DEVELOPMENT OF INCURSION RESPONSE TOOLS – UNDERWATER VACUUM TRIALS

AN UNDERWATER VACUUM RECOVERY AND FILTRATION SYSTEM AND ITS USE IN CONTROL OF *Didemnum vexillum* ON "STEEL MARINER" BARGE AND SEABED AT PICTON, NEW ZEALAND

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Project ZBS2002-02

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1. EXECUTIVE SUMMARY

In December 2001 Cawthron Institute divers on a routine survey in Shakespeare Bay, noticed a heavily fouled barge, the ‘Steel Mariner’ was being smothered by what they identified as *Didemnum sp*. There were fears that this could pose a threat to the marine ecosystem and aquaculture industry in the Marlborough Sounds. The organism has subsequently been identified as *Didemnum vexillum*.

The “Steel Mariner” provided an opportunity to develop and test marine incursion response tools and systems and the Ministry of Fisheries approached New Zealand Diving and Salvage Ltd. for a method to remove and/or kill in situ the fouling organism.

New Zealand Diving and Salvage Ltd. designed a system for capture and filtration of the organism to a specified maximum particle size of 100 um before discharge overboard. This involved a diver operated hydraulic cutter and vacuum head for recovery of the organism and a 3 stage filtration system on a support barge at the surface. After testing in Wellington New Zealand Diving and Salvage Ltd. mobilized to Picton to undertake field trials on the “Steel Mariner”. For these trials Cawthron Institute provided assistance with testing and investigation of the biological science aspects of the project.

On site a number of problems were found with various aspects of the system and after solving these a successful system was developed. Testing showed that the system was capable of gathering the *Didemnum vexillum* fouling on the barge with no detected release of propagules and little release of other material to the surrounding water. Testing also showed an ability to successfully filter the resulting effluent of all particles larger than 50 um at a flow rate of 270 Lt./min.

Problems were encountered collecting the *Didemnum vexillum* fouling on the seabed with this being only partially successful.

Approximately 80% of the fouling on the ‘Steel Mariner’ Hull was removed, with the total removal of the gross fouling.

2. OBJECTIVES

The objectives for Project ZBS2002-02 were specified in the proposal acceptance letter dated 31st July 2002 from Ministry of Fisheries and are:

1. To design, test and document the efficacy of an underwater vacuum system for use on vessel hulls and the seabed. The report will at a minimum include information on: problems and solutions identified, flow rates, filter clogging rates; particle dynamics – what material is being expelled into the water around the vacuum head; efficacy of the filter system at 100 and 50 um; efficacy of the device for removing *Didemnum vexillum* (incl. an estimate of cleaning efficiency) and other species; ability to target the *Didemnum vexillum*; an assessment of the level of disturbance to the target species and its response – e.g. is it shocked into releasing propagules.

2. Develop detailed specifications about the device, such that it may be copied so that other agencies can utilize the technology.

3. Identify areas for future development of this type of underwater tool.

3. INTRODUCTION & BACKGROUND

The barge "Steel Mariner" is an seventy two by twenty two metre steel construction dumb barge that was moored at the head of Shakespeare Bay, Picton, New Zealand. It was identified as being fouled with the organism, *Didemnum vexillum*. *D. vexillum* is not normally found in this area and its presence poses a potential threat to the marine ecosystem of the Marlborough Sounds and to the extensive aquaculture industries based in the area. Further information can be found in reference 1. (Coutts 2002).

P1. *Didemnum vexillum* fouling on "Steel Mariner" towing chain.

The "Steel Mariner" was heavily fouled with *D. vexillum*, mussel, sponge, and general weed fouling. This fouling typically covered the entire underwater surfaces of the barge with a thick matted coating of 100 to 200 mm thickness. The *D. vexillum* had inter-grown with the general fouling and formed long tendrils up to three meters long, see photographs P1 and P2. Fragments of the growth had dropped off the barge onto the surrounding seabed where in some cases, they had formed small active colonies on hard seabed substrate.

P2. *Didemnum vexillum* colonies growing under "Steel Mariner"

Ministry of Fisheries approached New Zealand Diving and Salvage Ltd to develop a method to remove and/or kill in situ the *D. vexillum* fouling. The equipment and methods developed would then be available for use in responding to other marine organism incursions in New Zealand.

New Zealand Diving and Salvage Ltd investigated a number of methods to deal with the *D. vexillum*. These included investigation of systems to gather and collect the *D. vexillum,* filter the collected material to prevent colonies or larvae of *D. vexillum* re entering the surrounding water, surround and kill in situ fouling remaining on the "Steel Mariner" after the gross fouling had been removed, and methods to gather or kill in situ the *D. vexillum* on the seabed.

From this Ministry of Fisheries awarded New Zealand Diving and Salvage Ltd a contract for further development work and for the use and testing of the developed system on the *D. vexillum* on the "Steel Mariner" and the surrounding seabed.

4. SYSTEM DESIGN AND DEVELOPMENT

The design of the underwater vacuum recovery and filtration system had to meet a number of criteria. To be effective it needed to be:

- -cost effective to build and operate particularly with regards to time needed to complete the operation and the cost of consumable filter materials.
- -able to capture *D. vexillum* and minimize loss to the surrounding water.
- -able to filter waste water to 100 um to prevent fragments and larvae of *D. vexillum* escaping to the surrounding water.
- -safe to operate for divers in the water and topside crew on the work barge.
- -of a modular design so that it could be easily packaged and shipped to where needed.
- -environmentally acceptable.

From these guidelines the broad design concept evolved. This was for a hydraulically powered cutter head to gather and shred the *D. vexillum* while minimizing the escape of particles or spores.

P3. New Zealand Diving and Salvage Ltd diver Maurice Kapua holding the hydraulic powered cutter head during trials in Wellington.

The water and entrained *D. vexillum* would then be pumped up on to the work barge and run through a three stage filtration system before the cleaned waste water was discharged overboard. Detailed specifications are contained in Section 8. SPECIFICATIONS.

CUTTER HEAD

A powered cutter head was designed to shred and gather the *D. vexillum* as it was feared that a simple suction device would not be able to break it into small enough fragments to prevent pump and hose blockages. It was also thought that for future use on other “tougher” marine organisms it may be necessary to have a system able to mechanically shred the organism. The cutter was hydraulically powered with a single “Shar Lynn” type hydraulic motor directly coupled to a 290 mm diameter bronze tunnel type propeller. The bronze propeller top and bottom surfaces were machined flat to provide a cutting edge against a central stainless steel bar. As the propeller rotated it would gather some material and cut it off against the central stainless steel bar.

P4. Cutter head during development in Wellington.

The propeller was contained in a fabricated stainless steel cylinder approximately 290 mm in diameter and 120 mm high. This had initially a single 50 mm outlet welded tangentially to the main housing. Attached to the 50 mm housing using cam lock quick release fittings was a 50 mm suction hose. The outlet was positioned to gather the water rotating around the inside surface of the main body. The water and entrained material was sucked up the hose by an air powered bellows type pump on the work barge.
The cutter head was powered hydraulically from a power pack mounted on the work barge and two Synflex hydraulic hoses were made up with the water suction hose into an

umbilical bundle. The cutter had diver operated controls mounted underneath the main body. These were designed for two handed operation which was a safety feature designed to reduce the chance of injury from the cutter. Divers would use surface supplied umbilical diving systems with band mask surface demand diving masks which allowed two way voice communications with the surface. This allowed the diver to communicate with the topside crew to turn on or off and to adjust the hydraulic power pack as needed. It also allowed communication to have the power pack shut down in an emergency.

P5. Hydraulic controls on cutter head during development in Wellington.

Trials of the cutter head were undertaken in Wellington prior to mobilization (see photograph P3) and while it was found to be very effective in gathering and shredding material it was not initially very effective at capturing the material. It was found that the cutter would become overloaded with water and shredded material and tend to throw some of this back out into the surrounding water. It was apparent that this was due to the propeller sucking in more water than could be carried away up the suction hose. A solution would have been to increase the size of the suction pump and hose but this would have meant dealing with much more water at the filter stage which would have had a large flow on effect to the cost of the filter system.
It was decided instead to reduce the amount of water the propeller was entraining to an amount that the design suction hose and pump could handle. A series of modifications was done to achieve this first by reducing the diameter of the cutter opening and

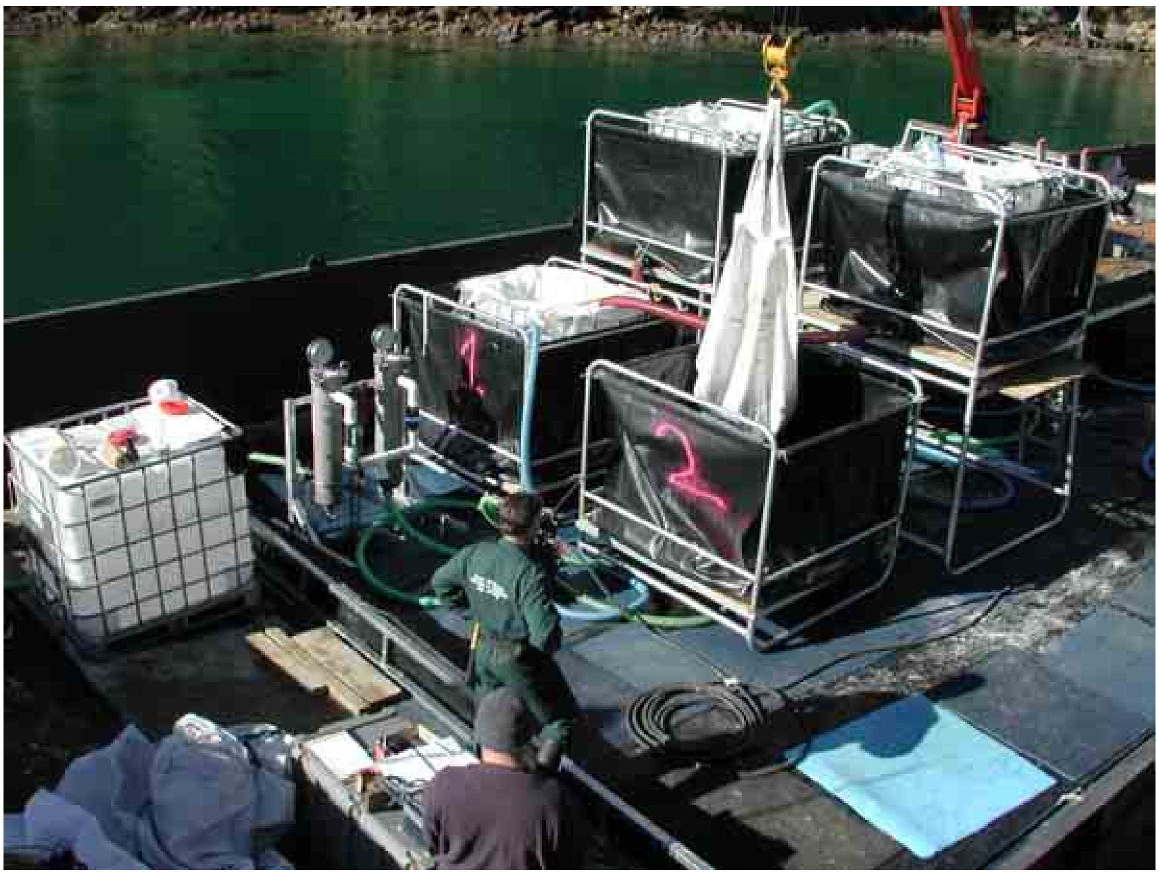
eventually by fitting a catch funnel to the opening and a second suction hose outlet on the opposite side of the cutter main body. Photograph P4 shows the cutter with a reducing plate fitted to reduce the opening surface area. Photograph P3 shows the catch funnel that was then fitted to the reducing plate in the final configuration. Photograph P6 shows the final suction hose arrangement with two suction hose outlets on the main body. By the end of this development work the cutter was much more effective with little or no water and shredded material escaping. Floatation was also added to make the cutter slightly buoyant to enable it's use underwater.

P6. The final hose configuration on the cutter with two outlets.

From the cutter head the water and entrained shredded material was sucked along a 50 mm hose by an air bellows type pump with flap valves instead of the more usual ball type valves. This allowed the pump to handle solids up to 50 mm in diameter without blocking. This pump then delivered the water and entrained material to the first stage of the filter system. The filter system was in three stages so as to allow filtering down to at least 100 um without a high cost in final stage filter bags.

FILTER SYSTEM

The filter system needed to be able to filter down to at least 100 um to be effective. To do this would take either a very large single stage filter system or a smaller multistage system. Investigation of available filter technologies ruled out a single stage filter system due to the initial high purchase cost and high operating costs with what would be very fast clogging of the filter material. It was decided to develop a multi stage filter system that would allow the bulk of the material to be filtered out in the first two stages using comparatively low cost filter materials. This would leave only a small amount of finer material to be dealt with by the third and final stage with it's more effective but also more expensive filter materials.



P7. Filter system on work barge "Waimarie 1".

To reduce the number of pumps needed in the system it was decided to raise the first stage on a stand so that the second stage could be gravity fed from it. The waste water from the second stage would then be pumped out and through the final filter. The first and second stages were constructed the same way with an aluminum tube frame that supported a 1 mm thick Ultraflex Polypropylene bag approximately 1.5 m x 1.5 m and 1 m high. This bag collected the waste water from the filter cages. Inside the polypropylene bag was the filter cage which was made using the frame from a 1000 Lt. fluid crate. This cage supported the filter bags.

The first stage filter bag was a “mussel bag”. These it was thought would fulfill the required criteria for the first stage of being able to filter out larger (above 1 mm) particles, large enough to hold a significant amount of filtered material, and strong enough to remain intact while being handled when full of filtered material. This bag was tied inside the fluid crate frame which held the filter bag open and provided support. This was then placed inside an outer 1 mm Ultraflex polypropylene bag supported by an aluminum tube frame. The stage 1 polypropylene bag had a 75 mm outlet fitting down the bottom of one side with a 75 mm cam lock fitting. This was connected to a short hose to take the water from the stage 1 filters to the stage 2 filters.

The second stage filter bag was made up of two bags, an outer mussel bag for support and strength and an inner bag fabricated from 100 um polyester needle felt. As with the first stage the filter bags and cage frame were contained inside a 1 mm Ultraflex polypropylene outer bag supported by an aluminum tube frame. This stage was designed to filter out almost all of the remaining material and so leave the final stage filters with a small load to deal with. The second stage filter outer bags were left intact without an outlet as the water was pumped out of them and through the final stage filter vessels. Both the first and the second stages were duplicated so as to allow the operation to continue in one stream while the filter bags were being replaced in the other.

The third and final stage of filtration was made up of Filter Specialists Inc. BFN 12 type filter vessels. Two of these were connected with 50 mm pressure grade PVC piping and valves to allow flow through either one or both of the filter vessels as required. The two vessels were mounted in a simple stand frame and were fitted with pressure gauges to monitor the pressure differential across the filter bag. Each vessel has a removable internal screen that supports the filter bag which is 7 “ in diameter and 32 “ long. We had a number of different types of filter bags with different filter media and with pore sizes ranging from 1 um to 200 um. Trials in Wellington established that we could flow the required amount of water through a single filter bag and vessel and further work on the “Steel Mariner” established what types and sizes of bags were practical for use.

Photograph P7 shows the complete filter system set up on the work barge “Waimarie 1”. On the right are the first stage filters mounted up high on stands. The water and entrained material was pumped into these and then gravity fed down to the second stage filters. The photograph shows the crane being used to change a bag in the second stage of stream 2. From the second stage the water was pumped out by an air bellows pump, which in the photograph is hidden behind the man in green overalls, and through the grey filter vessels on the left and overboard.

TESTING

The *D. vexillum* on the “Steel Mariner” provided an ideal opportunity to test the system in a real world situation and possibly contribute to the marine biosecurity of the Marlborough Sounds region. It was decided to undertake an on site test of the system to achieve the contract objectives and to remove the bulk of the *Didemnum vexillum* from the “Steel Mariner” and the barge moored alongside, the “Waimarie 1”. It was arranged that we could use the “Waimarie 1” as a work platform in return for checking it and removing any *D. vexillum* fouling found.

The Cawthron Institute was engaged to assist in testing how effective the filter system would be and to provide expert knowledge of the biological aspects of the field trials in Picton. The Cawthron Institute is a Nelson based marine research institute with knowledge and skill in marine biosecurity research work. On site their field investigator Mr Ashley Coutts would perform the biological science tasks necessary to achieve the objectives. From this work Cawthron and Ashley have prepared a report “The development of incursion response tools – underwater vacuum and filtering system trials” which is in included in this report as an appendix.

It was planned to use a microscope on site to check particle sizes passing through the filters and to take a series of water samples for later inspection to check for *Didemnum vexillum* larvae. The on site microscope would provide some quick quality assurance of the filter effectiveness.

5. OPERATION AND TESTING ON SITE

New Zealand Diving and Salvage Ltd and Cawthron Institute mobilized to Picton to undertake on site trials on 30th July 2002. New Zealand Diving and Salvage Ltd personnel involved were Richard Moore (Project Manager), Bill Humpheries (Principal Investigator), Maurice Kapua (Diver), Brendan Hall (Diver), Robbie Gasson (Diver), and Jim Brodie (Diver). Ashley Coutts from Cawthron Institute also arrived on site. It was intended that the on site operation would be undertaken in 2 phases and during both phases the vacuum recovery and filter system would be tested.

Phase 1 involved the removal and filtration of gross *D. vexillum* fouling on the hull, suspended chains and mooring wire of the "Steel Mariner"

Phase 2 involved seabed boundary marking and systematic removal of *D. vexillum* tendrils fallen from the barge in addition to the larger colonies active on the seafloor and finally, a clean up of *D. vexillum* on the hull of the operational support barge "Waimarie 1".

The vacuum recovery and filtration system was loaded on the work barge "Waimarie 1" in Picton and this was then towed around to the "Steel Mariner" on 30th July 2002. After a one day halt to allow finalization of the contract details the recovery and filter system was set up on the "Waimarie 1" on 1st August 2002. The filter system was set up inside a catch pond made from 1 mm Ultraflex polypropylene. This had sides 300 mm high supported by steel ladder frames and provided a work area for the filter operations. Any water or material spilling during filter changes would be caught in this area and returned to the filter system by a number of battery powered boat bilge pumps. The pond also provided a storage area for the used filters until they were sent to the land fill and allowed water draining from the full bags to be treated and returned to the filter system.

Inside the pond rubber mats were laid to protect it and the filter system was set up. Photograph P7 shows the filter system set up. A crane truck was used for handling of the filter components and of the full filter bags from the first and second stages. The hydraulic power pack to power the cutter head and the air compressor to power the air bellows pumps were placed outside the pond on the stern of the barge. The diving control station was set up outside the pond on the bow of the barge and diving operations were conducted from the stern with a ladder providing access to the water. The system was set up and commissioned on 1st of August 2002 and work on the "Steel Mariner" started on 2nd August 2002.

Prior to work commencing on the "Steel Mariner", Ashley Coutts undertook an assessment of the reproductive state of the *D. vexillum* (Appendix 1. Sections 2.1 and 3.1). This was to assess how likely it was that disturbing the *D. vexillum* during collection would cause the release of larvae and to assess the size of the larvae found in the *D. vexillum* which would dictate the final stage filter pore size. Randomly collected samples of *D. vexillum* from both the "Steel Mariner" and the seabed were collected and some were dissected on site with others archived for further investigation. These were then inspected on site with a microscope and the reproductive state and larvae size assessed. Water samples were also taken after the collection of each sample to assess the response to mechanical disturbance and these were inspected for released larvae. Water samples were also taken to assess total suspended solids before we commenced work.

From this it was found that the *D. vexillum* contained predominantly developing and underdeveloped larvae with occasional developed larvae. These larvae were approximately 300 to 400 um in size. No larvae or embryos were found in the water samples collected after sampling of the *D. vexillum* which indicated that mechanical disturbance did not cause larvae to be released. This was welcome news as one of the difficulties during development had been to build a system that could effectively gather the *D. vexillum* while leaving that remaining undisturbed.

Work on the "Steel Mariner" started on 2nd August 2002 using the hydraulic powered cutter head. Guide ropes were run through under the hull at approximately 10 m spacing to provide a reference for the diver and he then began gathering the *D. vexillum* with the cutter head. Unfortunately this quickly proved to be impractical for use on the scale of the operation involved. The cutter head and hose umbilical assembly proved too awkward for use. It could be used as intended but only very slowly. The equipment was too big with too much drag underwater to be easily maneuvered. The funnel on the cutter head housing also prevented the removal of all of the *D. vexillum* tendrils as it contacts the hull of the barge while the cutter blades are still approximately 200 mm away from the hull. This tended to leave a stub of the tendril intact on the hull approximately 100 – 150 mm long.

After assessing these problems and discussing them with the on site personnel, it was decided to use an alternative method. This was suspending the cutter head under the barge and hand gathering the *D. vexillum* tendrils that would then be fed into the cutter head. The tests on the reproductive state of the *D. vexillum* and its response to mechanical disturbance supported this method as we had not found any larvae being released to the water on disturbance. This implied that the hand picking would not significantly increase the risk of releasing larvae and as the cutter head was so slow and clumsy to use could in fact reduce the overall mechanical disturbance of the operation. Observation of the divers working under the barge showed that just by being there they caused a significant disturbance to the fouling from their bubbles and accidental contact with the fouling and minimizing the time involved working on the hull would minimize the disturbance.

The buoyancy of the cutter head was adjusted to be slightly negative so it could be suspended from the guide ropes and the hydraulic control system changed to allow the cutter to operate without the diver holding the controls. To ensure it was still safe for use the controls were fitted with a quick release cord that would shut the cutter down with a short pull and a man was stationed topside at the hydraulic power pack to enable immediate shut down if needed. The diver then began hand gathering and feeding the collected *D. vexillum* into the cutter head.

With the cutter head in use gathering *D. vexillum* the filtration system testing could be begun. The water and entrained shredded *D. vexillum* was sucked up onto the barge by a Sandpiper SA2-A air powered bellows pump. This type of pump has flap type water control valves rather than the more usual ball type. This allows the pump to pass solids up to 50 mm in size without blocking. Bellows positive displacement type pumps are also self priming which makes them easier to use operationally and minimizes the chances of release of *D. vexillum* to the surrounding water during the pump priming that would be necessary with centrifugal pumps.

From the suction pump the water and suspended material was discharged into the first filter stage. The mussel bag filter in this stage quickly proved to be ineffective. The suspended material quickly filled the small gaps between the fibers making up the bag and the bag overflowed while only approximately 10 % filled with collected material. After some unsuccessful experimentation with punching small holes in the side of the mussel bag we changed the first stage filter bag and put a 200 um polyester needle felt filter bag inside the mussel bag. The polyester inner bag then became the filter medium and although quite fine for a first stage filter at 200 um it still proved effective. The large area of filter pores in the fabric allowed a large amount of material to be collected before they became blocked and the bag overflowed.

P8. First stage filter bag partially full.

Numerous small cuts were made to the fabric of the mussel bag to allow water passing through the inner polyester filter bag to get out of the mussel bag even if a percentage of the mussel bag pores blocked. The polyester filter material proved to be quite delicate with the pulsing stream of water and suspended material from the suction pump quickly punching a hole in the fabric. To prevent this an improvised diffuser was made from a final stage filter bag. This caught the full force of the suction pump delivery and reduced it to a smoother flow. With these modifications to the first stage a filter bag was able to fill to approximately 50 % before blocking and needing replacement.

In the first stage the water and remaining suspended material was caught in the surrounding polypropylene bag and gravity fed into the second stage filters. These worked as planned with a 100 um polyester needle felt filter bag inside a mussel bag.

P9. Second stage filter.

As expected the second stage bags only slowly blocked and for every second stage filter bag used 3 or 4 first stage bags were used. Water filtering through the second stage filters was caught in the surrounding polypropylene bag and then pumped through the final pressure filters by a Price Pump Co 2AOD air bellows pump. An air bellows pump was used for its self priming ability which allowed it to regain prime easily if it pumped the second stage dry and sucked air. A problem was encountered with the second stage surrounding polypropylene bag and support frame with the bag tending to slip out of the lower part of the frame when more than ½ full of water.

P10. Polypropylene bag bulging out of support frame on second stage filter.

This could eventually result in failure of the bag. Simple modifications to the support frames would prevent this happening in future.

Between the second stage filter and the final filters a pressure relief assembly was installed. This was to prevent the pressure rising too high in the final stage. The filter bags in the final stage had a pressure limit of 35 psi that if exceeded could force unfiltered material past the filters and if high enough damage the filters. It was also recommended that the bag be changed when the differential pressure reached 15 psi. The pressure relief system was adjustable and was set to start opening at approximately 15 psi. Each filter vessel also had a pressure gauge to monitor the pressure.

The 2 final stage Filter Specialists Inc. BFN 12 filter vessels were mounted together on a frame with plumbing to allow flow through one or both of the vessels. An initial flow test was undertaken without a filter bag installed to get a base line for later comparison. The entire system was started up with the cutter in clean water and after the water levels in the first two stages had stabilized the output from the final stage was measured by timing how long it took to fill a graduated 1000 Lt. fluid crate. The result was 270 Lt./min. This was approximately ½ of the theoretical pump capacity of approximately 600 Lt./min. It was thought that a combination of hose friction due to the entrained material and pumping to a higher pump head than is used to rate pumps was causing this. It may be possible to increase the flow rate with a larger air compressor to power the pumps.

The size of *D. vexillum* larvae had been established at approximately 300 to 400 um so the first filter bag used was an NFPEIG 100 um bag. To be able to gain a quick on site assessment of the filter systems performance samples were taken and assessed on site. A water sample was taken from the discharge water at the third stage and after allowing it to settle for 15 minutes it was checked under a microscope. The microscope graticule was then used to measure the approximate size of the particulate matter in the sample. Initial samples showed a failed result with particles over 100 um in size. On reflection it was thought that this might be contaminate material on the filter bags or in the housing. This appeared to be the case as when the sampling was repeated 15 and 45 minutes after starting to use the filter bag no particles larger then 100 um were detected. Pressure differentials in the filter vessel were found to be quite low at only 1 – 3 psi. Once we had established that we could filter successfully to 100 um we tried NFPEIG 050 filter bags. The first two bags tried failed with particles larger then 50 um detected in the water samples. A further change of bag resulted in a pass sample with no particles larger then 50 um detected.

P11. Filter bag used in BFN filter vessels.

Once we had established whether a bag type or size was capable of filtering successfully to the advertised size, it was left in use to allow an assessment of how long it would take to block. This time varied from as little as 10 minutes before needing to be changed to over 3 hour of use and still working adequately. Effluent samples were also taken at the stage one and two filters to assess their filtering capabilities. Testing of a number of different type and pore size filter bags continued throughout the operation, the results of this testing are contained in section 6. RESULTS. Further water sampling around the cutter head was also undertaken during operation to assess total suspended solids and to check for released larvae or fragments of *D. vexillum.*

With use some blockage problems were encountered. It appeared that the shredded *D. vexillum* was causing blockages in the suction hose. The reason for this appeared to be related to the cutter head rotation speed. To ensure the shredded material was captured and sucked away with minimal escaping to the surrounding water, it was necessary to run the cutter head at a slow rotation speed. This meant that the hydraulic power pack and hydraulic motor powering the cutter head were running at less than optimum speed and tended to stall if a harder piece of fouling was encountered. With the tendrils of *D. vexillum* often overgrowing other fouling organisms this happened quite often. If the cutter head was run at a faster speed to ensure it did not stall then more material was lost to the surrounding water. It was thought that in the future modifications to the cutter head could solve this problem. The blockages were cleared by blowing the blockage back out of the hose by reversing the suction pump hoses on the surface. This was obviously undesirable as it resulted in whatever was causing the blockage being blown out into the surrounding water.

On 3rd August 2002 some on site thought and discussion resulted in us trying a change of method which turned out to be quite successful. This was to use the suction hose alone with a 50 mm pvc tap and nozzle on the end and directly vacuum to *D. vexillum* up.

While it had been initially thought that the *D. vexillum* would need to be mechanically broken up to be able to be pumped along a 50 mm hose this did not turn out to be the case and it was quite successfully pumped by vacuum alone. Some blockage problems were still encountered but these tended to be blockages at the nozzle. To clear these the diver could shut off the tap to temporarily stop the suction and remove or break up the blockage. Some hose blockages requiring flow reversal to clear were still encountered but far fewer than had been encountered when using the cutter head.

The direct vacuum nozzle proved effective with the diver easily able to maneuver the suction hose and nozzle. The nozzle appeared to capture all of the *D. vexillum* when used on short tendrils. When used on longer tendrils, the tendril tended to detach from the hull and fall down over the suction nozzle before it was all sucked up. This sometimes resulted in the tendril breaking up with the diver chasing small pieces of *D. vexillum*. A cone shaped funnel was tried on the suction nozzle to try to catch the tendril as it detached from the hull but it was not successful, being too large. It was thought that a smaller funnel of a different design would work well. Total suspended solid water sampling was taken during use of the suction nozzle.

P12. Suction tap and nozzle.

Removing the gross fouling from the hull of the “Steel Mariner” was completed on 4th August 2002 and attention shifted to the *D. vexillum* fouling on the seabed. This consisted of large (up to 300 mm) colonies that had detached from the “Steel Mariner” hull and were lying loose and unattached on the seabed and attached colonies growing on generally hard seabed substrate. The attached colonies ranged in size from a few mm to 400 mm.

To ensure a complete coverage and to guide the divers in the low visibility that is the usual result of work on the seabed, the limits of the *D. vexillum* on the seabed was surveyed and marked. The perimeter was marked using a lead core polypropylene rope staked to the seabed. From this, further ropes were run as needed to provide guidance to the divers.

The suction hose and nozzle were used to gather the *D. vexillum* on the seabed. This proved reasonably effective but inevitably there were a large number of blockages due to sticks, shells, stones, etc on the seabed. Problems were also encountered with visibility with the diver and hose stirring up the sea bed to the extent that the diver had difficulty seeing what he was doing. To reduce this a series of buoys were attached to the suction hose to lift it up clear of the seabed, with the exception of a short section at the divers end. This improved the visibility somewhat. The poor visibility resulted in the diver missing approximately ½ of the *D. vexillum*. While they were able to see and capture the larger unattached colonies they tended to miss the small attached colonies which it could be argued were the most important to deal with to prevent the *D. vexillum* establishing on the seabed.

Problems were also encountered with the pumps. The work that they had already done during removal of the gross *D. vexillum* fouling on the "Steel Mariner" combined with the increased amounts of sand and debris from the seabed quickly wore them out. We had some spare pump parts on site and the valves in both pumps were replaced on the 6th August 2002. The pumps continued to loose efficiency however due to deterioration of the bellows and internal seals and were inoperative by 7th August 2002.

On the 6th August 2002 the work barge the "Waimarie 1" was checked and cleaned of any *D. vexillum* found using a hand scraper and catch bag.

A survey on the 6th August 2002 revealed that a strip approximately 7 – 10 m wide by approximately 70 m long had been cleared with up to 60 % of the *D. vexillum* being missed and remaining on the seabed. From this it was estimated that it would take at least a further 7 days and up to 14 days to cover the remaining seabed area and it was likely that approximately ½ of the *D. vexillum* would not be removed. With the pumps inoperative the divers continued hand collection of the *D. vexillum* on the 7th August 2002 while New Zealand Diving and Salvage Ltd and Ministry of Fisheries assessed the situation.

A decision was made on 7th August 2002 to suspend operations and demobilize the diving and vacuum and filtering system. All surface buoys were removed from site but the seabed perimeter marking ropes were left in place to assist future survey work. The diving and vacuum and filter systems were broken down for transport and the barge towed around to Picton to unload. The *D. vexillum* that had been gathered up and until now stored in the pond was taken for disposal at Blenheim landfill. The *D. vexillum* was transported in one of the filter polypropylene bag and aluminum frames to ensure no *D. vexillum* escaped during transport. The transport truck was weighed on the Government Certified Weigh bridge at Provincial Coldstores Ltd in Blenheim before and after land filling the *D. vexillum* to weight the amount dumped. The total weight was 620 kilograms with 473 kilograms collected from the "Steel Mariner" hull and 147 kilograms collected from the seabed.

On return of the equipment to Wellington it was cleaned and dried with the runoff from the cleaning operation draining through a 100 um filter to avoid the accidental contamination of the local coast through the drains.

6. RESULTS

CUTTER HEAD

The development of the cutter head was partially successful. Use on site demonstrated the soundness of the operating principal it uses with the cutter head able to shred *D. vexillum* with little or none being released into the surrounding water. Total suspended solid measurements taken before and during the cutter head use showed no significant increase in particles in the water around the cutter head (Table 1. Appendix 1. See following page). In addition inspection of water samples taken around the cutter head during operation showed no *D. vexillum* larvae or fragments in the water (Section 4.2 Appendix 1.). It did not appear that the cutter head or any of the other operations undertaken caused the *D. vexillum* to release propagules. This may however not always be the case as the reproductive status of the *D. vexillum* at the time of the operations appeared to be dormant (Appendix 1. Sections 3.1 and 4.1). Problems with hose blockages probably due to the relationship between motor speed and hydraulic power were encountered and the practicality of its use was not so successful with the cutter head being too awkward and cumbersome for efficient use underwater.

While the basic principal appears sound the details need some more work which is to be expected with a development project such as this. Many of the problems with the cutter relate to a mismatch between the housing, cutter propeller, and hydraulic drive motor. The cutter propeller was too effective in sucking in water and overwhelmed the ability of the housing to contain and the pumps to remove the resulting water. A less efficient simple bar type cutter rather than a propeller should stop this problem with it being able to effectively shred the material without sucking in an excessive amount of water. The housing would work better if it was shaped like a pump scroll casing with the cross section changing around the diameter to allow room for the water to travel around to the inlet without spilling up and out. The hydraulic motor needs to be tailored to the cutter and housing. This system needed the cutter to turn fairly slowly to avoid material being spilt back out of the cutter head but at the slow speed the hydraulic power pack and drive motor were only idling and therefore stalled when the cutter hit some harder material. If the hydraulic drive motor system was geared to allow it to be at optimum operating revolutions when the cutter propeller was at optimum revolutions this would not happen. It is hoped that this would prevent the hose blockages encountered. An overall reduction in the size of the cutter head is needed. At its present size it is too large and awkward for efficient use. It was felt that a smaller one hand system approximately ½ the size of the present one would be more effective. The front shroud/funnel could be modified to mount it with a spring loaded system to allow a deep funnel to prevent material spilling out but also to allow the funnel to retract on contact with the hull. This would allow the cutters to move forward to cut fouling close to the hulls surface while still preventing material escaping from the cutter head.

VACUUM NOZZLE

Although a system improvised on site, the vacuum nozzle arrangement proved very effective. It was easy and efficient to use underwater and could gather the *D. vexillum* with little lost to the surrounding water. With a comparatively soft organism such as *D. vexillum* it is an effective system, but with tougher organisms such as *Undaria pinnatifida* it might not prove so successful.

A funnel was tried on the vacuum nozzle without success, but it is thought that a modified funnel would work well. A smaller diameter nozzle mounted on a spring system to allow it to retract would help to retain the long tendrils as they pulled off the hull but still allow the nozzle to get close to the hull surface as the funnel retracted. A system or tool to clear the nozzle without using flow reversal would also be useful. This could be a spike type tool to break up blockages or a filter bag to catch and contain material blow out while back flushing to clear the hose.

FILTER SYSTEM

The filter system proved to be effective at filtering particulate matter down to 50 um in size (Appendix 1. Table 3. See following pages).

While the planned first stage filter of a mussel bag was not effective as it quickly blocked, the 200 and 100 um polyester needle felt bags inside mussel bags used in the first and second stage filters proved very effective. Testing showed that they filtered to the stated pore size except for one instance where two 120 um particles were found in samples taken after a 100 um filter bag. On average the first and second stage filters required changing once each day of operation. The support frames worked well with the only problem encountered being a tendency for the second stage outer polypropylene bag to escape under the aluminum frame bars when more than ½ full, see photograph P 10.

The third stage BFN 12 filter vessels filtered down to 50 um successfully using NF PEIG 050 filter bags. Other smaller pore size bags were tried but none worked successfully and in all cases particles bigger then the stated bag pore size were found in water samples taken after the filter. It was not clear as to why this was and in an effort to see if the particles were being forced through or around the filter bag by pressure some trials pouring effluent through filter bags using only gravity were undertaken (Appendix 1, Section 4.4). These however showed particles up to 200 um in size downstream of the filter bag which lead us to believe they may have come from contamination on the outside of the bag rather than through it. The failure to filter to less than 50 um needs further investigation. It would also be valuable to develop a simple on site system to allow a quality check of the filters performance. While checking the water samples by microscope was effective it needed to be done by a trained and skilled person and was quite time consuming with a delay between the sample being taken and the results being available.

The flow rate handled by the third stage filter vessels was uniformly approximately 270 Lt./min regardless of final stage filter bag size. This is probably an indication that the system was running at less than the full capacity possible and was limited by pump capacity rather than filter flow capacity. The bags in the third stage filter vessels were changed when the pressure differential reached 15 psi. How quickly they needed changing depended on the bag type and size. NF PEIG 200,100, and 050 bags took at least 5 to 6 hours of operation before needing to be changed. NF PEIG 025 bags needed changing after 2 or 3 hours. NFW PENG 010, NF PEIG 005, and NF PEIG 001 bags needed changing after approximately 1 hour. BOS 5 PM2P and BOS 25 PM2P needed changing after only 5 or 10 minutes of operation. The limiting factor on the first and second stage filters was when they became so clogged that they overflowed and needed changing which was typically once a day. With the first stage filters this would be when they were approximately ½ full of captured *D. vexillum*. Obviously the type of material being filtered will have a large bearing on how long the filter media will remain effective.

The polypropylene catch pond which the filter system was set up in proved effective with the capture of the inevitable small spills resulting from filter changing etc. It proved hard wearing and was large enough to contain the filter system the crane truck and storage space for full filters. Rubber mats were used as protection in heavy traffic areas.

PUMPS

The air bellows type pumps used on the operation proved to be effective but suffered from a high rate of wear. The pumps proved resistant to blockages as none of the blockages encountered were in the pumps with all being in the suction hoses. The pump wear problems may be solved by either harder wearing pump parts for the existing pumps or replacement with a tougher type of pump.

OVERALL SYSTEM PERFORMANCE

Overall the system performance was good. An assessment of the *D. vexillum* remaining after the operation (Appendix 1. Section 3.1) showed that approximately 80 % had been removed. As the aim of the operation was to remove the gross mass of the *D. vexillum* and not total eradication this is a good result. The system worked well on the hull of the “Steel Mariner” but was not effective when used to collect the *D. vexillum* on the seabed.

7. CONCLUSIONS AND RECOMMENDATIONS

The largely successful execution of this contract has shown that it is possible to develop and use an underwater vacuum and filtering system able to gather marine organisms and filter the resulting effluent down to 50 um with minimal chance of release to the surrounding environment.

Not all areas of endeavor were however completely successful and a number of areas warrant further investigation specifically:

1. Further development of the cutter head to reduce its size and solve the blockage problems encountered.
2. Development of a system to deal with blockages when using the vacuum nozzle that does not result in material being deposited in the surrounding water.
3. Modifications to the first and second stage filter frames to better support the polypropylene outer bags.
4. Further investigation of the failure of filter bags smaller than 50 um.
5. Development of a simple particle size testing system to allow on site checking of filter performance.
6. Investigation of pumps better able to handle the wear encountered.
7. Development of an effective system to use for collecting material from the seabed.

In addition to the above which relate specifically to this operation it would be valuable to investigate the use of the filter system in ship hull cleaning. The filter system combined with an effective collection system on conventional hull cleaning brushes would minimize the material released into the marine environment during these operations. Specific tools should also need to be developed to effectively clean high risk areas on ships such as bow thruster tunnels, rope guards, and sea chests.

8. SPECIFICATIONS

CUTTER HEAD

Powered by a surface mounted hydraulic power pack with two Synflex hoses connected to a SHAR LYNN type hydraulic motor. This was coupled to a 290 mm diameter bronze tunnel type propeller. The propeller was contained in a fabricated stainless steel cylinder of approximately 290 mm diameter by 120 mm height. A heavy stainless bar was mounted across the top of the propeller to allow it to shear the material between the bar and the propeller. 50 mm suction hose was connected to the cutter head housing by Cam Lock quick release fittings. Hydraulic hoses and suction hose were made up as an umbilical bundle. Diver operated, spring loaded twin trigger controls were mounted underneath the main body.

P13. Cutter head see also P3, P4, P5, and P6.

HYDRAULIC POWER PACK

The cutter head was driven by a diesel powered hydraulic power pack delivering 7 US gal/min at 2200 psi. Supply and return hoses were 19mm Synflex.

SUCTION PUMP

P14. Sandpiper Model SA2 – A type 5 suction pump.

STAGE 1 AND 2 FILTERS

Stage 1 filters sat on an elevated stand 1500 mm high fabricated from 50 mm od aluminum tube, see P7. The filter frames were 1575 mm square by 1205 mm height. Fabricated from 40 mm od aluminum tubing with 50 mm x 50 mm aluminum box section base. The frames had a 12 mm ply flooring as a base support. The Stage 1 holding bag was made from 1 mm Ultraflex Polypropylene, 1 metre high and 1.5 metres square. This bag is rigged to the frame by four 12 mm stainless rods slotted through collars at the top of the bag and lashed in place. A 75 mm outlet was positioned at the bottom of the first stage outer bags. The outlet had a cam lock fitting to allow connection to an outlet hose. This outlet was only on the first stage filter outer bags.

P15. Stage 1 and 2 filter frames, see also P7

Inside the outer 1 mm polypropylene bag was the filter cage made from a 1000Lt. Fluid transport crate. The filter bag was lashed to the top of this. The effluent delivery hose in the first stage had a diffuser improvised from a third stage filter bag. This was to stop damage to the 200 um filter fabric from the pulsing water flow of the suction pump. See P7, P8 and P9. The filter bags were sewn bags 900 mm x 1100 mm and 1400 mm high fabricated from 100 and 200 um polyester needle felt fabric. In both the first and second stage filters these were placed in side mussel bags to provide support especially when removing a full filter bag.

P16. Stage 1 and 2 inner filter support frame.

FINAL FILTER STAGE PUMP AND PRESSURE RELIEF

The effluent was sucked out of the second stage filter outer polypropylene bas and pumped through the final stage filter vessels by a Price Pump Co model 2AOD_ABBB bellows pump.

Between the pump and the final filter stage filter vessels was a pressure relief system. This was fabricated from plastic pipe fittings and two 30 mm id stainless steel flap type non return valves. The non return valves were modified with the addition of springs and tension screws to allow adjustable pressure to be exerted on the flaps in them. This allowed them to be adjusted to open at approximately 15 psi. When open they vented effluent into the pond and prevented the pressure in the filter vessels rising too high.

P16. Price Pump Co 2AOD-ABBB pump.

P17. Pressure relief assembly.

STAGE 3 FILTER VESSEL

The final stage filters were formed from 2 Filter Specialists Inc. BFN 12 model BFNP 12 316SS filter vessels. These use a single # 2 filter bag each, see P11. The two filter vessels were mounted upright in an aluminum frame.

P18. BFN 12 filter vessels

The two filter vessels were linked with 50 mm high pressure pvc pipe and fittings in a "Y" arrangement. Taps on each branch of the "Y" allowed flow to be controlled with either or both of the vessels having flow. This allowed the bag to be changed in one vessel while the other was filtering effluent so as to allow a continuous operation. Each pressure vessel had a top mounted pressure gauge to monitor the internal pressure. Each filter vessel had a bottom drain tap and the outlet fitting was fitted with a 50 mm camlock fitting to attach a discharge hose to take the filtered effluent overboard.

POND

The filter system was contained in an approximately 8 x 20 m 300mm high pond fabricated from 1 mm thick Ultraflex polypropylene. This was supported at the edges by steel rhs ladder frames. Two 12 volt boat bilge pumps returned any spillage in the pond to the second stage filter. These were powered by 12 volt car batteries. Photograph P7 shows the filter system set up in the pond.

FLOW RATE TANK

A 1000 Lt. plastic fluid transport crate was used to measure flow rates. This was graduated and flow rates were measured by timing how long it took to fill. Photograph P7 shows the flow rate tank on the left.

9. REFERENCES

1. Coutts A. D. M. 2002 A biosecurity investigation of a barge in the Marlborough Sounds. Cawthron Report No. 744. July 2002: 59.

10. APPENDICES

1. Coutts A. D. M. 2002 The development of incursion response tools – underwater vacuum and filtering system trials. Cawthron Report No. 755 August 2002.