settling tanks are capable of removing 50-75% of total suspended solids (USEPA 1993, ARC2003). The USEPA (1993) reports that well-designed systems can retain up to 100% of particles during a first flush influent event. Overall treatment performance can be enhanced by supplementary add-ons after primary settling such as sand filtration.

Sand (or other media) filters

Sand filters consist of layers of sand of varying grain size (grading from coarse sand to fine sands or peat), with an underlying gravel bed for infiltration or perforated underdrains for discharge of treated water. Pollutant removal is achieved mainly by "straining" pollutants through the filtering media with detention time typically 4 to 6 hours (USEPA 1993), although increased detention time will increase performance. Sand filters are the second most common treatment method for hull-cleaning wastes in New Zealand and have also been shown to be effective secondary treatment for removing viable marine organisms (Objective 1, this study). They are an effective add-on to primary settling tanks but would be less effective as a stand-alone primary treatment because they clog quickly and require frequent maintenance when coarse particulates are not first removed. When added to polish the discharge from settlement tanks, sand filters can provide a very high level of confidence for reducing biosecurity risk and can also remove a large proportion (75-89%) of suspended particulate material associated with chemical hull-cleaning contaminants. Discharge of effluent onto a sandy beach, as is practiced in some locations, is not considered an appropriate form of sand filtration.

The initial outlay for installation of sand filters can be large. McClary and Nelligan (2000) reported a typical cost of $NZ15,000 for a small sand filter system suitable for most New Zealand slipways. Other systems (e.g. remedial Solutions Inc. Aquashield™ filter media, Hynds Pipe Systems Ltd in-line and source control sand filters) have roughly similar costs. US EPA (1993) estimated that the overall costs of treatment using sand filters were in the order of US$3.53 (~NZ$5.66) per 100L of run-off treated and that maintenance costs were approximately 5% of the initial capital costs.

Infiltration trenches or basins

Infiltration basins and trenches are essentially large holding basins or trenches with pervious floors. They operate in a similar way to sand filters except that the filtering material is located in a trench or basin rather than being contained within a sealed tank. Influent is treated by filtering down through the bed media and may infiltrate to uncontained groundwater or may be collected in contained underlying drains before piping to a point-source discharge. Infiltration devices should drain within 72 hours of an influent event and should be dry at other times (USEPA 1993) although permanent shallow wetlands can also be constructed to behave as infiltration basins. The performance of infiltration basins is similar to that of sand filters except that the entire discharge can potentially be assimilated through land, without the need for any liquid discharge to sea. However, infiltration basins require a large area of flat land and this will limit their utility for boat cleaning facilities. They have not been tested for treating hull-cleaning wastes in New Zealand.

Vegetative swales or filter strips

Vegetative swales and filter strips are low-gradient conveyance channels that remove contaminants by entrapment and settling of particulate contaminants as the flow runs perpendicular to surface vegetation. They are not practical on very flat grades or on steep slopes or in wet or poorly drained soils and require a reasonably large land area. They can be applied where flow rates are not expected to exceed 0.5 m per second (USEPA 1993), but again, the requirement for large areas of land makes them impractical for most boat yard situations. USEPA (2003) estimates an outlay of between NZ$20,000 and NZ$200,000 per hectare for the installation of vegetative filter strips. Where land is available, smaller (and cheaper) versions could potentially be used as a final treatment step for liquid residues after some form of initial particle removal. They have not been tested for treating hull-cleaning wastes in New Zealand.

Ponds and/or wetlands

Ponds and wetlands are designed to maintain a permanent pool of water and temporary storage capacity for influent. They provide treatment through several mechanisms including settling, coagulation and precipitation and via biological uptake by plants and microorganisms living in the pond or wetland. They would also provide treatment for removal of viable marine organisms by exposure to freshwater. The key issue is that they also require a relatively large area, are expensive to build, and are often problematic and expensive to maintain. Wetlands also require a continuous influent supply to remain effective unless another surface or groundwater sources are available. They have not been tested for treating hull-cleaning wastes in New Zealand.

Oil and grit separators

Oil and grit separators are constructed traps designed to catch solids via settling and oil via surface floating separation. They are commonly used for stormwater treatment where there is a high likelihood of hydrocarbon contamination. Oil and grit separators successfully reduce hydrocarbon contamination and particulates (coarse material only), when properly designed and installed. They are mainly suitable for oil droplets > 150 μm in size, but can remove a significant proportion of contaminants from relatively small flows, especially when space is limited because they can be built to occupy only a small area beneath the ground. However performance can be variable and generally only large particle sizes are removed with significant quantities of small suspended solids passing through (Appendix Table A4). The costs of installation are moderate. McClary and Nelligan (2000) reported that a typical unit of 3000L capacity was around NZ$5,000. They have not been tested for treating hull-cleaning wastes in New Zealand.

Coarse contaminant traps (or swirl concentrators)

These are contaminant traps usually constructed below ground that use the flow of influent from a pipe to create a centrifugal flow around a cylindrical tank to enhance particle separation. Various types exist (e.g., Hynds Pipe Systems Ltd Downstream Defender™ and CDS Technologies Continuous Deflective Separation system™). They are intended to operate under high flow regimes to generate a circular current and are unlikely to perform well at slow flow velocities. They can be effective at removing large particle sizes but, again, small suspended solids pass through. Costs of installation are likely to be in the order of NZ$10,000 – $NZ30,000. They have not been tested for treating hull-cleaning wastes in New Zealand.

Absorbant booms or pillows

Absorbent booms or pillows can be very useful additions to supplement other treatment systems where oil and grease contaminants are included in the waste stream. They can be placed in ponds, holding tanks, retention basins, coarse sediment traps and also in pipework.

Summary

In summary, all of these methods have been shown to be effective at removing different types of contaminants (see Appendix Table A4) and all have been shown to be useful in specific situations for urban stormwater in New Zealand. However only the settling tank and sand-filter methods have been tried and performance tested for reducing biosecurity risk for hull-cleaning situations in New Zealand.

The performance of the other 'through land' methods (i.e. infiltration trenches or basins, vegetative swales, filter strips, ponds and wetlands) will typically be variable from site to site because it depends on construction details, soil and vegetation types as well as local hydrogeology and hydraulic conditions. Therefore there would need to be a significant development and testing component if these options were applied to hull-cleaning operations.

The methods for removing oil and coarse contaminants (i.e., oil separators, coarse contaminant traps and absorbant booms) can be effective for this purpose, but are unlikely to be sufficient on their own to reduce biosecurity risk.

Ballast water treatment technologies

Treatment options for reducing the biosecurity risk of ship ballast water discharges have been reviewed relatively recently by Rigby and Taylor (2001), and in papers presented in the Proceedings of the 1st International Ballast Water Treatment Research and Development Symposium in London (Raaymakers 2001). From these sources, the available technologies that we consider could be relevant for hull-cleaning operations are summarised below:

- Use of fresh water to kill viable marine organisms
- Use of heat to kill viable organisms
- Self-cleaning mechanical filters
- Hydrocyclones or mechanical centrifugal particle separators
- Chemical biocides including hydrogen peroxide, chlorine (hypochlorite), chlorine dioxide, ozone, glutaraldehyde, copper/silver ion systems and natural biocides.
- Ultra violet (UV) irradiation to kill viable organisms

These options are compared in Table 2.3(B), with comments on cost considerations, performance reliability, and practical advantages and disadvantages. Only the freshwater exposure method has been performance tested for hull-cleaning residues (in this study). The application of all of the other technologies to ballast-water treatment or hull-cleaning operations for the management of risk to marine biosecurity, is a relatively new and developing area internationally. This is illustrated by the overall conclusions presented in Raaymakers (2001) that included:

- *"All of the various potential ballast water treatment technologies* [including those listed above] *are currently at a very early stage of development and significant further research is required.*
- *It is likely to be some years before a new ballast water treatment system is developed, proven effective, approved and accepted internationally for operational use.*
- *It appears that any new ballast water treatment system will involve a combination of technologies, for example primary filtration or physical separation followed by a secondary biocidal treatment."*

In summary, none of these alternatives is a guaranteed 'off-the-shelf' solution for treating hull-cleaning wastes. Therefore there would need to be a significant development and testing component if any of these options were applied to hull-cleaning operations.

Advanced technologies for toxic chemical contaminants

There are other treatment technologies, either in use or currently under development, to reduce the concentrations of anti-fouling chemicals in hull-cleaning residues and ballast waters. These treatments may also be effective in reducing the risk of release of harmful marine organisms. In situations where anti-fouling residues are likely to enter the hull-cleaning waste stream (e.g., in operations involving high pressure water blasting or abrasive cleaning) requirements for the retention and removal of fine particulate material associated with toxins may drive a requirement for additional treatment considerations for discharges regulated by consents under the Resource Management Act.

Any treatment system that removes particulate materials (e.g., settling, filtration or other particulate separation) will also remove a substantial proportion of anti-foulant chemicals associated with these particulates and viable marine organisms. However they are unlikely to remove all soluble contaminants, including anti-foulant chemicals such as tributyltin (TBT). Soluble contaminants are much more difficult to remove and few methods currently exist that are effective at a practicable scale for large hull-cleaning operations. This is confirmed in the proceedings of the Oceans '99 Conference in Seattle - Treatment of Regulated Discharges from Shipyards and Drydocks (Champ et al. 1999) whose overall conclusions included:

- *"There is only one advanced waste treatment system in the world that has successfully treated industrial volumes of TBT in wastewaters in accordance with shipyard operations (36 hours for washdown). The CASRM Barge Mounted System has evolved from bench type laboratory scale treatment systems to a shipyard size demonstration project.*
- *There is no inexpensive advanced treatment system or technologies available in commercial sizes that can rapidly treat million gallon quantities of TBT contaminated ship washdown or runoff wastewaters from shipyards and drydocks.*

In light of this, the most effective mechanism currently available for managing these toxic chemical contaminants is probably to remove as large a proportion as possible of particulate material for controlled disposal to land, and to discharge the liquid effluent via community sewer system to the local wastewater treatment plant. This assumes that the level of contamination does not adversely affect any microbiological treatment communities at the local treatment plant. If the discharge is not acceptable to the local treatment plant operator the only remaining option would be disposal at an appropriate hazardous waste facility.

Recommendations

(1) Results from this study show that reliance solely on physical cleaning processes, either in-water or on land (e.g., scraping, water blasting, brushing etc), without any containment or treatment of residues, is unlikely to reduce risks for marine biosecurity to acceptably low levels. The exception to this is where the risk is already low due to a vessel having remained in local waters since last being cleaned. This is consistent with the Australian Code of Practice for Antifouling

and In-water Hull Cleaning and Maintenance (ANZECC 2000) which recommends that; *"In-water hull cleaning is prohibited, except under extra ordinary circumstances and permission will not normally be granted"*.

(2) For vessels that have travelled outside local waters, and that therefore pose a risk to local marine biosecurity, the risk can be reduced to low levels (<1% survival of organisms, based on the results from this study) by containing and collecting the hull-cleaning waste and exposing it to fresh water in settling tanks with sufficiently long retention times. Key characteristics of the treatment systems shown to be effective in this study were:

- Hard-stand hull-cleaning work area above high tide mark or in dry-dock.
- Containment of all liquid and solid waste (usually achieved using walls, bunds, cut-off drains and isolated sumps).
- Collection of all solid and liquid waste residues with disposal of solids on land and diversion of liquids to settling tank treatment systems.
- Treatment of liquid waste residues by exposure to fresh water and particulate separation in settling tanks. Typically the tanks were baffled to provide at least three holding chambers operating in series with total retention time of at least 2 weeks. Shorter retention times may be effective but were not assessed during this study. Site-specific monitoring could be undertaken by operators to investigate the efficacy of shorter retention times at particular sites.
- Treatment in settling tanks was in some cases (but not all) followed by filtration via either sand-bed or sand and peat-bed filters.
- Discharge of settled or filtered solid residues on land. Discharge of treated liquid effluent to sea or to local sewer system.

(3) For operators that already have some form of collection and settling tank treatment system, the most cost-effective option is likely to be retain and/or modify the existing system to achieve the characteristics listed in (2) above.

(4) For operators that do not currently have treatment systems, the simplest and most cost-effective option is likely to be that described in (2) above. This recommendation is based simply on the fact that this is the most commonly used system in New Zealand and is a system that has been shown to be effective at reducing biosecurity risk in results from this study. This recommendation does not preclude the use of other, possibly more sophisticated, systems.

Another system shown to be effective in this study is the Devonport treatment plant that uses clarifiers and filters. This system is more expensive than simple settling tanks but is likely to perform to a higher standard for removing other potential contaminants (see recommendation (6) below).

(5) Notwithstanding (3) and (4) above, there are other methods that could, on site-specific consideration, also prove to be cost-effective for operators. These include the use of heat treatment (particularly if a waste-heat source is locally available), filtration devices (particularly if waste volumes are small),

centrifugal separation systems (particularly if space is limited), chemical biocides (if local circumstances allow) and targeted underwater hull vacuuming (in cases where removal of the vessel from water is not an option). The relative merits of these options would need to be considered on the basis of site-specific characteristics, locally-specific biosecurity risk and locally-specific environmental effects.

The literature suggests some alternative treatment options show promise, but their reliability and practicality for hull-cleaning applications remains to be confirmed. There would need to be a significant development and testing component as part of implementation of any of these options.

(6) The results from this study suggest that biosecurity risks can be reduced to low levels using containment and settling tank separation methods with exposure to fresh water and without subsequent filtration. However, there are likely to be additional benefits of including filtration or other more sophisticated treatment technologies as 'add-ons' to the operations process:

- First, filtration provides an additional buffer of confidence in reducing risks to marine biosecurity, by providing a final 'catch all' removal of particles greater than the McClary and Nelligan (2001) proposed 'particle standard'.
- Second, filtration will improve the removal of fine particulates and associated anti-fouling chemicals, and this will be important for operators who not only need to manage marine biosecurity risk, but who also need consents for discharges to the sea under the Resource Management Act, or may need permission to divert hull-cleaning waste to local community wastewater treatment plants.

15. Publications

Nil

16. Data storage

17. Acknowledgements

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List of tables, figures and plates

Table 1.1: Hull cleaning facilities that were visited or contacted during Research Project ZBS2002-04.

	Facility	Location	No. vessels cleaned p.a. (no. intern'l)[a]	Hull cleaning operations visited	Separation of solids and liquids	Filtration of liquids	Disposal Solids/Liquids
Vessels removed from water for cleaning	Westpark Marina	Auckland	2,000 (50)	Travel lift	Settling tanks	No (20 mm)	Landfill / Sea
	Lyttelton Port Co.	Lyttelton	70 (7)	Dry-dock Slipway	Settlement tanks & flocculating agent	No	Landfill / Sea
	Orams Marine Maintenance	Auckland	2,000 (15)	Travel lift Slipway	Grit arrestors	Sand filter	Landfill / Sea
	Tauranga Marina Society	Tauranga	2,000 (8)	Travel lift	Settling tanks / Sand filter	100 μm	Landfill / Sea
Vessels cleaned on tidal grids	Tauranga Marina Society	Tauranga	2,000 (8)	Tidal grids	n/a	n/a	Landfill
	Whangarei Cruising Club	Whangarei	75 (19)	Tidal grids	n/a	n/a	Landfill
					n/a	n/a	
Vessels cleaned in the water	Gulf Harbour Marina	Whangaparaoa	3,120 (80)	Diver services	n/a	n/a	Sea
	Orams Marine Maintenance	Auckland	2,000 (15)	Diver services	n/a	n/a	Sea

[a] Source: McClary & Nelligan (2001). These figures refer to the sum of vessels cleaned in all available operations offered by the facilities. For example 2,000 vessels are cleaned in the Tauranga Marina each year ; 5 % on the tidal grids and 95 % on the hard-stand (using a travel lift).

Table 1.2: Operations and facilities visited during this study, and details of name, type, size and abundance of fouling organisms of vessels that were sampled.

	Operation	Facility (no. vessels cleaned)	Vessel name (date sampled)	Vessel type	Length	Total wetted surface area	Area fouled; fouling weight (±SE)
1. Vessels removed from water for cleaning	Dry-dock	Lyttelton Port (3)	*A. Slobodchikov* (16/05/03)	Fishing trawler	104.5 m	1762.5 m^2	263.2±80.9 m^2; 614±285 kg
			Godley (16/07/03)	Harbour tug	28.7 m	213.7 m^2	36.1±16.7 m^2; 79±22 kg
			Hebe (28/08/03)	LPG Tanker	76.4 m	715.6 m^2	112.9±45.6 m^2; 122±57 kg
	Travel lift	Orams Marine, Auckland (3)	*Chancellor* (10/06/03)	Motor yacht	11.5 m	23 m^2	1.2±0.7 m^2; 1.6±0.4 kg
			Lady Crossley (10/06/03)	Sailing yacht	16.15 m	36.5 m^2	1.6±0.6 m^2; 0.6±0.1 kg
			Macushla (11/06/03)	Sailing yacht	12.03 m	33.0 m^2	15.5±2.4 m^2; 151±65 kg
		Westpark Marina, Auckland (3)	No. 1 (name n/a) (16/06/03)	Harbour tug	14.8 m	59.6 m^2	17.2±3.7 m^2; 69±41 kg
			No. 2 (name n/a) (16/06/03)	Motor yacht	13.4 m	43.7 m^2	1.6±0.5 m^2; 1.9±0.1 kg
			Bahia (16/06/03)	Sailing yacht	12.5 m	50 m^2	4.1±3.2 m^2; 0.9±0.1 kg
		Tauranga Marina (4)	*Chris Robertson* (02/07/03)	Sailing yacht	12.2 m	18.3 m^3	0.3±0.1 m^2; 0.05±0.006 kg
			Ma Chérie (02/07/03)	Launch	12.8 m	41.6 m^2	1.3±0.4 m^2; 1.6±0.1 kg
			No. 3 (name n/a) (03/07/03)	Launch	12.8 m	23.8 m^2	0.7±0.3 m^2; 0.9±0.2 kg
			No. 4 (name n/a) (03/07/03)	Sailing yacht	11.9 m	42.8 m^2	1.3±0.4 m^2; 0.7±0.1 kg
2. Vessels cleaned in the water	Cleaning by divers	Orams Marine, Auckland (3)	*Triptych* (11/06/03)	Motor yacht	21.3 m	127.8 m^2	4.8±1.2 m^2; 1.2±0.6 kg
			No. 2 (name n/a) (11/06/03)	Sailing yacht	15.24 m	48.8 m^2	1.5±0.8 m^2; 0.3±0.06 kg
			Sympatica (11/06/03)	Motor yacht	13.7 m	71.24 m^2	5.5±2.6 m^2; 0.6±0.1 kg
		Gulf Harbour Marina, Whangaparaoa (3)	*Lady Theodora* (27/06/03)	Sailing yacht	10 m	30 m^2	1.2±0.66 m^2; 1.0±0.4 kg
			Moana Ariki (27/06/03)	Sailing yacht	10 m	30 m^2	4.5±1.6 m^2; 3.6±0.5 kg
			No. 3 (name n/a) (27/06/03)	Sailing yacht	10.5 m	31.5 m^2	8.1±1.5 m^2; 30.9±10.4 kg

Table 1.3: Numbers of whole organisms or fragments (summarised to broad groups) examined in solid waste removed from cleaned vessels in each operation. For more detail see Appendix Table A2.

		Barnacles	Bivalves	Bryozoans	Ascidians	Hydroids	Tubiculous polychaetes	Errant polychaetes	Sponges	Algae	Motile crustaceans	Motile molluscs	Flatworms / nemerteans	Anemones
Lyttelton Port	*A. Slobodchikov*	42	156	1	0	0	0	11	0	0	2	0	0	0
	Godley	36	17	10	21	9	4	0	10	4	0	0	0	0
	Hebe	131	1	17	0	0	0	0	0	28	0	0	0	0
Orams Marine (haul-out)	*Chancellor*	4	11	47	26	0	65	0	3	0	0	0	0	0
	Lady Crossley	0	12	17	13	0	15	0	0	0	0	0	0	0
	Macushla	0	9	20	73	0	21	1	7	30	26	0	0	0
Westpark Marina	No. 1 (name n/a)	130	33	0	0	0	1	17	0	13	1	0	0	0
	No. 2 (name n/a)	24	2	200	50	0	8	0	0	2	0	0	0	0
	Bahia	4	0	54	0	0	70	0	0	0	0	0	0	0
Tauranga Marina	*Chris Robertson*	0	0	58	8	0	435	0	0	0	37	0	0	1
	Ma Chérie	1850	82	0	0	1	0	0	0	0	0	0	0	0
	No. 3 (name n/a)	13	0	132	64	0	1337	1	0	2	2	0	0	1
	No. 4 (name n/a)	14	0	104	0	0	47	0	0	0	0	0	0	1
Orams Marine (in-water)	*Triptych*	0	0	166	5	0	120	0	0	3	20	0	120	0
	No. 2 (name n/a)	0	0	150	0	0	100	4	1	0	5	5	2	0
	Sympatica	0	0	5	1	0	1011	1	3	0	0	0	0	0
Gulf Harbour Marina	*Lady Theodora*	134	3	32	146	0	396	9	9	0	4	0	0	34
	Moana Ariki	72	2	45	38	0	1407	8	2	0	4	4	0	0
	No. 3 (name n/a)	48	40	15	169	0	252	15	1	0	7	0	0	0
	Total no. sampled	**2502**	**368**	**1073**	**614**	**10**	**5289**	**67**	**36**	**82**	**108**	**9**	**122**	**37**

Table 1.4: Concentrations of organisms in the liquid waste sampled in the dry-dock and haul-out operations at various stages of treatment. All concentrations are given as abundance 10 L^{-1} (± s.e.) except filamentous algae, for which a ranks scale of abundance (0-5) was used.

		Nematodes	Crustaceans	Gastropods	Bivalves	Rotifers	Larvae	Ciliates	Diatoms	Tintinnids	Filamentous algae	Spores	Eggs
Lyttelton Port	Cleaning runoff	5343.2 (1883)	1275.2 (363.4)	43.2 (43.2)	8.2 (7.1)	0	6.2 (6.2)	1368 (499.2)	769.7 (375.4)	119.5 (88.1)	4.8 (0.1)	258.3 (205.1)	295.4 (105.5)
	Settlement tanks	521.7 (503.8)	371.3 (336.7)	0	0	0	0	0	0	0	1.0 (0)	252.9 (252.9)	89.5 (72.8)
	Tank discharge	1.8 (1.8)	0	0	0	0	0	0	20.4 (11.7)	0	0.8 (0.2)	0	5.1 (3.2)
Orams Marine	Cleaning runoff	36727.5 (6357)	873.3 (629.3)	287.5 (103.5)	0	0	78.0 (77.9)	1938.7 (555.4)	0	1539.7 (662.7)	4.6 (0.2)	0	72.2 (47.4)
	Settlement tanks	9.9 (9.9)	0	7.4 (7.4)	0	0	0	0	0	6.6 (6.6)	0.7 (0.2)	0	11.2 (11.2)
	Tank discharge	0	0	0	0	0	0	0	0	0	0.5 (0.2)	0	1.2 (1.2)
Westpark Marina	Cleaning runoff	1595.3 (442.5)	42.8 (42.8)	0	0	0	0	1034.1 (351.2)	137.0 (137.0)	5015.9 (3035.6)	5 (0)	0	134.9 (889.4)
	Settlement tanks	106.7 (50.9)	155.5 (89.5)	12.1 (11.5)	0	0	0	52.1 (30.1)	11.5 (11.5)	0	4.3 (0.3)	0	38.8 (9.6)
Tauranga Marina	Cleaning runoff	8628.3 (34.6)	1474.8 (476.1)	87.7 (41.0)	1 (1)	0	56.5 (40.0)	926.8 (519.9)	0	419.6 (133.1)	3.6 (0.2)	174.5 (98.5)	252.7 (76.7)
	Settlement tanks	6466.1 (2383)	31.9 (31.9)	426.1 (146.1)	0	0	0	2151.5 (1016)	0	2119.4 (1294.8)	3.0 (0.8)	0	834.4 (327.7)
	Tank discharge	34.8 (16.8)	29.8 (13.4)	0	0	56.1 (31.6)	0	23.2 (4.6)	0	0	1.3 (0.4)	0	0

Table 1.5: Presence ('+') of visible movement (examined by microscope) and mitochondria (vital staining with Janus Green) in the liquid samples taken at various stages of treatment in the operations visited. It was not possible to sample run-off from water blasting for some of the vessels whose cleaning was attended (Lyttelton: *Hebe*; Orams Marine: *Macushla*; Westpark Marina: Boat 2; Tauranga: *Chris Robertson*).

		Movement	Mitochondria present
Lyttelton Port	Cleaning runoff		
	A. Slobodnich	+	+
	Godley	-	+
	Settlement tanks	-	+
	Tank discharge	-	-
Orams Marine	Cleaning runoff		
	Chancellor	+	+
	Lady Crossley	+	+
	Settlement tanks	-	-
	Tank discharge	-	-
Westpark Marina	Cleaning runoff		
	Boat 1	-	+
	Bahia	-	+
	Settlement tanks	-	-
Tauranga Marina	Cleaning runoff		
	Ma Chérie	-	+
	Boat 3	-	+
	Boat 4	-	+
	Settlement tanks	-	+
	Tank discharge	-	-

Table 1.6: Salinity tolerances of some well-known NIS.

Species	NZ distribution (Cranfield *et al.* 1998)	Salinity tolerance	Source
Ficopomatus enigmaticus (formerly *Mercierella enigmatica*); serpulid polychaete	Whangarei and Waitemata Harbours, Hawkes Bay	Can live and grow at 0-0.5 ppt. for up to 80 d. No survival and growth at 21 ppt.	Hill (1967); Straughan (1972)
Hydroides elegans; serpulid polychaete	Waitemata and Lyttelton Harbours	LD_{50} at < 4 h in 5 ppt., 100 % mortality after 9.5 h. Lowest salinity range 15-20 ppt.	Mak & Huang (1982)
Crassostrea gigas, Pacific oyster	Northern NZ harbours, Waikanae River, Tasman Bay, Pelorus Sound	LD_{50} at 3 ppt., can survive up to 55 ppt. However, published tolerances vary and suggest 2-35 ppt., 4-35 ppt. and 5-56 ppt.	NIMPIS (2002a) and references therein
Bugula neritina; erect bryozoan	All harbours except Onehunga, Gisborne and Oamaru.	Optimum at > 30 ppt.; survival and maturation in > 20 ppt. Short exposure to freshwater causes severe damage; salinities < 14 ppt. can be fatal to colonies.	Matawari (1951); Kitamura & Hirayama (1985)
Balanus amphitrite; acorn barnacle	Waitemata Harbour	Larvae can develop in 10-30 ppt. (or more) but developmental period longer at low salinities. At 10 ppt. there is 99 % larval mortality. Larval survival dependent on the speed of the osmoshock as much as on the magnitude of drop in salinity.	Anil *et al.* (1995) Cawthorne (1978)
Botrylloides leachi; colonial ascidian	Whangarei, Tauranga and Wellington Harbours, Hauraki Gulf, Cook Strait, Otago Harbour, Stewart Island, Chatham and Auckland Is.	Growth and survival in a minimum of 24 ppt. if temperatures > 18 °C. Maximum tolerance 44 ppt.	NIMPIS (2002b) Brunetti *et al.* (1980)
Undaria pinnatifida; kelp	Entire south and east coast of the South Island, extending up the East coast of the North island as far as Gisborne.	Optimum at 27 ppt.; lowest salinity in which the species is established: 20 ppt. (Australia) and 22-23 ppt. (NZ)	Saito (1975) Sanderson and Barrett (1989) Wallentinus (1999) (NIMPIS 2002c)
Sabella spallanzanii; sabellid polychaete	Not recorded in NZ.	Tolerates salinities of 26 – 38 ppt. Dies after 2-12 hours exposure to freshwater.	Currie *et al.* (2000) NIMPIS (2002d)

Table 2.1. Summary of systems currently used in NZ for the collection, treatment and disposal of wastes generated from vessel hull-cleaning operations [Sources: McClary and Nelligan (2001), (ANZECC 2000), NZ Diving and Salvage Ltd (2002)].

Site type	Cleaning method	Collection method	Treatment method	Solids disposal	Liquid disposal
In water	Divers using scrubbers	No collection – material falls to the sea-floor	none	Sea	Sea
In water	Divers using hydraulic cutter head and vacuum hose	Material collected by vacuum head and pumped to treatment system	Filtration via polypropylene filter bags (50-100 µm pore)	Landfill or other solid waste facilty	Sea
In water	Small vessels moored in bags with herbicides or biocides added within bag	No collection – material falls to the sea-floor	Chemical herbicides and/or biocides	Sea	Sea
Out of water below high tide (tidal grids, careening bays)	Scraping or scrubbing	Some collection of solids but no containment	none	Some solids may be disposed to landfill but remainder reclaimed by rising tide	Sea
Out of water above high tide (dry-docks, travel lifts, synchro lifts or slipways)	Water-blasting, scraping or sanding	Liquid and solid material collected in a contained hard-stand area	Settling tanks, either single compartment or baffled with several compartments in series	Landfill or other solid waste facilty	Sea (and in some cases recycled to water-blasting)
Out of water above high tide (dry-docks, travel lifts, synchro lifts or slipways)	Water-blasting, scraping or sanding	Liquid and solid material collected in a contained hard-stand area	Settling tanks with some chemical enhancement of separation process (e.g., flocculants such as *Magnafloc* and alum for pH correction)	Landfill or other solid waste facilty	Sea (and in some cases recycled to water-blasting)
Out of water above high tide (dry-docks, travel lifts, synchro lifts or slipways)	Water-blasting, scraping or sanding	Liquid and solid material collected in a contained hard-stand area	Settling tanks followed by sand filter and/or sand/peat polishing filter	Landfill or other solid waste facilty	Sea (and in some cases recycled to water-blasting)
Out of water above high tide (dry-docks, travel lifts, synchro lifts or slipways)	Water-blasting, scraping or sanding	Liquid and solid material collected in a contained hard-stand area	Equalizing tank, clarifier, sand filter, final filters (1µm)	Landfill or other solid waste facilty	To community waste-water treatment plant

Table 2.2. Summary of measured performance of existing treatment systems

Removal and treatment method	Description	Performance conclusions
Removal of fouling from vessel hulls (Treatment Stage 1[1])	Hull-fouling material is physically disrupted by cleaning removal processes (e.g., scraping, water blasting, brushing etc) but is not further treated in any way. Three types were assessed including: • in-water cleaning • dry-dock operations • haul-out facilities	Significant proportions of marine organisms sampled were in a viable state, as follows: • in-water (72% viable) • dry-dock (43% viable) • haul-out (16% viable) Overall risk to biosecurity is <u>more than minor</u>.
Collection and treatment of liquid fouling waste in settlement tanks (Treatment Stage 2[1])	Liquid fouling waste is collected in settlement tanks where marine organisms are held in fresh water and particulates are separated from liquid by settling.	Treatment removed >99% of animals, larvae and unicellular organisms. Of the <1% that passed through treatment, very few were viable. Filamentous algae were abundant post-treatment but were probably of terrestrial origin. Some very low-salinity-tolerant organisms could potentially survive. Overall risk to biosecurity is <u>low</u>.
Physical screening and filtration of settlement tank effluent (Treatment Stage 3[1])	Primary treated effluent from settlement tanks is subsequently passed through a sand-filter	No marine animals, larvae, eggs, spores or unicellular organisms were found post-treatment. Some *filamentous algae were found but were* likely to be freshwater species from other sources. Overall risk to biosecurity is <u>negligible</u>.

[1]See the schematic diagram of various stages of treatment system in Figure 1.1.

Table 2.3. Treatment technologies that could potentially be used for the treatment of wastes generated from vessel hull-cleaning. Two types of treatment method are listed;

A) Suspended particle removal technologies commonly used for stormwater (Sources: ARC 2003; USEPA 1993)

B) Ballast water treatment technologies (Sources: Rigby and Taylor 2001)

Treatment method	Cost considerations	Performance	Advantages	Disadvantages
A – SUSPENDED-PARTICLE REMOVAL TECHNOLOGIES COMMONLY USED FOR STORMWATER				
Holding (settling) tanks	- Initial capital cost depends on type. A simple system could cost around NZ$5 - 10,000. - Ongoing maintenance costs low but include removal of accumulated material from bottom.	- Remove most viable organisms. - 50-75% of total suspended solids (TSS) removed	- Relatively cheap installation and on-going operation costs - Potentially high removal of organisms when combined with fresh water storage - Operationally & technologically simple - Likely to remove other contaminants (e.g., oils, fine particulates [paint flakes] and some soluble contaminants).	- Requires moderate storage capacity to hold influent discharge for suitable retention period
Sand filters or contained bed filters with other bed-media	- Initial capital installation cost is relatively high. - Ongoing maintenance costs include removal and replacement of fouled sand layers. - Requires some pre-treatment to remove gross solids and reduce clogging.	- Effective at removing viable organisms. - Capable of removing particles down to the 60μm 'particle standard'. - Capable of removing between 75% (Hynds Pipe Systems Ltd) and 89% (Remedial Solutions Inc.) of TSS.	- Relatively cheap on-going operation costs - Potentially high reliability of organism control - Operationally and technologically fairly simple - Likely to remove a high proportion of other contaminants in addition to marine organisms (e.g., oils,	- Requires some pre-treatment (e.g., primary settling) with reasonable storage retention volume because water passage rate through sand filter is slow.

		- Likely to remove some proportion of soluble contaminants.	fine particulates [paint flakes] and some soluble contaminant removal).	
Infiltration trenches or basins	- Initial capital installation cost high - Requires a large flat area. - Ongoing maintenance costs include removal and replacement of upper layers of trench beds or basins. - Requires some pre-treatment (e.g. primary settling) to remove gross solids	- Similar to sand filters. - May be no need for liquid discharge to sea if the infiltration area is large enough, porous enough and if evaporation rates are favourable.	- High removal of organisms - Operationally and technologically simple - Likely to remove a high proportion of other contaminants (e.g., oils, fine particulates [paint flakes] and some soluble contaminants.	- Requires large area of flat land.
Vegetative swales, filter strips, ponds or wetlands	- Initial capital installation cost is high (vegetation swales or filter strips) to very high (constructed ponds or wetlands). Ongoing costs include maintenance of vegetation	- Potentially the entire discharge can be assimilated without the need for any liquid discharge to sea if the vegetated area or pond/wetland area is large enough, porous enough and if evaporation rates are favourable	- High removal of organisms - Operationally and technologically simple - Likely to remove a high proportion of other contaminants (e.g., oils, fine particulates [paint flakes] and some soluble contaminants.	- Requires large area of flat land preferably at lower level than hull-cleaning work area. - Can require high on-going vegetation maintenance depending on design.
Oil and grit separators	- Installation costs moderate (~NZ$5000) - Ongoing maintenance costs include removal of accumulated oil and grit.	- Not a suitable 'stand alone' treatment for hull-cleaning waste. They would be a useful addition to a treatment process to remove hydrocarbon contamination.	- Reliable targeted method of removing hydrocarbon contaminants. - Relatively cheap on-going operation costs - Operationally and technologically simple	- Not an effective 'stand-alone' treatment system
Coarse contaminant	- Initial capital	- Removes coarse	- Requires only small	- Requires wastewater

traps relying on cylindrical circular flow separation (swirl concentrators)	installation cost is high. Likely to be ~NZ$10,000 – $30,000.	material only. Unlikely to provide reliable performance for small particle sizes. Useful only as primary treatment prior to other method such as sand filtration	area and sited below ground - Relatively cheap on-going operation costs - Operationally and technologically simple	stream to be flowing (i.e., through pipe system) - Not an effective 'stand-alone' treatment system
Absorbant booms or pillows	- Capital cost very low – around NZ$250 per pillow or small boom	- Very effective at removing oil, particularly surface floating oil that has not yet been emulsified by turbulence	- Relatively cheap on-going operation costs - Operationally and technologically simple	- Only really suitable for removing surface oil - Not an effective 'stand-alone' treatment system
B - BALLAST WATER TREATMENT TECHNOLOGIES				
Fresh water exposure	- Fresh water is cheaply available. - Estimated cost of between NZ$0.07 per m^3 to NZ$1.37 per m^3 depending on the use of recycled process water or potable fresh water[1]	- Shown to be effective at retention times > 2 weeks (this report). - "*Can provide a very effective means of organism control*" (Rigby and Taylor, 2001).	- Cheap on-going operation costs - High reliability of organism control - Discharge of fresh water is potentially environmentally friendly, provided solids are removed	- Requires construction of a large storage capacity (and therefore potentially high initial capital costs) to achieve consistent minimum retention periods, particularly if rainfall contributions are large.
Heat exposure	- Costs variable depending on the availability of waste-heat sources - Estimated cost of NZ$0.02 per m^3 to NZ$ 0.05 per m^3 for ballast tank applications where waste heat is available from ship engines[1].	- Likely to be effective at temperatures in the vicinity of 35-45°C for a few hours (Rigby et al., 2001). - "*Can provide a very effective and environmentally attractive option*" (Rigby and Taylor, 2001).	- Rapid treatment requiring only small retention times and therefore small storage capacities. - High reliability of organism control - Discharge of cooled treated water is potentially environmentally friendly, provided solids are removed	- Energy inefficient with high on-going operation costs unless an effective waste-heat source is available.
Self-cleaning screen filtration	- Initial capital cost is likely to be relatively high	- effective treatment technology for removing	- Potentially rapid treatment requiring only	- Mechanically complex requiring skilled development

	(NZ$0.14 per m^3 to NZ$0.37 per m^3 for ballast tank applications) [1]. - On-going maintenance is likely to require skilled operators and relatively high costs.	marine organisms from ballast water. Turbidity and particle size distribution affect performance and existing "off-the-shelf" technologies may not perform efficiently with seawater.	small retention times and therefore small storage capacities. - Potentially high removal of organisms	and testing during implementation as well as likely high on-going maintenance.
Hydrocyclones or mechanical centrifugal particle separators	- High initial capital cost (NZ$0.13 per m^3 to NZ$0.50 per m^3 for ballast tank applications) [1] - On-going maintenance is likely to require skilled operators and relatively high costs.	- Effective at removing particulates from liquid but post treatment (e.g. UV radiation normally required) for controlling organisms (Sutherland *et al.*, 2001).	- Rapid treatment requiring only small retention times and therefore small storage capacities.	- Mechanically complex requiring skilled development and testing during implementation as well as likely high on-going maintenance. - Likely to require further post-treatment (e.g., biocides, UV).
Chemical biocides (includes hydrogen peroxide, chlorine (hypochlorite), chlorine dioxide, ozone, glutaraldehyde and copper/silver ion systems)	- Relatively low initial capital cost. (NZ$0.27 per m^3 to NZ$0.46 per m^3 for ballast tank applications) [1] - On-going cost is likely to be relatively high but variable depending on the chemical used.	- May be effective, but only copper ion, hypochlorite and glutaraldehyde are "currently available" (McCracken, 2001). - Peraclean® Ocean (a formulation based on peroxy acetic acid) is very effective (100% mortality with range of test organisms) and breaks down rapidly in seawater (Fuchs *et al* 2001). - SEAKLEEN® (a natural organic oxidant) is also effective on broad range of organisms and breaks down quickly in the environment (cost = US$0.20/metric tonne treated water). (Wright and Dawson 2001)	- Potentially rapid treatment requiring only small retention times and therefore small storage capacities. - Potentially high removal of organisms - Operationally and technologically simple	- Biocide residues discharged to environment requiring careful assessment and management of effects. - Relatively high on-going cost of biocide.

Ultra violet (UV) irradiation	- Initial capital cost is high (NZ$0.18 per m^3 to NZ$0.60 per m^3 for ballast tank applications)[1]. On-going maintenance is likely to require skilled operators and relatively high costs. - Considerable pre-treatment required to reduce effluent turbidity for UV to be effective. This is also expensive.	- *"Commonly currently used in wastewater treatment; promising, but turbidity must be removed first"* (McCracken, 2001). - Preliminary tests of UV on seawater are not encouraging even at high UV doses. Turbidity is a problem. UV unlikely to be effective against large zooplankton (>35 µm) Waite et al. 2001).	- Potentially rapid treatment - Environmentally friendly discharge (no contaminants)	- Questionable removal of organisms. - Requires considerable pre-treatment to remove turbidity (potentially expensive). - Mechanically complex requiring skilled development and testing as well as high on-going maintenance.

[1] Rigby and Taylor (2001) analysed the relative cost-effectiveness (in Australian dollars) of several treatment options for treating ship ballast-water. Note that their analysis assumes that wastewater is already contained in vessel ballast tanks, and therefore no consideration is made for the capital costs of building hardstand containment and collection areas, as would be required for hull-cleaning operations. Therefore Rigby and Taylor's (2001) cost estimates are broadly indicative of the relative cost differences between options, but should not be treated as reliable estimates of costs to implement the options at hull-cleaning sites.

[2] The USEPA Management Measure for Marinas and Recreational Boating (USEPA 1993) gives cost estimates in $US (1993) for a range of technologies on a 'volume treated' or 'catchment area' basis.

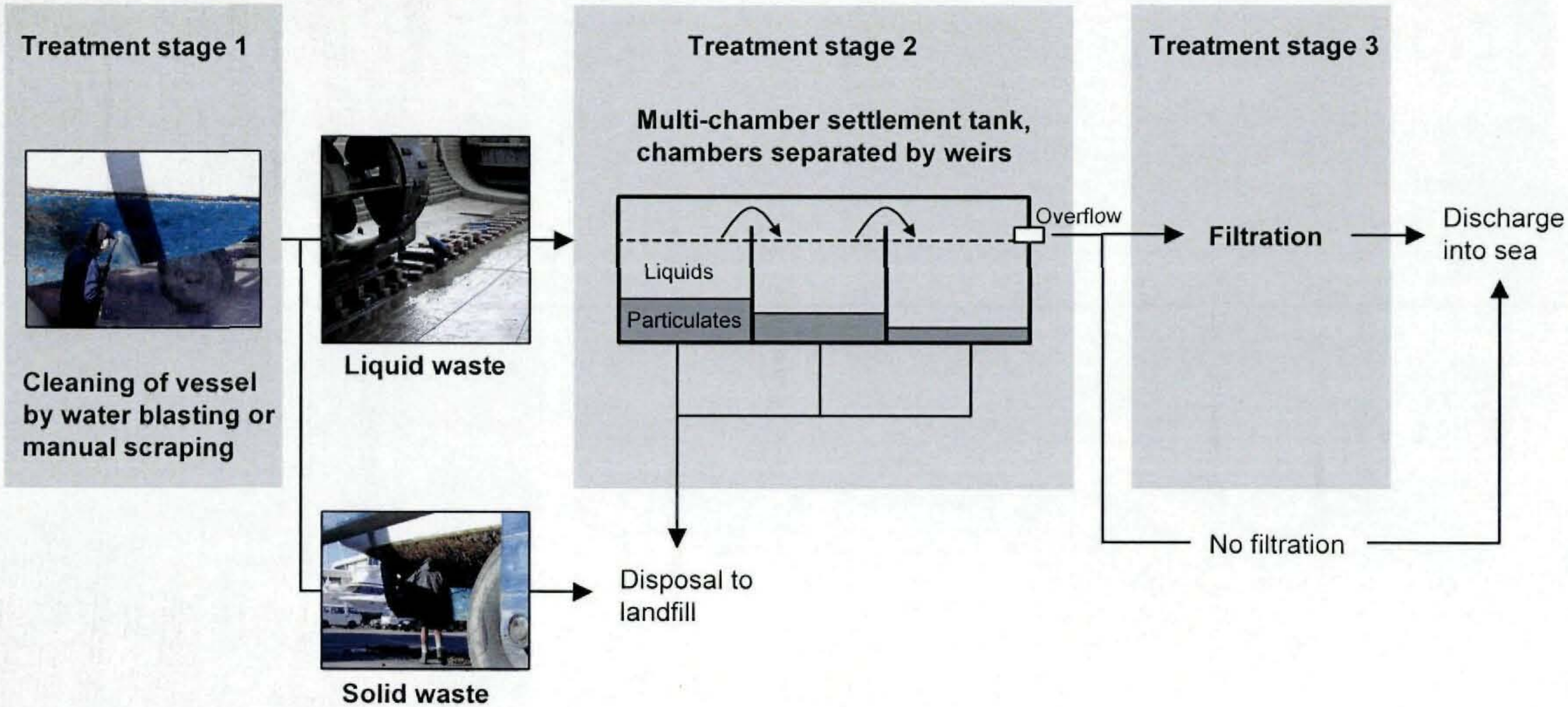

Figure 1.1: Treatment methods for solid and liquid fouling material in the facilities visited. Differences in treatment methods among facilities are limited to treatment stage 3 (filtration: Orams Marine and Tauranga Marina; no filtration: Lyttelton dry-dock and Westpark Marina).

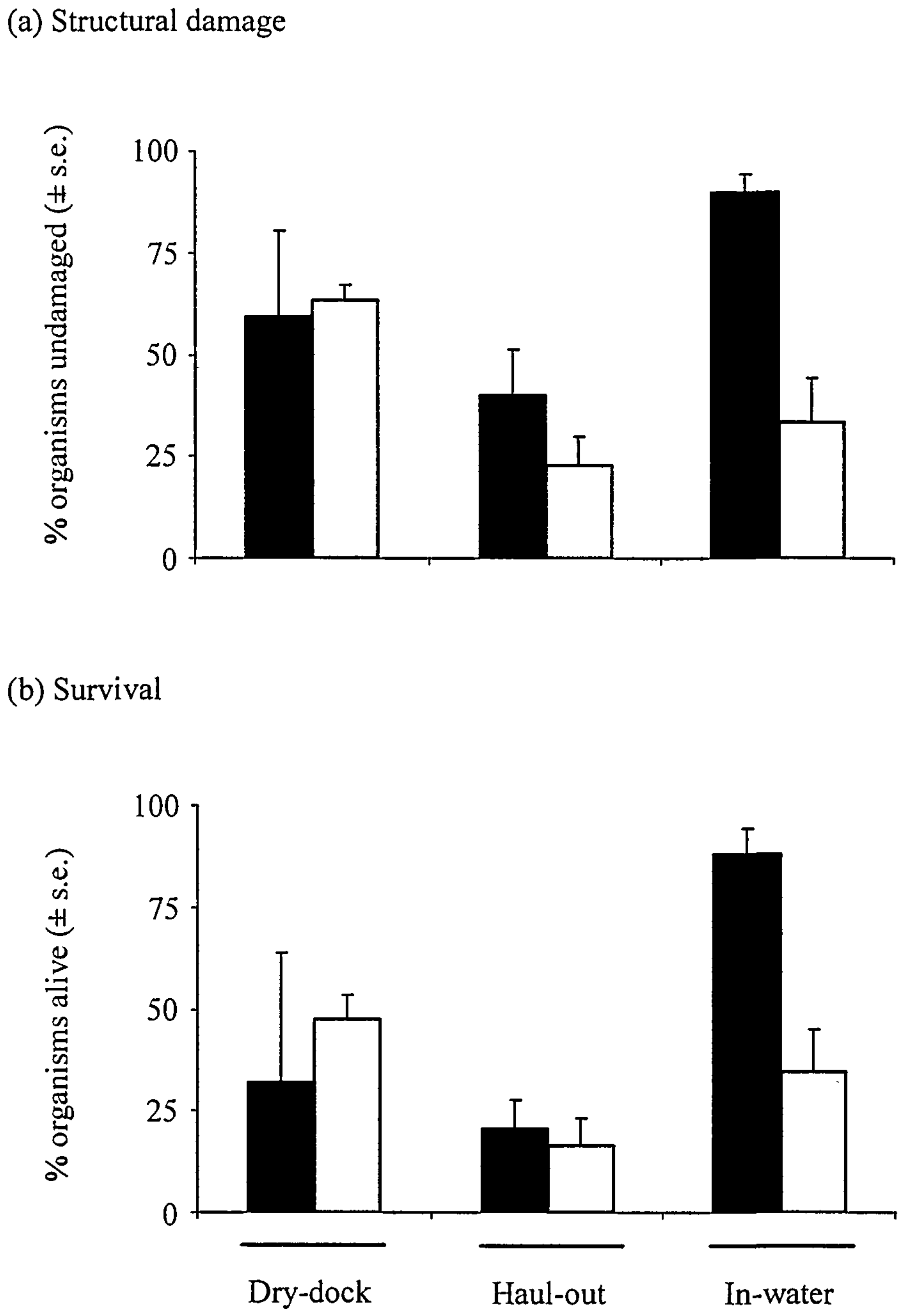

Figure 1.2: Damage and survival that occurred in organisms removed from vessel hulls in the dry-dock, haul-out and in-water cleaning operations visited. Black bars: soft-bodied taxa (ascidians, hydroids, sabellid and errant polychaetes, sponges, motile molluscs, flatworms, nemertean worms, anemones); grey bars: hard-bodied taxa (barnacles, bivalves, bryozoans, serpulid and spirorbid polychaetes, motile crustaceans).

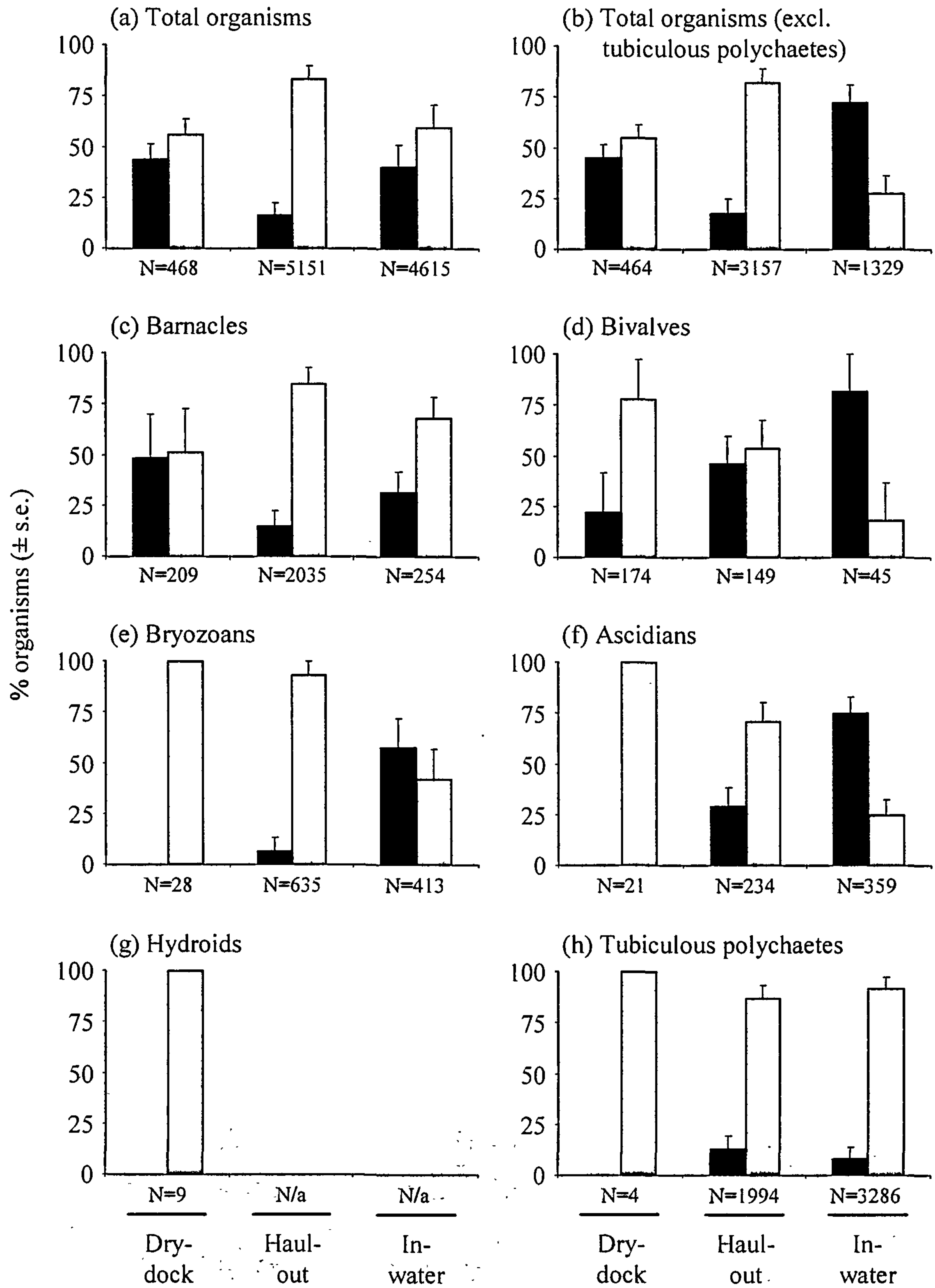

Figure 1.3: Viability of broad taxonomic groups following their removal from vessel hulls in dry-dock, haul-out and in-water cleaning operations. Black bars: viable; grey bars: non-viable.

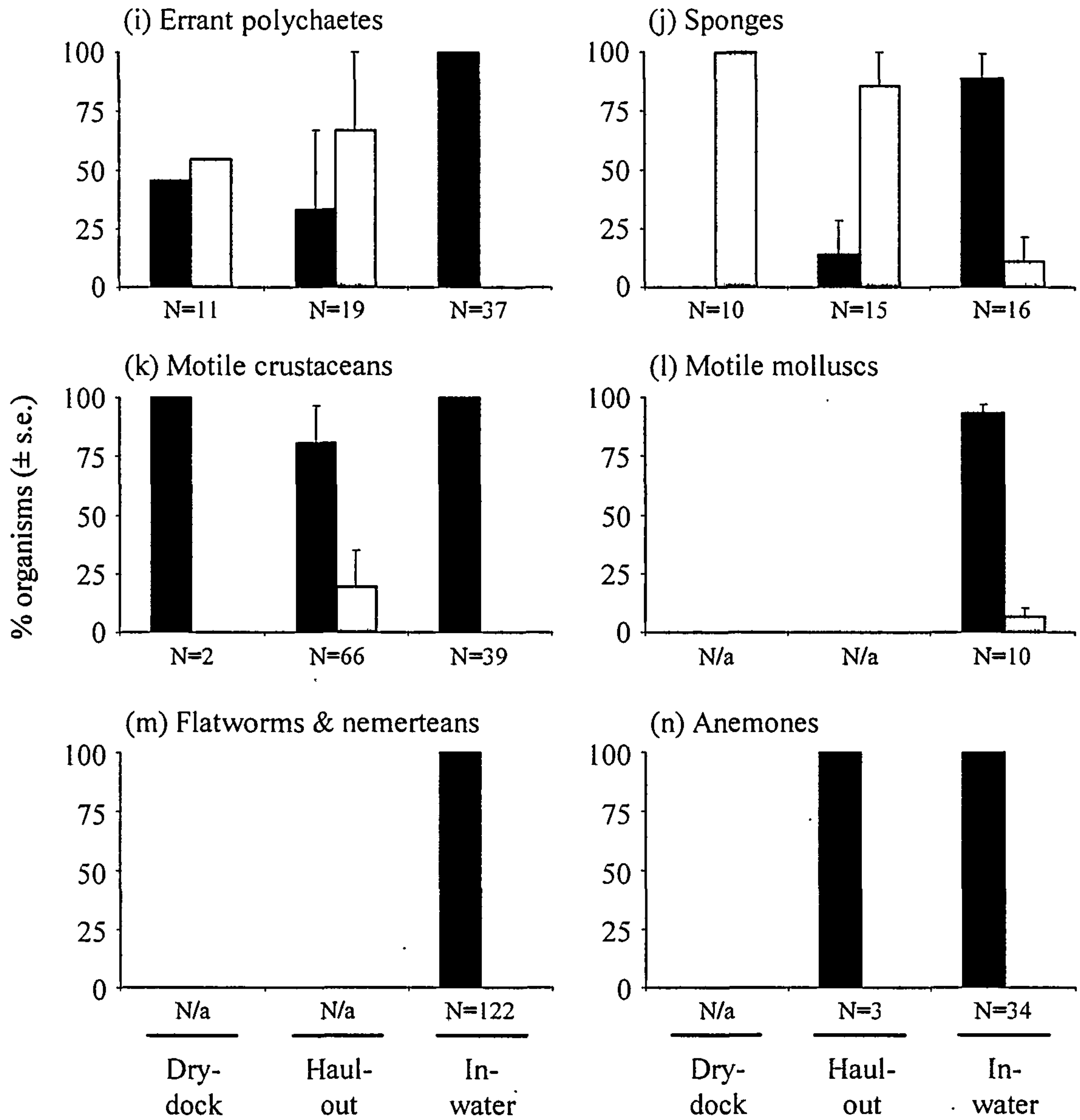

Figure 1.3 (continued): Viability of broad taxonomic groups following their removal from vessel hulls in dry-dock, haul-out and in-water cleaning operations. Black bars: viable; grey bars: non-viable.

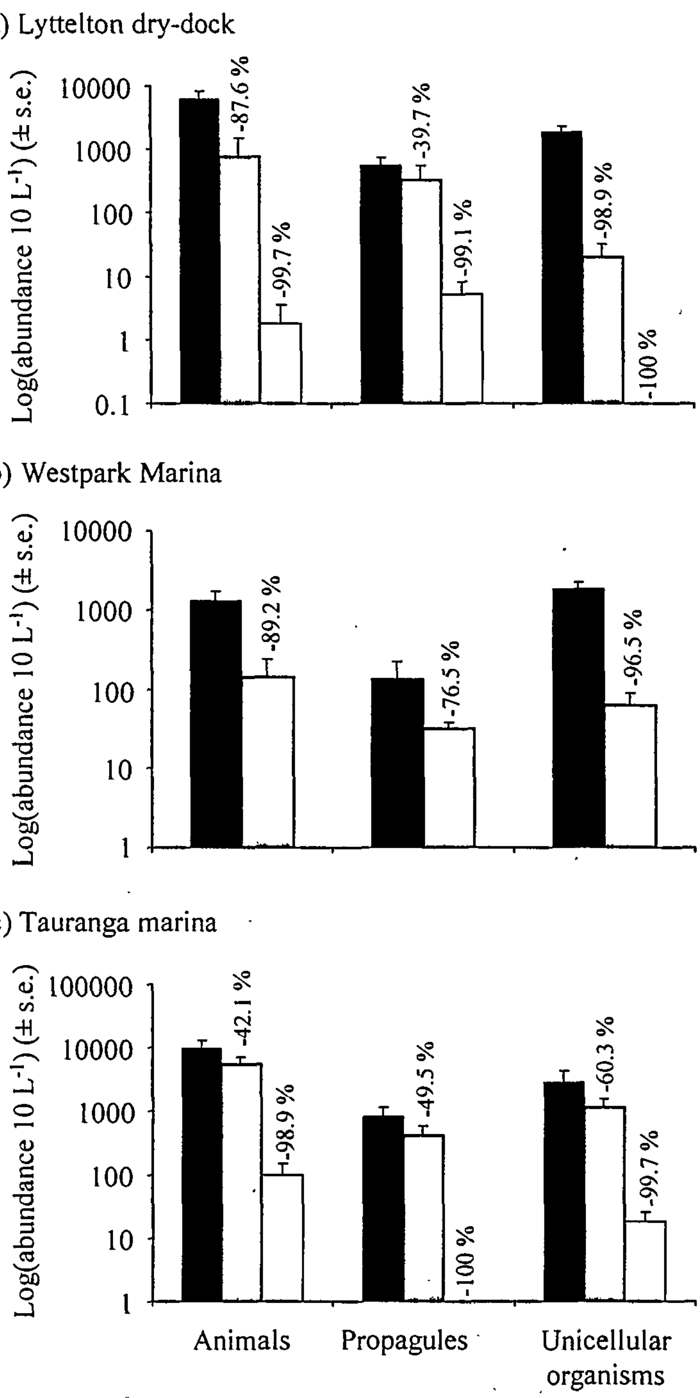

Figure 1.4: (a) – (d) Concentrations (abundance 10 L^{-1}) of animals, propagules (larvae, spores and eggs) and unicellular organisms in liquid samples taken at various stages of treatment. (e) Average rank of abundance (1 – 5) of filamentous algae. Black bars: water blast run-off; grey bars: first chamber of settlement tanks; white bars: effluent discharged (N.B, this includes liquid from the final chamber of settlement tanks (Tauranga), unfiltered (Lyttelton) and filtered (Orams Marine) discharge. Percentages above the bars represent the reduction in abundance relative to concentrations in the water blast run-off. For example, in the effluent discharged from the Lyttelton dry-dock, the abundance of animals is 99.7 % lower than their abundance in the water blast run-off.

(d) Orams Marine

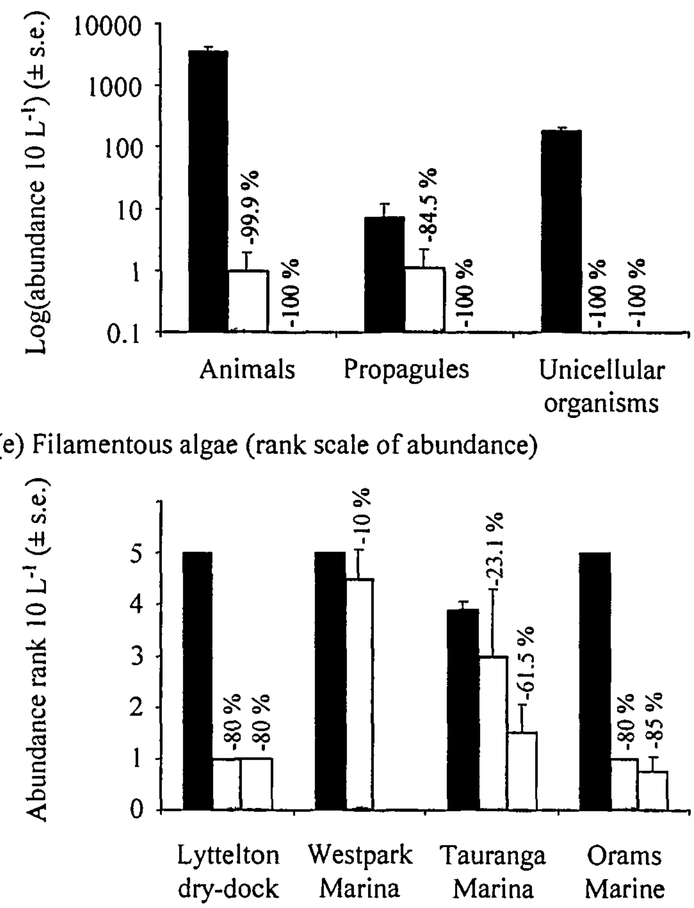

Figure 1.4 (continued): (a) – (d) Concentrations (abundance 10 L^{-1}) of animals, propagules (larvae, spores and eggs) and unicellular organisms in liquid samples taken at various stages of treatment. (e) Average rank of abundance (1 – 5) of filamentous algae. Black bars: water blast run-off; grey bars: first chamber of settlement tanks; white bars: effluent discharged (N.B, this includes liquid from the final chamber of settlement tanks (Tauranga), unfiltered (Lyttelton) and filtered (Orams Marine) discharge. Percentages above the bars represent the reduction in abundance relative to concentrations in the water blast run-off. For example, in the effluent discharged from the Lyttelton dry-dock, the abundance of animals is 99.7 % lower than their abundance in the water blast run-off.

Plate 1.1: The abundance of fouling organisms on the ship hulls examined varied widely. Left: abundant and diverse assemblage on the hull of the *Macushla* sampled in Auckland. Right: a clean and unfouled part of the *Hebe*'s hull sampled in Lyttelton. Photo: O. Floerl, NIWA

Plate 1.2: Mechanical damage from water blasting and trampling by cleaning staff in dry-dock and haul-out operations resulted in damage or mortality of a high percentage of organisms examined. In some cases, fouling organisms were crushed and ground nearly beyond recognition. Photo: C. Middleton, NIWA.

Plate 1.3: The sea chests of the *Alexander Slobodchikov*, cleaned in the Lyttelton dry-dock, contained large clumps of greenshell mussels (*Perna* sp.). Viable errant polychaetes and motile crustaceans and molluscs were common within these clumps. This picture was taken after approximately 90 % of the mussels had already been removed from the sea chest. Photo: O. Floerl, NIWA.

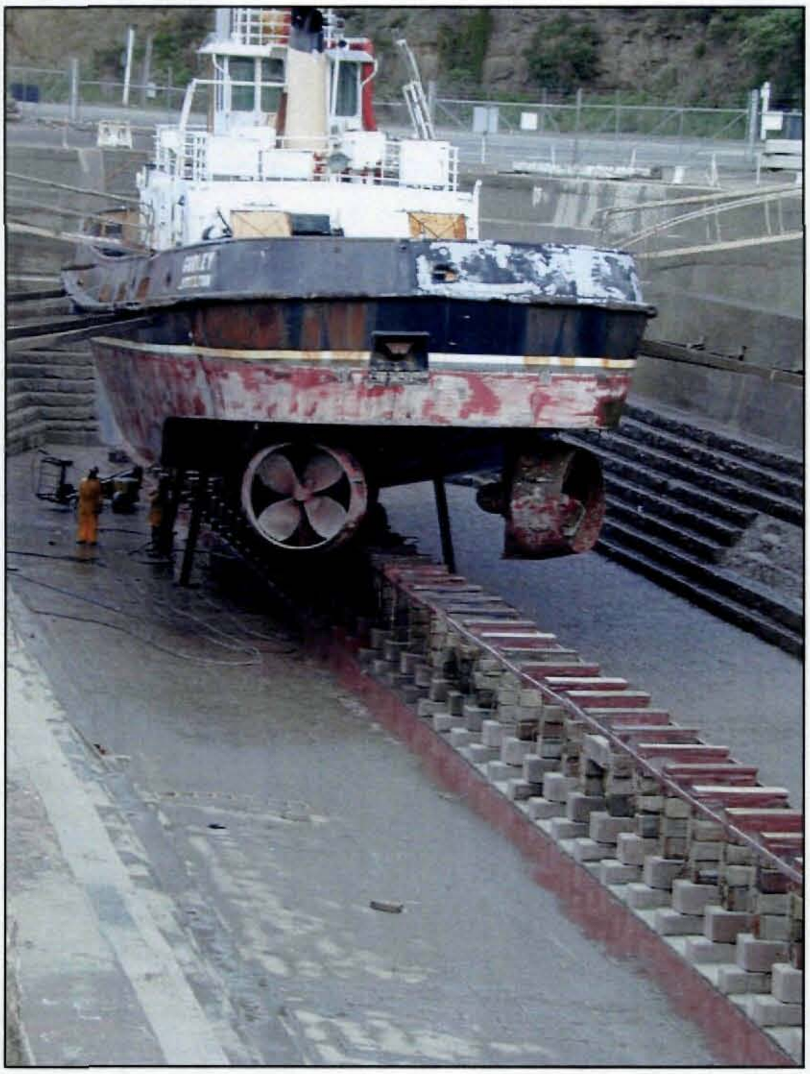

Plate 1.4: Cleaning of the harbour tug *Godley* in the Lyttelton dry-dock by water blasting. The pressure of the cleaning jet removed fouling organisms and the top layer of the underlying antifouling paint, resulting in red run-off to the settling tanks. Photo: O. Floerl, NIWA.

Appendix

Table A1: Guidelines used by field staff to assess viability of fouling biota removed from vessel hulls.

	Indicators for live and viable individuals/colonies	Indicators for non-viability of individuals/colonies
1. SESSILE TAXA		
Barnacles	Structure: All shell plates present and intact, opercular plates present (acorn barnacles only – gooseneck barnacles have no opercular plates) Feeding/movement: Feeding structures (cirri) protrude out of the test and perform sweeping feeding movements. OR opercular shells closed by muscular action.	Structure: Shell/opercular plates and/or feeding structures (cirri) broken or missing. Feeding/movement: Feeding structures visible but motionless and slack and/or no reaction when poked.
Bivalves	Structure: Both shells present and intact. Feeding/movement: Shells may be locked by muscular action (i.e. this bivalve lives). Shells may also be open (feeding), exposing mantle tissue and siphons (or gaps in mantle), but will close when poked (reaction)	Structure: One shell missing or one/both shells cracked or fragmented. Feeding/movement: Shells open but no reaction to touch.
Encrusting bryozoans	Structure: Colony/fragment contains several intact zooids (check for animal inside against light). Feeding/movement: Filtering apparatus (lophophore) protrude through opening in zooid.	Structure: All zooids damaged/smashed, no soft tissues visible. And/or: all colonies dried out, loss of all moisture. And/or loss of pigmentation. Feeding/movement: Zooids' soft tissues and/or feeding structures may be visible but no movement or reaction to touch.
Erect bryozoans	Structure: Colony/fragment contains several intact zooids (check for animal inside against light). Feeding/movement: Filtering apparatus (lophophore) protrude through opening in zooid.	Structure: All zooids damaged/smashed, no soft tissues visible. And/or: all colonies dried out, loss of all moisture. Feeding/movement: Feeding structures may be visible but no movement or reaction to touch.
Colonial ascidians	Structure: Colony/fragment in reasonable 'shape', moist to the touch (not dried) and not entirely crushed. Several polyps intact. Feeding/movement: Inhalant and/or exhalant siphons (these sometimes look like holes) open but close when poked.	Structure: Shredded or crushed so that badly damaged. No polyps visible (polyps may have 'popped out' from mechanical pressure on colony). And/or colony dried out, loss of all moisture. Feeding/movement: Siphons open but no reaction to touch.
Solitary ascidians	Structure: Test (body) intact, no holes or gashes, not crushed flat or severely deformed. Moist, not dried. Feeding/movement: Inhalant and/or exhalant siphons open but close when poked (reaction).	Structure: Test badly damaged, crushed or deformed. Branchial basket exposed and/or damaged, guts hanging out. And/or colony dried out, loss of all moisture. Feeding/movement: Siphons open but no reaction to touch.

	Indicators for live and viable individuals/colonies	Indicators for non-viability of individuals/colonies
Hydroids	Structure: Body reasonably intact, feeding polyps (often at distal ends of braches) present. Feeding/movement: Feeding tentacles exposed.	Structure: All polyps damaged/smashed. And/or colony dried out, loss of all moisture. Feeding/movement: Feeding structures may be visible but no movement or reaction to touch.
Tubiculous polychaetes	Structure: Intact (body within tube), not crushed, no holes or gashes. Feeding/movement: Worm retracts into tube when poked (reaction), and/or feeding structures (tentacular crown) visible and moving.	Structure: Tube missing, loss of tentacular crown, body badly crushed or lacerated. And/or dried out, loss of all moisture. Feeding/movement: Feeding structures may be visible but no movement or reaction to touch.
Sponges (assessment of viability very difficult or impossible)	Structure: Fragments retain natural colour, firm texture (don't fall apart). Sponges retain a "fleshy / translucent / shiny" appearance. Look for "translucent" tissue between fibres Feeding/movement: Impossible to observe.	Structure: Colony/fragment faded and bleached, falling apart. Sponge a mass of golden fibres / hair-like structures without "translucent fleshy tissue" between the fibres. And/or colony dried out, loss of all moisture. Usually no chance for survival if removed from water for more than 3 hours. Feeding/movement: Impossible to observe.
Macroalgae	Structure: Contain pigment and have natural colour. Dryness often not a good indicator as some species are intertidal. Look out for and keep (preserve) reproductive structures (anything like little pocks or compartments or other unusual external structures). Feeding/movement: n/a	Structure: Badly crushed, fragmented, or faded (loss of pigments). Feeding/movement: n/a
2. MOTILE TAXA		
Crabs	Visible movement / reaction. Eyes/sensory organs in head region moving. (missing limbs no problem unless all are gone...). Carapace intact.	All limbs or both pincers missing. Carapace damaged (e.g. large holes or parts missing). No movement / reaction to touch. Loss of moisture - dried out.
Molluscs (gastropods, sea slugs, chitons)	Body intact (gastropod snails: shell present), reaction to touch.	Body damaged, crushed or lacerated. No movement / reaction to touch. Loss of moisture - dried out.
Seastars / brittlestars	Basal disc or parts of it present (can regenerate from that), body (or whatever's present) has natural shape, not crushed.	Arm only without part of basal disc (can't regenerate), body damaged, crushed or lacerated. No movement / reaction to touch.
Amphipods / Ispopods	Visible movement / reaction, especially feeding limbs will beat if submerged and alive. Missing limbs no problem unless all are gone. Carapace intact.	All limbs or feeding structures missing. Carapace damaged (e.g. large holes or parts missing). No movement / reaction to touch. Loss of moisture - dried out.

Table A2: Detailed list of taxa (presence/absence) removed from the hulls of the vessels sampled in each operation.

		Acorn barnacles	Goose barnacles	Bivalves	Encrust. bryoz.	Erect bryozoans	Colon. ascidians	Solit. ascidians	Hydroids	Serpulids	Sabellids	Spirorbids	Errant polych.	Sponges	Algae	Crabs	Amphipods	Isopods	Other decapods	Gastropods	nudibranchs	Nemerteans	Flatworms	Anemones
Lyttelton Port	*A. Slobodchikov*	+	+	+		+							+			+								
	Godley	+		+	+			+	+	+	+			+	+									
	Hebe	+		+	+	+									+									
Orams Marine (haul-out)	*Chancellor*	+		+	+	+	+	+		+	+	+		+										
	Lady Crossley			+		+		+		+														
	Macushla			+	+	+	+	+		+	+	+	+	+	+	+	+	+	+					
Westpark Marina	No. 1 (name n/a)	+		+							+		+		+			+						
	No. 2 (name n/a)	+		+		+	+					+			+									
	Bahia				+	+				+		+			+									
Tauranga Marina	*Chris Robertson*					+	+			+		+					+		+					+
	Ma Chérie	+		+					+															
	No. 3 (name n/a)	+			+	+	+	+		+		+	+		+	+	+							+
	No. 4 (name n/a)	+			+	+				+		+		+										+
Orams Marine (in-water)	*Triptych*				+	+		+		+		+			+		+	+				+	+	
	No. 2 (name n/a)					+				+			+	+		+		+			+		+	
	Sympatica				+	+				+	+	+	+	+										
Gulf Harbour Marina	*Lady Theodora*	+		+	+	+	+	+		+	+	+	+	+		+								+
	Moana Ariki	+		+	+	+	+	+		+	+	+	+	+		+				+				+
	No. 3 (name n/a)	+		+	+	+	+	+		+	+	+	+	+		+	+			+				

Table A3 Summary of projects under the Marine Waste Reception Facilities Program funded by the Australian Government. The programme assisted with up to 50% of the cost of installing upgraded facilities for the management and treatment of marine wastes at a number of ports and marinas throughout Australia.

Facility	Operations	Current treatment	Proposed upgrade	50% Cost[1]
McLean Slipway	Vessel maintenance & cleaning	No wastewater collection or treatment	• upgrade slipway • install collection drain and silt trap • seal washdown area to collect contaminated water	$19 600
Fergussons Boatshed Marina	Vessel servicing and maintenance	No facilities to manage solid and liquid wastes	• replace existing slipway with a ship lift • install sand trap containment of solid and liquid waste contaminants	$100 000
Harwood slipway and engineering facility	Vessel servicing and maintenance	No containment of slipway waste	• install sand trap containment of solid and liquid waste	$21 593
Clontarf Marina	Vessel repainting	Not specified	• construct concrete containment area to collect washdown wastes • residues collected and screened to a standard allowing discharge to the Sydney Water sewerage system	$100 000
Bermagui Marine Services	Cleaning & painting of vessels up to 70 ft	Not specified	• install concrete containment area around slipway • pump collected material to a separation system (a Static Separator Polisher) • upgrade sewage collection system	$34 985
Royal Prince Alfred Yacht Club	Vessel maintenance	Not specified	• install submersible pumps located in grated solids pits • install a holding tank, an oil/water separator, a recycled water storage tank and pressurised recycled water outlets	$50 000

Dinah Beach Cruising Yacht Association	Careening for vessel maintenance	No containment of wastes	• move careening area to above the high water mark. • install 15 tonne straddle lift • develop careening area next to hardstand area. • contain wastewater from vessel maintenance and pump into settlement tanks for appropriate disposal	$50 000
Pelican's Slipway	Not specified	Not all wastewater captured	• concrete hardstand areas • install pump out system and sand filtering	$10 275
Coconut Slipway Pty Ltd	Trolley slipway for large vessels	Washdown waste water collected in two sullage pits	• install vortex pumps to pump contaminated water into a 5000 litre cone shaped sullage tank. • chemically treat water to settle heavy metals to the bottom of the cone. • install separate 1600 litre sludge tank.	$8 900
Rosshaven Marine Ltd	Slipway facility for recreational, charter & fishing vessels	Poor containment of untreated wastewater	• install dedicated wash-down area to contain wastewater. • install triple interceptor pit system to treat the wastewater before disposal to sewerage.	$13 320
Bundaberg Port Marina	Marina	Planned expansion to include hardstand & travel lift	• install concrete washdown area • install triple interceptor pits • install Geotech vertical sand and activated carbon filtration unit. • install boat sewage pump out facility	$47 000
Whyte Island Operations Bases, Port of Brisbane	Washdown facility for Port vessels &	Inadequate containment of wastewater	• install 'high tech' washdown pad • full containment of wastewater	$24 500

	equipment		• install oil trap and tanks to hold wastewater for appropriate treatment.	
Tropical Reef Shipyard Pty Ltd	Slipway for vessels up to 3000 t	Inadequate containment of wastewater	• install tidal gates to prevent inundation of slipway • install settling tank for wastewater treatment for disposal to sewer	$50 000
DSM Slipway Pty Ltd	Servicing & maintenance of vessels	Two slipways: one with fully contained treatment, Proposal to upgrade the second	• install settling tank & pump • install evaporation pit	$65 000
Hobart Ports Corporation	Slipyard & 3 cradles for vessel maintenance	Not specified	• install waste liquid collection drains and pits • install waste liquid treatment/separation systems • install solid waste collection system • install a system for discharging treated water to the sewer.	$110 000
Westernport Boat Harbour Pty Ltd	Washdown area & launching ramp	Sediment collection pit in the wash-down area inadequate for current usage	• install fully contained wash-down bays for boats up to 20 m	$11 000
Royal Geelong Yacht Club	Slipway for recreational vessels	Slipway waste currently returned to the sea	• upgrade wash down area to ensure full containment of wastewater • install pump & Novachem treatment and recycling system to remove all contaminants from the wastewater, which will then be held for reuse.	$72 685
Port of Apollo Bay Slipway	Slipway for maintenance of	Limited containment of marine waste	• install waste interception structure on slipway to trap	$25 000

	fishing & recreational vessels		• install settling tanks and an oil/water separator for disposal to sewer.	
Port of Geraldton Hardstand	Drydock for fishing boats	No containment of contaminants	• install trapping facilities at the hardstand • commence regular water and sediment monitoring programs	$15 200

[1]All estimates represent the Australian government contribution in Australian dollars

Table A4 Reproduced from the USEPA Storm Water Runoff Management Measure for Marinas and Recreational Boating (Chapter 5 USEPA 840-B-92-002, Table 5.3 - Stormwater Management Practice Summary Information).

Practice – Characteristics	Pollutants Controlled	Removal Efficiencies (%)	Use with Other practices	Cost	Retrofit Suitability	References (In USEPA 840-B-92-002)	Pretreatment of Runoff Recommended
Sand Filter	TSS TP TN Fecal Col Metals	60-90 0-80 20-40 40 40-80	Yes	US$1.11 per ft of runoff	Medium	City of Austin, 1990 Schueler 1991; Tull 1990	Yes
Wet Pond	TSS TP TN COD Pb Zn Cu	50-90 20-90 10-90 10-90 10-95 20-95 38-90	Yes	US$349-823 per acre treated; 3-5 % of capital cost per year	Medium	Schueler, 1987; 1991; USEPA, 1986	Yes, but not necessary
Constructed Wetlands	TSS TP TN NO_1 COD Pb Zn	50-90 0-80 0-40 5-95 20-80 30-95 30-80	Yes		Medium		Yes
Infiltration Basin/Trench	TSS TP TN BOD Bacteria Metals	50-99 50-100 50-100 70-90 75-98 50-100	Yes	Of Capital costs: Basins = 3-13% Trenches = 5-15%	Medium	Schueler, 1987, 1991	Yes

Practice – Characteristics	Pollutants Controlled	Removal Efficiencies (%)	Use with Other practices	Cost	Retrofit Suitability	References (In USEPA 840-B-92-002)	Pretreatment of Runoff Recommended
Porous Pavement	TSS TP TN COD Pb Zn	60-90 60-90 60-90 60-90 60-90 60-90	No	**Incremental cost** US$40,051-78,288 per acre	Low	Schueler, 1987; SWRPC, 1991; Cahill Associates, 1991	
Vegetated Filter Strip	TSS TP TN COD Metals	40-90 30-80 20-60 0-80 20-80	Combine with practices for MM	<u>Seed</u>: US$200-1000 per acre; <u>Seed & mulch</u>: US$800-3600 per acre; **Sod:** US$4500-48,000 per acre	High	Schueler et al. 1992	No
Grassed Swale	TSS TP TN Pb Zn Cu Cd	20-40 20-40 10-30 10-20 10-20 50-60 50	Combine with practices for MM	<u>Seed</u>: US$4.50-8.50 per linear ft. <u>Sod</u>: US$8.50 per linear ft.	High	SWRPC, 1991; Schueler, 1987, 1991; Honer, 1988; Wanielistra and Yousef, 1986	No
Swirl Concentrator	TSS BOD		Yes		High	WPCF, 1989; Pisano, 1989; USEPA, 1982	No
Catch Basins	TSS COD	60-97 10-56	Yes	US$1100-3000	High	WPCF, 1989; Richards, 1981; SWRPA, 1991	No

Practice – Characteristics	Pollutants Controlled	Removal Efficiencies (%)	Use with Other practices	Cost	Retrofit Suitability	References (In USEPA 840-B-92-002)	Pretreatment of Runoff Recommended
Catch Basin with Sand Filter	TSS TN COD Pb Zn	70-90 30-40 40-70 70-90 50-80	High	US$10,000 per drainage acre		Shaver, 1991	No
Absorbents in Drain inlets	Oil	High	Yes	US$85-93 for 10 pillows		Silverman, 1989, Industrial Products and Lab Safety, 1991	No
Holding Tank	All	100 for first flush	Yes			WPCF, 1989	No
Boat Maintenance Design	All	Minimizes area of pollutant dispersal	Yes	Low	High	IEP, 1992	No
Oil-grit separators	TSS	10-25	No		High	Steel and McGhee 1979 Poruano 1990 Schueler 1987 WPCF 1989	No

TSS = Total suspended solids, TP = Total phosphorus, TN = Total nitrogen, Fecal Col. = Faecal coliform bacteria, BOD = Biological Oxygen demand, COD = Chemical oxygen demand, NO_1 = nitrate and nitrite nitrogen, Pb = Lead, Zn = Zinc, Cu = Copper.