Results of an attempt to control and eradicate *Undaria pinnatifida* in Southland, New Zealand

April 1997 - November 2004

Department of Conservation
Te Papa Atawhai

New Zealand Government

Results of an attempt to control and eradicate *Undaria pinnatifida* in Southland, New Zealand, April 1997 - November 2004

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Cover photo – *Undaria pinnatifida*. CH Hay

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Abstract

This report documents an attempt to eradicate the introduced seaweed *Undaria pinnatifida* in Southland, New Zealand between 1997 and 2004. The first established New Zealand populations of Undaria, a large brown kelp native to Asia, were recorded in Wellington in 1987. The species spread steadily around New Zealand's coast and was discovered in Big Glory Bay, Stewart Island on March 13 1997. Delimitation surveys the following month around Stewart Island and the South east coast of the South Island, including Bluff Harbour, suggested Undaria was restricted to a localised area of marine farms in Big Glory Bay. Attempts to eradicate this founding population were initiated by the Department of Conservation in late April, on the advice of recognised national algal and pest management experts. The aim was to prevent establishment, and further spread around Stewart Island, and into Fiordland and the Subantarctic Islands.

The eradication programme in Big Glory Bay consisted of the manual removal of any Undaria plants located during regular dive inspections of marine farm structures and shoreline areas neighbouring known populations. Monthly or bimonthly diver surveys were timed to detect and remove all sporophytes before they reached sexual maturity and release spores. Mussel rafts, barges, ropes and boats harbouring Undaria were also treated or removed from the water to kill the microscopic gametophyte life stage. A surveillance programme was implemented at high-risk invasion sites at Bluff Harbour and around Stewart Island to detect spread or new Undaria incursions. The eradication programme was extended to Bluff Harbour (1999), and Halfmoon Bay (2000) following the discovery of new founding populations.

The programme successfully controlled the original founding population of Undaria to low densities, and prevented spread from Big Glory Bay. However, eradication was not achieved, primarily due to two new incursions arising from independent founding events at Bluff Harbour and in Halfmoon Bay, Stewart Island. Ongoing costs of control at all three sites could not be sustained without central government funding and development and adoption of a national Undaria management program. Central government support was withdrawn in 2004 when the Southland Conservancy was unable to convince the funding agency (Biosecurity New Zealand) that the ongoing eradication/control programme was justified particularly when prioritised against other biosecurity projects. The programme therefore ceased on November 30, 2004.

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1.1 SPREAD OF UNDARIA TO SOUTHLAND

Undaria pinnatifida (Harvey) Suringer is a large brown annual kelp, native to temperate regions of Japan, China and Korea. Introduction of *U. pinnatifida* (henceforth referred to as Undaria) to New Zealand is thought to have occurred via the persistence of propagules within ballast water (Hay & Luckens 1987). Coastal dispersal around New Zealand is believed to have occurred via external hull fouling and transfer of marine farm equipment or mussel spat. Since its discovery in Wellington Harbour in 1987, Undaria has spread throughout New Zealand forming established populations in Auckland, Coromandel, New Plymouth, Porirua, Wellington, Gisborne, Napier, Nelson, Golden Bay, Wainui Bay, Picton Kaikoura, Lyttleton Akaroa, Timaru, Oamaru, Moeraki, Otago Harbour, Bluff and Stewart Island. Populations have spread from enclosed Harbours onto the open coast at Wellington, Nelson, Timaru, Moeraki and Otago Harbour (M. Stuart, *pers. obs.*).

The spread of Undaria has caused concern overseas as it has invaded the coastal environment in parts of Europe, Tasmania, mainland Australia, Argentina and the USA (Hewitt *et al*. 2005 and citations therein). Although published evidence of ecological impacts are equivocal (e.g., Forrest & Taylor 2002) recent studies suggest that Undaria has the potential to displace native seaweed species and significantly alter habitat for associated fauna including commercial species like abalone (*Haliotis iris*) and sea urchins (*Evechinus chloroticus*) (Casas *et al.* 2004, Curiel *et al.* 2001, Silva *et al.* 2002, Valintine and Johnson 2003).

Undaria was first reported growing on a marine farm structure in Big Glory Bay, in Paterson Inlet, Stewart Island in March 1997. This represented a major southern extension in its range, with Undaria previously unrecorded south of Otago Harbour. Various recognised marine ecologists (W. Nelson, C. Hay, R. Cole *pers. comm.*) raised concerns to Department of Conservation (DOC) about the potential impacts of Undaria on native marine algal communities in Southland. Wider consultation also elicited concerns that Undaria could have economic impacts on the aquaculture industry on Stewart Island. These concerns centred on the potential fouling risks to mussel and salmon farms resulting in increased harvesting costs and farm maintenance.

In April 1997, Southland Conservancy of DOC initiated a programme to eradicate Undaria from Big Glory Bay. The programme was developed following consultation with and independent advice from a group of New Zealand's leading marine ecologists and plant pest control experts. The eradication programme was based on the following rationale:

1. Undaria was believed to pose a significant threat to the internationally significant near shore marine communities of Stewart Island, Fiordland and the Subantarctic Islands;
2. Undaria appeared to have a localised distribution in Big Glory Bay and was largely limited to artificial structures, suggesting eradication was feasible;
3. Undaria could not naturally colonise Southland coastal waters as all known populations were downstream of prevailing oceanic currents, thus further introductions to Stewart Island waters were reliant upon human vectors.

The eradication programme in Big Glory Bay consisted of the manual removal of any Undaria plants located during regular dive inspections of marine farm structures and shoreline areas neighbouring known populations. Mussel rafts, barges, ropes and boats harbouring Undaria were also treated or removed from the water. The programme was extended into Bluff Harbour (1999) and Halfmoon Bay (2000) after new founding populations were discovered at these sites. A vessel-monitoring program was implemented in May 1999 at key Otago and Southland ports to identify fouled vessels that might introduce Undaria into southern waters.

This final report documents the Undaria eradication attempt in Southland coastal waters between 1997 and the cessation of operations in 2004

1.2 UNDARIA BIOLOGY

Undaria pinnatifida is an annual laminarian kelp with a heteromorphic life cycle characterised by macroscopic sporophytic and microscopic gametophytic stages (Figure 1). The sporophylls of Undaria are produced at the base of the stipe and consist of fluted and sinuate thickenings along each edge of the stipe, bending laterally around the stipe in such a way as to give the appearance of a single helix (Hay 1990). Microscopic sacs are arranged at the margins of each sporophyll and release spherical, biflagellated zoospores of 5-6 μm diameter (Perez *et al*. 1981). Released spores attach to available substrate and germinate into dioecious gametophytes which can remain viable for longer than 2.5 years (Hewitt *et al.* 2005). Mature gametophytes produce motile sperm and non-motile eggs, which fuse to form a zygote, which adheres to the substratum before developing into a mature sporophyte (Figure 1). The reproductive temperature boundaries of Undaria are 7 to 23° C (Sanderson 1990).

There are no native annual laminarian kelps in New Zealand. The closest related laminarian species are perennial (e.g. *Macrocystis pyrifera*, *Lessonia* spp. and *Ecklonia* spp.) and the only other annual kelp is a fucoid (e.g. *Sargassum sinclairii*). The closest ecological equivalent to Undaria is *Desmarestia ligulata*, which has a similar life history characterised by an annual alteration between heteromorphic life history stages (e.g. sporophyte and gametophyte).

Undaria exhibits several traits characteristic of an invasive species that may favour its spread and colonisation of New Zealand tidal rocky shores (Stuart 1997). These traits include:

- A broad ecological niche characterised by an ability to complete its life history over a wide range of temperatures and in different habitats, ranging from highly modified enclosed harbours to semi-exposed open coast.
- A preference for artificial substrates and rapid growth rates.
- An r-selected life strategy characterised by short sporophyte longevity (6-9 months), rapid growth rates (1 cm/day), early maturation (ca. 40-50 days), and high fecundity (Campbell and Burridge 1998, Saito 1975, Schaffelke *et al*., 2005, Stuart 1997).
- Phenotypic plasticity and the presence of different morphological forms (Stuart 1999).
- No close phylogenetic relatives in the indigenous marine flora.

1.3 PROGRAMME HISTORY

The initial discovery of Undaria on a marine farm structure in Big Glory Bay, in Paterson Inlet, Stewart Island was made by a National Institute of Water and Atmospheric (NIWA) research scientist in March 1997. In early April a delimitation survey was carried out by divers from DOC, NIWA and the Cawthron Institute. The following week, a meeting of plant pest management and algal experts from DOC, NIWA, the Cawthron Institute and the Museum of New Zealand determined eradication was practicable and should be attempted. The group considered that the spread of Undaria to the rest of Stewart Island was likely to follow establishment in Big Glory Bay. Furthermore, introductions to Fiordland and the Subantarctic Islands could occur if the population was permitted to expand unchecked. In all cases they considered that the biodiversity values of the sub-tidal communities of Stewart Island, Fiordland, and the Subantarctic Islands were too important (both nationally and internationally) for this potential threat to be ignored.

Eradication appeared feasible because Undaria seemed to be restricted to a few marine farms, farm equipment, and one small shoreline area. Suitable rocky sub-tidal habitat was limited to a shallow (<10 m deep) narrow band of coastal rock. Most of Big Glory Bay is over 20 metres deep (below assumed depth limit of Undaria),

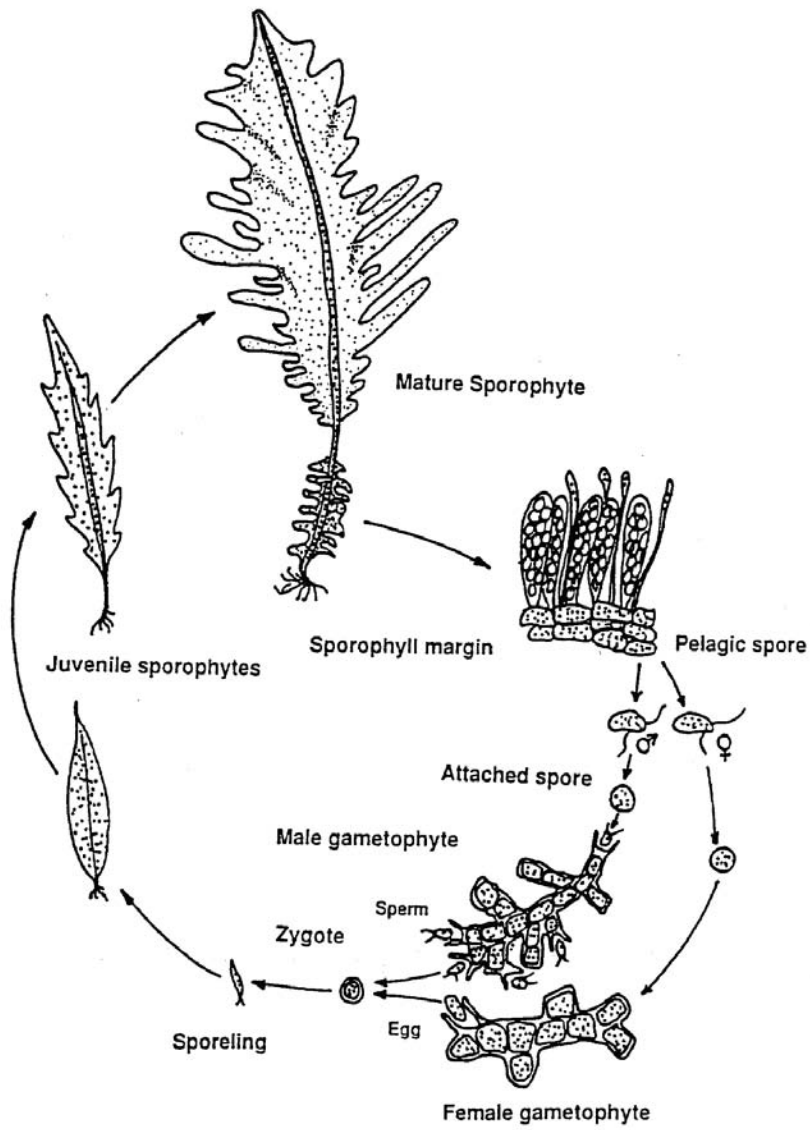

Figure 1, Life Cycle of *Undaria pinnatifida* (from Stuart 1997).

and has a soft mud or sand substrate, unsuitable for Undaria colonisation. The few marine farm structures fouled with Undaria were largely mussel lines that would eventually be harvested, or boats and barges that could be removed from the water and treated. Hence if further spread could be prevented then the microscopic gametophytic stages could be treated on these sites. This left a small area of shoreline that required suitable treatment techniques to be developed in order to achieve eradication.

On the basis of this advice, the Southland Conservancy of DOC initiated a control programme to maintain the potential opportunity for eradication while central and local government agencies determined responsibility and funding sources. In November 1997 a formal Technical Advisors Group (TAG) was established comprising the original advisors and an additional scientist from Otago University. The group met to review progress, evaluate suitability of methodologies and set performance guidelines for an eradication programme. Thereafter the Undaria programme was reviewed annually by the TAG. Their advice and recommendations were used to refine methods and provide central government with an independent assessment of the programme's progress against preset milestones.

1.3.1 Undaria Eradication Programme

Chronology of Events:* Undaria *on Stewart Island.

March 1997	*Undaria pinnatifida* was discovered by NIWA scientists growing on a marine farm fuel barge in Big Glory Bay, Paterson Inlet, Stewart Island.
April 1997	An initial delimitation survey found the Undaria infestation was restricted to a small number of marine farm structures (3 farms and 6 small rafts/barges) in Big Glory Bay. A meeting of DOC, Ministry of Fisheries (MFish), and Environment Southland representatives agreed introduction was a concern, but was unable to resolve response accountability. An informal consultation meeting with scientific experts on Undaria ecology, and weed management convened by DOC considered that eradication was feasible, but intervention was urgently required owing to concerns of imminent spore release. DOC initiated a response and all visible plants were removed from structures in Big Glory Bay. Colonised rafts and barges were treated with chlorine in an attempt to sterilise gametophyte banks.
May 1997	An ongoing control programme was initiated. All farm structures and the shoreline in the immediate vicinity of the original infestation were inspected at an approximately six weekly interval. Any sporophytes identified were removed by hand. All initial costs were funded through redirection of Southland conservancy resources including staff time.
June 1997	Funding was sought from central government under the Biosecurity Act (1993) for ongoing control programme (to achieve containment and eradication). The Conservancy was unable to sustain the programme with limited local Vote Conservation resources.

August 1997	Approximately a third of the estimated annual budget for an ongoing control programme was provided by way of a $145 000 allocation from Vote Biosecurity for the 1997/1998 financial year.
November 1997	The Department convened a formal Technical Advisory Group (TAG) that was made up of independent scientists with Undaria expertise and plant pest management specialists. The TAG were asked to review and advise upon eradication methodology, and to set performance targets as a basis for evaluating whether the programme was meeting its stated objectives. Review was set for April 1998.
February 1998	Southland Marine Farmers Association met and agreed to co-operate where possible with the eradication programme.
March 1998	The Cabinet Economic Development Committee (CEDC) considered the ongoing DOC led eradication programme. The committee requested the programme be assessed against an agreed set of technical standards and targets.
April 1998	All data collected to April 1998 was collated and the complete report was presented to the TAG for formal review and assessment against performance targets. Although two of the reviewers considered the recent discovery of another shoreline population (in Big Glory Bay) would make eradication more difficult, all agreed that efforts to eradicate Undaria from Big Glory Bay (by 2002) were still on target and achievable. They unanimously recommended that the programme should continue.
May 1998	Undaria found in Bluff Harbour. The plants appeared morphologically different to those in Big Glory Bay, indicating a likely second introduction into Southland waters. Subsequent genetic studies (Uwai, 2006) confirmed this.
July 1998	Cabinet approved a single $330 000 allocation from Vote Biosecurity funds for the continuation of the eradication programme through to January 1999. Continuation of the eradication programme beyond January 1999 would be contingent on a positive scientific review of the feasibility of eradication and a complete cost/benefit analysis.
December 1998	Regular dive surveys previously carried out by DOC staff were contracted out. DOC staff shift focus to managing the programme and auditing monthly or bimonthly checks of Big Glory Bay.
January 1999	TAG undertake a complete review of all data collected up to December 1998. They agree programme still on target, but recommend Bluff Harbour incursion needs to be managed. TAG reiterates that programme will fail unless the appropriate agencies manage Undaria vectors at national scales.
April 1999	CEDC approved funding allocated from Vote Biosecurity to fund the next five years to allow the eradication efforts in Big Glory Bay and Bluff Harbour to continue. Ministry of Fisheries (MFish) are directed by Cabinet to develop a National Pest Management Strategy (NPMS) for Undaria management.

June 1999	DOC redirects some eradication resources to establish a vessel monitoring programme for key South Island ports with regular vessel traffic into Southland waters. Programme identified and removed Undaria from several vessels that visited Bluff harbours.
March 2000	DOC informed MFish that the deep sea trawler *Seafresh 1*, which had just sunk at the Chatham Islands, had been identified as fouled with Undaria during its vessel monitoring programme. Subsequent inspections confirmed Undaria growing on the vessels submerged hull.
April 2000	MFish declared Undaria an Unwanted Organism under the Biosecurity Act 1993 (Wotton et al. 2004). Eradication response to Seafresh initiated. NPMS for Undaria put on hold.
June 2000	Wharf pile sterilisation project tested PVC sleeves injected with algacide. Results were equivocal, and approach abandoned following further toxicity testing. Development of an underwater hot water treatment system to treat shoreline populations initiated.
August 2000	Another shoreline population of Undaria was discovered in Big Glory Bay Stewart Island. Presumed to represent spread from nearby marine farms.
August 2000	An independent scientific review of the programme concludes that eradication was still feasible in Big Glory Bay, but a lack of data made the June 2002 outcome less certain. They recommend that additional management approaches were needed to target the gametophyte stage and new shoreline populations.
October 2000	A new shoreline population of Undaria was found in Halfmoon Bay Stewart Island. The plants appeared to be the same morphology as those present in Bluff harbour. Management of these populations was initiated and funded from within the existing Undaria budget. Subsequent genetic analyses (Uwai, 2006) suggest a more northern origin.
November 2000	Annual independent review outcomes are in agreement with the findings of the August 2000 review. Concerns raised about the ability of the programme to meet eradication deadlines particularly in Bluff (June 2004) and Halfmoon Bay (June 2002). However, there was general agreement that the programme should continue.
March 2001	CEDC approve continuation of funding through to 2002 and direct the Ministry of Fisheries to develop a national framework for the management of Undaria
June 2001	DOC hot water treatment system modified and successfully used to eradicate Undaria on *Seafresh 1*, in Chathams Islands. *Seafresh 1* had undergone monthly monitoring and removal of mature plants since sinking in March 2000.
September 2001	Hot water treatment of gametophytes initiated in Halfmoon Bay and the largest Big Glory Bay shoreline population.

November 2001:	Independent review concedes that eradication would not be possible by the 2002 target date. Detection of new founding populations was not seen as a programme failure, but a need for wider surveillance.
June 2002	Contracted surveillance and sporophyte removal was halved to 11 days per month total for Bluff and Stewart Island due to a reduction in funding.
October 2002	Programme goals revised in conjunction with a reduction in funding. Objective shifted to control rather than eradication of Undaria. New objectives were: Stewart Island: 1. Surveillance for and control of Undaria to zero density at sites from which risk of Undaria spreading is high (e.g.; Scollay Rocks, Halfmoon Bay and selected sites within Big Glory Bay). 2. Surveillance for and control of Undaria to low densities (e.g. containment to levels recorded in June 2002) at sites from which risk of Undaria spreading is low to moderate (e.g. remainder of Paterson Inlet and Big Glory Bay). 3. Detailed vector management (monitoring vessels that visit the island). 4. Ongoing public awareness/education programme to focus on vector management and surveillance opportunities. 5. Incursion response capability to be maintained in order to control any new founding populations in accordance with points 1 and 2 above. Bluff Harbour: 1. Localised control of Undaria to prevent its spread to parts of the harbour where risk of vessels contaminating is high. 2. Detailed vector management (monitoring of vessels likely to visit Stewart Island, Fiordland or Subantarctic Islands). 3. Ongoing public awareness/education programme to focus on vector management opportunities. Other key South Island ports (Otago, Port Chalmers, Timaru): 1. Targeted vector management (monitoring of vessels likely to visit Stewart Island, Fiordland or Subantarctic Islands). 2. Ongoing public awareness/education programme to focus on vector management opportunities.
September 2004	TAG reviewed results of ongoing programme and concluded control was both feasible and practical. They agreed that Undaria was effectively being controlled to low density at all sites, but that this work would be difficult to sustain without national funding or management.
November 2004	Funding unable to be secured. Control programme abandoned. Low level monitoring initiated to document subsequent spread.

1.4 FUNDING HISTORY

Operational costs, including significant redirection of staff hours, between April 1997 and August 1997 were sourced from Southland Conservancy core budget. All diving, cleaning and sterilisation was undertaken by DOC staff using DOC equipment and boats.

On 18 August 1997, Cabinet (CAB (97) M31/4D(4)) agreed that despite the absence of a clear responsibility to undertake control action, Government intervention was warranted in the short term to manage the threat to a pristine environment of international repute. Cabinet agreed to DOC conducting an eradication programme in 1997/98 with costs to be met by way of a fiscally neutral transfer from within Vote: Biosecurity, as follows:

YEAR	TOTAL ($ GST INCLUSIVE)	CABINET REFERENCE
1997/98	163 000	CAB (97) M 31/4D(4)

The allocation was about half of that requested by Southland Conservancy. It was used to cover fuel costs and employ two to three contract divers to supplement existing DOC diver capacity. The internal costs to DOC for the 1997/98 fiscal year were estimated at $150 000.

On 20 July 1998, Cabinet (CAB (98) M 25/5D) approved funding of the eradication programme for the 1998/99 year. This was by way of a fiscally neutral transfer from within Vote: Biosecurity. This allocation was used to employ a full time coordinator and cover all costs associated with the programme including funding of a contract dive team to undertake the monitoring and harvest of Undaria.

YEAR	TOTAL ($ GST INCLUSIVE)	CABINET REFERENCE
1998/99	371 000	CAB (98) M 25/5D

On 12 April 1999, Cabinet (CAB (99) M 10/5(5)) approved additional funding for the eradication programme in the 1998/99 year by way of a fiscally neutral transfer from within Vote: Biosecurity, and approved conditional funding for subsequent years, concluding at the end of the 2003/04 year, as follows:

YEAR	TOTAL ($ GST INCLUSIVE)	CABINET REFERENCE
1998/99 (additional)	146 000	CAB (99) M 10/5(5)
1999/2000	648 000	CAB (99) M 10/5(5)
2000/01	648 000	CAB (99) M 10/5(5)
2001/02	620 000	CAB (99) M 10/5(5)
2002/03	115 000	CAB (99) M 10/5(5)
2003/04	115 000	CAB (99) M 10/5(5)

Cabinet (CAB (99) M 10/5(5)) agreed that appropriations beyond 1999/2000 were to be conditional upon:

- receipt and acceptance of an annual report back to the Treasurer, Minister of Finance, Minister for Food, Fibre, Biosecurity and Border Control, and Minister of Conservation on the effectiveness of the programme by 31 December of the financial year preceding the year in which ongoing Crown funding for the programme is sought; and

- the preparation of a proposal for a national pest management strategy for Undaria by 30 June 2000. [Note: this action was superseded by a new direction from Cabinet (CAB(01) M 01/12/6(4)) to develop a framework for the management of Undaria.]

In 1999, Cabinet (CAB (99) M8/1D) directed the Ministry of Fisheries (as lead agency for marine biosecurity issues) to prepare a proposal for a National Pest Management Strategy (NPMS) for Undaria. As part of the analysis required to develop and fund the NPMS it was determined that future decisions on the management of Undaria be made in light of the relative threat it poses to the marine environment compared to other biosecurity threats. For that reason Ministers determined not to proceed with a NPMS in the immediate future. Instead Cabinet provided limited funding to the Ministry over a two-year period ($275 000 per annum for 2001/02 and 2002/03), to study the establishment of an appropriate framework for the management of Undaria.

Due to the decrease in Undaria Vote: Biosecurity funding in 2002/03 DOC sourced core funding to the value if $100 000 to provide interim weed management until a "whole of government approach" was developed. On October 8, 2003 the Cabinet Economic Development Committee agreed to provide a further $100 000 (EDC(03) 209) to manage Undaria until 2004/05 budget bids had been considered.

In the 2004/05 biosecurity budget new initiative bids were considered and prioritised by the biosecurity Chief Executives Forum and presented as a package to the Biosecurity Ministers for further consideration. Undaria was part of an environmental package. Through the budget process the Environmental Ministers made decisions on priority funding and Undaria management was one of a number of biosecurity bids that failed to receive funding.

As a result of loss of national funding the Southland Undaria programme was reviewed according to the DOC Weed-led Reporting and Reviewing SOP in September 2004. The financial implication for continuing the control programme was an ongoing cost of $450 000 per annum from 2004/05. DOC was unable to reprioritise to meet the additional $350 000 per annum therefore the control programme was ceased on 30th November 2004. The total weed-led operating work carried out by Southland Conservancy in 2004/05 consisted of 43 projects with an total budget of $989 000, hence in order to fund ongoing Undaria work 45 % of existing weed-led work would have been curtailed.

TABLE 1. BUDGET AND SOURCE OF FUNDING USED TO RUN THE SOUTHLAND UNDARIA PROGRAMME FROM 1997- JULY 2004.

FISCAL YEAR END	VOTE: BIOSECURITY	VOTE: CONSERVATION (BIODIVERSITY)	VOTE: CONSERVATION (CORE)	**TOTAL**
1997			50 000	**50 000**
1998	146 000		150000	**296 000**
1999	459 000			**459 000**
2000	576 246			**576 246**
2001	600 635			**600 635**
2002	551 360			**551 360**
2003	97 048	100 000		**197 048**
2004	102 000	89 000	81 000	**272 000**
Total	**2 532 289**	**189 000**	**81 000**	**2 802 289**

2. Methods

The Undaria control and eradication programme consisted of seven aspects:

1. Delimitation to assess the scale of the incursion;
2. Surveillance monitoring of areas free of Undaria to detect new incursions into Stewart Island or Bluff Harbour;
3. Control of existing incursion, through regular monitoring of all known populations, and physical removal of macroscopic sporophytes to prevent spore release to achieve eradication;
4. Sterilisation and removal of structures and debris providing substrate for microscopic sporophytes and gametophytes;
5. Vessel monitoring to detect potential Undaria vectors;
6. Marine farm containment measures to prevent introductions from spat or infected marine farm equipment;
7. Post control monitoring to study the spread of Undaria.

2.1 DELIMITATION SURVEY

A survey of marine farm structures in Big Glory Bay, and wharf facilities in Bluff Harbour and around Oban was carried out from April 5-10, 1997. The survey of farm structures was undertaken with one diver snorkeling each mussel line and weaving in and out of the droppers, and checking buoys from one side. A short area of coast line was also inspected by divers immediately around the most heavily infected barges in Big Glory Bay. Where small numbers of plants were located on outer marine farms these were removed and taken back to the support vessel.

The two existing salmon farms were also inspected by divers using snorkel, and a single SCUBA dive inspection of the farm closest to the main infestation was also undertaken.

Moorings, vessels and wharves in Halfmoon, Horseshoe, Golden and Thule bays on Stewart Island were also inspected by a single diver on snorkel.

Wharf areas and moored vessels around Bluff Harbour were surveyed using a combination of snorkel dives and surface inspection of the immediately subtidal areas from a boat at low tide.

In Riverton a surface inspection was used to check for any established plants.

2.2 SURVEILLANCE MONITORING

Since 1997 surveillance has been conducted around the main harbours and wharf facilities on Stewart Island and within Bluff Harbour to identify any new incursions. Effort concentrated on wharf structures, mooring lines and blocks, stern lines, slipway areas and the shorelines adjacent to popular sites. Surveillance areas were surveyed on a triannual basis or as resourcing allowed. Any new infestations detected were added to the monthly control survey sites.

Surveillance monitoring was also undertaken at the main moorings and wharf facilities in Fiordland in April 1998 then regularly since 2001.

Surveillance for Undaria has been limited at the New Zealand Subantarctic Islands due to their isolated nature. On October 3rd 2000 an Undaria surveillance dive was carried out by two divers on SCUBA and one diver on snorkel in Port Ross, Auckland Islands. They focused on a 5 – 7 m deep band around the shore and covered most of the coast from Johnson Point to Davis Island. In February 2004 a marine biodiversity survey to the Auckland Islands also surveyed a number of additional sites for Undaria including SCUBA dives at Tagua Bay and around the shoreline of the Grafton in Carnley Harbour and snorkel checks in Port Ross (Terror Cove, Deas Head, Enderby), Ranui, Waterfall Inlet and Camp Cove. In September 2004 the Met Service Wharf at Beeman Base, Campbell Island was checked using snorkel.

2.3 CONTROL (PHYSICAL REMOVAL) TO ERADICATE

Regular inspections and manual removal of Undaria have been the primary methods of control aimed at preventing spore release and stopping further spread of Undaria within or from Big Glory Bay. Eradication would be achieved (it was thought) once the existing gametophyte population was exhausted, removed or killed off by the regular removal of sporophyes, as well as the combination of divers stripping colonised substrates and marine farmers harvesting mussel lines and carrying out ongoing farm maintenance (e.g. cleaning mussels buoys).

At regular intervals , pairs of snorkelers would inspect mussel farms by swimming on opposite sides of the back bone lines, completing regular breath-hold dives to 5-10 m depth to inspect the mussel dropper lines. The water clarity in Big Glory Bay is generally > 7 m but can significantly decrease during plankton blooms or in the presence of a fresh water layer. The diver would weave in and out of the dropper to detect Undaria. If sporophytes were observed, divers would remove the entire plant by hand and often the mussels associated with its hold fast. From 2001 divers also cut out the infected dropper lines. Infected areas were often marked with flagging tape to enable close inspection the following month. Sporophytes in deep water (7-10 m) were removed by divers using scuba and the immediate area was searched to locate any additional plants.

Up until September 1997 buoys with large numbers of small sporophytes (1-5 cm) were scraped clear with the substrate (tunicates, mussels, tubeworms and algae) and collected in commercial catch bags. From October 1997 onwards, small sporophytes (1-5 cm) were left until the next check due to concerns that divers' had difficulty with collecting or retaining all the small sporophytes in the dive bag and there was a risk of dislodging gametophytes and small plants, which might resettle in deeper water.

Mooring lines at either end of mussel lines were initially inspected on multiple breath hold dives of 5 -7 m depth. From November 1997 lines on farms containing Undaria were inspected using SCUBA and underwater scooters on a bimonthly basis. Any deep water infestations were also monitored using SCUBA. Again, where plants were located these were removed. Where appropriate mussels or substrate holding large Undaria plants were also removed and disposed of on land.

The two salmon farms were also inspected on snorkel with individual divers swimming between the salmon nets and farm superstructure (pontoons). Again all mooring lines were inspected by scuba divers.

Parts of the shoreline within Big Glory Bay were searched periodically from 1997 as resources enabled and on a priority basis. Original survey effort was on the affected marine farm structures, although in February and March of 1998 the entire shoreline of Big Glory Bay was searched for new founding populations as monitoring workload decreased. Shoreline searches were carried out on snorkel, with aid of underwater scooters.

Plant material was removed from dive bags on the boat and counted, or put into labeled bags. Plants were generally preserved in salt and labeled for later measurement. However, data integrity was sometimes sacrificed especially in the early and closing stages of the program where limited resources were deployed with an emphasis on completing a full inspection and clearance.

After the November 1997 technical review, changes were made to dive monitoring practices. All material was removed from bags between sites and dive bags were sterilised in a solution of chlorine before re entering the water. The use of sealable bags to hold mature sporophylls and to prevent possible spore dispersal by divers was trialed but found to be impractical and time consuming and was discontinued.

The idea of using chlorine pills in bags as a possible method to kill any released spores was not attempted due to concerns about contamination of mussels and the need for consultation with farmers and health officials.

From 2002 all catch bags and gloves were sterilised between sites using heptanes disinfectant. These precautions were introduced to reduce the chance that divers might be enhancing Undaria dispersal if the action of sporophyte removal was inducing spore release from mature plants. On the contractor's boat, bilge water was held onboard until decks were washed with HTH Chlorine to prevent spore dispersal.

Monitoring effort fluctuated over the seven years of operation (Figure 2) reflecting resource availability and Undaria population density. Prior to December 1998 all work was undertaken using a DOC dive team. Thereafter, monthly monitoring and Undaria removal was contracted to an independent company.

Department staff undertook monthly audits of contractors control efforts. Audit data was incorporated into the control data referenced in Appendix 3. From July 2002,

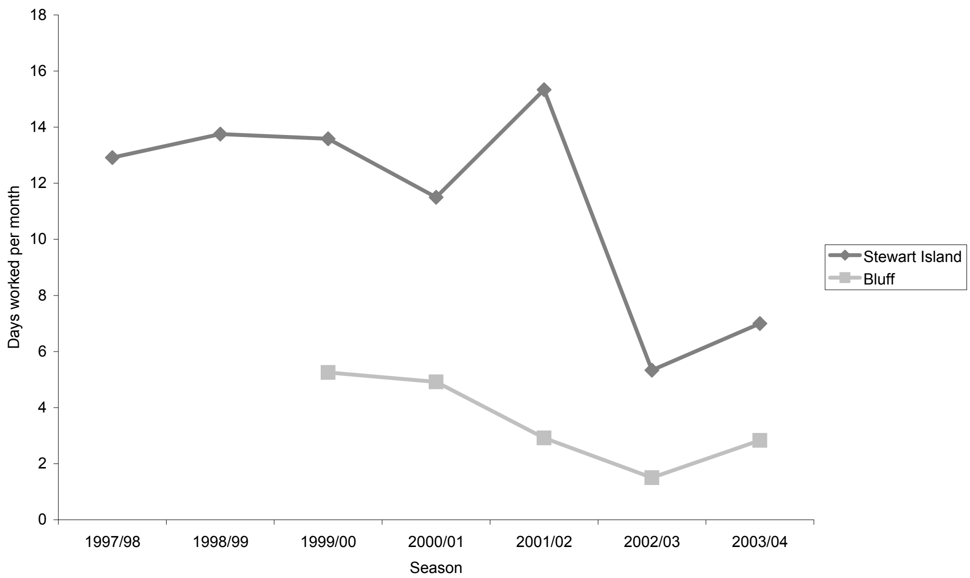

Figure 2. Season averaged manual removal work days per month at Stewart Island and Bluff.

due to funding limitations, monthly surveillance efforts were directed towards sites with a recent history of Undaria sporophytes. Every second month marine farm sites that had historically held Undaria but that had not produced sporophytes within the past year were also checked. Bluff Harbour and Halfmoon Bay were monitored each month due to the risk of translocation posed by vector traffic.

Marine farmers took responsibility for their own Undaria monitoring and removal for a period of time in 2003. Sanford Ltd supplied their own divers, while the other farmers paid the DOC contractors to carry out the monthly Undaria removal. The farms were still audited by DOC divers during this time. This process was ceased by the end of 2003 as the industry was suffering from the drop in mussel value and could no longer afford to fund the Undaria control.

Contractor reports were supplied each month with a cover letter detailing specifics of the monthly operations. The original reports are stored in the Southland Conservancy References Database (appendix 3).

All removed sporophytes were preserved in salt and supplied to DOC for measurement until 2001. Thereafter measurements were undertaken by the contractors.

Data was recorded by the contractor and from the salt preserved plants. Contractors sent in monthly reports on the location and numbers of sporophytes removed from each farm. Often numbers were recorded down to the level of mussel line. Any surveillance sites or areas checked for Undaria were also recorded on the maps. In Big Glory Bay sporophyte length, midrib width and the reproductive status of each plant was recorded (appendix 3). Whereas in Bluff Harbour and Halfmoon Bay due to the large number of sporophytes initially removed, specimens were counted in 5 cm size classes and reproductive status recorded (appendix 3). Reproductive status was recorded as juvenile if no sporophyll tissue was visibly present. All other sporophytes were considered to be mature once the sporophyll was present. This assessment of reproductive maturity at intermediate stages was likely to be highly conservative due to the subjective nature of the assessment.

2.4 STERILISATION AND REMOVAL OF STRUCTURES

2.4.1 Removal

Throughout the course of the programme various marine structures and debris infected or at risk of inoculation were removed from Big Glory Bay and Bluff Harbour. This was effective in reducing the amount of available substrate for Undaria to colonise as well as removing some established gametophyte banks. Structures range from marine farm associated equipment, old barges, buoys and discarded rubbish (e.g. metal and plastic trays) to natural substrates such as logs, rocks and trees. From 1999, all material removed was recorded by the contractors (appendix 3).

From 2001 onwards an agreement with the marine farmers of Big Glory Bay allowed the contractor to trim mussel lines with repeated sporophyte growth, or new areas with a significant spore shadow. Contractors were shown by marine farmers how to tie infected areas of dropper line out of the main dropper and remove the excess loop. Removal of substrate colonised by Undaria was very effective and significantly reduced the number of infested farms by removing the gametophyte stage with minimal economic impact on the farmer.

2.4.2 Early Sterilisation Techniques

The first sterilisation attempts of infected structures consisted of using HTH chlorine in diluted spray form. Large structures such as barges and mussel rafts were beached at low tide and wrapped in polythene plastic. HTH chlorine granules were hand broadcast over the infected surfaces and also added to the water trapped between the polythene and the rafts at high tide. This technique reduced but did not successfully eliminate all gametophytes, as sporophytes were detected within 2-3 months on some barge surfaces. Many of these mussel rafts and barges were subsequently antifouled to kill remaining gametophytes and some surplus barges were later removed and destroyed on land.

Marine farmers also treated infected lines after harvest by soaking them in baths of HTH chlorine and then drying them in the sun before returning them to the water. Buoys were also sprayed with HTH chlorine or left out of the water until growth had dried and any Undaria present was likely to have dessicated. Infected buoys on active lines were turned over so any growth would dry in the sun, before being rotated back into the water.

Hot-water pressure washing was also trialed with a high pressure water blaster attached to a portable heat pump. However, the system failed to heat the contact water sufficiently and there were concerns that gametophytes may be dislodged and spread so this approach was abandoned.

Throughout the project marine farmers were proactive in developing sterilisation methods for marine farm equipment and spat. For example some farmers treated rope using a fresh water bath that becomes anoxic over time. However, the efficacy of this approach was unknown.

The original 1999 budget included $70 000 for research into the development of gametophyte sterilisation techniques. However, these funds were redirected to vessel surveillance and additional control operations in Bluff Harbour following detection of this population. Thereafter limited resources were applied to the development of effective sterilisation practices. Nevertheless a wharf pile sterilisation process was trialed in 2000, and a hot water sterilisation technique was developed in 2001.

2.4.3 Wharf Pile Sterilisation Project

The Wharf Pile Sterilisation Project was initiated in July 2000 once a 12 month Resource Consent was granted. The objective of the project was to develop technology that could eliminate gametophyte banks on wharf piles and speed up the eradication process in Bluff Harbour.

The sterilisation method developed used a PVC sleeve wrapped around a pile to create a small area of enclosed water into which a dispersant and biocide were injected. Two biocides, Amersperse 261T and Amersperse 17 were trialled. Amersperse 261T is an oxidising biocide that uses bromine and chlorine as active ingredients. Amersperse 17 is a broad spectrum biocide and wetting agent. The sleeves were successful at containing the chemicals and enabling the maintenance of a high concentration of chemical around the piles. However, independent toxicological studies of Amersperse 261T and Amersperse 17 found that to kill the gametophyte stage of Undaria, the principal chemical had to be present at 20 ppm, which was 40 times the manufacturer’s recommended dose.

Due to the proximity of the study site to seawater extraction pipes for seafood processing and aquaculture facilities the approach was deemed unsuitable. Subsequent development of a successful hot water treatment approach meant no further work was undertaken on this technique.

2.4.4 Hot Water Sterilisation

Hot water was also tested as a treatment method and found to be very effective at killing Undaria gametophytes at water temperatures of 60 oC and 95 oC (Webb and Allen, 2001). Gametophyte exposure times of 5 seconds, 10 seconds and 60 seconds produced 100 % mortality.

On the basis of these results a diver hand held hot water sterilisation system was developed (Figure 3). Hot water was heated by a diesel burner up to a maximum temperature of 150 °C using fresh water pumped from shore and/or stored in a tank on the support vessel. It was delivered to a diver operated lance via an insulated hose. Low pressure was used to minimise the amount of material dislodged during the sterilisation process and avoid the possibility of dispersing Undaria gametophytes. The lance was fitted with a funnel to help concentrate the hot water, and temperatures were monitored by a temperature probe inside the funnel that was connected to a data logger for later analysis.

Prior to the sterilisation of an area, rock and wooden surfaces infested with Undaria gametophytes were stripped of all macroinvertebrates (which were relocated) and macroalgae (disposed of).

Hot water was used to treat shoreline infested areas of Halfmoon Bay and in Big Glory Bay at the Nugget. This technique was also modified and used successfully to treat and eradicate Undaria from a sunken fishing vessel (Seafresh I) at the Chatham Islands (Wotton *et al*. 2004).

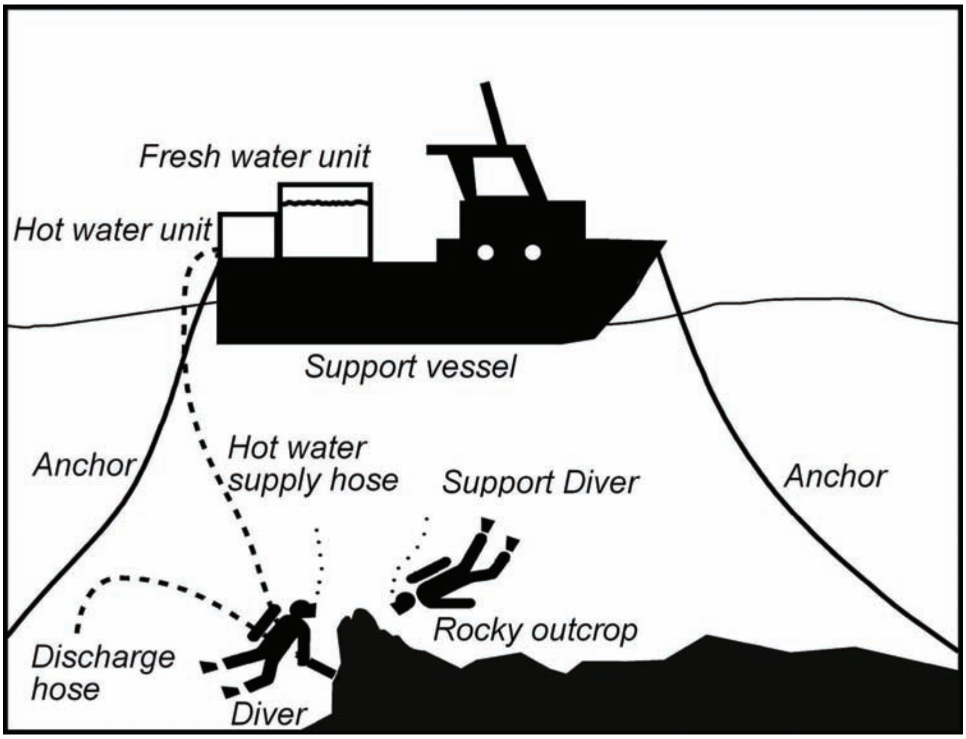

Figure 3. Schematic diagram of hot water sterilisation.

2.5 VESSEL MONITORING

A vessel monitoring programme was implemented by DOC in May 1999 to manage and evaluate the threat to the control program of re-invasion through vessel hull fouling. The key objective of the programme was to identify individual vessels fouled with Undaria sporophytes that were likely to enter Southland's coastal waters. The extent to which the coastal fleet was fouled by Undaria, the volume of vessel traffic between surveyed locations and the proportion of vessel traffic that comprised vessels fouled with Undaria were all determined by this surveillance program.

A detailed analysis of the vessel monitoring programme is reported in Stuart (2002).

2.6 MARINE FARM CONTAINMENT MEASURES

Movement of infected marine farming vessels, spat, structures, rope and wet dive gear into Big Glory Bay from sites outside the southland region increase the risk of Undaria reinvasion. For instance spat collected from Kaitaia had historically been stored in the Marlborough Sounds before being transported to Stewart Island but measures were put in place to prevent spat arriving from areas with established populations of Undaria.

From 1997 until 2004 no equipment is known to have been transferred into Big Glory Bay from other marine farming regions known to have Undaria. From February 1998 marine farmers agreed to use new equipment or sterilise all ropes to minimise the risk of transferring of Undaria around or into Big Glory Bay.

Sanford Ltd trialed a transfer of seed mussels grown in Marlborough Sounds to Big Glory Bay in 2002 under a very tight management plan drafted by DOC and agreed to by the Ministry of Fisheries. The area in the Sounds was inspected for the presence of Undaria and was considered visibly clear of sporophytes. Sanford Ltd was warned that the mussels were likely to have been inoculated by Undaria gametophytes and growth would not occur until water temperatures were optimal. They proceeded with the transfer and within three weeks Undaria was growing on the seeded lines. 1500 immature sporophytes were removed from the lines over a two month period. Sanford Ltd removed (at a significant cost) the seed mussels and line and these were transfered back to the Marlborough Sounds.

Big Glory Bay marine farmers actively cooperated with the eradication programme throughout its duration. They voluntarily removed heavily infected mussel and mooring lines, harvested and decommissioned the most heavily infected farm sites, and carried out a buoy treatment programme. The latter involved sterilising the submerged section of colonised mussel buoys by turning these over and spraying with HTH chlorine and allowing sun to desiccate and kill all Undaria. They also decommissioned and destroyed a number of surplus barges known to be colonised by Undaria and antifouled all remaining barge surfaces.

During 2003 the marine farmers each formally agreed to finance and oversee the ongoing monitoring and removal of any new plants on their farms. This was of significant advantage to programme operations, particularly at a time when central government funding was reducing. Each marine farm ensured that monthly checks were carried out on their structures, accurate records of the location of any sporophytes detected were maintained and any plants were preserved and provided to DOC. The incursion response team shifted their effort to focus on monthly audits of marine farm operations and treatment of remaining shoreline populations. This partnership, while in operation, enabled an effective incursion response to continue despite a major drop in government funding.

2.7 POST-CONTROL MONITORING

In November 2004 a monitoring program (appendix 3) was developed to monitor the spread of Undaria following the cessation of the control programme. The monitoring was conducted biannually in May and November until May 2007. Six sites were selected for calculating regular Undaria density measurements along permanent transects. Belt transects were set up around recently reported Undaria populations at Barge Bay, Cob's Corner, Scollay Rocks, Big Glory Nugget, a control site in Big Glory Bay (no history of Undaria presence) and the Bluff rockwall (Figure 4, 5, 6). Sporophyte density counts and percentage rock cover were estimates at each of the six sites. Additionally, a number of uninfected sites around Stewart Island and Bluff were surveyed twice a year to monitor for the potential spread of Undaria.

3. Results 1997 - 2004

3.1 DISTRIBUTION OF UNDARIA IN SOUTHLAND NOVEMBER 2004

At cessation of the programme in November 2004 Undaria distribution within Southland was restricted to three geographical locations: Big Glory Bay and Halfmoon Bay on Stewart Island, and Bluff Harbour (figures 4, 5 & 6). In Big Glory Bay during the last year of full operation, (November 2003 to November 2004),Undaria was recorded on four farms (<10% of all farms in the bay) and three shoreline sites (Figure 4). Fewer than 70 plants were deteted and removed, all of which were limited to localised areas within each farm.

The two shoreline sites detected and controlled since 1997/98 (Cob's Corner and Barge Bay, Figure 4) were also largely free of Undaria by November 2004 with less than 50 plants collected over the previous year. The majority of Undaria still present in Big Glory Bay in the 12 months prior to November 2004 were found at the shoreline around The Nugget (164 plants) a site that had only been managed since the population was discovered in 2000. Numbers of sporophytes removed from this site have generally halved each year of control.

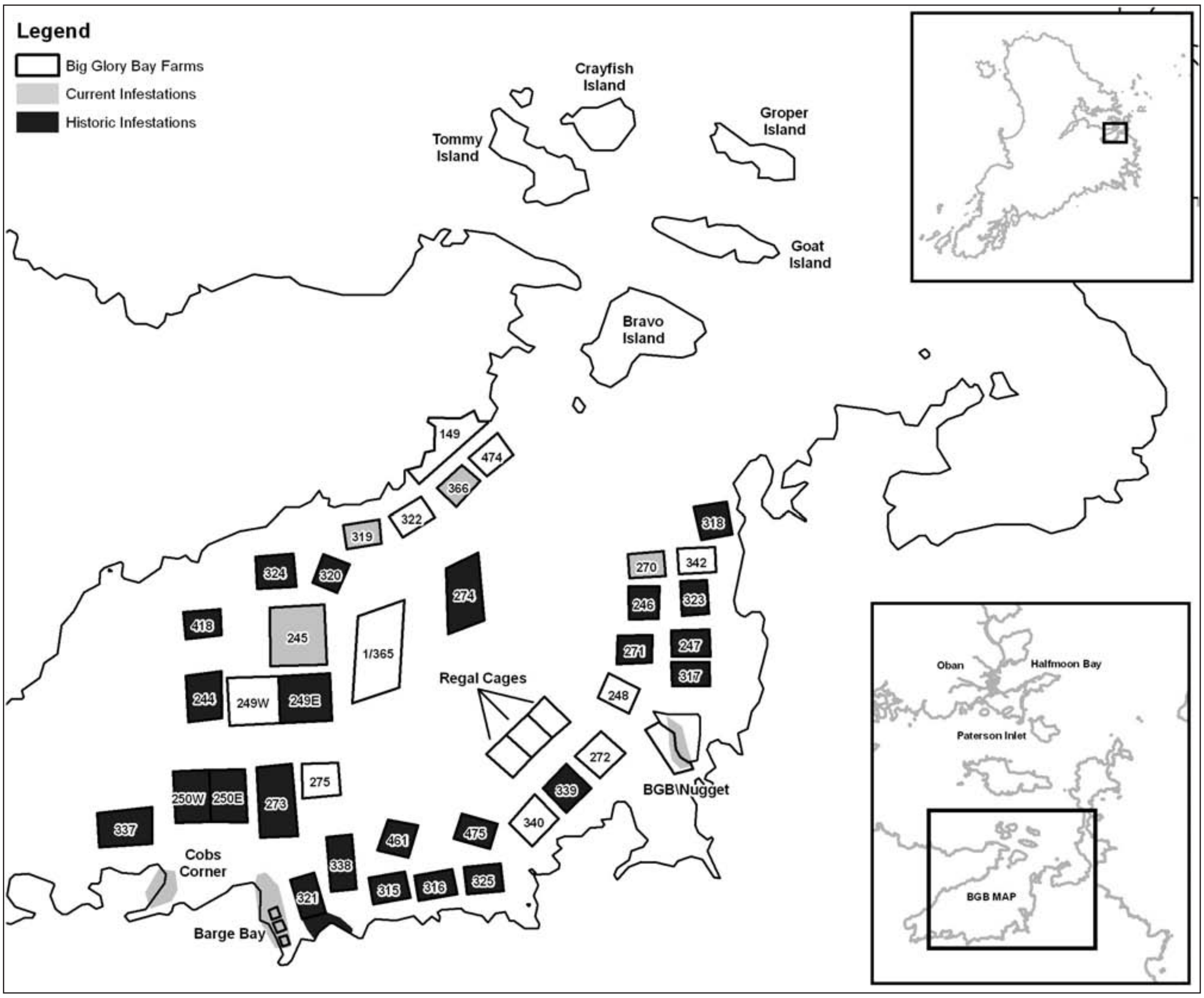

Figure 4. Map of Big Glory Bay and marine farms showing sites with Undaria. Farms and shoreline sites with current Undaria infestations (removals October 2003 – October 2004) are shaded grey, sites of historic infestations (prior to October 2003) are coloured black.

Undaria was discovered in Bluff Harbour during a routine annual check in September 1998. The infestation was confined to a single site at Island Harbour and several piles at the ferry wharf. The morphology of the sporophytes discovered in Bluff Harbour was similar to populations found in east coast ports and differs from specimens collected from Big Glory Bay. Plants in Big Glory Bay were more similar to populations observed in Marlborough and Tasman Bay (M. Stuart *pers. obs*.). These differences were later confirmed by Uwai *et al*. (2006) who found the haplotype of sporophytes collected in Bluff to be genetically distinct from those in Big Glory Bay. Samples from Halfmoon Bay were also different and found to have the same haplotype as plants from Dunedin and Nelson and Picton. Specimens analysed from Big Glory Bay were of the haplotype found between Moeraki and Christchurch. Genetic data (Uwai *et al*. 2006) clearly indicates that the populations in Bluff, Halfmoon Bay and Big Glory Bay arose from three independent founding events and not as a result of spread from Big Glory Bay.

By November 2004 Undaria populations within Bluff Harbour were controlled to low density and restricted to limited areas of Island Harbour, the town wharf, and the adjoining shoreline. The maximum distribution of Undaria in Bluff extended out to the North Wall on Island Harbour, and to the Westend Shore, as well as areas surrounding the 2004 populations (Figure 5).

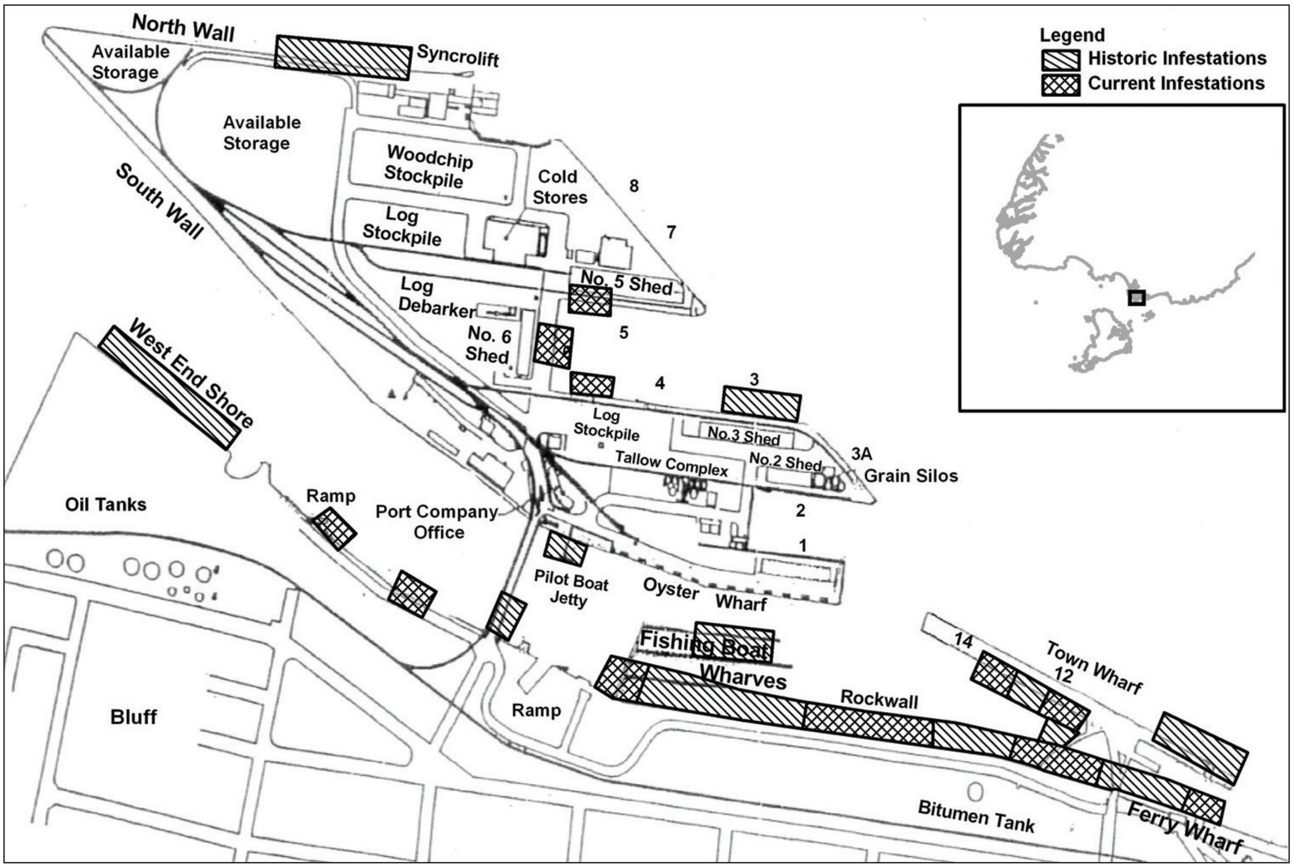

Figure 5. Map of Island Harbour and surrounding Bluff coastline showing sites with Undaria. Sites with current Undaria infestations (removals between October 2003 and October 2004) are crosshatched, sites of historic infestations (prior to October 2003) are hatched.

Undaria was first identified in Halfmoon Bay in October 2000. The original population was located on an area around Scollay Rocks. This population contained mature sporophytes and had presumably been present for some time. Subsequently further populations were located at the slipway, along the coastline to the west corner of Lonnekers Beach and out around the rocks to the north of Scollay Rocks (Figure 6).

Undaria was not detected during any of the surveillance trips to the Subantarctic Islands prior to 2005.

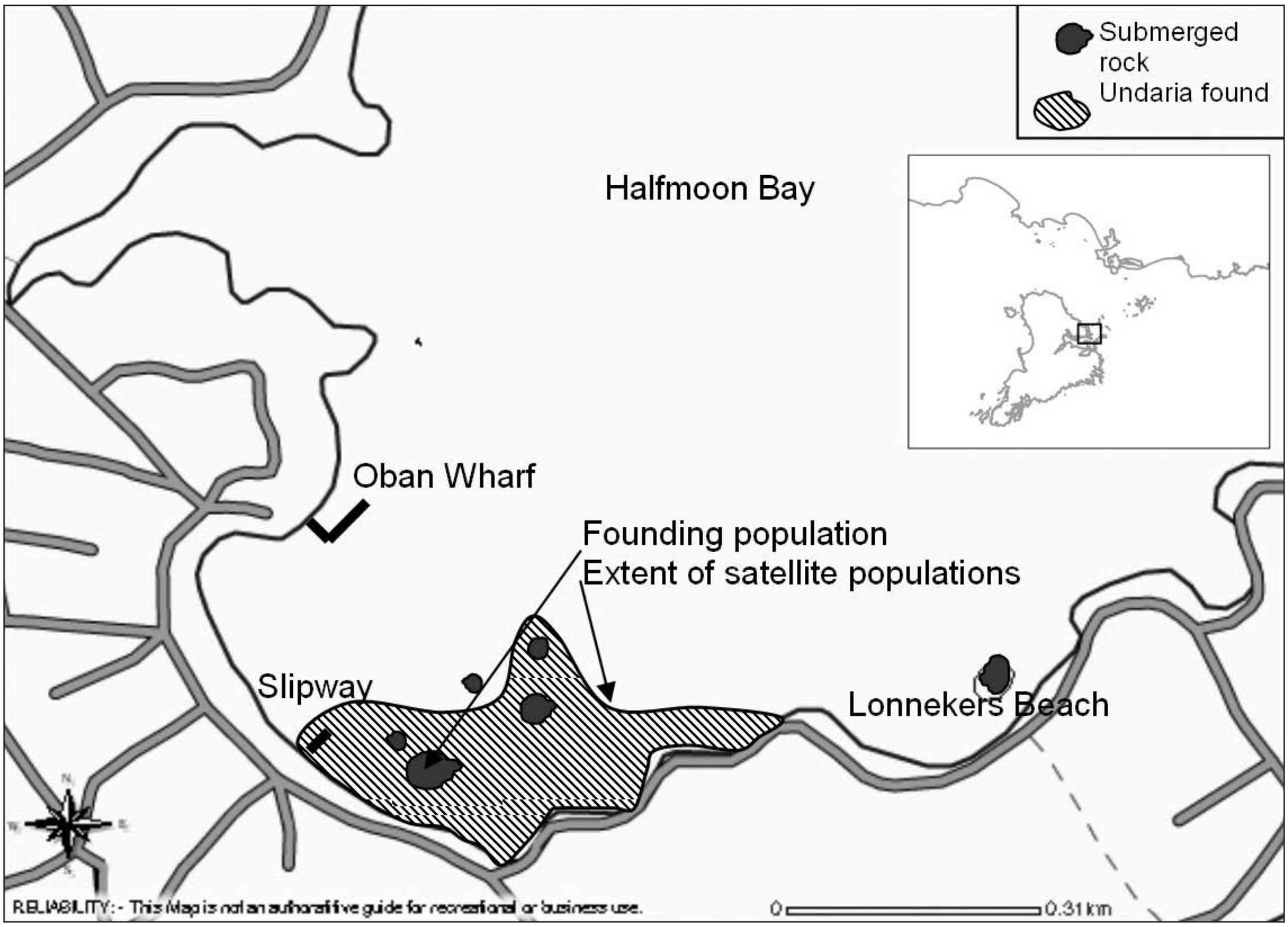

Figure 6. The distribution of Undaria in Halfmoon Bay. The founding population on Scollay Rocks is shaded grey and the maximum known extent of satellite populations hatched.

3.2 CONTROL (PHYSICAL REMOVAL) AND MONITORING RESULTS

The survey of marine farm structures in Big Glory Bay, and wharf facilities in Bluff Harbour and around Oban during April 5-10 1997 revealed Undaria was restricted to a localised area in Big Glory Bay. Plants were present on 2 moorings, 6 mussel rafts and a fuel barge in high densities that included old degenerating sporophytes as well as new growth. Sporophytes were only detected on three mussel farms (site 321, 337 and 317, Figure 4). However, in the first year of operation the extent of the infestation was found to be considerably larger and by April 1998 a total of 23 farm sites were found to harbour Undaria.

After the first year of control the number of Undaria sporophytes removed from Big Glory Bay decreased annually (Figures 7 & 8). The most dramatic reduction in sporophyte numbers harvested was recorded over the first three seasons. This drop equates to a 43 % reduction in sporophytes removed between year one and two, and an 85 % reduction between 1998/1999 and 1999/2000 harvest years.

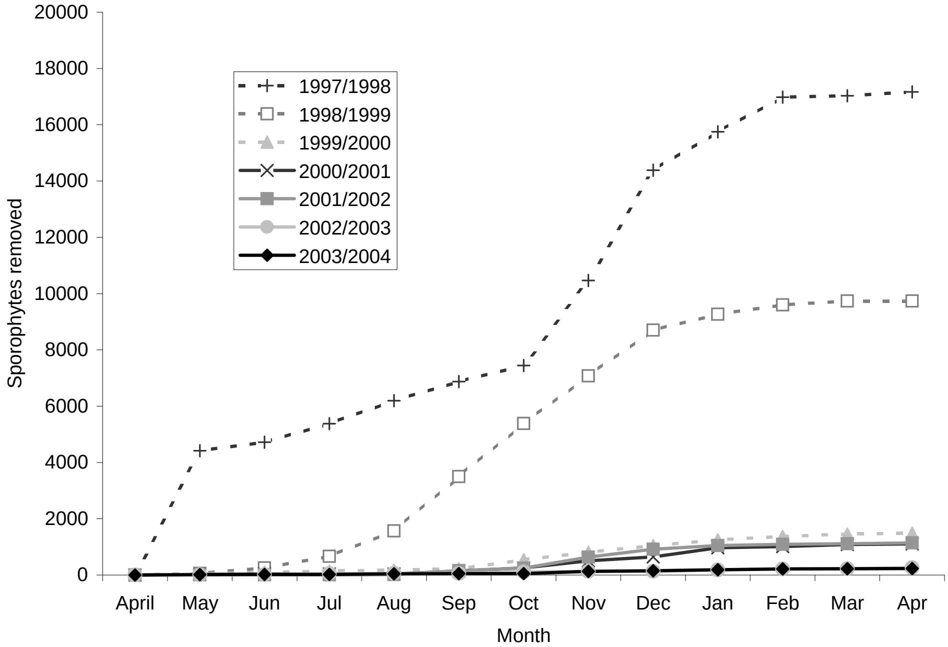

Figure 7. Seasonal cumulative total of Undaria sporophytes removed from Big Glory Bay, Stewart Island between 1997 and 2004. Data presented excludes The Nugget population detected in 2001.

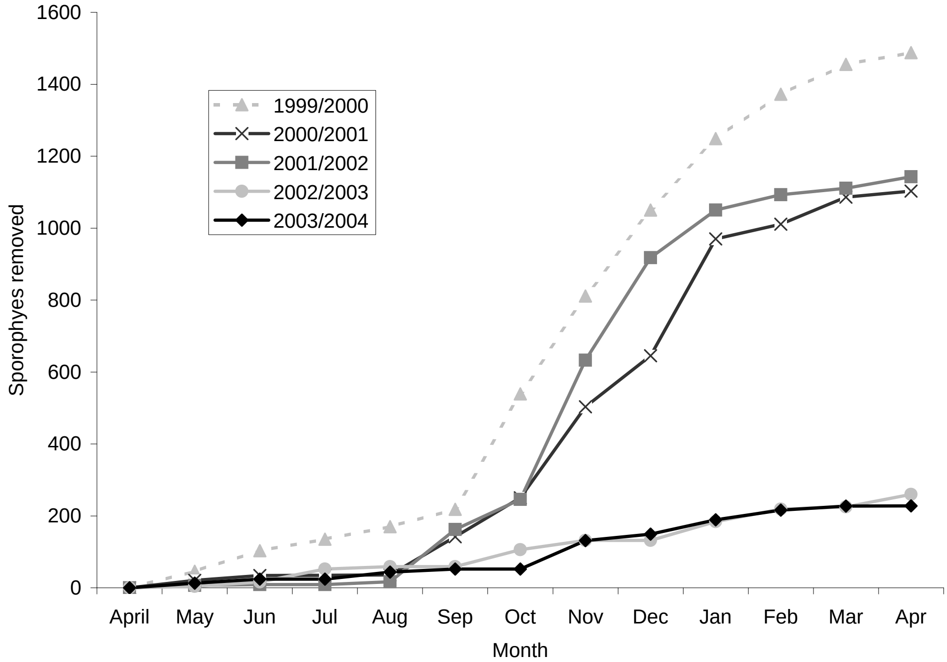

Figure 8. Seasonal cumulative total of Undaria sporophytes removed from Big Glory Bay, Stewart Island between 1999 and 2004, excluding The Nugget population.

In the subsequent 1999/2000 year, a further 26 % reduction was recorded in Big Glory Bay (figure 8) whereas during the following 2000/2001 harvest year the numbers of plants harvested remained steady at about 1100 plants/harvest year. In the 2002/2003 year there was another large reduction in number of plants removed (77 %) with a further 12 % fall in the annual total during final year of control operations (2003/2004). However, the final year of data was taken from the estimate provided by the contractor reports rather than counts of plants measured (as in all previous years). Audits had shown that the contractors report typically over estimated the numbers of plants removed hence this reduction may have been larger. These discrepancies arose from contractor misidentification of juvenile Macrocystis propagules, or plants being thrown out prior to salting and measuring.

In August 2000 a large population of Undaria was located at The Nugget in Big Glory Bay (figure 4). An initial population of about 3800 plants was removed in the first year after discovery (figure 9). Subsequent annual removal totals declined by over 70 % (2000/2001) then a further 64 % (2001/2002) the following two years. In the last year of the programme less than 200 plants were removed, or 5 % of the original number of sporophytes recorded in the first year. The Nugget population represented 46 % of the total numbers of plants removed from Big Glory Bay in the final season of the programme.

There was a major decline in the number of sporophytes detected on marine farm structures and barges in Big Glory Bay after 1997 (figure 10). The 2000 shore outbreak shown in figure 10 refers to the discovery of the population at The Nugget. Since 1997 the targeted removal of Undaria from the marine farms has resulted in more than a 99 % decline in the number of sporophytes removed from farms, structures and barges, and a 30 % drop in the number of infected farms (figure 11). .

Despite the decline in survey and control efforts (as expressed by total annual number of contractor days) over the last two years, sporophyte numbers continued to decrease (figure 12). However, the reduced effort was associated with an increase in the percentage of mature sporophytes.

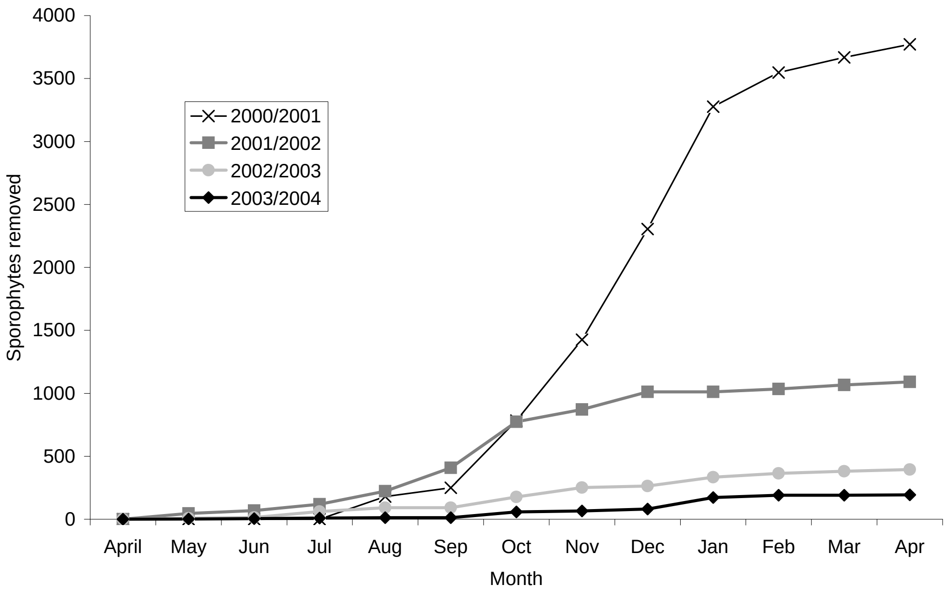

Figure 9. Seasonal cumulative total Undaria sporophytes removed from The Nugget, Big Glory Bay, Stewart Island between 2000 and 2004.

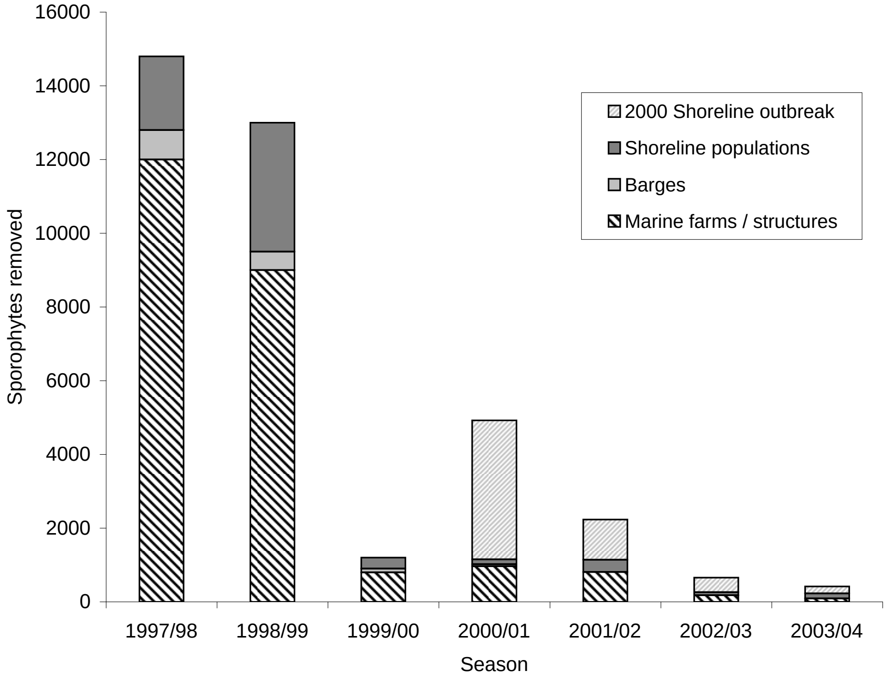

Figure 10. Abundance of Undaria sporophytes removed from Big Glory Bay 1997 – 2004, broken into general substrate type.

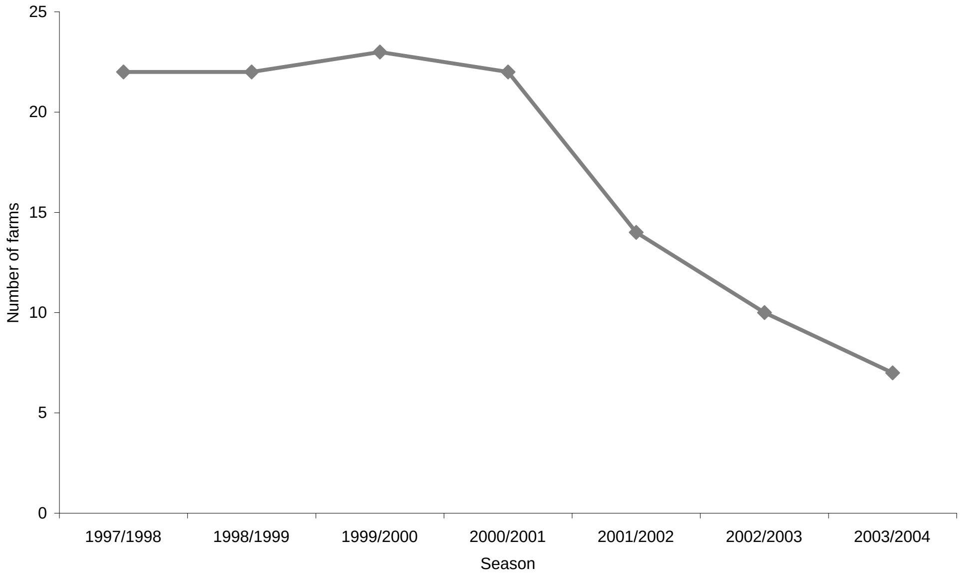

Figure 11. Total farm sites within Big Glory Bay infested with Undaria per season from 1997 – 2004

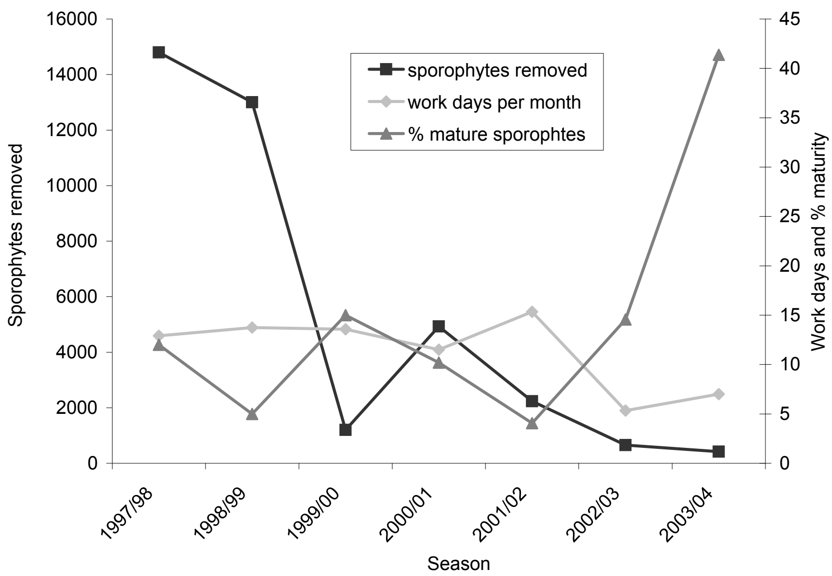

Figure 12. Big Glory Bay data showing total number of Undaria sporophytes removed per season, against average number of workdays per month over the season, and averaged percentage of mature sporophytes.

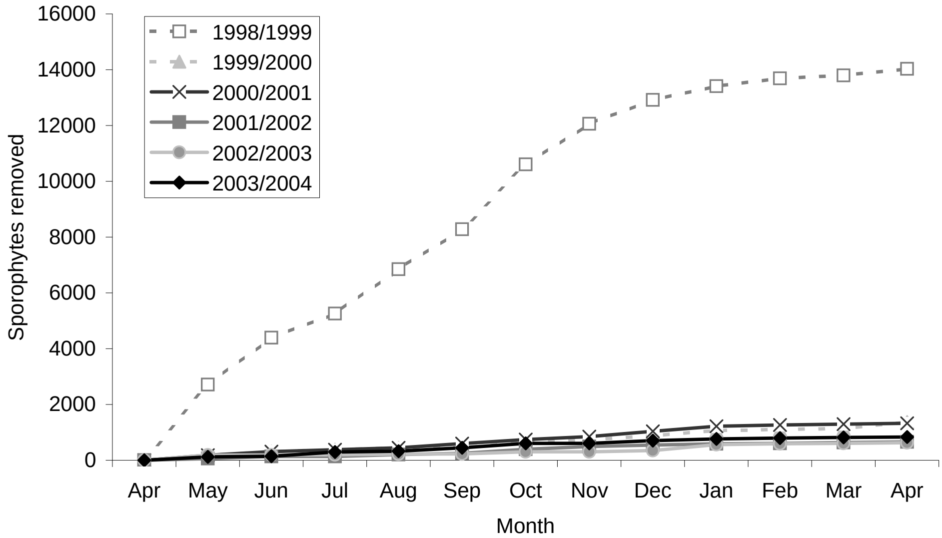

Figure 13. Seasonal cumulative total of Undaria sporophytes removed from Bluff Harbour between 1998 and 2004.

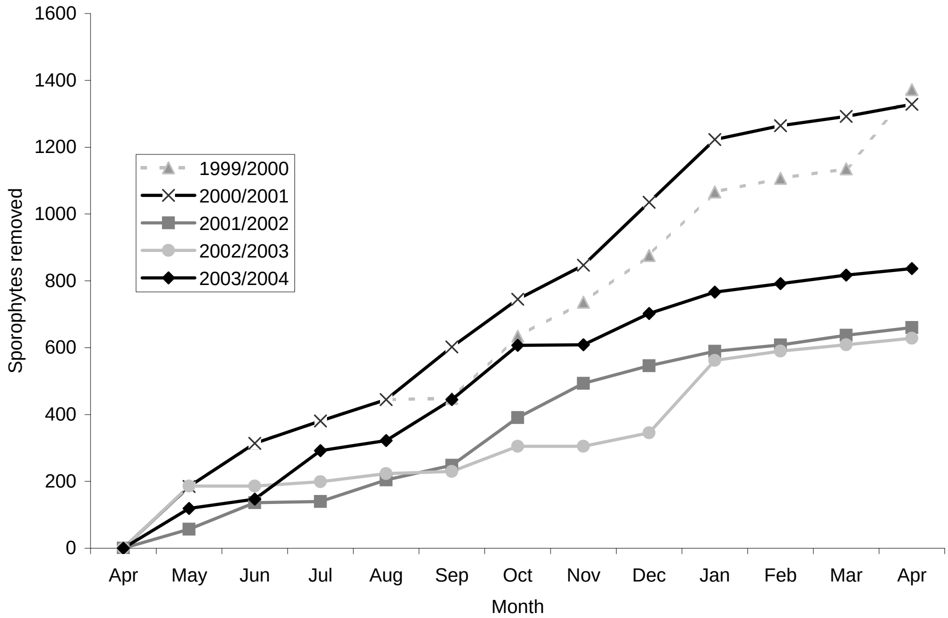

Figure 14. Seasonal cumulative total of Undaria sporophytes removed from Bluff Harbour between 1999 and 2004.

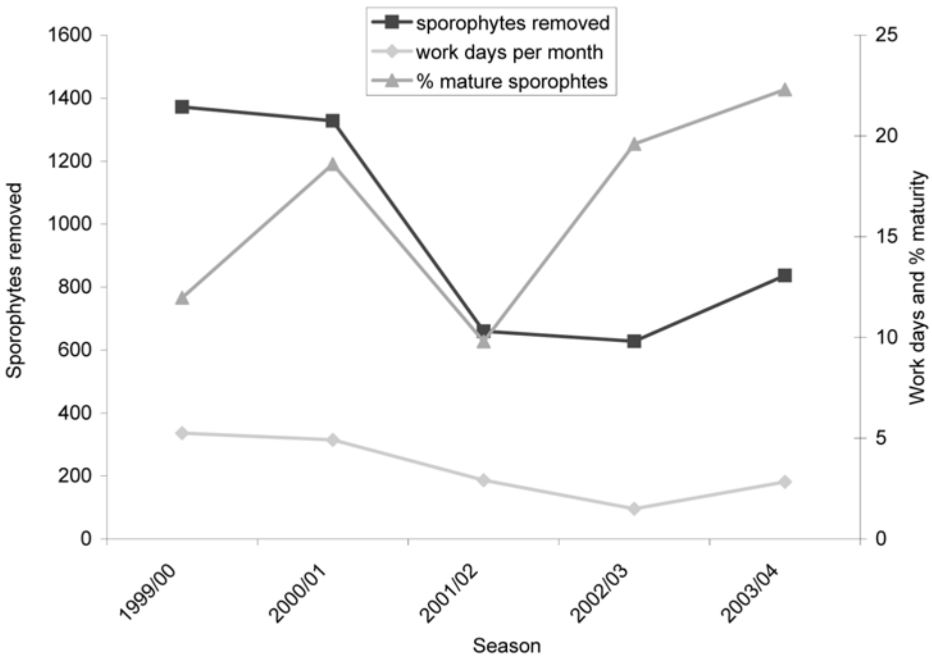

Figure15. The total number of Undaria sporophytes removed from Bluff Harbour per season, compared with average number of workdays per month percentage of mature sporophytes.

In Bluff Harbour a large reduction in the Undaria population was achieved in the first few years of operation (figures 13, 14) with a 90 % decrease in sporophytes removed after the first season. The number of sporophytes removed decreased each year until the final season, that corresponded to a reduced sampling effort and increase in the percentage of mature sporophytes (figure 15).

The last season was also characterised by poor weather conditions and an increase in water turbidity that is likely to have contributed to reduced detection and an increase in sporophyte survivorship and maturity.

In October 2000 Undaria was discovered at Scollay Rocks in Halfmoon Bay, Stewart Island. This population was again noted to differ morphologically from the Big Glory Bay population. In the seven months from October 2000 approximately 15000 sporophytes were removed from Scollay Rocks (figure 16). Approximately 8000 and 4000 plants were removed from this site over the same period in 2001 and 2002 respectively. In the 2003/ 2004 season, only four months of Undaria specimens were measured, because the remaining eight months of plants were accidentally destroyed prior to measurement. It was not possible to estimate missing data from the contractor reports as described for other sites, due to the higher number of plants being removed from Scollay Rocks. The contractor reports generally only included sporophyte counts when the number removed was low (<50) and abundance was described using terms like a 'sack full', 'bag full' and 'heaps' when plants were removed in higher densities.

In Big Glory Bay growth and sporophyte production peaked in the summer (figure 17) between October and March and an average of 76 % of all Undaria were removed during this period. This strong seasonal pattern was not observed in Bluff and Halfmoon Bay, where 53 % and 40 % respectively of annual plant removal occurred over the same six-month period.

The average sporophyte size, represented as both plant length (measured from the holdfast to the midrib tip) (figure. 18) and midrib width (figure.19), increased as the numbers of plants collected decreased. In the final season of the programme, the largest plants with the widest midribs were recorded, even though the lowest number of sporophytes was removed (figure. 8). The smallest mature sporophylls were usually recorded in warmer summer months (December – April), suggesting plants were sacrificing growth (length and width) for sporophyll development (figure 18, 19).

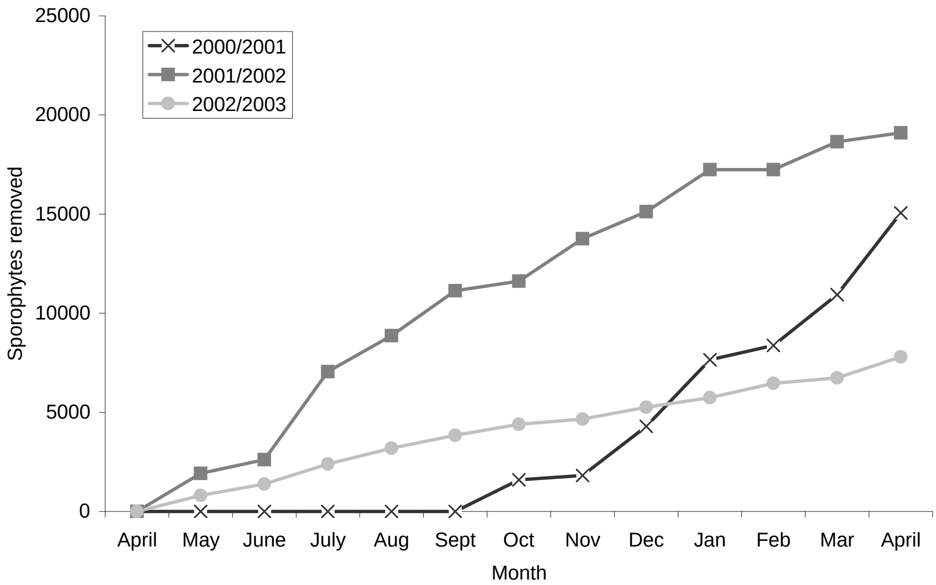

Figure 16. Seasonal cumulative total of Undaria sporophytes removed from Halfmoon Bay, Stewart Island between 2000 and 2003.

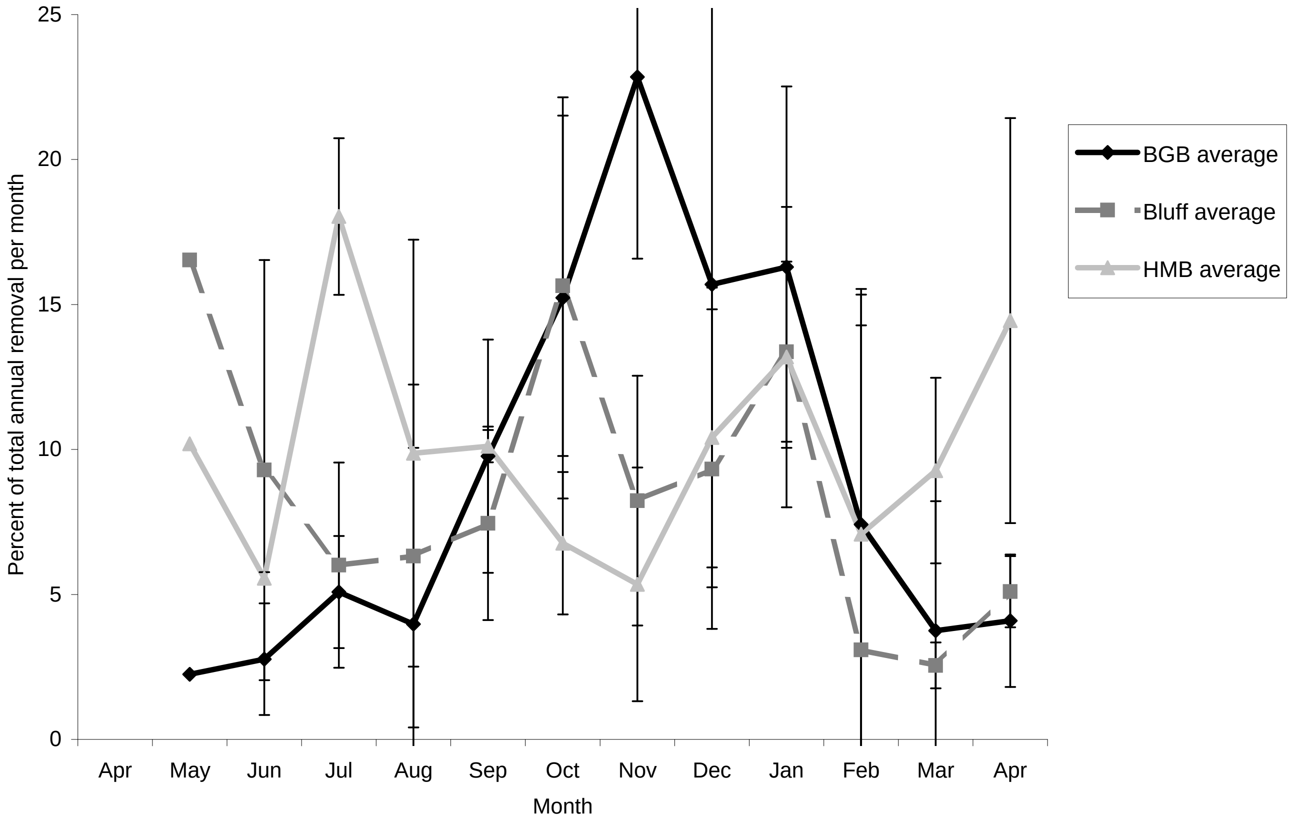

Figure 17. Percent of total annual sporophytes removed per month.

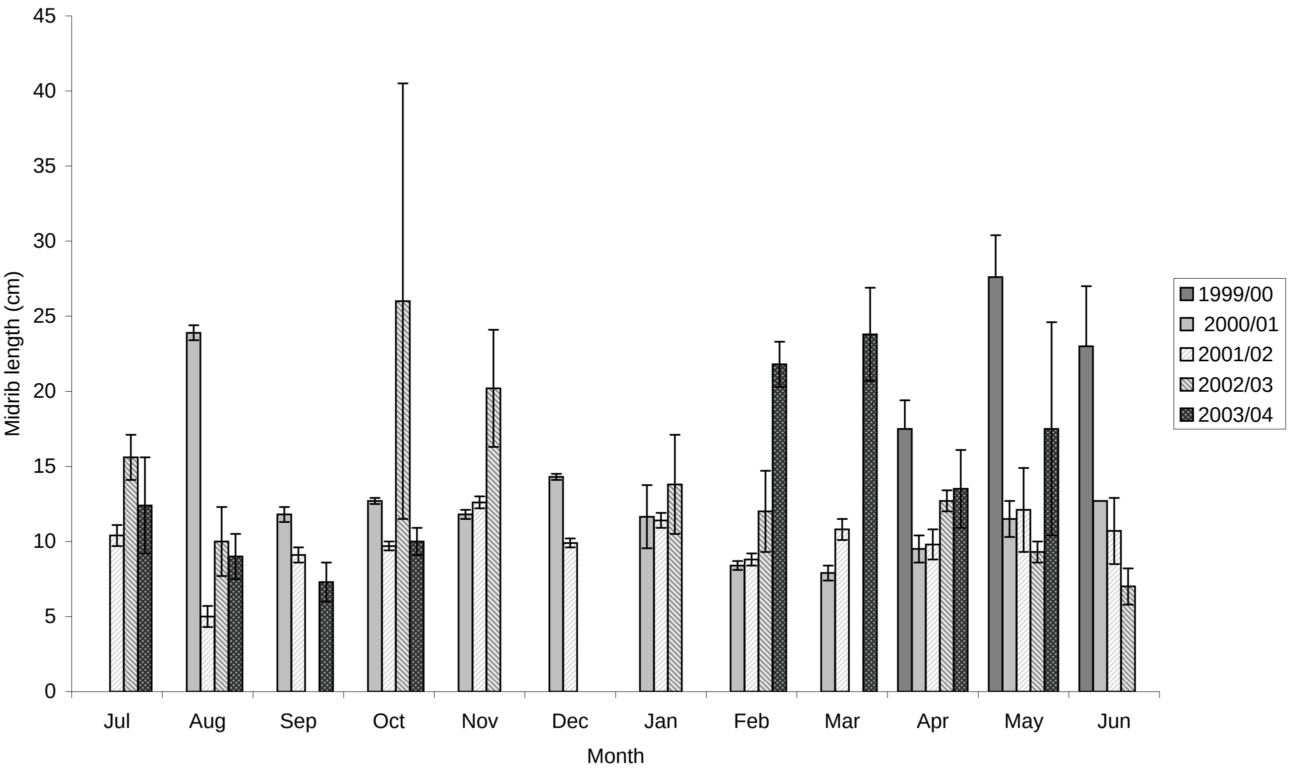

Figure 18. Monthly averaged midrib length (cm) of removed sporophytes from Big Glory Bay. Missing bars indicate missing data.

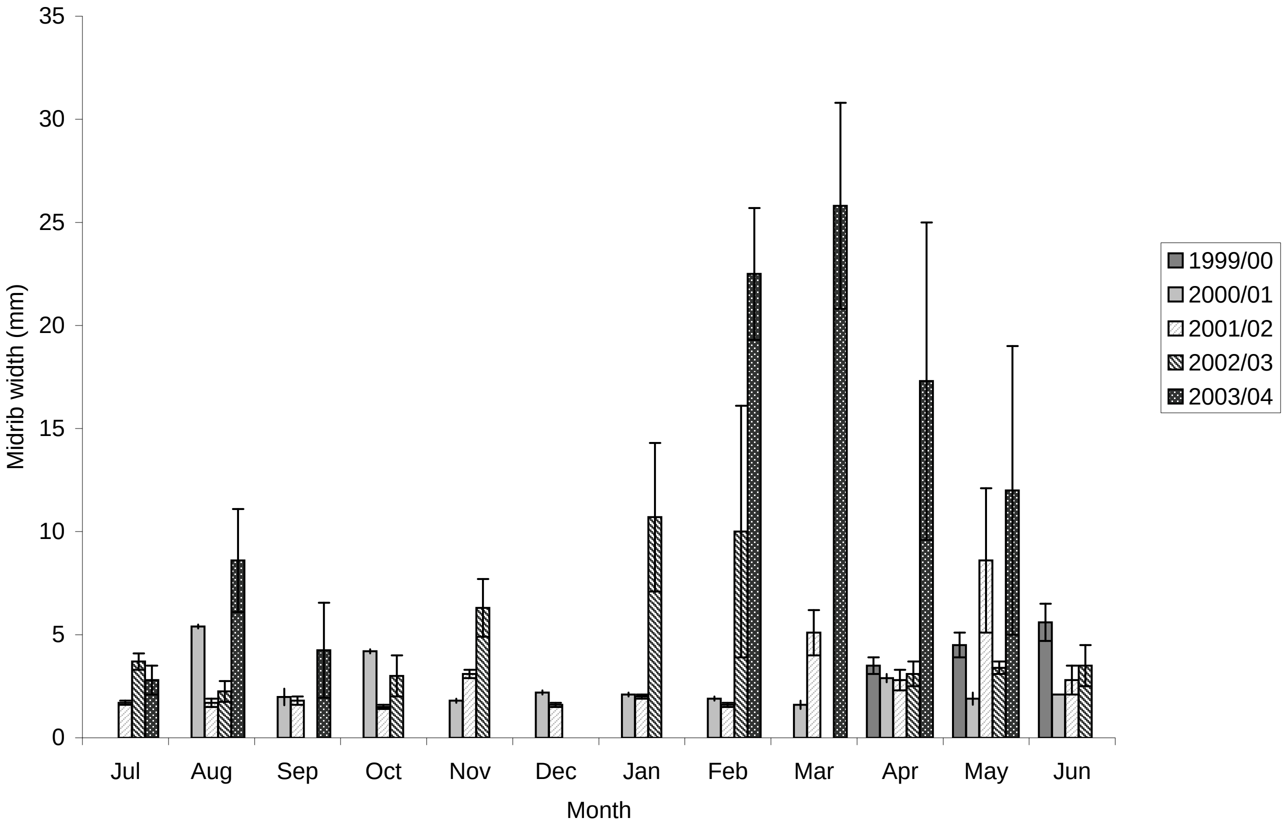

Figure 19. Monthly averaged midrib width (mm) of removed sporophytes from Big Glory Bay. Missing bars indicate missing data.

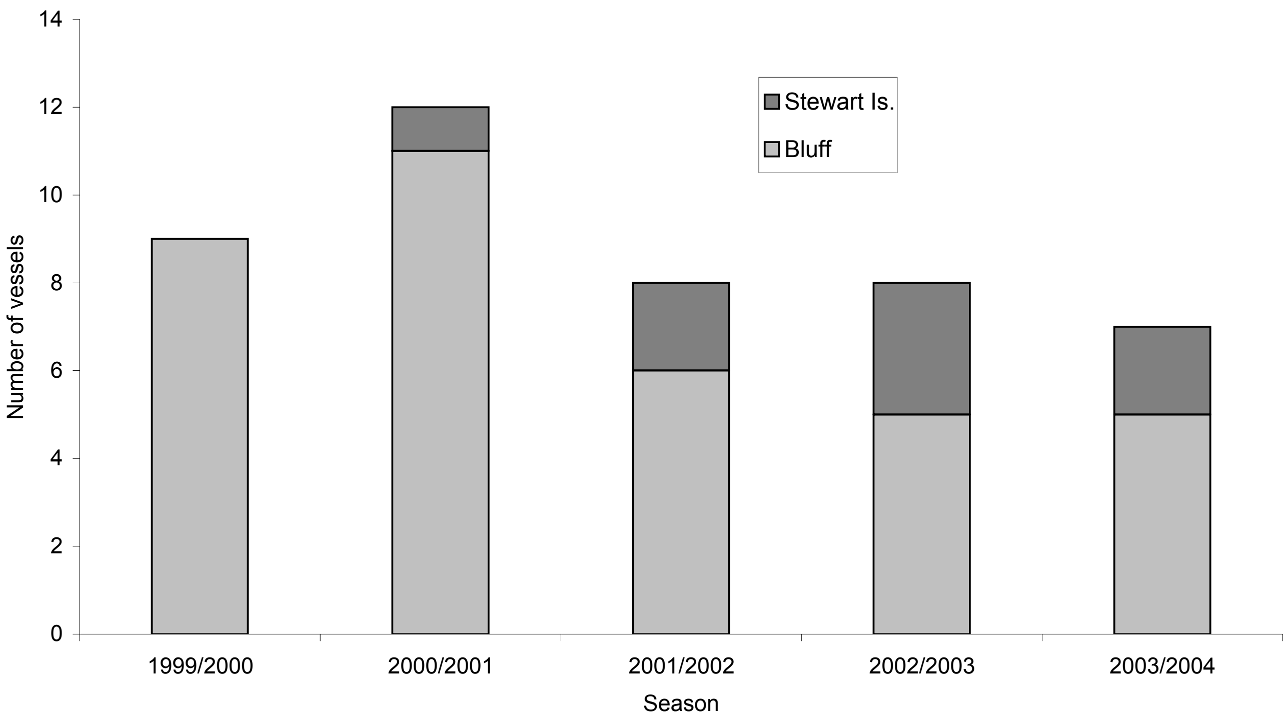

Figure 20. Number of vessels identified as being fouled with Undaria at Bluff and Stewart Island between August 1999 – November 2004

3.3 VESSEL HULL MONITORING

The number of vessel hulls found fouled with Undaria at Stewart Island and Bluff remained consistently low since the onset of monitoring in 1999. The number of infested vessels in Bluff declined from a maximum of eleven in 2000 to only five vessels in 2004 (figure 20). At Stewart Island the first infected vessel was recorded in December 2000, with three more fouled vessels detected in 2001, one of which was moored in Halfmoon Bay adjacent to the Scollay Rocks incursion. During the 2002/2003 vessel monitoring season a further three infested vessels were found in Horseshoe Bay. During the 2003/2004 season two fouled vessels were found in Horseshoe Bay, and the most heavily infested boat then moved to Bluff Harbour, where it was eventually cleaned and antifouled on dry land.

There are multiple pathways by which Undaria can colonise Stewart Island, Fiordland and the Subantarctic Islands (figure 21). Significant numbers of vessels regularly move into and through high value areas around Southland's coastline, and hence there is an ongoing risk of new Undaria introductions. Boat vectors for the Subantarctic Islands are recreational, charter, tourist and fishing vessels. The volume of vessels visiting the islands is relatively low but these vessels represent a high risk as many are moored for extended periods in harbours known to have estasblished Undaria populations. The DOC permit system for landing at the Subantarctic Islands requires that the hull be checked and free of Undaria before departure. However, fishing vessels which regularly shelter around the islands during adverse weather conditions, or to carry out maintenance or rest and recreation, do not require a DOC permit and are often from Undaria infested ports. A small number of unreported recreational visits also occur. Between 1997 and 2004 a total of 52 different vessels were permitted by DOC for a total of 158 trips to the New Zealand Subantarctic Islands. Of the 158 trips, 77 of the permits were for multiple destinations within the Subantarctic Islands. The average trip duration for these permitted trips was 27 days.

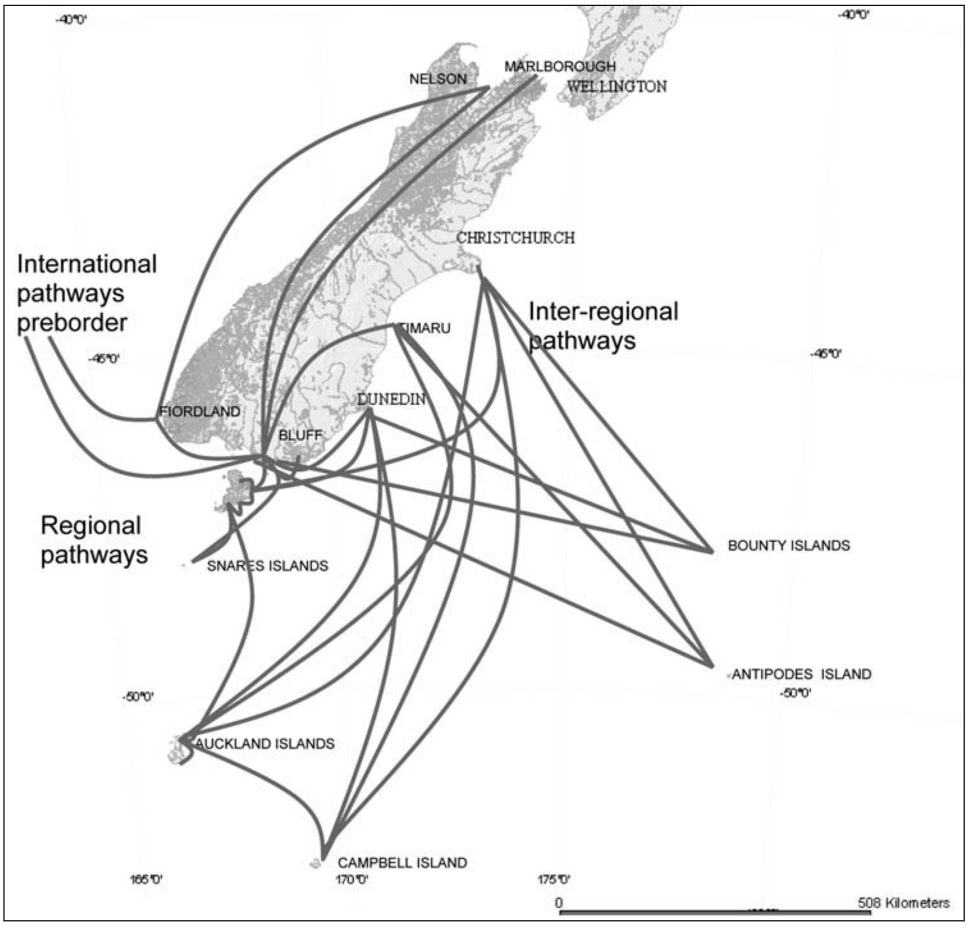

Figure 21. Vector pathways between Stewart Island, Bluff Harbour, Fiordland and the Subantarctic Islands.

4. Discussion

The Southland Undaria Programme successfully contained Undaria within Big Glory Bay, Stewart Island, and reduced the original founding population to very low abundance. The programme demonstrated that Undaria can be effectively controlled through regular and directed harvest of sporophytes.

The primary goal of the initial incursion response was to eradicate Undaria from Big Glory Bay within five years. Eradication potential was based on the assumption that the majority of sporophytes could be located and removed before maturation and spore release. The bathymetry, current flow and habitat configuration within Big Glory Bay was considered favourable to enable this. Rocky reef suitable for Undaria colonisation was generally limited in area, shallow (<10 m depth) and lacking any significant macroalgae canopy, therefore allowing easy inspection by surface swimming divers. Other potential Undaria substrate was associated with marine farms, where all structures could be inspected by surface or scuba divers and removed for sterilisation if required. This ability to target all individuals within a population is a key criterion for eradication success (Cromarty *et al*. 2002, Simberloff 2003).

At the beginning of the programme, no published data existed on the longevity of the microscopic gametophyte stage of Undaria. It was therefore difficult to reliably predict the rate of sporophyte decline resulting from the natural mortality of the gametophyte stage. The Technical Advisory Group (TAG) reasoned that gametophyte lifespan on fouled mussel lines was finite and largely determined by how regularly the mussels were harvested. Furthermore, provided existing Undaria populations were contained and controlled, there would be time to develop gametophyte treatment options for localised shoreline populations. The hot water treatment system was subsequently developed for this purpose.

Results indicate that the initial five year time-frame for eradication was reasonable. Over this period, manual removal was successful both in containing the founding population within Big Glory Bay and in significantly reducing sporophyte abundance. However, even after several years of intensive removal, recruitment of sporophytes was still occurring at shoreline sites where the abundance of mature sporophytes was otherwise low. This indicated that microscopic stages (i.e., zoospores, gametophytes or sporelings) of Undaria were capable of surviving many years, a feature also reported in a Tasmanian incursion response programme (Hewitt *et al*. 2005). The prolonged survivorship of these microscopic stages was probably a major factor behind the continued occurrence of sporophytes at shoreline sites.

While gametophyte persistence was perhaps key, spore release from the small numbers of overlooked mature sporophytes would also have been a cause of ongoing sporophyte production. Sporophytes were more difficult to detect at low densities particularly on mussel farm structures or at sites with a dense canopy of macroalgae and in warmer summer months when plant size was stunted. In summer, plants appeared to mature at an earlier age and allocate more resources to reproductive development than to frond growth. Thus a greater percentage of sporophytes missed in late summer months were mature. Nevertheless, incremental reductions in sporophyte abundance and number of affected sites were observed annually throughout the programme.

Reduced diver attention and motivation also contributed to sporophytes being missed during monthly checks. The large declines in sporophyte density observed in 1999/2000, appear to have contributed to diver complacency and resulted in an increased percentage of mature sporophytes detected during this period. Poor detection of sporophytes at later stages of the operation may have been further exacerbated by the high staff turnover. This corresponded with fluctuating programme management and direction, including uncertainty over future employment for field staff. The large increase in percentage of mature sporophytes detected in 2003/04 coincided with a decrease in search effort as a result of reduced funding.

Despite these issues, the programme still appeared on track for eradication and quite possibly would have been successful had further incursions of Undaria in Southland waters been prevented. The re-introduction of Undaria to Stewart Island was always identified as a significant threat to the long-term feasibility of localised eradication. Re-invasion control, fundamental to successful eradication (Cromarty *et al*. 2002, Simberloff 2003), and widespread vessel monitoring were therefore undertaken. Data was collected on vessel types, movement patterns and presence and maturity of Undaria on hulls, which was removed where possible. Monitoring records enabled the rapid response to known fouled vessels that were travelling to Stewart Island or other high value coastal areas like the Subantarctic Islands, Fiordland and Chatham Islands. Most notably these records enabled initiation of a rapid and successful eradication response when the Undaria-fouled *Seafresh 1* sank at the Chatham Islands (Wotton *et al*. 2004). Various other fouled vessels were identified at Stewart Island and Bluff Harbour between 1997 and 2004 (figure 22).

The likelihood of introductions constantly increased with the spread and establishment of Undaria along the east coast of New Zealand. Prevailing westerly currents through Foveaux Strait and along the Southland's south coast prevent natural spread of Undaria to Bluff and Stewart Island. However, the risk of dispersal via hull fouling was high. Stewart Island is a popular destination for many domestic and occasionally international, recreational vessels. Bluff Harbour also contains a sizable fleet of domestic and international vessels, many of which travel from areas that are infested with Undaria and regularly voyage between Bluff and Stewart Island (Stuart 2002).

New incursions of Undaria were discovered in Bluff Harbour in 1999 and on Stewart Island in 2000, which differed genetically to those in Big Glory Bay (Uwai *et al*., 2006). Haplotype analysis suggests that the Bluff Undaria may have represented a new introduction to New Zealand, whereas the Halfmoon Bay plants appear to have originated from either Otago Harbour or populations in central or northern New Zealand. These invasions, coupled with the discovery of a new population in Big Glory Bay, seriously undermined the feasibility of eradication.

Arguably these new incursions should have been detected earlier, but surveillance efforts were limited by budget constraints and the need to sustain sporophyte removal at known sites. It is uncertain whether additional allocations of resources towards wider surveillance would have resulted in earlier discovery as founding populations are difficult to detect, especially where they comprise a small localised number of sporophytes. At many of the locations, this difficulty was compounded by the presence of dense native macroalgal communities. At known Undaria hot spots in Big Glory Bay large brown native canopy species were cleared to enhance the potential for detection, but clearance was not possible around the entire shoreline. In Halfmoon Bay environmental conditions, such as poor visibility, strong currents and complex substrates, also hampered detection and control efforts. On the other hand, the Bluff Harbour population was missed in 1998 principally because, in the interest of saving time, some areas were inspected from a boat at low tide rather than by divers. Subsequently, all survelliance monitoring was carried out using divers in the water.

Additional introductions, detected through the course of the response, were probably the greatest contributing factor leading to cessation of programmatic funding. Maintaining funding for the incursion response was a problem throughout the duration of the project, however, with annual budgets varying from year to year. This uncertainty impacted programme management, field operations and staff morale which, in turn, most likely influenced the programme outcomes. The absence at the time of both a national policy and definition of agency roles in the management of regional spread of established marine pests like Undaria also did not help the incursion response. This lack of clarity made it difficult to compel action and engender support from decision makers, funding agencies and stakeholders. Ultimately, the program ceased in 2004, after the key funding agency withdrew all support. The decision was justified on the basis that costs and benefits of the programme did not weigh up against other national marine biosecurity priorities. This was despite knowledge gains made in terms of development of local Undaria control techniques, marine biosecurity response best practice and development of general marine biosecurity management tools.

At a regional level there was strong community interest in the incursion response. The public engaged with the programme and, over its course, vessel owners showed increased understanding of marine biosecurity issues, some demonstrating this through regular hull cleaning. The Big Glory Bay marine farmers were also hugely supportive, undertaking control at their own cost when funding was reduced. This was a great advantage to the programme while it lasted, as it enabled the response team to concentrate efforts on shoreline areas and auditing marine farms.

The uncontrolled spread of Undaria in Southland waters poses several environmental risks. These include potential impacts on the subtidal communities of Stewart Island, the Subantarctic Islands, and Fiordland. The most immediate threats appear to be to high value marine areas including the Marine Reserve in Paterson Inlet, the Auckland Islands/ Motu Maha Marine Reserve and the Fiordland/ Te Moana o Atawhenua Marine Reserves. All three areas are relatively unmodified, have a constant supply of potential vectors and, in the case of Paterson Inlet, the possibility of natural spread from neighboring Big Glory Bay. Subsequent to cessation of control efforts Undaria has spread in distribution both on Stewart Island and at Bluff and, in November 2006, was discovered in HoHo Bay at the Snares/ Tini heke.

5. Conclusion

By its close, the Southland Undaria incursion response had significantly reduced sporophyte density in the original founding populations and had helped prevent the spread of Undaria from Big Glory Bay. The programme demonstrated that it is possible to contain a marine plant pest over a wide area through good science advice, early detection, removal, sterilisation and vector management.

In terms of effective management of marine incursions, the programme highlighted the need to have established management procedures in place to respond rapidly, as well as appropriate and assured funding for the duration of the response. It emphasised the importance of understanding both the invasive species' biology and the environmental conditions in the affected area. Local awareness and support for the programme was also a great advantage.

A further positive outcome of the programme was the development and trial of marine biosecurity management techniques, which have since been used effectively to detect and respond to other Undaria incursions. Information from vessel monitoring data enabled a quick response to an Undaria incursion off the Chatham Islands, stemming from the sunken *Seafresh I,* and hot water sterilisation was then used to achieve successful eradication (Wotton *et al*, 2004).

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References

Arakawa, H. & Morinaga, T. 1994: Influence of suspended particles on dispersion of brown algal zoospores. Nippon Suisan Gakkaishi 60(1): 61-64

Casas, G.; Scrosati, R.; Luz Piriz, M. 2004: The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argintina). Biological Invasions 6, 411–416.

Cromarty, P. L.; Broome, K. G.; Cox, A.; Empson, R. A.; Hutchinson, W. M.; McFadden, I. 2002: Eradication planning for invasive alien animal species on islands – the approach developed by the New Zealand Department of Conservation. P85-91 Turning the tide: the eradication of invasive species. IUCN SSC Invasive Species Specialist Group. IUCN

Curiel, D.; Guidetti, P.; Bellemo, G., Scattolin, M., Marzocchi, M. 2002: The introduced alga *Undaria Pinnatifida* (Laminariales, Alariaceae) in the Lagoon of Venice. Hydrobiologia 477: 209-219.

Forrest, B. M; Taylor, M. D. 2002: Assessing invasion impact: survey design considerations and implications for management of an invasive marine plant. Biologival Invasions 4:375-386

Hay, C. H.; Luckens, P. A. 1987: The Asian kelp *Undaria pinnatifida* (Phaeophyta: Laminariales) found in a New Zealand harbour. N. Zeal. J. Bot. 25, 329-332.

Hay, C.H. 1990: The dispersal of sporophytes of *Undaria pinnatifida* by coastal shipping in New Zealand, and implications for further dispersal of Undaria in France. Br. Phycol. J. 25, 301-313.

Hewitt, C. L.; Campbell, M. L.; McEnnulty, F.; Moore, K. M.; Murfet, N. B.; Robertson, B.; Schaffelke, B. 2005: Efficacy of physical removal of a marine pest: the introduced kelp *Undaria Pinnatifida* in a Tasmanian Marine Reserve. Biological Invasions 7, 251-263

Pérez P, Lee J.Y. and Juge C, 1981: Observations sur la biologie de l'algue japoniase *Undaria pinnatifida* (Harvey) Suringar introduite accidentellement dans l'etlang de Thau. Science et Pêche 315: 1-12.

Saito, Y. 1975: Undaria. In: J. Tokida and H. Hirose (eds.) Advances of phycology in Japan. Dr. W. Junk, The Hague. pp. 304-320

Sanderson, J. C. 1990: A Preliminary Survey of the Distribution of the Introduced Macroalga, *Undaria pinnatifida* (Harvey) Suringer on the East Coast of Tasmania, Australia. Botanica Marina Vol. 33, 153-157

Silva, P.C.; Woodfield, R. A.; Cohen, A. N.; Harris, L. H.; Goddard, J. H. R. 2002; First report of the Asian kelp *Undaria pinnatifida* in the northeastern Pacific Ocean. Biological Invasions 4: 333-338

Simberloff, D 2003: Eradication – preventing invasions at the outset. Weed Science, 51:247-253

Sinner, J.; Forrest, B.; Taylor, M. 2000: A Strategy for Managing the Asian Kelp Undaria: Final Report. Cawthron Report No. 578 prepared for the Ministry of Fisheries.

Stuart, M.D. 1997: The seasonal ecophysiology of *Undaria pinnatifida* (Harvey) Suringar in Otago Harbour, New Zealand. Doctoral thesis, University of Otago. 193 pp.

Stuart, M. D. 2002: Translocation of Undaria pinnatifida by vessel fouling: Analysis of the Department of Conservation vessel monitoring database, May 1999 – May 2001. MFish Project ZBS2001-04. 55p.

Stuart, M. D. 2003: Review of research on *Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island. DOC Sci. Internal Series 166. 40p.

Uwai, S.; Nelson, W.; Neill, K.; Ding Wang, W.; Aguilar-Rosas, L. E.; Min Boo, S.; Kitayama, T.; Kawai, H. (2006) Genetic Diversity in *Undaria pinnatifida* (Laminariales, Phaeophyceae) deduced from mitochondria genes – origins and succession of introduced populations. Phycologia 45 (6): 687-695

Valintine, J. P.; Johnson, C. R. 2003: Establishment of the introduced kelp *Undaria pinnatifida* in Tasmania depends on disturbance to native algal assemblages. J. Exp. Mar. Biol. Eco. 295, 63-90.

Webb, V.L.; Allen, S.E. 2001: Efficiency of hot water treatments against the gametophytes of *Undaria pinnatifida*. NIWA Client Report WLG 01/23; 7p.

Wotton, D. M.; O'Brien, C.; Stuart, M. D.; Fergus, D. J. 2004: Eradication success down under; heat treatment of a sunken trawler to kill the invasive seaweed *Undaria pinnatifida.* Mar. Pol. Bul. 49 844-849.

Appendices

A1 THE SIGNIFICANCE OF PATERSON INLET

Paterson Inlet is one of the largest sheltered harbours in southern New Zealand, being comparable in size to Port Ross in the Auckland Islands and Port Pegasus in the south east of Stewart Island. The catchment area surrounding Paterson Inlet consists of relatively unmodified native forest and produces clear water with a low sediment loading. This results in a largely undeveloped, coastal environment with a diverse range of organisms unaffected by run-off and pollution from land development. Based on sedimentation studies conducted in New Zealand and overseas, the preliminary sedimentation rates calculated for Paterson Inlet appear to be representative of sedimentation rates pre-dating the human occupation of New Zealand. Due to the high volume of tidal exchange in Paterson Inlet, high tidal flows are present between islands, around headlands and through the relatively narrow entrance to the inlet. These conditions often lead to abundant assemblages of species which prefer increased water flow. The wide range of tidal current regimes present in Paterson Inlet, combined with a wide variety of hard and soft shore types, increases the potential for habitat and species diversity by providing a diverse mosaic of habitat types. As Paterson Inlet is a shallow, drowned river valley (ria), the entire area of the ria is available for colonisation by marine organisms in contrast to the limited fringe of the Southern Fiords.

The algal flora of Stewart Island and Paterson Inlet is well documented and represents the most diverse flora of any area in New Zealand.

Species diversity in Paterson Inlet

The species diversity of the rocky shore communities at the entrance of Paterson Inlet is greater than for those occurring within the inlet. Within the inlet, species diversity decreases relative to wave exposure and the presence of rocky substrate. The total number of algal species recorded from Paterson Inlet is 262, represented by 31 species of Chlorophyceae, 57 species of Phaeophyceae and 174 species of Rhodophyceae. The seaweed flora of Paterson Inlet has affinities with both mainland New Zealand and Subantarctic floras, reflecting the position of Paterson inlet at the boundary of the Subtropical Convergence and the Southland Current. The Paterson Inlet flora comprises 70% of the entire Stewart Island flora, which reflects the diversity of suitable habitats within Paterson Inlet. With the exception of the Stewart Island flora, the number of species in Paterson Inlet exceeds that of all other seaweed floras documented in New Zealand.

TABLE 2: REGIONAL SEAWEED SPECIES DIVERSITY ABOUT NEW ZEALAND.

REGION	NO. OF SPECIES	AUTHOR
Paterson Inlet	262	Adams et al. 1974
Stewart Island	381	Adams et al. 1974
Subantarctic Islands	225	Hay et al. 1985
Otago coast	197	Naylor 1954
Chatham Islands	235	Nelson et al. 1991
Kaikoura coast	234	South and Adams 1976
Marlborough Sounds	192	Nelson et al. 1992
Tasman/Golden Bays	104	Nelson et al. 1992
Three Kings Islands	160	Adams and Nelson 1985
Kermadec Islands	165	Nelson and Adams 1984

Compared to the southern fiords, where marine assemblages are typically restricted to a shallow fringe about the margins of the fiord by low surface salinity and limited light penetration through the surface freshwater layer, the convoluted coastline of Paterson Inlet produces a large area of shallow rocky reef suitable for colonisation by seaweeds. The shallow waters of Paterson Inlet also contain a diverse assemblage of soft substrate communities including extensive beds of brachiopods and the red seaweed, *Lenormandia*.

Marine Algal Associations in Paterson Inlet

Semi-exposed subtidal reef

Semi-exposed rocky reefs are typically identified by the presence of the dominant perennial bladder kelp, *Macrocystis pyrifera*. This seaweed forms a dense canopy extending 7-10m offshore. An extensive fringe of Macrocystis exists from Ackers Point along the northern coastline of Paterson Inlet to Ryans Beach. Macrocystis is also found about the northern coast of Ulva, Refuge, Crayfish and Groper Islands, as well as along the coastline of Glory Cove and the Neck. The Macrocystis fringe broadens to form submarine forests at Native Island, Ringaringa and Schoolhouse Point In the most exposed sites near the entrance of Paterson Inlet, the sublittoral fringe is dominated by the bull kelp, *Durvillaea antarctica*, strap weed, *Xiphophora gladiata* and crustose coralline algae.

The Macrocystis forest supports several species of subcanopy species which are dominated by the fucoids *Cystophora scalaris*, *Carpophyllum flexuosum*, *Marginariella boryana*, *U. urvillana* and *Sargassum sinclairii*. *Sargassum verruculosum* and *Cystophora platylobium* are occasionally present while *Ecklonia radiata* occurs sporadically. *Lessonia variegata* is confined to the exposed headland at Bullers Point. Beneath the subcanopy of fucoids, a diverse community of red seaweeds includes species such as *Asparagopsis armata, Ceramium sp., Champia chathamensis, Craspedocarpus erosus, Dasya collabens, Delisea elegans, Echinothamnion hystrix, E. lyalli, Hymenena palmata, H. curdieana, Plocamium augustum, Polysiphonia sp., Rhodophyllis gunnii, Shizoseris dichotoma* and *Streblocladia glomerulata*. In regions where a rich undercanopy is not present, filamentous red algae (Ceramiales) and crustose coralline algae occur. Likewise, a band of *Ulva* spp. and *Codium convolutum* is present where Macrocystis has been grazed by the sea urchin, *Evechinus chloroticus*.

Semi-sheltered subtidal reef

Semi-exposed subtidal reefs occur in the mid-regions of the inlet and are characterised by a narrow band of algae extending to a depth of five metres. Unlike the semi-exposed sites, no Durvillaea is present and, although Macrocystis is widespread, it does not form broad forests as near the inlet's entrance.

The zonation pattern typically consists of a sublittoral fringe of *Xiphophora gladiata* associated with *Cystophora torulosa* and *Hormosira banksii*, whereas the sublittoral zone is dominated by *Carpophyllum flexuosum* with associated *Cystophora scalaris*, *C. retroflexa*, *Codium convolutum, Ulva* sp. and *Adenocystis utricularis*. *Sargassum verruculosum* is occasionally present and crustose coralline algae are a common feature. Whilst the red algae are less diverse than on semi-exposed reefs, the sublittoral fringe may contain a luxuriant growth of red algae in localised areas. Other algal species include *Asparagopsis armata, Asperococcus bullosus, Ceramium sp., Chordaria cladosiphon, Codium fragile, Colpomenia sinuosa, Culteria multifida, Curdiea flabellata, Dasya collabens, Ectocarpus* sp. *Glossophora kunthii*, *Halopteris* sp., *Delisea elegans*, *Hymenena* sp., *Plocamium* sp., *Euptilota formosissima, Brongniartella australis, Anotrichium crinitum* and *Streblocladia glomerulata*.

Sheltered rocky shores

Sheltered rocky shores in the upper reaches of Paterson Inlet consist of small broken rocks and the occasional rock platform. The sublittoral fringe consists of *Gracilaria chilensis*, *Polysiphonia* sp. and *Hormosira banksii*.

A2 POSSIBLE IMPACTS OF UNDARIA ON THE MARINE ECOSYSTEMS OF STEWART ISLAND, THE NEW ZEALAND SUBANTARCTIC ISLANDS AND FIORDLAND.

An extensive paper reviewing research o*n Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island has been completed recently (Stuart 2003).

Stuart (2002) notes that the natural dispersal capabilities of Undaria are relatively unknown due to a lack of basic information on the viability and settlement rates of this species. Although studies of other laminarian kelps remain equivocal, dispersal seems to occur on two scales, the first occurring from ca. 1-10 m and the second occurring over a range of several kilometres. With respect to the spread of Undaria, dispersal over shorter distances will result in the gradual spread of founding populations over the immediate area. However, chance dispersal will establish other founding populations separated by several kilometres. Recent studies conducted in Queen Charlotte Sound indicate that the along-shore dispersal of Undaria in regions of low current may be in the order of 400 m per year (Brown 1999). These results are similar to a rate of between 50 m and 2 km per year estimated from experiences in other countries (Hay 1990, Casas and Piriz 1996, Floc'h *et al.* 1996, Curiel *et al.* 1998). However, rates of spread of 5-10 km per year have been documented in Tasmania (Sanderson 1997). The rate of natural spread no doubt depends on local hydrology, the availability of suitable substrate and the ability of Undaria to settle and establish in these environments. Consequently, the rate of natural dispersal of Undaria varies considerably between sites and is difficult to predict.

Although long distance dispersal and the establishment of founding populations of Undaria is very much dependent on human activity, the localised spread of founding populations is limited by its natural dispersal capabilities. Algae with heteromorphic alternation of generations, such as Undaria, have two sedentary stages (sporophytic and gametophytic), punctuated by pelagic propagules (gametes, zoospores, and embryos). It is the viability, dispersability and settlement rates of these pelagic propagules which determine how far and fast a population may disperse over successive generations (Santelices 1990). Compared to reproductive propagules of terrestrial plants (e.g. seeds), the viability of free-floating algal spores is generally short (Hoffmann and Santelices 1991). Studies on Undaria indicate that zoospores stay motile for as long as 1-2 days and may enter a state of quiescence after the loss of motility (Saito 1975, Tamura 1970). However, most recent data suggests that motility may be limited to less than a day (S. Brown *unpubl. data*). Zoospores lack phototaxis and will actively swim against a current (Saito 1975). Investigations of spore fixation show that fixing ability is strongest immediately after sporulation and then decreases rapidly (Suto 1950, Arakawa and Morinaga 1994).

Given the invasive characteristics of Undaria it is highly possible that it will be able to colonise many of the habitat types associated with Stewart Island's marine environment. The possible environmental and cultural impacts are as follows:

- Competition between Undaria and native understory algal and invertebrate species for space, nutrients and light may represent a major threat to indigenous benthic communities. As the density of the Undaria canopy increases it is highly possible that these species will be excluded.
- Infestation by Undaria of disturbed areas may lead to extra food availability for grazing invertebrates leading to an increase in population. However, as Undaria dies off at the end of summer extra predation pressure will then be put on native seaweed. Grazers may increase the disturbed area for Undaria to colonise. This may result in further exclusions of larger indigenous species like *Macrocystis pyrifera* (bladder kelp) if dense stands of Undaria persist.
- Undaria infestations will substantially alter the natural character, scientific and intrinsic values of the Ulva Island / Te Wharawhara Marine Reserve, Stewart Island and the Auckland Islands / Motu Maha Marine Reserve.
- Undaria infestations have a strong influence on cultural values by the exclusion of native species in the coastal area. Adverse effects on the seabed will ultimately damage the mauri (represents the force that binds the spiritual and the physical) of Stewart Island (in particular Te Whaka a Te Wera Mataitai) and the New Zealand Subantarctic islands coastal areas.

Cessation of the eradication/control programme may lead to dense establishment of Undaria around Stewart Island in the next 5-20 years. Undaria's invasive characteristics will allow it to colonise many of the pristine habitat types of the Island from the sheltered inlets to the open coastline. Stewart Island provides many of the artificial and disturbed substrate types where Undaria is able to establish dense populations.

A3 PROGRAMME DATA REFERENCES

Document Management Extensions (DME) is the Microsoft software DOC uses to save electronic files. The DME references can be accessed by DOC staff only and different files will have different user privileges as determined by the document author.

DME REFERENCE	DOCUMENT DESCRIPTION
SOUCO_53203	Monitoring program for Undaria following cessation of the Southland Undaria control program in November 2004. Overview of the biannual monitoring includes references to monitoring data DME's.
SOUCO_34370	Undaria measurements of length, midrib width, and reproductive status for plants removed from Big Glory Bay by site / farm. One sheet per month from Apr 00 to Dec 01. Missing: Jul 00.
SOUCO_48902	Summary of correspondence received monthly from contractor. Includes SST. From 27th September 1998 until 19th April 2005. Full monthly reports are stored in the Southland Conservancy References Database.
SOUCO_50399	Undaria removed from Stewart Island. Data from contractor tables of sites checked and plants removed. 1/8/98 – 18/9/04. Six worksheets: 'Site History 98-00' lists each site with dates checked and Undaria absence/removal is noted 1/8/98 – 31/3/00; 'Infested Sites 98-00' lists sites, dates, and number of plants removed; 'Site History 00-04' lists each site with dates checked and Undaria absence/removal is noted 11/2/00 – 18/9/04; 'Infested Sites 99-04' lists sites, dates, and number of plants removed 22/5/99 – 29/8/04; 'Temperature' lists the monthly water temperate recorded by divers in Big Glory Bay, Bluff, and Halfmoon Bay; 'Summary ' contains a table for each year from 99/00 listing infested sites and total plants removed, followed by a table listing all vessels checked at Stewart Island from 24/4/00 with site, date presence / absence of Undaria, followed by a summary table of infested vessels.
SOUCO_42505	Summary of Undaria data. Includes worksheets for each site and summaries above data for production of total removal graphs in this report
SOUCO_48855	Undaria removed from Bluff. Data from contractor tables of sites checked and plants removed. 15/11/98 – 7/9/04. Four worksheets: 'Bluff Clear' lists each site with dates checked and Undaria absence/removal is noted; 'Bluff Infested' lists sites, dates, and number of plants removed; 'Bluff Vessels' lists infested vessels at Bluff, site, date, then a table below lists all vessels checked and clear with site, date; 'Annual summary' contains a table for each year listing infested sites and total plants removed.
SOUCO_42470	Undaria measurements of length, midrib width, and reproductive status for plants removed from Big Glory Bay by site / farm. One sheet per month from Jan 02 to Jul 04. Missing: Dec 02, Mar 03, Nov 03, Dec 03, Jan 04, Feb 04.
SOUCO_42465	Undaria measurements of length into 10 cm size class bins, and reproductive status for plants removed from Bluff Harbour by site / farm. One sheet per month from Apr 00 to Jul 04. Missing: Jun 02, Oct 02, Dec 02, Mar 03, Dec 03, Jan 04, Feb 04, Apr 04, Jun 04, Jul 04.
SOUCO_42472	Undaria measurements of length into 10 cm size class bins, and reproductive status for plants removed from Scollay Rocks by site / farm. One sheet per month from Apr 00 to Jul 04. Missing: Sept 01, Jan 02, Mar 02, Aug 03, Sept 03, Dec 03, Jan 04, Feb 04, Apr 04, May 04. Data entered into few evenly spaced bins (estimated data) Oct 00, Nov 00, Dec 00, Aug 02, Sept 02, Oct 02, Dec 02, Jan 03, Feb 03, Mar 03, May 03.
SOUCO_49954	Subantarctic vessel visits database. Lists vessel, dates, sites visited home ports, previous ports, trip duration, trip purpose, permit number when available / known. 1787 - 2005.