Final Report

MECHANICAL REMOVAL OF BIOFOULING

FRDC Project Number 92/153

RESEARCH ORGANISATION

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Fisheries Research and Development Corporation

SUMMARY

A prototype mechanical device for *in situ* removal of fouling organisms from salmon cages was designed and developed during the summer months of 1993/94 and 1994/95.

Quantitative analysis of the efficacy of the cleaner was delayed by the need to develop a robust, non-destructive technique to ascertain the level of fouling on salmon nets. Development, testing and refinement of such a technique, was funded by Saltas during the summer of 1993/94.

A series of on-going design modifications to the prototype net cleaner, during the summer of 1994/95, have resulted in a system capable of significantly reducing fouling-related net blockage of salmon nets, without necessitating the removal of nets from service.

These trials, including the development of the quantitative fouling analysis technique mentioned above, were designed and conducted in association with Mr Stephen Hodson, Department of Aquaculture, University of Tasmania at Launceston, and form part of his PhD research program.

BACKGROUND

One of the major costs incurred during farming of Atlantic salmon in net pens in Tasmania involves the control of aquatic organisms which grow on nets immersed in seawater.

At present, there are two main strategies employed to control biofouling on nets. The first involves replacing fouled nets with clean ones, and then washing, drying and repairing the nets in preparation for the next net change. This procedure is very labour intensive and leads to increased wear and tear on nets and equipment and increased risk of damage to, and/or loss of, stock during each net change. During summer, when the rate of growth of fouling organisms is greatest, each net needs to be changed every 5 - 8 days. When it is considered that there are in excess of 300 pens in use within the industry, the need for such frequent net changes clearly constitutes a massive drain on resources.

The second method of biofouling control occasionally employed at some sites within this industry is the application of antifouling products to nets. Since its inception, Saltas has been researching the efficacy of various marine antifoulants when applied to nets, and, equally importantly, any effects these products may have on fish health, human health and/or the environment. To date, the product which has shown the best combination of these factors is a cuprous oxide (Cu_2O)-based paint. However, although this product does offer significant retardation of net biofouling, there are a number of factors (eg. cost, physical changes to nets, weight) which render its use inappropriate in most situations.

The Tasmanian Atlantic salmon industry is keen to retain its image as a producer of pure, unpolluted foodstuffs and wishes to reduce, and eliminate where possible, reliance on environmentally foreign chemicals. It is felt that the development of a mechanical, *in situ*, net cleaner will, in addition to increasing efficiency of production, be a positive step in this direction.

OBJECTIVES

The overall aim of this project was to design and manufacture a prototype mechanical device for *in situ* cleaning of salmon nets.

Intermediate aims were as follows:

i. To determine a practical mechanism by which biofouling organisms can be removed from salmon nets, without necessitating removing the nets from service.

ii. To design and commission an automated system by which a suitable net cleaning device can be applied, *in situ*, to salmon nets.

INTRODUCTORY INFORMATION

Preliminary investigations, conducted by Saltas during 1992/93, into operating parameters for *in situ* removal of biofouling from nets, resulted in the design and commissioning of a diver-operated, hydraulic brush-test unit. This unit was designed to allow easy interchange of brushes, thus facilitating evaluation of the cleaning efficacy of brushes with different bristle characteristics.

Six brushes (as indicated below) were manufactured for this work.

		Bristle stiffness (nominal rating)		
		"Soft"	"Medium"	"Hard"
Bristle length (mm)	25 ("short")	✓	✓	✓
	45 ("long")	✓	✓	✓

Bristle types and lengths were chosen for their anticipated range of abrasive action against biofouling and netting material.

Early trials on fouled nets revealed that, of the bristle types selected, the longer, softer bristles were very effective at removing fouling organisms from net surfaces. It should be noted that while the shorter, harder bristles were also very effective at removing fouling organisms, they also caused significant damage to the net material. Thus, the former bristle type was selected for the next phase of this project; *viz* the development of a prototype net cleaner.

One of the major problems concerning research into biofouling dynamics on salmon nets is the large variation between fouling communities forming on nets placed in the water on the same day and on different areas of individual nets. This large variation makes it necessary for large numbers of samples to be collected for statistically significant quantification of fouling levels to be achieved. In previous years, analysis of fouling levels has been performed either by removing and weighing fouling organisms from net panels, or by removing sections of net for Scanning Electron Microscopic (SEM) examination. Both these methods are very time consuming and destructive, making quantitative analysis of large numbers of samples impractical. Destructive sampling also renders temporal analyses of fouling development, an integral part of the mechanical net cleaning trials, impossible. Thus, the development of a rapid, non-destructive technique for quantifying fouling levels on nets was given high priority.

A novel technique allowing non-destructive sampling and rapid processing of samples was developed during the summer of 1993/94 (Hodson *et al.* in preparation: Appendix 1). This technique involves "sampling" nets *in situ* by means of underwater macro-photography and analysing the photographs with image-analysis computer software. The development of this technique has made possible a more detailed assessment of the efficacy of the prototype net cleaner than would have otherwise been possible.

DESIGN DEVELOPMENT AND RESEARCH METHODOLOGY

Prototype Development

When considering possible design parameters for the prototype net cleaner, a decision had to be made as to whether the proposed cleaner would be aimed at removing fouling organisms from heavily fouled nets, or at keeping clean nets relatively clean. Discussions with the consulting engineers suggested the second option would be the most practical, in terms of both complexity of design and overall energy efficiency. To this end, a number of trials using the brush test unit, were conducted, whereby a discrete area of a recently changed net was lightly brushed on a weekly basis for 3 weeks. Results showed that, despite significant regrowth of fouling between cleanings, regular light brushing maintained relatively low fouling levels (Hodson 1994; Appendix 2).

This outcome had a significant bearing on design parameters for the prototype net cleaner. The fact that softer bristles were found to be effective against relatively heavy fouling meant that the cleaner would require less motive power, and would therefore be lighter, than one designed to operate using stiff bristles. The final design for the prototype cleaner (Figures 1&2) was developed by Saltas, in conjunction with consultant engineers (Terratec Asia-Pacific P/L, Hobart, Tasmania), following extensive consultation with farm managers.

The basic design for the prototype net cleaner is a hand rail-mounted gear-box which powers twin, contra-rotating drive shafts. The drive shafts connect to vertical brush-lines which hang against the inside surface of the net. The gearbox also provides power to two drive-wheels which move the cleaner around the hand rail (Figures 1&2). Each brush-line consists of four brushes, linked by specially designed plastic bushes to allow the twin brush lines to curve with the net.

The prototype cleaner was designed to be powered by a boat-mounted hydraulic unit, powered by a 5 hp petrol-motor. This was not necessarily the final, nor best, configuration, but conformed with existing facilities at Saltas' marine farm at Dover.

Two types of brushes, using either 0.76 mm or 1.01 mm diameter polypropylene bristles, were manufactured for this project (P&C Brushes, Melbourne). All brushes consisted of 55 mm (effective length) bristles punched, at medium density, into an 800 mm long, 40 mm diameter polyethylene core, yielding an overall brush diameter of 150 mm. Each brush line consists of 4 brushes made with the same bristle type, and arranged so that the line with the stiffer bristles was the first to contact the fouled net.

To further simplify design considerations, and to keep design and manufacture costs to reasonable levels, it was decided to keep constant the ratio between the speeds at which the unit moved along the hand rail and at which the brushes rotated. The final ratio chosen (unit speed ~0.3 m min^{-1}; brush rotation speed 25 rpm), yielded a strike rate per unit length ratio of ~40 (*i.e.* each metre of net contacts the equivalent of ~40 metres of bristles per brush-line).

Detailed field trials of the prototype mechanical net cleaner commenced in September 1994. However, prior to actual testing of the effectiveness of the mechanical cleaner against fouled netting, substantial modifications were required, as hitherto unforeseen design problems came to light. The nature of these problems, and their solutions, are detailed below (Results and Discussion). Once these modifications had been made, and the prototype was reliable enough to run without risk of damage either to itself or to the net to be cleaned, trials to ascertain its efficacy at removing fouling organisms from salmon nets commenced.

Fouling analyses

Analyses of fouling were performed using one of two methods. The majority of sampling was performed using the non-destructive underwater photography/image-analysis technique developed for the current and other biofouling-related projects. Details relating to the development of this technique, and to its application in the assessment of the efficacy of the prototype net cleaner are given in Appendix A (Hodson *et al.* in preparation).

Sample sites, selected at random in the same manner as for the image analysis technique, were destructively sampled for the final trial. All fouling present on selected sites was removed from the net, *in situ,* and stored in ambient seawater until processing (<24 hours post sampling). Wet weights were determined by blotting dry the sample, to remove excess water, and weighing to 0.01 g.

RESULTS AND DISCUSSION

Prototype Development

The design for the original prototype net cleaner is shown in Figures 1&2. Initial trials revealed a number of design faults which required modification prior to assessment of the cleaning efficacy of the unit. These modifications were an integral part of the development of the prototype, and are discussed below.

- Brush line twisting

  Unequal torque reactions resulted in the brush-lines twisting around each other. This resulted in one line of brushes being lifted away from the net and the other buckling away from the net. Aluminium side arms (600 x 150 x 12 mm) (Figure 3) designed to counter the twisting moment, were attached to both sides of each connecting bush.

- End piece separation

  The stainless-steel brush end pieces, designed to provide purchase between the brushes and connecting bushes were found to easily become separated from the brushes to which they were attached. To counter this, each end piece was firmly attached to a brush by means of two 50 mm stainless-steel self-tapping screws.

- Net tangling

  The concept of contra-rotating brushes was to prevent loose net between the brush lines becoming tangled around the brushes. In practice it was found that tangling of the net did occur, even when using well weighted, 150 ply netting. This was due to loose net on either side of the prototype net cleaner being drawn in towards the brushes. It was therefore necessary to construct a "frame" around the two brush lines, consisting of side bars (Figure 4) and wire lacing (Figure 5). This configuration proved to be very effective when using heavy (96-150) ply netting, but did not consistently prevent smaller ply netting from wrapping around the brushes. It was also necessary to carefully tie together the edges of netting overlaps and gates, so that the net to be cleaned was kept taut. Any loose netting, or large open areas within folds were every likely to become caught in the brushes

- Insufficient brush pressure on near vertical nets

  At times, especially when the salmon net was hanging near-vertically, there was insufficient contact between brushes and fouling to have any significant effect on fouling levels. To counter this problem, weighted (~1.5 kg) aluminium lever arms (200 x 65 x 6 mm) (Figure 6) were attached at each connecting bush. These provided sufficient force to maintain contact between the brushes and fouling organisms.

- Brush line angle

  Unless particular care was taken when preparing the net for cleaning, the final angle between the drive shafts and top brushes was too great to be accommodated by the uppermost plastic bushes. Each of these bushes was replaced by a steel universal joint (Figure 7), one end of which was welded to a drive shaft, while the other was securely connected to the top brush in each brush line. In some cases (eg. when operating the prototype net cleaner on a smaller pen), it was impossible to arrange the net to provide a suitable contact angle for the net cleaner. An aluminium spacer, attached to the bottom of the main drive unit (Figure 8), decreased the contact angle sufficiently to allow the cleaner to operate normally.

- Destruction of plastic bushes

  After several hours service, it was found that the plastic bushes between the second and third brushes were becoming badly damaged by the stainless-steel brush end-pieces (Figure 9), resulting in breakage of the central cables. Replacement of these damaged plastic bushes with stainless-steel bushes remedied this problem.

- Insufficient removal of fouling

  Analysis of the results from the fouling removal trial (Appendix 1) found no significant difference in blockage before and after cleaning ($P=0.75$, ANOVA). The prototype net cleaner used in this trial did remove some fouling from the net during operation. However, contact between the cleaning brushes and the netting was insufficient to remove material close to the net. Consequently, the cleaner effectively cropped off the upper fraction of the fouling community, but left the lower structures unaltered, resulting in no significant reduction in net blockage.

  Further modification of the cleaner, achieved by removing ~5 mm from the bottom (closest to the net) side of the plastic connecting bushes, provided greater contact between the brushes and net. Operation of the prototype net cleaner under this new configuration resulted in a significant increase in cleaning efficiency. A trial, incorporating a destructive sampling strategy, demonstrated that a significantly greater amount of fouling (wet weight) was removed from an established community, with the fouling reduced from 5.9 ± 1.3 g/100 cm^2 to 3.3 ± 0.7 g/100 cm^2 and from 4.9 ± 2.1 g/100 cm^2 to 0.8 ± 0.5 g/100 cm^2 using the original and modified configurations respectively (Figure 10).

- Insufficient clearance along hand-rail

  It was necessary to slightly modify the brackets for drive mechanism to allow the unit to negotiate thin ropes and other small protuberances on the hand-rail. It is suggested that the drive system for subsequent models be designed to allow it to negotiate larger ropes and stanchion attachments (eg. larger diameter drive-wheels with a high friction tread).

General Discussion

This project has seen the successful development of a prototype device which can track around the hand-rail of a polar-circle type fish-pen and significantly reduce the level of fouling-related blockage of salmon nets. However, there are a number of salient points to be considered prior to pursuing the design and development of the next model/s.

Size and weight of the cleaner

It is now thought that, due to considerations detailed below, any future models could be designed to be significantly smaller and lighter than the prototype, which weighs about 150 kg.

The prototype cleaner used during these trials was deliberately over designed, to withstand the maximum output of the hydraulic power pack. In its final configuration, the cleaner required a hydraulic pressure of up to 900 psi for cleaning fouled nets. This is about half of the maximum rated output of the power pack (*i.e.* 2100 psi @ ~5.5 hp). Based on these figures, it has been estimated that the strength of the gearbox and drive shafts could be safely reduced to bring their final weight to around 70-80 kg (Tony Peach, Terratec Asia-Pacific Pty. Ltd., *pers. comm.*).

Preliminary trials (T. Lewis/S. Hodson, unpublished data) have also shown that operating the prototype net cleaner with only one brush line results in satisfactory removal of fouling from nets. The original concept behind running two, contra-rotating brush lines was to prevent tangling of netting in the brushes. As discussed earlier, this original system did not prevent netting from outside the brush-lines from being drawn into the brushes. It was therefore necessary to build a "frame" around the brushes to prevent tangling, thus negating the need to run two brush lines. Subsequent trials showed that by running only one brush line, the hydraulic operating pressure was reduced to ~700 psi. Design of a gearbox to operate at this lower pressure would result in yet further weight savings. More importantly, the overall size and complexity of the gearbox could be significantly reduced, as the current dimensions of the gearbox, and design of the gears themselves, are made necessary by the need to run two brush lines, whose centres of axis are separated by 20 cm.

It should be noted that the operating pressures mentioned above relate directly to brush lines configured as detailed earlier. Any changes to this configuration will alter the power required to operate the cleaner.

Extraction of dislodged fouling material

It is acknowledged that extraction of dislodged fouling material from the water-column will be important for 3 main reasons *viz:*

i. to minimise recolonisation of the net by dislodged fouling organisms

ii. to minimise irritation of the fishes gill by dislodged material

iii. to minimise impact on the environment

However, this issue should not be addressed until a final design for the cleaning head and tracking system has been reached.

Farm management considerations

At present, it is envisaged each net cleaner will be used to service several pens. However, individual farm management practices will determine final usage patterns. The prototype cleaner was designed to operate on a salmon pen unencumbered by extraneous structures on, or adjacent to, the hand rail (eg. bird netting, mooring lines, feeder poles etc). This situation is rare on commercial salmon farms in Tasmania It has always been acknowledged that an iterative co-evolution of both net cleaner and pen design would be necessary for the full potential of this system to be realised. It is therefore imperative that future design work occur in full consultation with farm managers and staff, as they are the ones for whom this system is being designed.

IMPLICATIONS

Control of biofouling on nets is estimated to cost the Tasmanian Atlantic salmon industry in the order of $800,000 pa. Successful development of the prototype net cleaner to a practical, farm-based system would achieve significant savings for this industry alone.

Similar savings are likely for other pen-based industries in Australia (eg. tuna farming in South Australia, Barramundi farming in Queensland).

The potential for sale of net cleaners to overseas industries has not been ascertained, but could be assumed to be much greater than within Australia.

INTELLECTUAL PROPERTY

The results of the present study (concept, design and performance of the prototype *in situ* net cleaner) should be considered confidential until the question of further developments, if any, can be clarified.

It is important to protect the Fisheries Research & Development Corporation and Tasmanian salmon farming industry's investments to date without stifling further development of a fully functional commercial product.

In this context, the Tasmanian Atlantic salmon farming industry expects to retain a proportion of any intellectual property rights in acknowledgment of its role in the development of the prototype mechanical net cleaner. In the event that a working product is marketed by a commercial company, it is envisaged that such intellectual property rights would entitle members of the Tasmanian salmon farming industry to purchase the product at a discounted rate. Furthermore, it is expected that the Tasmanian salmon farming industry would receive some form of agreed royalty on any other sales.

TECHNICAL SUMMARY

1. Fouling organisms can be effectively removed from salmon net-pens, with negligible damage to net structure, by brushes constructed and used as follows:

    - cylindrical brushes incorporating polypropylene bristles with either 0.76 mm or 1.01 mm diameter, 55 mm (effective length) punched, at medium density, into an 800 mm long, 40 mm diameter polyethylene core, yielding an overall brush diameter of 150 mm.

    - brushes revolving around a vertical axis at a strike rate per unit length ratio of ~40 (*i.e.* each metre of net contacts the equivalent of ~40 metres of bristles per brush-line).

2. Contra-rotating brush-lines are very effective at removing fouling from nets. However, a single brush line will also significantly reduce fouling-related net blockage. Designs incorporating a single brush line will be significantly smaller and lighter than those using twin brush-lines.

3. The transmission linkage connecting drive shafts to brushes, and between individual brushes, needs to be robust and able to operate at angles of up to ~30° from the vertical. Standard universal joints are adequate for this purpose, but a system whereby brushes can be quickly and easily separated is recommended. This would enable subsequent models of net cleaner to be broken down into smaller units, and thus allow it to be deployed by only 1 or 2 people.

4. Nets need to be set-up so as to be taut and angled in from the hand rail for optimum performance of the net cleaner. This is not unusual practice on Tasmanian Atlantic salmon marine farms. However, to minimise net-management considerations (eg labour and equipment considerations while preparing nets for cleaning), brush lines should be encased in some kind of framework. This will minimise the risk of nets becoming entangled in the brushes.

REFERENCES

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Hodson, S.L., Burke, C.M. and Lewis, T.E.. (in prep). *In situ* quantification of fish-cage fouling by underwater photography and image analysis. submitted to *Biofouling*.

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Peter Lee, Harry King and the farm staff at Saltas Marine Operations for help with moving the cleaner to and from the test pens and for help with setting-up the test pens for this trial.

Figure 1. Transverse view of prototype net cleaner on pen hand-rail

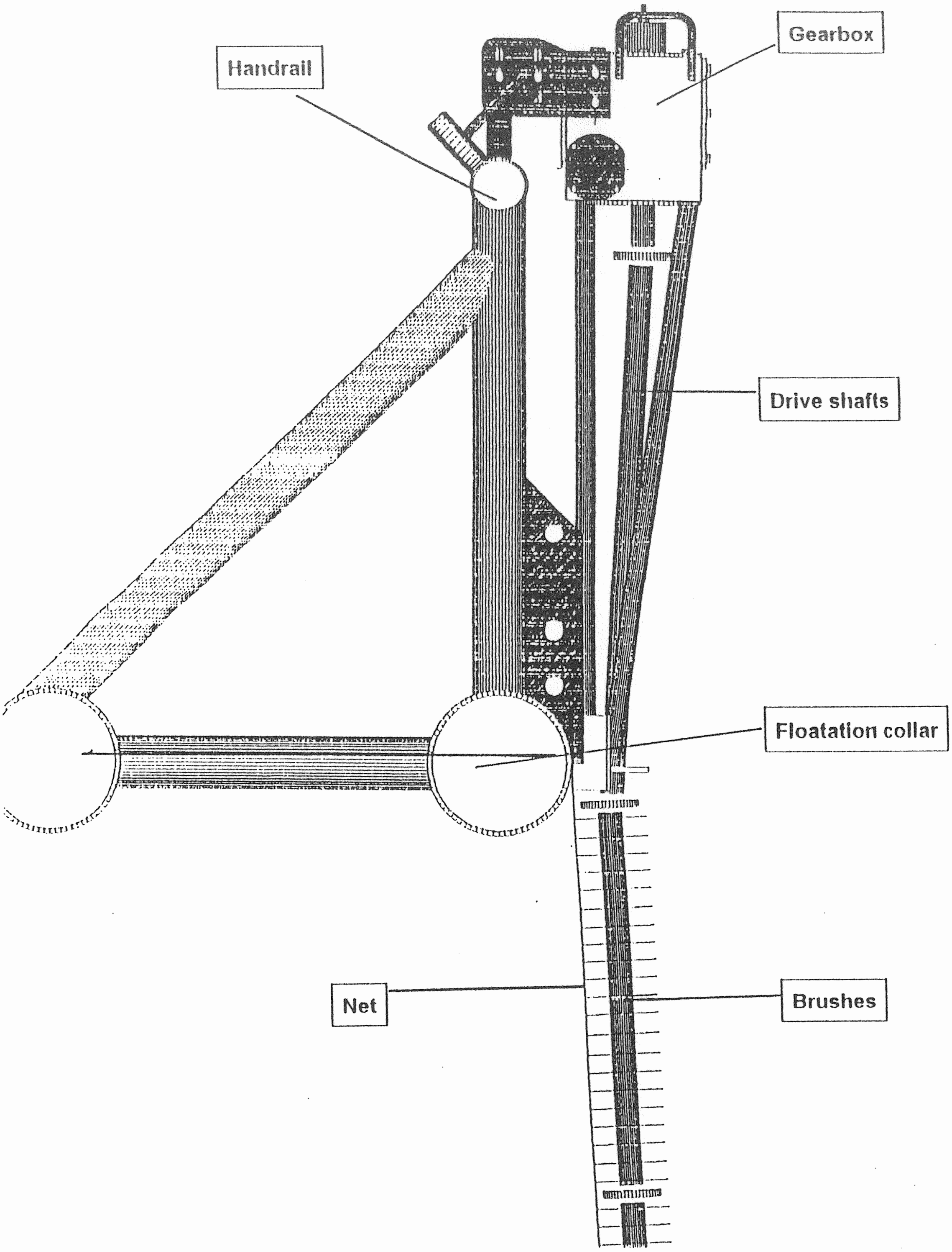


Figure 2. View of prototype net cleaner from inside pen

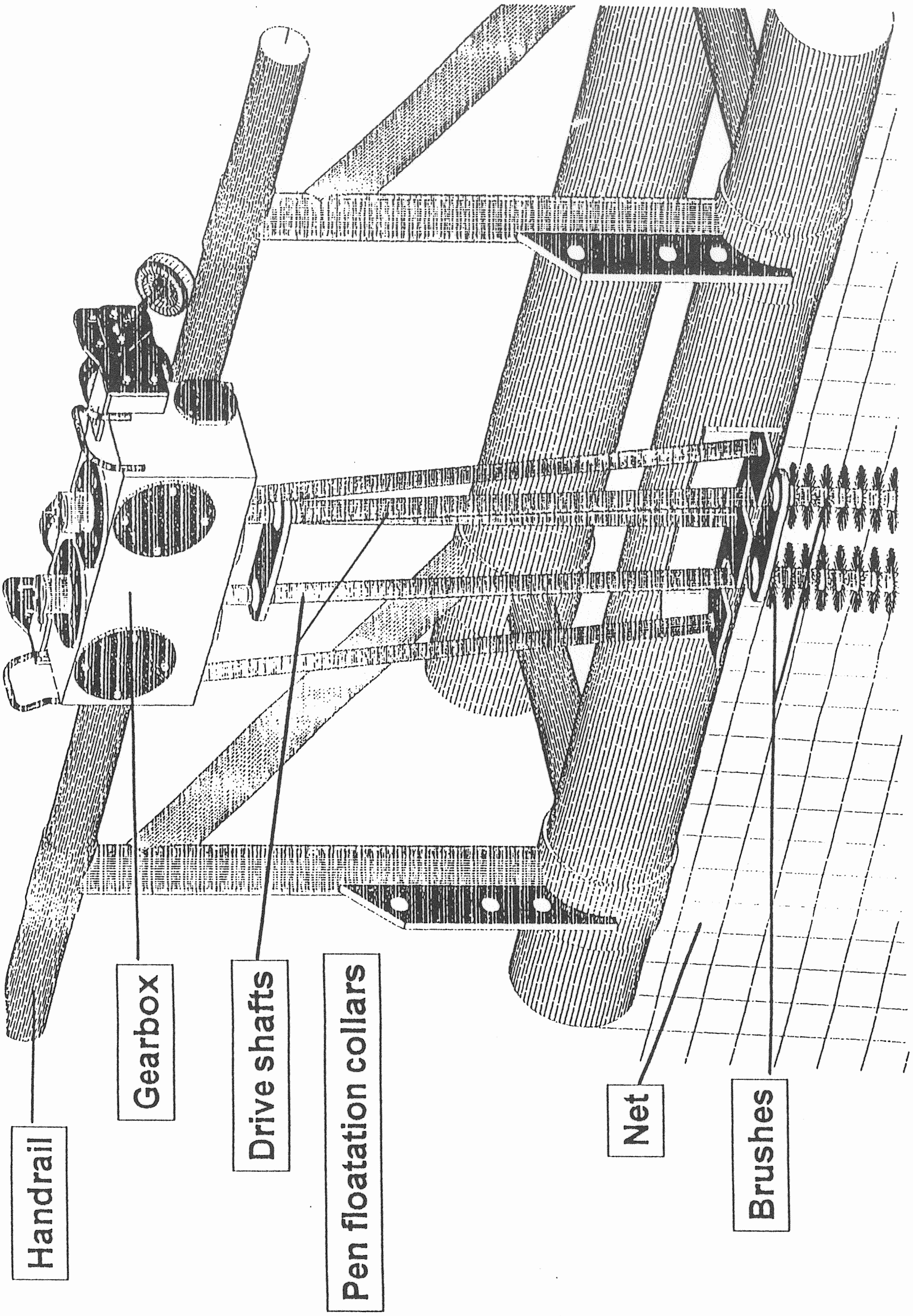


Figure 3. Prototype net cleaner showing lateral, aluminium side arms, designed to help stop twisting of brush lines

Figure 4. Close-up of join between brushes on one brush line showing aluminium side bars, designed to help prevent net tangling

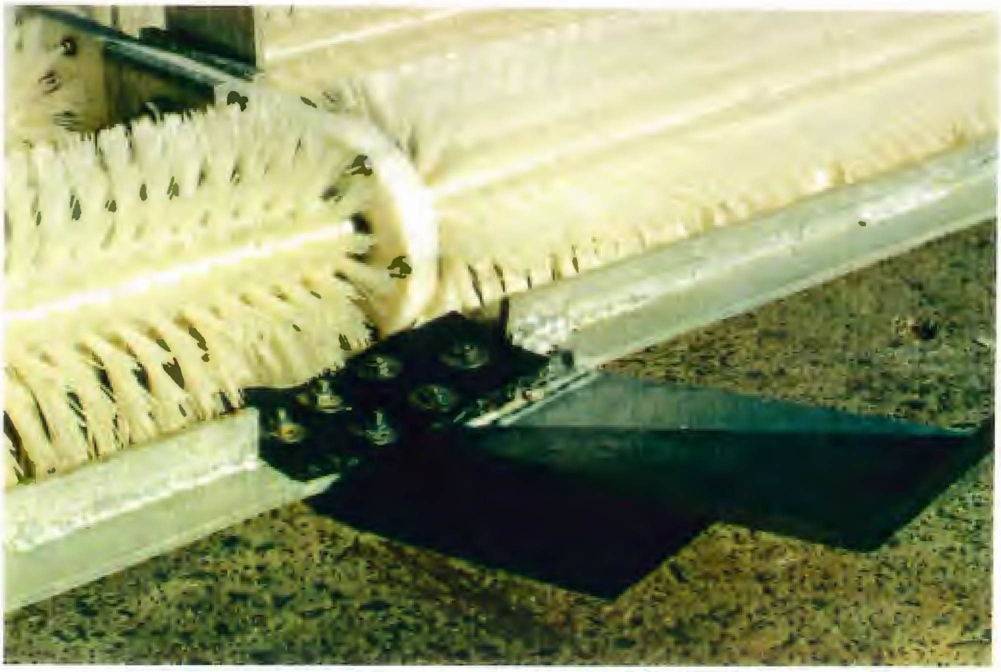


Figure 5. Close-up of gap between parallel brushes on two brush line showing stainless steel wire lacing, designed to help prevent net tangling

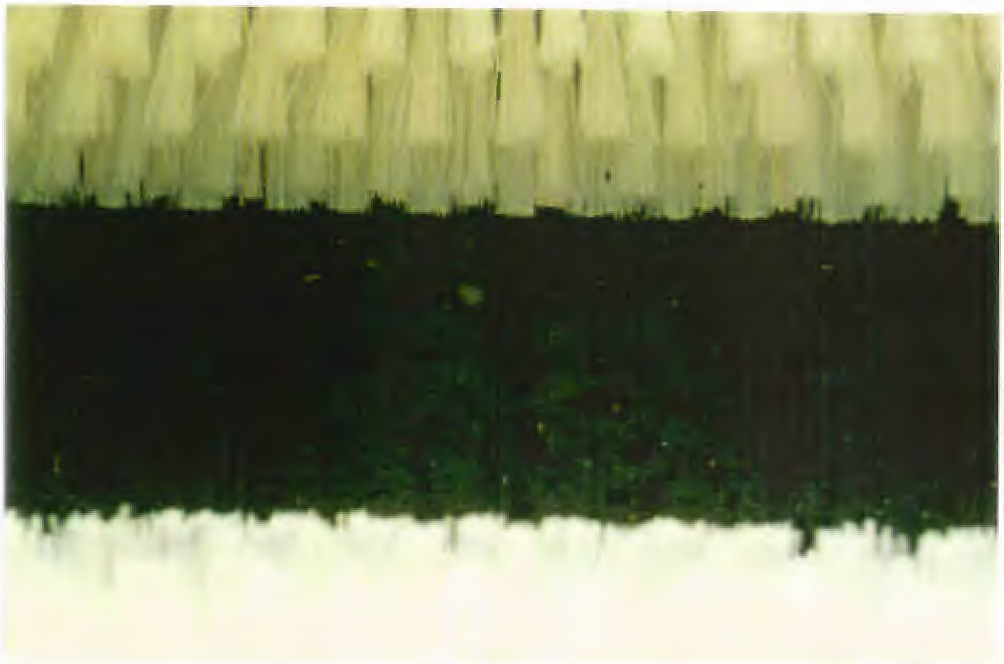


Figure 6. View of parallel brush lines showing aluminium lever arms (pointing vertically in this picture) designed to hold ~1.5 kg weights and thus to increase pressure of brushes against fouling organisms

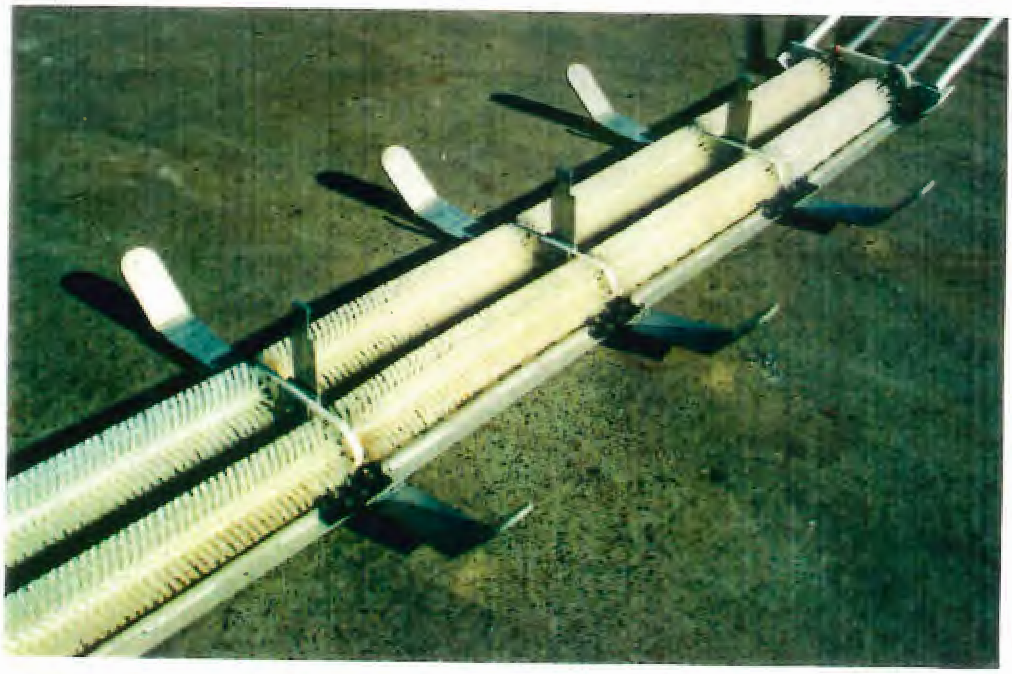


Figure 7. Close-up of join between drive shaft and the top brush of one brush line showing the universal joint used to replace the uppermost plastic bushes

Figure 8. Aluminium spacer designed to reduce the contact angle between the top brushes and nets on some pens

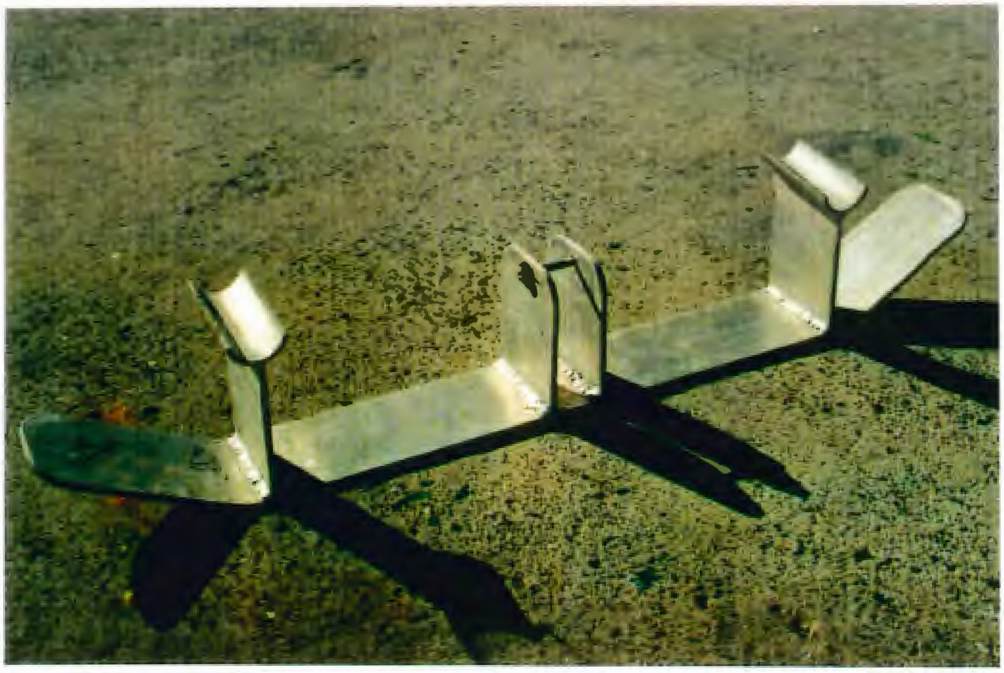


Figure 9. Close-up of plastic bushes damaged by the stainless steel end pieces of the drive shafts

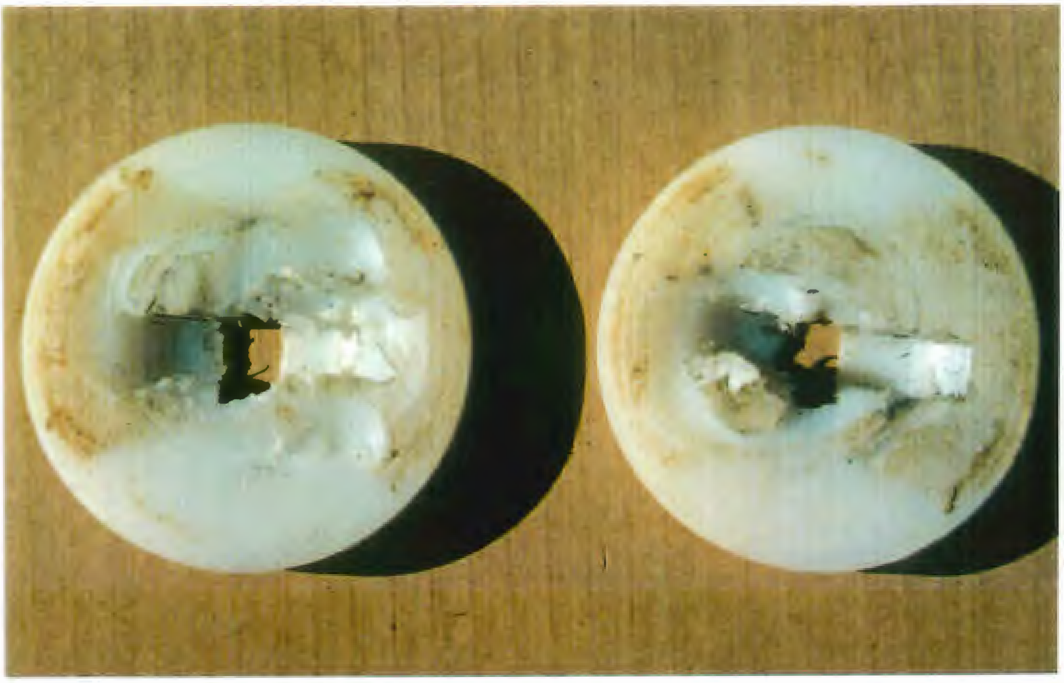
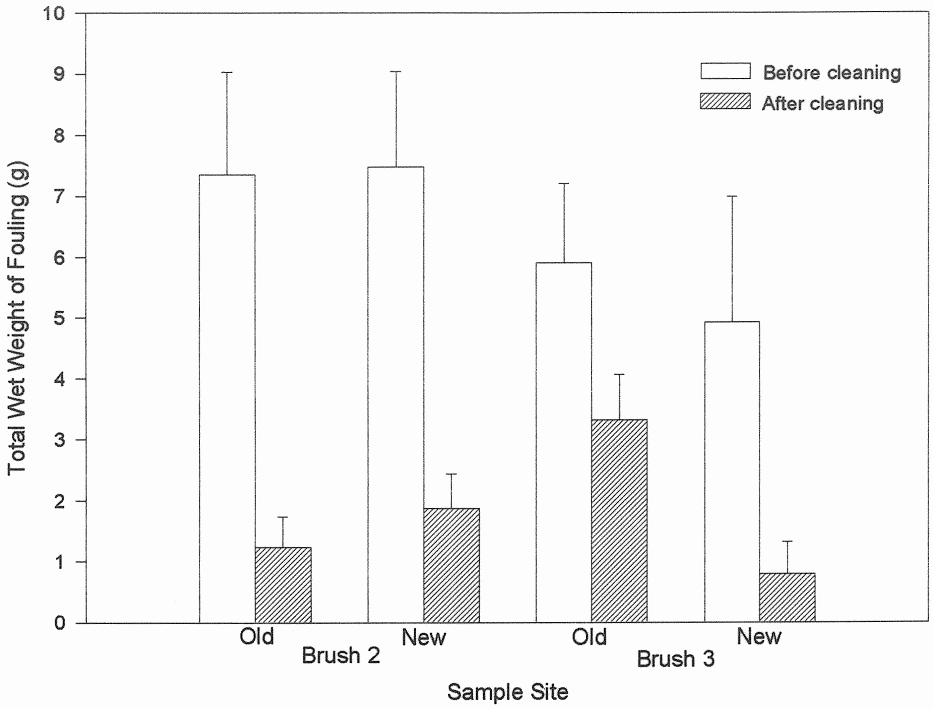


Figure 10. Wet weight (gm) of fouling before and after cleaning using modified brush configuration



Appendix 1 **Draft document only. Not to be cited without permission from author.**

Short Communication

IN SITU QUANTIFICATION OF FISH-CAGE FOULING BY UNDERWATER PHOTOGRAPHY AND IMAGE ANALYSIS

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Shortened Title:

QUANTIFICATION OF FISH-CAGE FOULING

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ABSTRACT

Close-up underwater photography and image analysis were used to quantify macrofouling on salmon-cage netting. This technique allows fast, non-destructive sampling of cages *in situ* for the determination of temporal and spatial changes in fouling. The area of net blockage can be easily determined, allowing rapid evaluation of cleaning or antifouling performance.

KEY WORDS: Image analysis, fish-cages

INTRODUCTION

Fouling on netting has previously been quantified by wet weights of test panels (*e.g.* Milne, 1975) or of communities removed from cages (*e.g.* Cheah & Chua, 1979; Lee *et al.*, 1985). However, the removal of fouling material from cages is destructive, time consuming and, given the shape and structure of netting, is awkward. The occlusion of netting has been assessed either subjectively (*e.g.* Huguenin & Ansuini, 1981) or by the measurement of seawater exchange with a current meter (*e.g.* Gormican, 1988). Our experience in Tasmanian waters is that significant differences in fouling occur at different depths and sides of cages, and between adjacent cages. Given this high degree of variability, considerable effort must be made to obtain sufficient samples to ensure accuracy. Sensitivity is also required for some trials, such as for the comparison of similar antifoulants or daily fouling growth.

The quantification of sessile aquatic macroorganisms has recently been conducted through image analysis (*e.g.* Ben-Zion *et al.*, 1991; Rahav *et al.*, 1991; Wright *et al.*, 1991; Haddad & Ormond, 1994). Wright *et al.* (1991) used image analysis to quantify tubeworm fouling on flat panels removed from the water, a method which resulted in substantial time-savings over manual counting techniques. They identified three critical factors for the successful use of computers to quantify fouling: sufficient contrast between substratum and fouling, homogeneity of colour or texture in the substratum, and the absence of light reflection during image capture as this reduces contrast.

Image analysis of photographs of net fouling enables large numbers of non-destructive samples to be taken and analysed quickly, compensating for the high degree of natural variability in the fouling communities. It also provides a permanent record of the fouling, allows dominant species to be identified and counted, and permits multiple sampling of the same area. As samples are recorded *in situ* the reduction in mesh area can also be quantified, and related to the reduction in water exchange. This paper describes a method for image analysis of close-up underwater photographs of net fouling to quantify fouling removal and regrowth.

MATERIALS AND METHODS

Trial 1: Fouling Regeneration Trial

A 65 m circumference cage (96 ply, 25 mm bar, cleaned black netting) was immersed on 1 November, 1993, and mechanically cleaned *in situ* on 11, 17 and 24 November. Nine cable ties were placed at 6-bar intervals across the sample area at both 1 and 1.5 m depth, to identify 18 sample sites for repeated observation. Photographs were taken on 24 November (immediately after cleaning), 26 November and 1 December, using a Nikonos-V camera with an SB-103 strobe, 1:3 macro-extension tube and 100ASA film. To increase background contrast a black sheet was suspended behind the netting for photography (Fig. 1). However, this background proved difficult to distinguish from clean black netting, so in subsequent work a blue sheet was used (Fig. 2).

Trial 2: Fouling Removal Trial

A 65 m circumference cage (96 ply, 22 mm bar, new white netting) was immersed on 30 September, 1994, and mechanically cleaned *in situ* on 16 November and 14 December. On the northern face of the cage 2 blocks were marked for sampling, one from 20-70 cm depth and one from 100-150 cm depth. Each block was divided into 2 replicate sections each 90 mesh-holes wide (2m) by 20 high. Photographs were taken on 13 December and 15 December to evaluate the efficacy of fouling removal by the cleaner. Both times 12 randomly-located sites (each 6 by 4 mesh holes, Fig. 3) in the sample sections were photographed twice. To reduce shadowing effects (Fig. 2, arrow A), a second SB-103 strobe was added to the camera. To increase the field of view (Fig. 3), a Nikonos close-up outfit (1:4.5) was substituted for the macro-frame.

Image Analysis

Photographs were scanned into an IBM-pc computer (80486DX2-66) with an Epson® GT-6500 scanner and the software Epson Scan! (V. 1.30). To remove blue material outside the sample area (Fig. 2, arrow B) the edges were trimmed from each photograph (Fig. 3). The photographs from trials 1 and 2 represent cage areas of 56 mm X 38 mm, and 160 mm X 107 mm, respectively. The field of view for all photography was fixed by a frame attached to either the macro-tube or close-up outfit, and thus the absolute size of the sample could be determined. Photographs from trial 1 (*e.g.* Fig 1) were scanned at a resolution of 75 dots per inch (dpi). Due to the difference in scale, the images from trial 2 (*e.g.* Fig. 3) were scanned at 150 dpi to obtain comparable resolution. To identify clearly the black mesh holes in the photographs from trial 1, the images were edited with Adobe Photoshop™ (V. 2.5.1) to give a distinct blue colour.

Image analysis was conducted using IDRISI (V.4.1) to determine the area (cm^2) of open mesh in each photograph. IDRISI is a geographic information and image-processing system developed at Clark University, Massachusetts, USA. Four IDRISI modules were used for fouling analysis. Images were first converted into IDRISI format (from 24-bit TIFF format) using the BIPIDRIS module. During the conversion process, images are separated into 3 colour bands so the module COMPOSIT was used to produce a 216-colour composite image. Each pixel in the image thus had a numeric value (from 0 to 215) which represented its colour. With the RECLASS module the value 9 (bright blue) was assigned to all areas in the image that contained values corresponding to the range of blues in the background. The AREA module was then used to measure the area covered by pixels with a value of 9. These 4 modules can all be used from the command line in MS-DOS®, and were included in 2 batch files so they ran automatically, and repetitively, on the collection of scanned images. The measured value from each photograph was saved during processing.

RESULTS AND DISCUSSION

The results from the regeneration trial (Fig. 4) demonstrate rapid blockage of netting with a greater amount of blockage at 1 m than 1.5 m. At 1 m the open area of the mesh decreased by 37% in 7 days, from 6.48±0.11 cm^2(approximately the total area for two clean mesh holes) to 4.10±0.37 cm^2. By determining the rate of fouling growth and regeneration during different seasons a minimum time interval between cleaning can be recommended. The usefulness of this data could be further enhanced through correlation of mesh blockage (Fig. 4) with reduction in water flow.

Analysis of the fouling-removal trial (Fig. 5) found no significant difference in mean blockage before and after cleaning ($P=0.75$, ANOVA). The cleaner used in this trial (a different machine from that of trial 1) did remove some fouling from the net during operation. However, contact between the cleaning brushes and the netting was insufficient to remove material close to the net. Consequently, the cleaner cropped the upper fraction of the fouling community, but left the lower structures unaltered, resulting in no reduction in net blockage.

For the fouling-removal trial each site within a replicate section was photographed twice and both pictures were used for image analysis. The open area (cm^2) for each site was then calculated as the mean of each pair of pictures. The data from the four sections before cleaning were analysed as a nested ANOVA; this indicated that the pairs of photographs within each site contributed only 1.4% of the total variance, whereas the sites within each section accounted for 31.1%. This large variation among sites, but relative precision of the pairs of photographs, shows that the resources would be better allocated by taking only one photograph per site and doubling the number of sites. This design improvement was confirmed by estimates of the expected variance of the means for two experimental designs (Sokal & Rohlf, 1981, p. 309); if 12 sites were sampled per section and each photographed twice, the expected between-section variance is 4.6, however, if 24 sites are used and each photographed once the variance is only 2.4.

In the fouling-removal trial, different sites were measured before and after cleaning. However, as the image analysis technique is non-destructive, this type of trial could be improved, but by repeated measures sampling, rather than by increasing the number of sites. That is, the same 12 randomly-located sites could be photographed before and after the treatment and directly compared.

Differences between the replicate sections in the fouling removal trial were identified. The two sections in block 1 (20-70 cm depth) were not significantly different ($P=.16$ before cleaning; $P=.87$ after, t-test), however, there were significant differences ($P=9.6 \times 10^{-5}$ before; $P=.038$ after) between the 2 sections in block 2 (100-150 cm depth). Thus, although relatively intense sampling is needed within a section, it is also important to have a fast sampling technique that permits examination of more than one section, as large-scale spatial variation occurs.

Image analysis of underwater photographs is an easy and rapid method for quantifying the blockage of netting from the initial fouling growth on net cages. Four rolls of film (36 exp.) can be taken within 3 hours, thereby covering an area of 3064 cm^2 with a 1:3 macro frame, or 24,652 cm^2 with a 1:4.5 close-up outfit. The photographs from 1 roll of film can be scanned into the computer within 30 minutes. The image analysis required for 1 film took 1 h for the 75 dpi images, and 4 h for 150 dpi images. However, this processing requires no interaction from the user once the batch file has been executed.

This technique can be difficult to apply with some types of fouling. Compound ascidians are transparent and so can not be recognised against the blue background (Fig. 2, lower mesh hole). Long filamentous forms of algae are difficult to photograph and assess for mesh occlusion as their form will vary greatly with different rates and direction of water flow.

The application of image analysis to determine open areas in netting is simpler than counting fouling organisms on flat panels, as the organisms may overlap or have little contrast with the panel surface (Wright *et al.*, 1991). The ability to measure fouling *in situ* is advantageous, as repeated removal of the substrate from water may alter fouling communities (Schoener and Greene, 1981). A further benefit of the method is that photographs are taken close to the netting, this allows samples to be recorded in dark or turbid waters. Furthermore, the area of any colour in a photograph can be quantified with IDRISI, and thus the areas of different coloured fouling may be determined. The ability to sample fouling *in situ* and non-destructively, together with the creation of a permanent photographic record, combine to provide an excellent tool for net-fouling analysis.

ACKNOWLEDGEMENTS

This research was funded by the Department of Aquaculture, University of Tasmania at Launceston, Salmon Enterprises of Tasmania Pty Ltd (Saltas), and by the Cooperative Research Centre for Aquaculture. SLH was supported by a University of Tasmania Postgraduate Research Award funded by Saltas, and by an Australian Postgraduate Award. Dr G Maguire is thanked for some advice in biostatistics. Prof A Osborn and Prof N Forteath are thanked reviews of the manuscript.

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FIGURE CAPTIONS

Figs 1-3 *In situ* photographs of net fouling to be used for image analysis.

(1) Fouling growth dominated by the red alga *Antithamnion*, 7 d after cleaning. A black sheet suspended behind the netting increased background contrast with fouling. Bar = 1 cm; (2) A blue sheet behind the netting provided marked contrast with both the fouling and black netting, and was easy to recognise for image analysis. A: shadow caused by the use of only one strobe. B: blue material outside the 2 mesh holes in the sample area must be removed before image analysis. Bar = 1 cm; (3) Fouling left after cleaning during trial 2. The blue material outside the sample area was cut from the photograph prior to scanning. The removed material was replaced by a white background. Bar = 5 cm.

Fig. 4 Occlusion by fouling organisms during the 7 days following cleaning (24 Nov - 1 Dec). Each point represents the mean of 9 samples. Bars = 95% confidence levels.

Fig. 5 The mean area (n=12) of open mesh in each sample block, before and after cleaning. Bars = 95% confidence levels.

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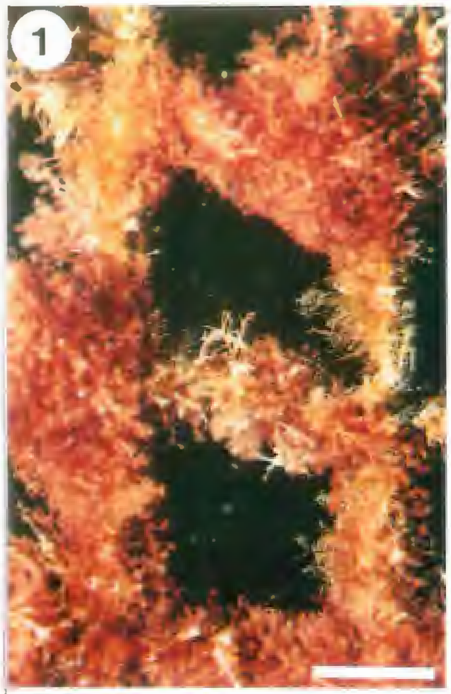
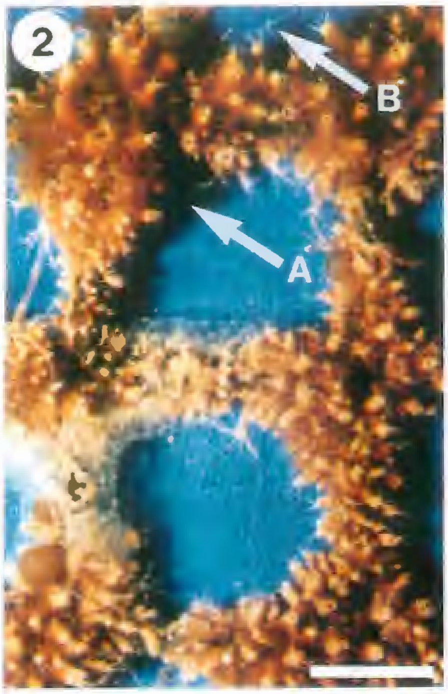
Figures 1-3.





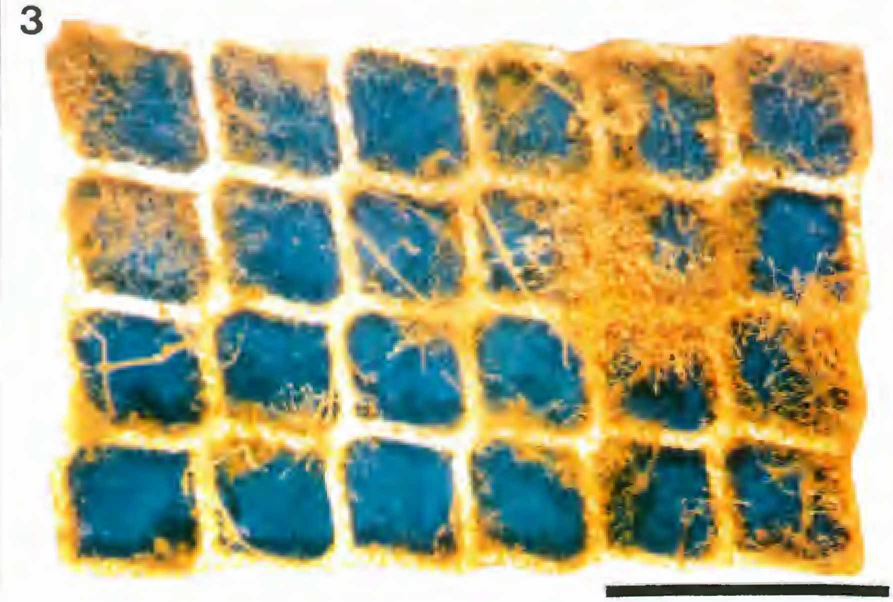


Figure 4.

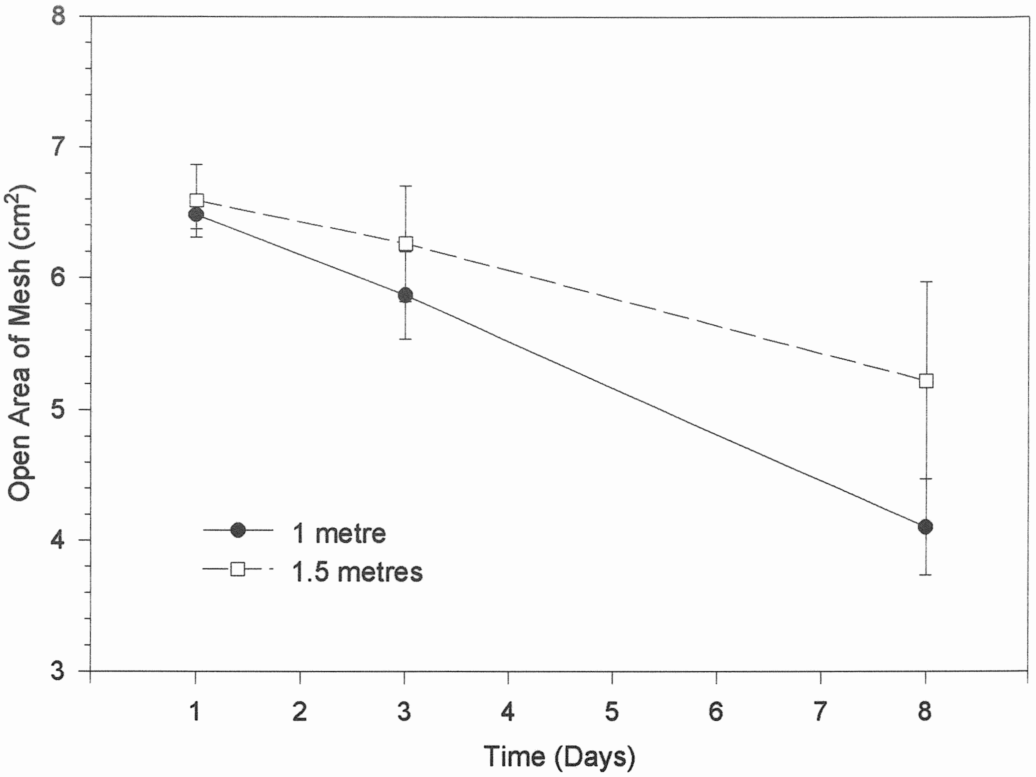

8
7
6
5
4
3
Open Area of Mesh (cm²)
1
2
3
4
5
6
7
8
Time (Days)
1 metre
1.5 metres

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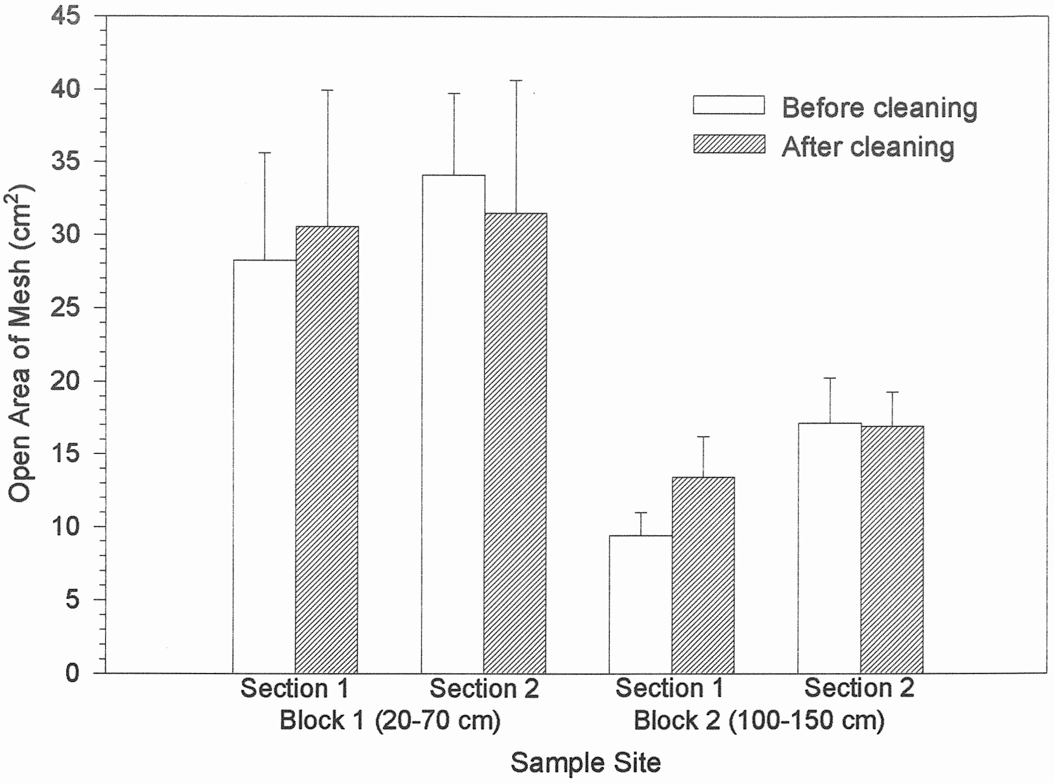
Figure 5.



Appendix 2.

In situ mechanical cleaning of netting: Evaluation of the brush tester and development of an analysis technique

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ABSTRACT

The efficacy of a technique for *in situ* mechanical cleaning of nets, and methods for recording fouling removal and regrowth, were evaluated at Saltas Marine Operations in Dover. The cleaning equipment, consisting of a rotating brush, was found to remove all fouling from the surfaces with which the bristles came into contact. Both hydroid and algal fouling were easily removed, and repeated weekly cleaning kept fouling to a minimum. The soft, long bristles used with the cleaner did not cause any damage to the netting.

A technique employing close-up underwater photography and image analysis was developed to quantify the area of net blockage by the fouling. This technique allows rapid, non-destructive sampling of cages *in situ* for the determination of temporal and spatial changes in fouling. The area of net blockage can be determined within 24 hours following collection of samples (photographs), allowing rapid testing of cleaning techniques. This has proven to be an excellent tool for evaluation of mechanical cleaning and could equally well be applied to comparisons of antifoulants.

Appendix 2.

INTRODUCTION

The rapid development of biofouling on salmon-cages in Tasmania necessitates frequent removal of netting from the water for cleaning. This labour- and capital-intensive process is a significant cost to the industry. Fouling must be kept to a minimum to ensure adequate water flow through netting, in order to supply dissolved oxygen and remove excess food and waste products (Cheah and Chua, 1979; Lee *et al.*, 1985). Furthermore, the weight of a large fouling community can hamper net changing and may result in structural failure. The multi-filament netting material is unfortunately an ideal fouling substrate as it is non-toxic, contains many crevices which can entrap and protect organisms, and has a high surface-area to volume ratio. The waters of fish farms, usually with low-moderate current flow and enriched in nitrogen and phosphorous, allow rapid settling and growth of fouling. Fouling protection has successfully been achieved through the use of toxic antifoulants. However, these are expensive, greatly increase the weight of netting, and potential environmental effects make them undesirable to the salmon industry. Antifouling treatments are also ineffective in preventing the settlement and growth of large masses of drift weed. An important and necessary tool for the management of fouling is an efficient mechanical cleaning system which can be operated without removal of netting from the water.

Underwater scrubbing of surfaces to remove fouling has been evaluated for ship hulls (Moss and Marsland, 1976a, b) and the internal surfaces of seawater cooled heat exchanger tubes (Nickels *et al.*, 1981). This research has identified problems associated with brush cleaning. Nickels *et al.* (1981) found that the cleaning process selected for a residual microfouling community which regrew faster following repeated cleaning. They suggested that continued cleaning over long periods may select for an increasingly resistant microbial community. Moss and Marsland (1976a) found macroalgae regrew rapidly and in greater density within a short period following scrubbing. During scrubbing the majority of algae was effectively removed. However, small quantities of rhizoids and basal parts of filaments remained, particularly in small crevices. Each of these remnants have the capacity to regenerate into a new plant. Moss and Marsland (1976b) observed that cutting off *Enteromorpha* thalli just above basal rhizoids stimulated rhizoid growth and production of many new branches. Furthermore, during scrubbing, vast quantities of swarmers are released from reproductive cells, and these immediately recolonise the surface (Moss and Marsland, 1976a). Thus it could be expected that the scrubbing of salmon-cage netting may ultimately select for specific types of fouling that have the capacity to recover quickly. This regenerative capacity will have to be assessed in order to determine the frequency of cleaning and the design of brushes.

In order to determine the effectiveness of mechanical cleaning it was necessary to develop a new technique which would quantitatively describe the removal and regrowth of fouling on the cages (Hodson *et al.*, in preparation). Previous researchers have quantified fouling on netting either from wet weights of panels (*e.g.* Milne, 1975) or of communities removed from cages (*e.g.* Lee *et al.*, 1985). However, removal of fouling from cages is both difficult and destructive. Blockage of netting has been assessed either subjectively (*e.g.* Huguenin and Ansuini, 1981) or by the measurement of seawater exchange (*e.g.* Gormican, 1988). This latter technique is both time consuming and complex, given the marked changes in water current within cages and around groups of cages (Wee, 1979).

During trials with the brush tester it was found that image analysis of close-up underwater photographs was an effective method for quantifying blockage of netting. This method enables large numbers of non-destructive samples to be taken quickly across the surface of a salmon cage. It also provides a permanent record of the fouling, allows dominant species to be identified and counted, and permits multiple sampling of the same area. As samples are recorded *in situ*, the reduction in mesh area can also be quantified and related to reduction in water exchange.

The present study describes the results of the evaluation of the brush tester. Remnants of hydroid fouling, regeneration of algae, and damage to netting following cleaning are discussed with regard to the effectiveness of brush cleaning. The application of underwater macro-photography and image analysis for the description of fouling removal and regrowth on netting are described.

MATERIALS AND METHODS

Hydroid removal

The brush tester (Fig. 1) was used on the eastern side of a 65 metre cage (96 ply, 25 mm bar) on the 4th of August, 1993. The cage had been immersed for 2 months and on the eastern face was heavily fouled with the hydroid *Obelia australis*. This was chosen as the first test site because hydroids are reported to be more difficult to remove from cages than algae (Huse *et al.*, 1990).

Operation of the cleaner and collection of samples was conducted using SCUBA. The cleaner was operated by one diver at 50 to 100 cm depth whilst a second diver, at approximately 4 m depth, held the net taut. The trial was conducted on the inside surface of the salmon cage with the cleaner held in a horizontal position. The cleaner was operated with the brush rotating downward.

Both hard and soft bristles (both of shortest length) were tested, with 8 samples of cleaned netting collected for each. Samples of netting were cut from the cage, immediately placed into plastic sample tubes, and fixed for scanning electron microscopy (SEM) (Hodson and Burke, in press) within 1 hour. Variations in cleaning efficiency over the cage surface were minor.

Damage to netting

The mechanical cleaner was fixed to net panels (with new 96 ply, 25 mm bar netting), immersed over the side of a boat, and operated for 5 minutes. Both soft and hard bristles were tested (both of short length). Both bristle types showed damage over the area of contact, with no apparent difference between soft and hard bristles. Netting damage was also observed on samples taken from the cleaned cage during the hydroid removal trial.

The longest and softest bristle type has been used in all subsequent trials, and on no occasion has any damage been observed.

Fouling regeneration

A 65-metre circumference cage (96 ply, 25 mm bar) was immersed on 1 November, 1993, and an area on the northern face mechanically cleaned on 11, 17 and 24 November. To create a taut surface for cleaning the cage was temporarily tied to the predator net on each occasion. The brush tester was operated with the brush in a vertical position (longest bristles, softest compound), and the area cleaned by making horizontal sweeps at increasing depths. To identify 18 sample sites for repeated observation nine small cable ties were placed at 6-bar intervals across the sample site (approx. 2 m x 2 m) at both 1 and 1.5 m depth. Photographs were taken on 24 November (immediately after cleaning), 26 November and 1 December.

Photographs were taken using a Nikonos-V camera with SB-103 strobe, 1:3 macro-extension tube and 100ASA, 36 exposure film. A black sheet was suspended behind the netting during photography to increase background contrast. Photographs were scanned into an IBM-pc (80486DX2-66) computer with an Epson® GT-6500 scanner and the software Epson Scan! (V. 1.30). Images were edited using Adobe Photoshop™ (V. 2.5.1) to give a distinct colour to the mesh holes and to remove material outside the sample area. Each photograph represents a 76mm x 51mm area on the cage surface (Fig. 2) (fixed by a frame attached to the macro-tube on the camera), and thus gives a size reference for the image analysis. Image analysis was conducted using IDRISI (V.4.1), to determine the areas (cm^2) of fouling, and of open mesh.

RESULTS

Hydroid removal

The cleaner was highly efficient in removing hydroids on those areas which were in direct contact with the brushes. Visible fouling was removed from the inner surface of the cage, and SEM demonstrated that microalgae and protista were also removed (Figs. 3, 4). However, the outer and lower surfaces of the bars retained much hydroid fouling (Figs. 3, 4, 5). At these sites the stems of the hydroid colonies remained intact; only the hydranths (regions bearing tentacles) had been removed.

Fouling regeneration

The repeatedly cleaned area developed communities dominated by the red alga *Antithamnion* (Fig. 2) and the hydroid *Syncoryne*. The brush tester successfully removed nearly all of these types of fouling during all three cleaning sessions. Any remnants left after cleaning caused almost no blockage of the mesh (eg. November 24, Fig. 6). However, this fouling regenerated quickly (Figs. 6, 7), and at 1 m the open area of the mesh decreased by 37% in 7 days, from 11.81±0.20 cm^2 (approximately the total area for two clean mesh holes) to 7.47±0.67 cm^2. The greatest amount of mesh blockage occurred at 1 m (Fig. 6).

DISCUSSION

Fouling removal and regeneration

Both the hydroid removal and the fouling regeneration trial demonstrated that the brush tester effectively cleaned the majority of fouling off the netting. However, remnants of hydroids were clearly visible on the outer surface of the cage, and the bulk of these were only slightly damaged. The regenerative capacity of hydroids is well recognised (Buchsbaum *et al.*, 1987). The colonies which remained on the outer and lower sides of bars should recover quickly, however, the recovery of the small remaining basal areas on the cleaned surfaces (Figs. 8, 9, 10) may be limited.

The small pieces of algae left on the netting during the regeneration trial quickly regrew and caused significant blockage of netting after 1 week (Fig. 6). Repeated trials on different cages, mesh sizes, and during different seasons, will need to be conducted to examine the speed at which other species recover, and thus determine the minimum time intervals between cleaning. The usefulness of this data could be further enhanced by correlation of mesh blockage with reduction in water flow. General observations on fouling variation at Dover have shown that significant differences in fouling occur at different depths and sides of cages, and between adjacent cages. This large variation is beneficial to net cleaning trials as it should provide a suitable testing ground for the majority of fouling organisms that will be encountered in southern Tasmanian waters. Following successful testing of the prototype net cleaner, a system for removing the debris created during cleaning will be constructed. The removal of these small fragments and reproductive cells should reduce the speed of recolonisation and thus fouling regrowth.

Image analysis

The image analysis technique has been improved following the regeneration trial, greatly reducing processing time. All current trials are conducted with a blue sheet suspended behind the netting which gives higher contrast with both the netting and fouling. As the majority of processes in the image analysis software can be run from the command line in MS-DOS®, batch files have been written to automatically analyse the fouling photographs. Consequently, the majority of user interaction is restricted to the scanning of the photographs, which is relatively fast (36 photographs can be scanned into the computer within 30 minutes). The computer automatically converts the images into area of mesh blockage (cm^2), taking approximately 1 hour per roll of film (36 photographs). During the analysis stage no user interaction is required. A full description of the image analysis process is in preparation for publication elsewhere (Hodson *et al.*, in preparation).

Appendix 2.

This technique is an easy and rapid method for quantifying the blockage of netting and the initial fouling growth on net cages. Four rolls of film can easily be taken within 3 hours, thereby covering an area of 5581.44 cm^2 (144 photographs X 38.76 cm^2 sample areas). The application of this technique to evaluation of mechanical cleaning is well suited, as the cleaning process appears to select for the more dense, compact forms of fouling.

The application of image analysis to determine open areas in netting is simpler than the counting of fouling organisms on flat panels, as the organisms may overlap or have little contrast with the panel surface (Wright *et al*., 1991). A further benefit of the method is that photographs are taken close to the netting, allowing samples to be recorded in dark or turbid waters. Furthermore, the area of any colours in a photograph can be quantified with IDRISI, and thus the areas of different coloured fouling may be determined. The ability to non-destructively sample fouling *in situ*, and the creation of a permanent photographic record for later reference, provides an excellent tool for net-fouling analysis.

CONCLUSIONS

- Mechanically cleaning netting *in situ* is a very efficient and effective method for fouling removal.

- The long, soft type of bristle used in the net cleaner caused no damage to netting.

- Two brushes operating in opposite directions would increase ease of cleaning. This would temporarily create a taut surface and also increase the area of contact that bristles have with the netting bars.

- The use of image analysis of underwater macro-photographs is an excellent method for evaluating fouling removal and regrowth on netting. This novel technique will allow rapid evaluation of the prototype net cleaner.

- Repeated trials on different cages, mesh sizes, and during different seasons, will need to be conducted to examine the speed at which different fouling species recover, and thus determine minimum time intervals between cleaning. This will allow assessment of different brush types and their effective operation.

FUTURE RESEARCH

1) For the remainder of 1994 the efficacy of the prototype mechanical cleaner will be assessed. This work will be completed by December, 1994.

2) Non-biocidal eg. silicone-based) fouling inhibitors will be evaluated during the coming spring and summer. Large test panels on which the prototype cleaner can be operated will be designed. The fouling inhibition, increased ease of cleaning, and characteristics of fouling communities which develop on the antifoulants, will be examined.

Appendix 2.

ACKNOWLEDGMENTS

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Wright, M., Bakus, G.J., Ortiz, A., Ormsby, B. and Barnes, D.M. (1991). Computer image processing and automatic counting and measuring of fouling organisms. *Comp Biol Med* **21**: 173-180

Appendix 2.

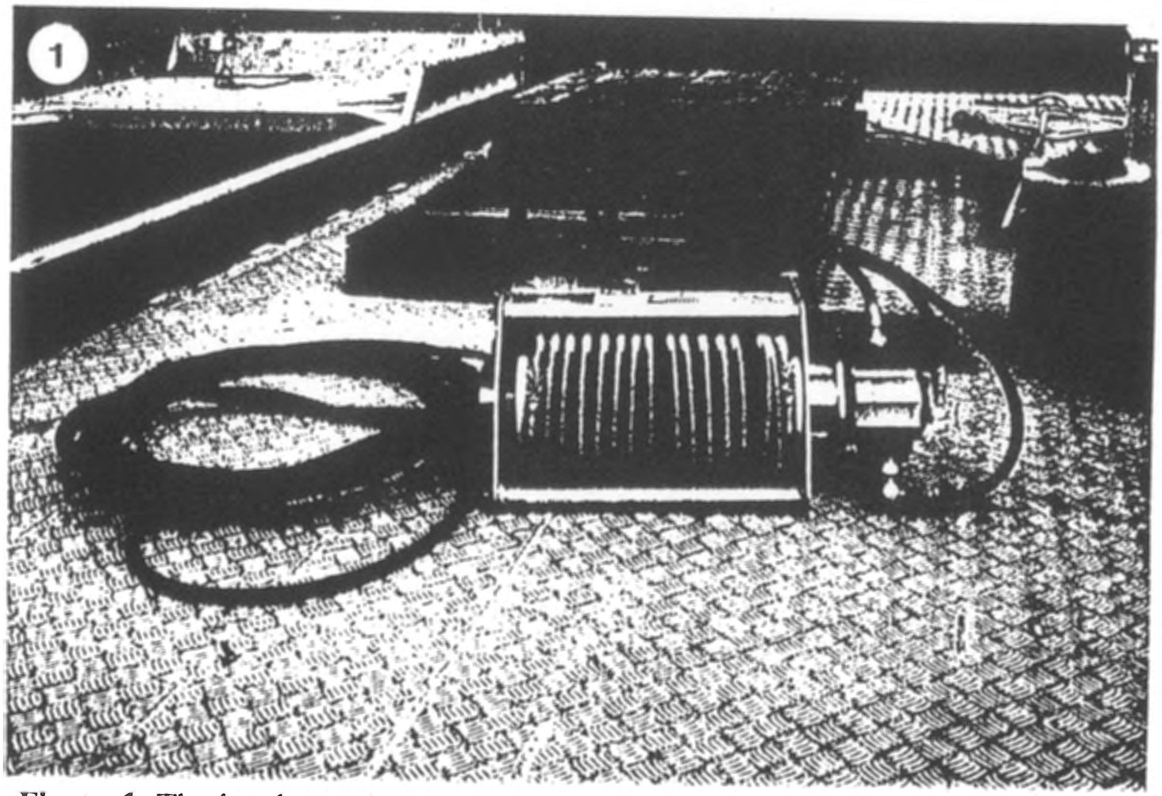


Figure 1. The brush tester

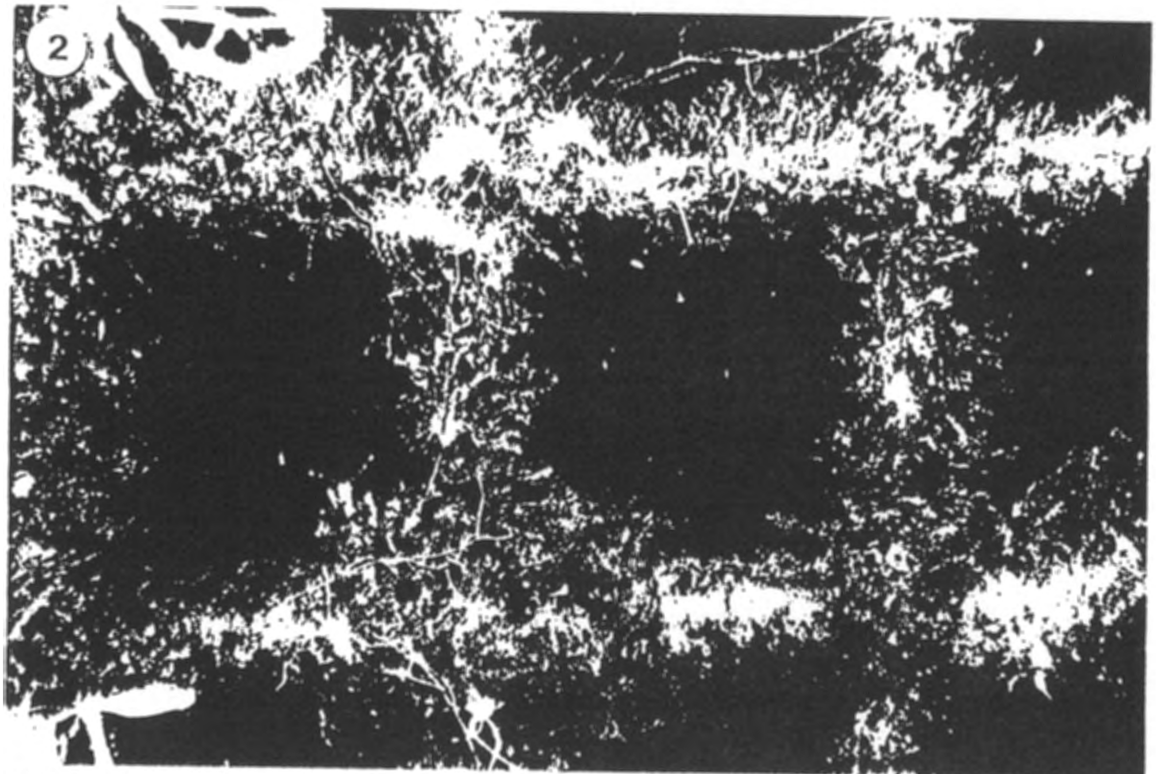
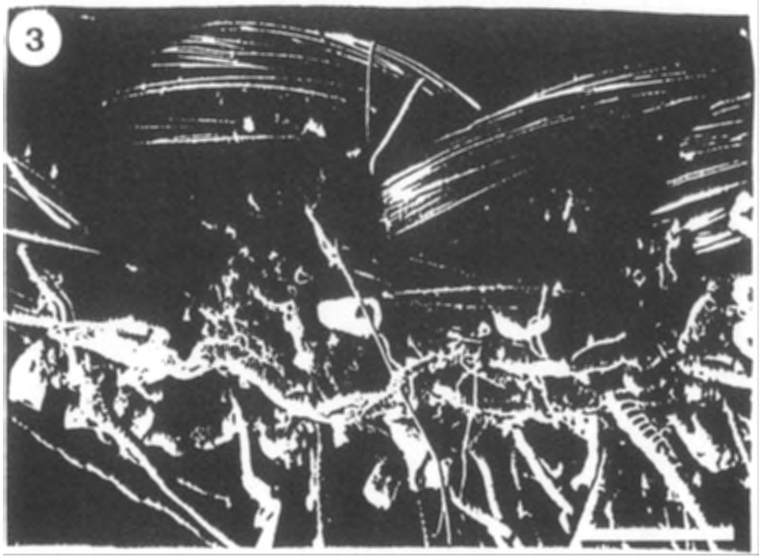
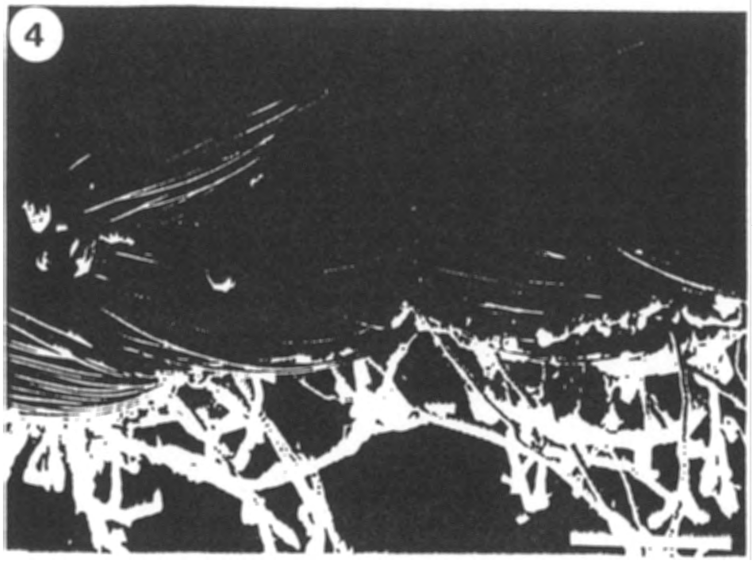


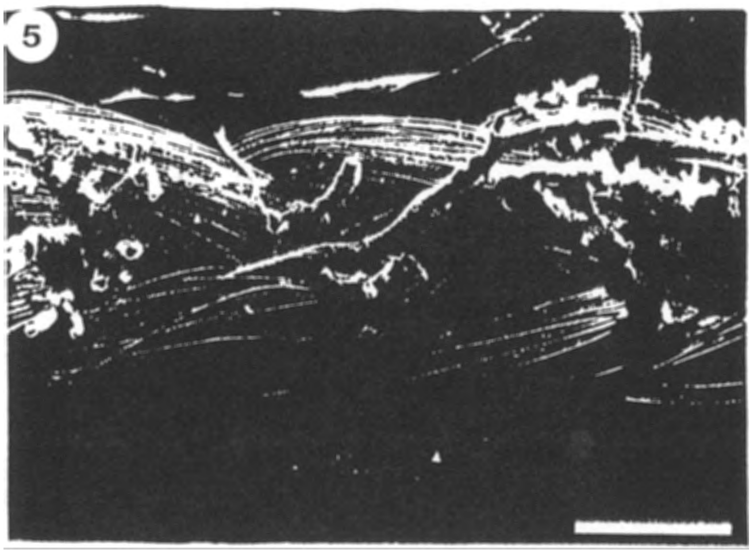
Figure 2. Macro-photograph of two mesh holes on 25 mm bar netting (Area = 76 X 51 mm). As shown, the dominant fouling during the regeneration trial was by the alga *Antithamnion*.

Appendix 2.





Figures 3-5. Hydroid communities remaining on netting after cleaning. The inner and upper surfaces are very clean, however the lower surfaces show many hydroids.



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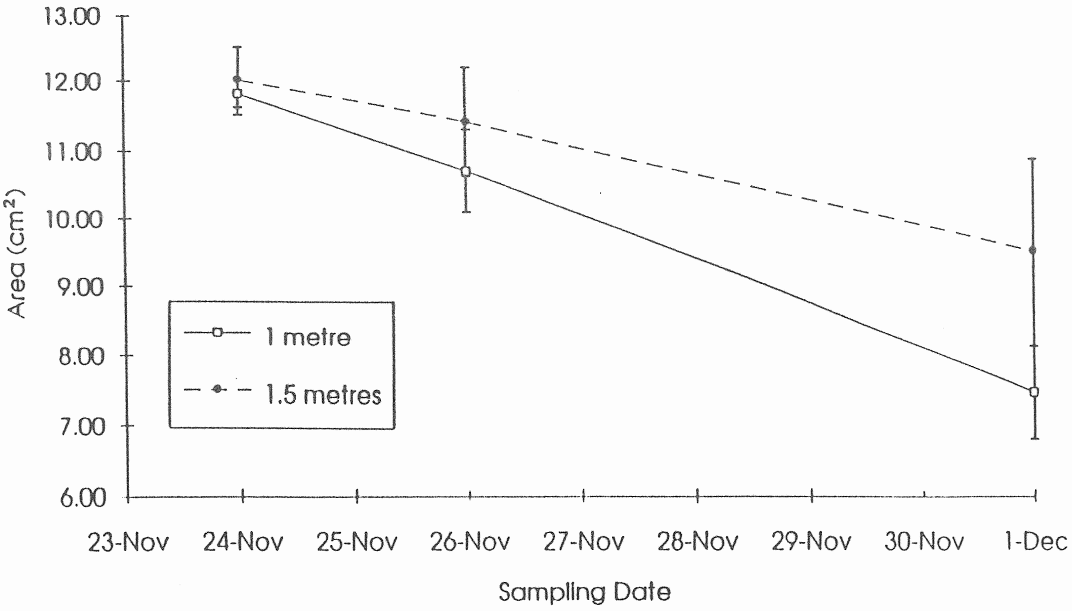


Figure 6. Reduction in open mesh area during the 7 days following cleaning. Immediately following cleaning (24 November) the open mesh area at 1m was 11.81±0.20cm^2, which represents almost completely clean netting (approx. 12.5 cm^2). Each point represents the mean of 9 samples. Bars = 95% confidence levels.

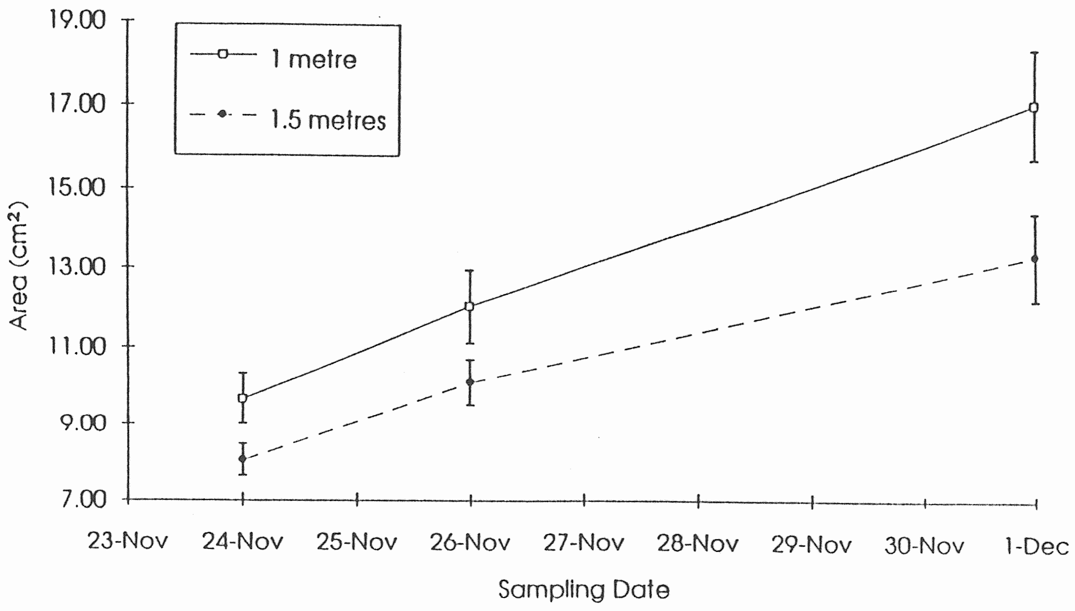
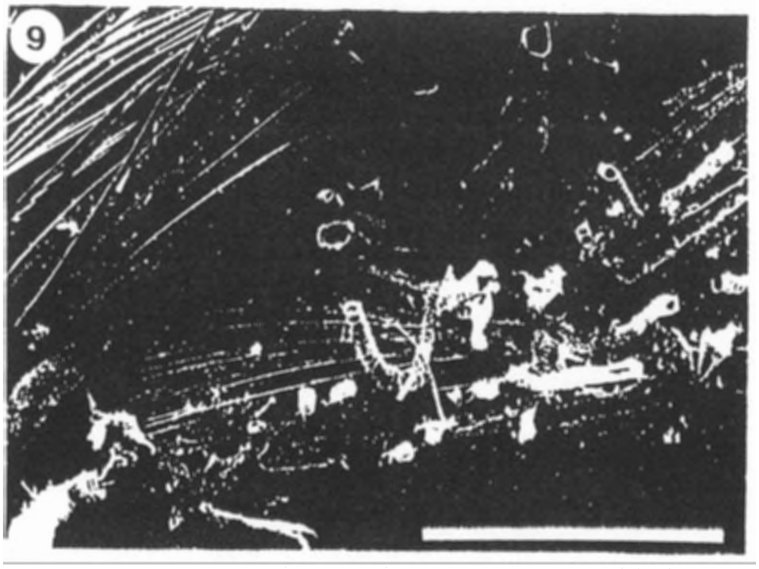


Figure 7. Increase in area fouled during the 7 days following cleaning. Each point represents the mean of 9 samples. Bars = 95% confidence levels.

Appendix 2.



Figures 8-9. Absence of microalgal fouling after cleaning. The hydroid remnants which remain have been severed close to the surface.

Figure 10. Large hydroid community remaining on netting after cleaning. The hard bristles damaged the netting, as seen by the free filaments which project above the upper surface.