# Review of research on *Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island

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Mike D. Stuart

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# CONTENTS

# Review of research on *Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island

Mike D. Stuart

Enviromarine Limited, 36 Tidewater Drive, RD2, Dunedin, New Zealand
undaria@ihug.co.nz

## ABSTRACT

*Undaria pinnatifida* is a laminarian kelp, indigenous to the temperate regions of Japan, China and Korea. It has been spread about the world by international shipping and mariculture and was discovered in Wellington Harbour in 1987. Its subsequent spread about mainland New Zealand has raised concerns about the possible impacts it may have on the natural state, marine life and natural habitat values of high-value areas. Undaria may colonise substrates that do not otherwise contain a dense canopy of seaweed. It can exclude seaweeds from established algal assemblages by forming a dense cover in cleared regions, thereby preventing the recruitment of ephemeral or canopy-forming species. Such colonisation by Undaria has been shown to result in increased biodiversity in areas otherwise devoid of diverse indigenous seaweed assemblages; but it can also reduce biodiversity in regions where it displaces species or causes a decrease in species' abundance. Direct competition between Undaria and canopy-forming marine algae such as *Macrocystis pyrifera, Ecklonia radiata, Carpophyllum mascalocarpum*, *C. flexuosum*, *Cystophora* spp., *Hormosira banksii* and *Xiphophora gladiata* is likely to favour established species in stable environments. However, Undaria may be able to cohabit with, or even exclude such species in environments that are subject to regular storm events or moderate grazing pressure. The establishment of a dense canopy of Undaria would likely lead to the exclusion of subcanopy and undercanopy species and a reduction in biodiversity. The greatest impacts of Undaria along the eastern coast of the South Island are likely to be in areas where the frequency and magnitude of storm events result in the periodic removal of indigenous algae, particularly if they correspond with the seasonal appearance of Undaria in spring and early summer.



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# 1. Introduction

*Undaria pinnatifida* is a laminarian kelp, indigenous to the temperate regions of Japan, China and Korea. It has extended its range to include 12 countries on four continents since 1981, including New Zealand, with the discovery of *U. pinnatifida* (henceforth referred to as Undaria) in Wellington Harbour in 1987 (Hay & Luckens 1987; Stuart 2002). Concern has been raised about the possible impacts of Undaria on New Zealand's marine environment. This led to the determination of Undaria as an unwanted organism under the Biosecurity Act 1993, and its inclusion as a pest species in several regional pest management strategies. Central Government's approach to the management of Undaria is to slow its spread around mainland New Zealand and reduce the probability of it spreading to remote locations such as the Subantarctic and Chatham Islands (Ministry of Fisheries 2002a). While the Ministry of Fisheries is the lead agency for the management of marine biosecurity in New Zealand, the Department of Conservation's (DOC's) responsibilities include providing advice on the impacts of introduced species on indigenous species and in high value areas, including marine reserves.

The potential impact of intentional or unintentional species introductions to marine reserves is recognised as an important factor requiring consideration when developing monitoring and management options for these reserves (McCrone 2001). At present there are 16 established marine reserves managed by DOC comprising 763 629 ha; only one is present on the eastern coastline of the South Island, at Flea Bay, Banks Peninsula. Pohatu (Flea Bay) Marine Reserve comprises 215 ha situated east of the entrance to Akaroa Harbour, and was gazetted in 1999. A further 17 sites are under investigation as possible marine reserves, including formal marine reserve applications at Kaikoura, Akaroa Harbour and the Nuggets (Department of Conservation 2000; McCrone 2001).

The purpose of marine reserves is to preserve areas of New Zealand's marine environment of national interest for the scientific study of marine life[1], by protecting and preserving their natural state and marine life, and maintaining the values of the natural habitat[2]. Protecting marine reserves from the impacts of marine pests is therefore an important element in achieving this purpose. Undaria is a marine pest that could significantly impact on the natural state, marine life, and natural habitat values of marine reserves. The intention of this report is to provide information to assist in the assessment of Undaria's potential impacts in such areas.

Specific objectives of this report are to provide:

- A list of past and present research programmes carried out on Undaria in New Zealand.
- An assessment of the potential impact of Undaria on the South Island's east coast.
- A bibliography of published and unpublished literature on Undaria.

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[1] Marine Reserves Act 1971, s3(1)

[2] Marine Reserves Act 1971, s3(2)

## 1.1 LIFE HISTORY OF UNDARIA

Undaria has an annual, heteromorphic life history characterised by macroscopic sporophyte and microscopic gametophyte stages (Fig. 1). The longevity of the sporophyte stage is approximately 6 months, but the dioecious gametophyte stage appears to be perennial, and gametophytes may remain viable for at least 24 months (Stuart 2000).

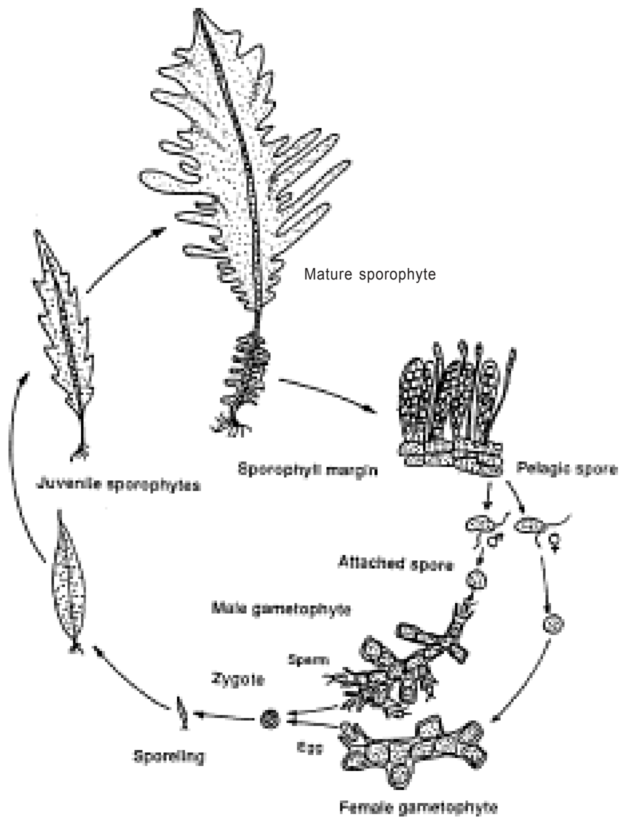
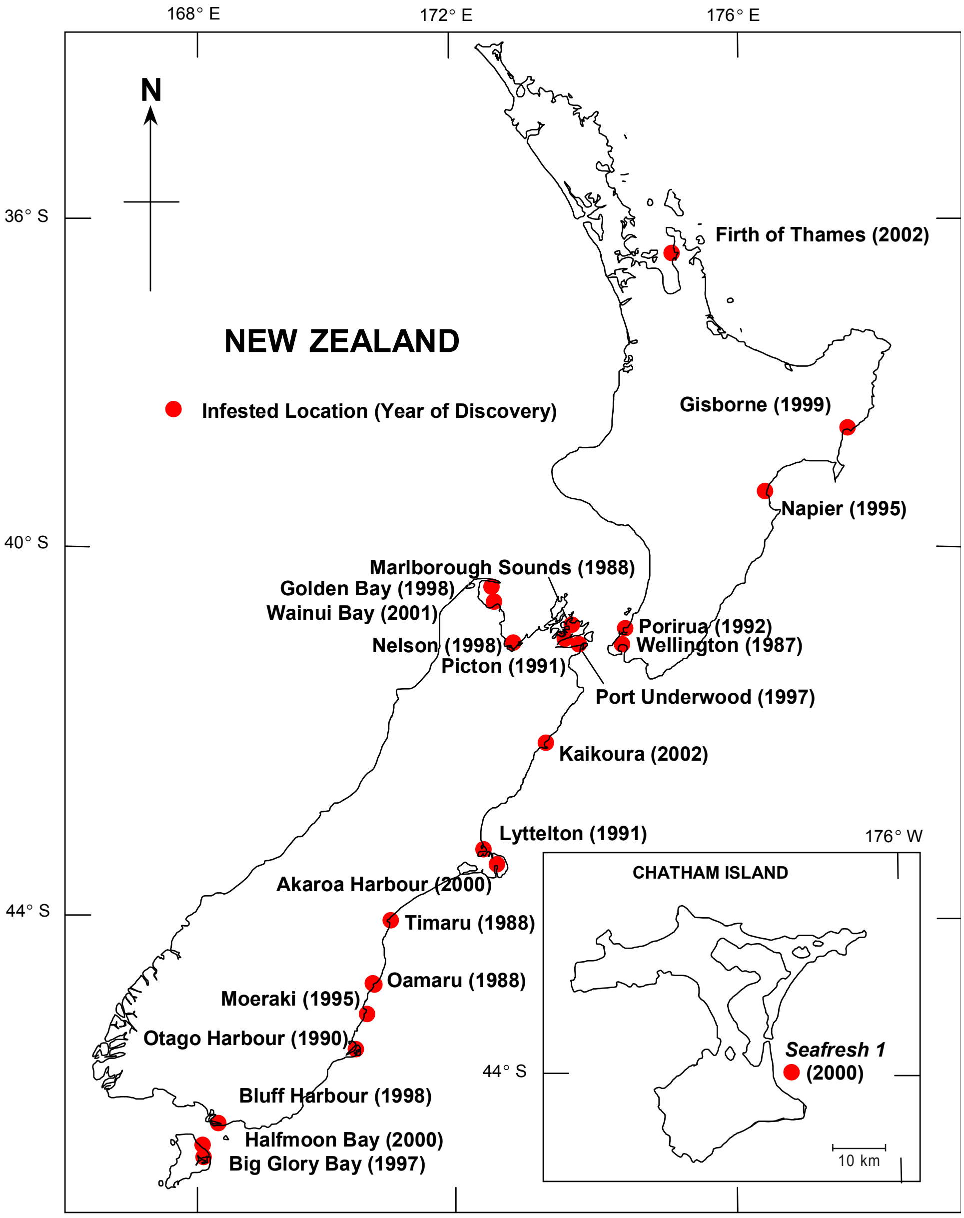



Figure 1. The life history of Undaria showing the visible sporophyte (seaweed) stage and the microscopic gametophyte stage. Note that the gametophyte stage has separate male and female plants that produce a sporophyte through sexual reproduction. The sporophyte (seaweed) stage releases millions of asexual spores that germinate into dioecious gametophytes.

## 1.2 SPREAD OF UNDARIA

The distribution of Undaria in New Zealand is generally restricted to ports and harbours frequented by coastal vessels, and areas utilised for marine farming (Fig. 2). Spread of Undaria by vessel fouling has almost certainly occurred, as indicated by the close association of many founding populations with areas frequented by vessels. Translocation of Undaria as fouling on vessels has been implicated in the introduction of Undaria to ports and harbours at Gisborne, Wellington, Porirua, Marlborough Sounds, Nelson, Lyttelton, Akaroa, Timaru, Oamaru, Bluff and Halfmoon Bay (Hay 1990a; Hay & Sanderson 1999; pers. obs.). The spread of Undaria about the Marlborough Sounds was closely associated with marine farming activities, as were more recent introductions to Big Glory Bay, Golden Bay, Wainui Bay and the Firth of Thames (Fig. 2).

Figure 2. Known dispersal of Undaria about New Zealand, and year of discovery.




## 1.3 NATURAL DISPERSAL OF UNDARIA

Natural dispersal of laminarian kelps, such as Undaria, occurs over different spatial scales ranging from c. 1–10 m to several kilometres (Anderson & North 1966; Dayton 1973; Vandermeulen & DeWreede 1986; Forrest et al. 2000). Forrest et al. (2000) propose that spore dispersal from fixed stands of Undaria results in short-range dispersal over metres to hundreds of metres, whereas the dispersal of fragments or whole sporophytes ranges from hundreds of metres to kilometres. Saltation of sporophytes attached to mobile substrates, such as rocks, pebbles and shells, can lead to the dispersal of individual sporophytes over 10–100 m per annum (TAFI 2000). The egg and zygote of Undaria are non-motile and have limited dispersal capabilities, but spores of laminarian seaweeds are motile and typically disperse over distances of up to 10 m (Anderson & North 1966; Dayton 1973; Vandermeulen & DeWreede 1986). Field observations of the spread of Undaria suggest that it may spread at a rate of between 50 m and 10 km per year (Casas & Piriz 1996; Floc'h et al. 1996; Sanderson 1997; Curiel et al. 1998; Brown 1999). However, this rate of spread largely depends on local hydrology and the availability of substrate suitable for colonisation. Observations of the distribution of Undaria in Tasmania also suggest that it has the capacity to tolerate a wide range of exposure to wave action, and that wave exposure would not be a barrier to its spread (Sanderson 1990, 1997). The rate of natural dispersal of Undaria may, therefore, vary considerably between sites and is difficult to predict because of the often overriding influences of human-mediated dispersal, principally by hull fouling.

# 2. Past and present research programmes

Following the discovery of Undaria in Wellington Harbour in 1987, research on it described the mechanisms and extent of its spread, ecology and ecophysiology. Programmes were also established to describe the ecological impacts of Undaria, and investigate the feasibility of Undaria mariculture in New Zealand. More recent research has focused on management of Undaria, including the development of control methods and vector management. Such research has been conducted by various agencies including the New Zealand Oceanographic Institute (of the former DSIR[3]), Department of Conservation, Cawthron Institute, National Institute of Water and Atmospheric Research (NIWA), and various universities. Local government and stakeholder groups have also implemented measures and undertaken actions to control the spread of populations at places such as Akaroa Harbour, Golden Bay, Nelson Haven, and Stewart Island. References directly associated with the research conducted in these programmes are listed under the appropriate agency names in Appendix 1. [There may be some duplication between these lists and the references cited in the main part of this report and listed in Section 4, and the bibliography in Appendix 2.]

## 2.1 DEPARTMENT OF CONSERVATION

The discovery of Undaria in Wellington was reported in Hay & Luckens (1987) while Cameron Hay was employed at the New Zealand Oceanographic Institute. Dr Hay later took up a position at the Department of Conservation, where a DOC Science project investigated the distribution, abundance and means of dispersal of Undaria (Hay 1992). The project also sought to measure and assess the environmental impact of Undaria on native marine flora and fauna. Outputs of this research comprised various reports describing the spread of Undaria about New Zealand (Hay 1990a), the seasonality of the sporophyte stage (Hay & Villouta 1993), and a report on the Korean and Japanese *Undaria* mariculture

[3] Department of Scientific and Industrial Research

industry (Hay 1991). In 1993, a report was commissioned by Nelson/ Marlborough Conservancy of DOC that considered the environmental implications of proposals to cultivate Undaria in New Zealand (Parsons 1994). This report presents information on the biology and ecology of Undaria, and answers specific questions presented by the Department. It also discusses the feasibility of Undaria control in New Zealand and the introduction of other exotic seaweeds, as well as presenting a bibliography of relevant literature.

Undaria was discovered by NIWA scientists at Big Glory Bay, Stewart Island in March 1997 (see Fig. 2). A survey of the entire bay was conducted by DOC during April 1997, and a formal programme was implemented by Southland Conservancy to monitor and remove the sporophyte stage. While this programme was initially supported from Vote Conservation, Vote Biosecurity funding was later approved to 30 June 2003. Manual removal of Undaria by divers resulted in a significant reduction in sporophyte abundance, but eradication was not achieved (Stuart & Chadderton 2001).

Immediately after the discovery of Undaria in Big Glory Bay, an attempt was made to sterilise floating structures with sodium hypochlorite. The floating structures were towed to nearby tidal flats were they were enclosed in polythene sheets at low tide. Sodium hypochlorite granules were placed within the area confined by the sheeting (L. Chadderton, DOC, pers. comm.). However, this technique did not kill all Undaria (pers. obs.). Following the discovery of Undaria at Bluff Harbour in 1998, a bromin-ated micro-biocide (Amersperse 261-T, Ashland Chemical) was considered as a possible biocide alternative to chlorine-based products, because bromine is more active than chlorine at the pH of seawater (c. 8.2). Bromine is also less corrosive, less likely to evaporate at high temperature, and breaks down more rapidly (Drew-Chemicals 1994). The use of brominated oxidising agents, however, proved to be ineffective and attention was applied to the development of other techniques such as the use of heat treatments (S. Cooper pers. comm. 2002). DOC commissioned laboratory experiments to assess the efficacy of hot water treatments against the gametophyte stage (Webb & Allen 2001). These experiments indicated that exposure of Undaria gametophytes to hot water at 60°C for 5 seconds induced 100% mortality *in vitro*. Such data was influential in the treatment of the m.v. *Seafresh 1* at Chatham Island (see Section 2.5 below), and the development, by DOC, of techniques that apply super-heated steam to benthic substrates. Such techniques were applied to benthic populations of Undaria in Halfmoon Bay, Stewart Island (S. Cooper pers. comm. 2001).

A vessel monitoring programme was implemented by DOC in May 1999 to evaluate and manage the threat that hull fouling by Undaria represented to the eradication programme. The key objective of the programme was to identify individual vessels fouled with Undaria sporophytes and specific biosecurity threats to Southland. However, the programme was also able to determine 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 was fouled with Undaria. Data collected by the monitoring programme from May 1999 to May 2001 are presented in a report commissioned by the Ministry of Fisheries (Stuart 2002).

## 2.2 CAWTHRON INSTITUTE

The Cawthron Institute, Nelson, has conducted a considerable amount of research on Undaria as part of several research programmes investigating marine biosecurity issues and mariculture.

A research programme funded by the Public Good Science Fund (PGSF) in the 1990s investigated the feasibility of commercial Undaria cultivation in New Zealand (Contracts CAW403 and CAW602). The programme had two main objectives. The first was to maintain gametophyte cultures of the microscopic gametophyte stage from the plant's life cycle. This focused on the application of French and Japanese cultivation techniques involving the laboratory culture of gametophyte stocks and sporophytes upon seed string that was later translocated to the field. Gametophyte cultures preserved the characteristics of the originally introduced populations, and provided material from which large harvestable sporophytes were grown. The second objective involved monitoring the growth of trial crops in the sea to determine which treatments and methods were most productive. Field trials at Mahanga Bay, Wellington and in the Marlborough Sounds met with varied success, and later focused on identifying the most favourable genetic strains and environmental conditions for commercial cultivation (Gibbs & Hay 1998). The effect of various environmental factors on crop production was assessed, and it was found that flood events, biofouling and El Niño weather patterns appeared to have a negative effect on yields. Timing and depth of planting were also identified as important factors for growth. The Undaria aquaculture programme concluded in June 2000 (Gibbs 2000).

The Cawthron Institute's marine invaders and ballast water programmes have investigated aspects of the management of marine adventive species; this includes work on Undaria. The Cawthron Institute is carrying out research funded by the PGSF on marine bio-invasions that aims to provide the shipping industry and coastal managers with ways to reduce invasion rates of non-indigenous species, and to improve management of species already established in New Zealand (Contracts CAW804 and CAWX0001). Work is being carried out to construct a risk-assessment model to estimate the link between the transport and establishment of species. Research on the establishment, impact and management of marine bioinvaders focuses on three species already widespread around the New Zealand coast; these are the Pacific oyster, the saltmarsh cordgrasses and Undaria. Work on Undaria has involved laboratory and field experiments to identify its natural dispersal potential, ecological impact, and the critical processes required for its successful establishment[4].

The Ballast Water Programme investigated heating and oxygen removal for the treatment of ballast water in laboratory-scale experiments on organisms which are either introduced or indigenous species, and those that are closely related to potentially harmful species transported in ballast water. Research focused on the free-swimming life cycle stages, and included zoospores of Undaria and larvae of the indigenous starfish *Coscinasterias calamaria*[4]. Research on ballast water issues was carried out between 1996 and 1998, but research funding ceased before a practical shipboard method for sterilising ballast water could be developed beyond the prototype.

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4 www.frst.govt.nz/database/reports/index.cfm (10 Feb. 2004)

Additional work has been conducted by the Cawthron Institute on the management of Undaria. In 1999 the Government requested the Ministry of Fisheries to prepare a proposal for a National Pest Management Strategy (NPMS) for Undaria and a discussion paper was prepared describing options for managing it (Sinner et al. 2000a). This paper was released for public comment in January 2000, with more detailed information provided in a technical report (Sinner et al. 2000b). A final report was prepared in May 2000 (Sinner et al. 2000c); this recommended a management framework including the following measures:

- Surveillance and response to new infestations in high-value areas, including areas of local significance
- Intensive vector monitoring in key donor areas, particularly targeting vessel fouling
- A prohibition on persons knowingly spreading or introducing Undaria
- Controls on ballast water discharge and hull de-fouling in or near high value areas
- Controls on wild harvests, farming and research involving Undaria
- Education and public awareness campaigns, including (where relevant) codes of practice for marine farmers, vessel owners / operators and others
- Research on impacts, improved management techniques, and other topics

After prioritisation of the NPMS proposal against other biosecurity requirements, notification of it did not take place.

As part of investigations into management options for Undaria, the Ministry of Fisheries contracted a project to identify the risks posed by the various human activities which can lead to the spread of the seaweed. This project was undertaken by Kingett Mitchell Ltd, and considered the pathways by which Undaria may be spread by coastal vessel traffic and marine farming activities. Kingett Mitchell Ltd contracted the Cawthron Institute to provide an assessment of likely introduction pathways associated with marine farming to identify measures that could be incorporated into their overall project (Forrest & Blakemore 2002). Another Ministry of Fisheries-funded project, undertaken by the Cawthron Institute, involves the assessment of methods to kill Undaria on marine farming equipment and seed mussels (MinFish Project ZBS2001-11).

## 2.3 NATIONAL INSTITUTE OF WATER AND ATMOSPHERIC RESEARCH (NIWA)

Research on Undaria at NIWA documents the seaweed's spread and ecological impacts (Miller et al. 1997; Battershill et al. 1998). Undaria is also included in a surveillance programme undertaken by NIWA for the Ministry of Fisheries (Project ZBS2001/01), and work to assess the efficacy of heat treatments against Undaria gametophytes was commissioned by DOC (see above).

## 2.4 MINISTRY OF AGRICULTURE AND FISHERIES (MAF)

The suitability of Undaria as a feed source for paua was investigated by MAF Fisheries[5] in the course of feed trials of the casein-based abalone food, Makara, produced by Promak Technologies (NZ) Ltd. Results indicate that paua (*Haliotis iris*) fed on separate diets of Maraka and *Gracilaria chilensis* consistently grew faster than paua fed Undaria (Redfearn 1994). Paua fed Undaria and *Gracilaria chilensis* ad libitum at 4-day intervals consumed more Undaria (0.55 g/day compared with 0.34 g/day), but had a lower food conversion index (25:1 compared with 11:1). Hence paua ate more Undaria, but were less efficient in converting this to biomass and, consequently, grew more slowly on a diet of Undaria than on *G. chilensis*.

## 2.5 MINISTRY OF FISHERIES (MFISH)

In June 2000, the New Zealand Government announced it would spend $9.8 million on developing information and management systems to enhance New Zealand's marine biosecurity. This funding is part of a comprehensive 5-year Biodiversity Strategy package involving conservation, environment, fisheries and biosecurity (Ministry of Fisheries 2002b). The Ministry of Fisheries therefore supports marine biosecurity research that aims to provide a knowledge base to improve marine biosecurity management, and lead to the development of tools and systems to reduce marine biosecurity risks to marine biodiversity. Much of the research presently conducted on Undaria is currently supported by the Biodiversity Strategy package.

The Ministry of Fisheries' policy toward Undaria is detailed in an action plan for unwanted species (Ministry of Fisheries 2002a). Specific steps being taken to slow the spread of Undaria comprise:

- Implementation of vector management programmes for selected areas, e.g. the Subantarctic and Chatham Islands
- Education of marine stakeholder groups on how best to avoid spreading Undaria
- Support of research on methods for treating vectors so that the incidence of translocation events is minimised
- Support of regional initiatives to control Undaria by developing treatment methods and educational material

The Ministry of Fisheries also led the biosecurity response to the introduction of Undaria at Chatham Island in March 2000. This occurred after the *Seafresh 1*, a motor vessel previously fouled with Undaria, foundered in Hanson Bay (see Fig. 2). Subsequent inspection of the sunken vessel confirmed that it was fouled with Undaria and eradication was attempted in June 2001 by sterilising the hull with hot water. This work was conducted by New Zealand Diving and Salvage Ltd and comprised sterilising sections of the vessel hull by attaching a wooden marine-ply box to the side of the hull with magnets. Industrial electrical

[5] In 1995 MAF became Ministry of Agriculture and Forestry, and a separate Ministry of Fisheries (MFish) was established.

elements within the box heated the encapsulated water to 70°C within 15 minutes (D.J. Fergus pers. comm. 2001). A total of 524 Undaria sporophytes were removed from the vessel prior to March 2002, including one mature plant. Microscopic examination of the sporophyll tissue, however, indicated that spores had not been released. Treatment of the vessel hull was completed on 28 June 2001 and no Undaria sporophytes have been found on the vessel during subsequent monthly inspections to January 2003 (pers. obs.).

### 2.6 UNIVERSITY OF OTAGO

Research on Undaria undertaken at Otago University principally comprises dissertations and theses investigating various aspects of its physiology and ecology. Collaborative research between the University of Otago and the Cawthron Institute investigated the dispersal characteristics of Undaria.

### 2.7 VICTORIA UNIVERSITY OF WELLINGTON

Bob Wear and Jonathan Gardner monitored the spread of populations of Undaria at Island Bay, Wellington (New Zealand Marine Sciences Society: NZMSS 1998), and Sheree Christian has conducted post-graduate research on the ecology of Undaria as part of a master's degree in conservation science (S. Christian pers. comm.).

### 2.8 UNIVERSITY OF CANTERBURY

Glen Thompson is presently working on his doctoral thesis[6] which describes the effects and impacts of Undaria on native flora and fauna in shallow marine habitats. The research objectives are to compare the population demography of Undaria at different sites along the east coast of the South Island, examine the invasiveness of Undaria within shallow marine habitats, and investigate factors that affect the survival and development the early life history stages of Undaria.

# 3. Potential impacts of Undaria

Assessing the potential impacts of Undaria on indigenous species requires adequate knowledge of the ecology of the seaweed and how its presence may affect the structure and composition of indigenous species assemblages. Undaria has a high visual impact because of its preference for growing on artificial substrates that are typically colonised by smaller, inconspicuous algae. However, demonstrable impacts on species abundance and diversity are

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6 www.zool.canterbury.ac.nz/MERG/personnel.htm (10 Feb. 2004).

difficult to determine because of a general paucity of baseline data on species assemblages in areas invaded by Undaria. Much assessment of the impacts of Undaria has consequently been based on anecdotal information, but several initiatives are currently underway to collect baseline data on New Zealand's marine biodiversity including development of the National Aquatic Biodiversity Information System (NABIS) and Marine Ecology Research Group (MERG)—Reef Database (Ministry of Fisheries 2002b; Wood 2002). However, research on the biology and ecology of Undaria has identified several characteristics that indicate its potential to have a significant impact on indigenous species (see below). More recent research has begun to assess the impacts of Undaria and investigate factors that affect its ability to invade and persist amongst indigenous species assemblages (Forrest & Taylor 2002; Valentine & Johnson 2003).

## 3.1 INVASIVE CHARACTERISTICS OF UNDARIA

Biological characteristics that predispose species to be invasive, typically comprise *r*-selected traits such as rapid growth, early on-set of reproductive maturity, and high fecundity. Invasiveness is often attributed to more general traits such as a short life cycle, uniparental reproduction, a broad ecological niche, genetic polymorphism, phenotypic plasticity, and phylogenetic distance from native plants (Bazzaz 1986; di Castri et al. 1995; Dean 1998). Undaria displays several such characteristics. The sporophyte stage of Undaria is *r*-selected, as demonstrated by short life span (6–9 months), rapid growth (1 cm/day), early maturation (c. 50–70 days), high fecundity (millions of spores/ sporophyte) and rapid rates of nutrient uptake (Saito 1975; Stuart 1997; Campbell & Burridge 1998; Campbell 1999; Campbell et al. 1999). A biphasic life history enables Undaria to adapt to a wide range of environmental conditions due to the different physiological requirements of the gametophyte and sporophyte stages. Not only do the phases of Undaria's life history differ in their physiological requirements, they also differ in morphology and seasonality. Alternation between macroscopic sporophyte and microscopic filamentous gametophyte life history stages thereby results in the spatial and temporal partitioning of habitat requirements, and competition with indigenous species, at both macroscopic and microscopic scales.

Adding to its invasive characteristics is the fact that Undaria has no close phylogenetic relatives in New Zealand. New Zealand has no indigenous annual laminarian seaweeds. The closest related indigenous laminarian algae are perennial (e.g. *Macrocystis pyrifera*, *Lessonia* spp. and *Ecklonia* spp.). *Desmarestia ligulata* (Desmarestiales) is perhaps the nearest ecological equivalent, as it has a similar biphasic life history to Undaria, comprising the alternation between macroscopic sporophyte and microscopic gametophyte stages (Adams 1994). The annual appearance of *D. ligulata* sporophytes in summer corresponds with the release of Undaria spores and the onset of senescence in the Undaria sporophyte generation. Hence, competition between these species is likely to be complex, and include interactions within and between both gametophyte and sporophyte life history stages.

## 3.2 ALGAL ASSEMBLAGES ON THE EASTERN COAST OF THE SOUTH ISLAND

One of the most significant features of subtidal algal assemblages on exposed mainland coastline of New Zealand is the abundance of large brown seaweeds (Adams 1972). Eleven genera all produce thalli of a metre or more in length, of which 20 species are found along the east coast of the South Island e.g. *Carpophyllum flexuosum*, *C. mascalocarpum*, *Cystophora retroflexa*, *C. congesta*, *C. distenta*, *C. platylobium*, *C. scalaris*, *C. torulosa*, *Desmarestia ligulata*, *Durvillaea antarctic*, *D. willana*, *Ecklonia radiata*, *Landsburgia quercifolia*, *Lessonia variegata*, *Macrocystis pyrifera*, *Marginariella boryana*, *M. urvilleana, Sargassum sinclarii*, *S. verruculosum*, and *Xiphophora gladiata* (Adams 1972, 1994).

General patterns of algal distribution are evident along the eastern coast of the South Island, where the lower sublittoral fringe and upper subtidal of the open coast is occupied by *Durvillaea antarctica* and *D. willana* (Schiel 1990). Fucalean species predominate to a depth of 8 m and *Ecklonia radiata* may form stands in both shallow and deep water, about much of mainland New Zealand (Schiel 1988). However, *Macrocystis pyrifera* appears to be the dominant canopy-forming laminarian seaweed along much of the eastern coast of the South Island where rock reefs north of Otago Peninsula at Karitane, Shag Point, Kakanui and Moeraki perhaps contain the greatest concentrations of *M. pyrifera* around the North and South Islands of New Zealand (Hay 1990b). The fuciod alga *Carpophyllum mascalocarpum* is absent from the south-eastern parts of the South Island, reaching its southern limit on the east coast at Banks Peninsula but extending to Milford Sound on the west coast (Morton & Miller 1968; Adams 1994). *Carpophyllum flexuosum* and *Xiphophora gladiata* are both inexplicably absent from the Kaikoura coast (South & Adams 1976). *Sargassum verruculosum* is native to Western Australia, but was found at Akaroa in 1845 (Adams 1994). Subsequent collections have all been made in places frequented by whaling and sealing vessels, so it may represent an early introduction, brought in on these sailing vessels (Adams 1983, 1994).

### 3.2.1 Harbour environments

The principal harbours at Otago, Lyttelton and Akaroa have steep, drowned coastlines with good stretches and outcrops of rocky shore, kept clean of sediment by moderate wave action and swift tidal currents in the main channels (Morton & Miller 1968). In the lower limits of Lyttelton and Akaroa harbours, *Macrocystis pyrifera* and *Pyura* sp. occupy the low water mark, giving way to a fringe of *Cystophora torulosa* and *C. scalaris* in sheltered backwaters relatively free of current (Morton & Miller 1968). A notable feature of Banks Peninsula is the extension of a narrow band of *Durvillaea antarctica* and *D. willana* into the harbour regions and the occurrence of extensive stands of *M. pyrifera* (Morton & Miller 1968; Schiel et al. 1997). Such features are not evident in Otago Harbour (pers. obs. 2002).

In Otago Harbour, canopy-forming seaweeds are limited to a narrow band of *Macrocystis pyrifera* and *Carpophyllum flexuosum* from < 1 to 15 m depth in sheltered areas subject to strong tidal currents (Kain 1982; Nyman et al. 1993). This was particularly evident at Weller's Rock, where an artificial groyne extends into the main shipping channel. A thin region of rocky substrate in 2–10 m of water on the seaward side of the groyne has been colonised by a canopy of *Macrocystis pyrifera* with undercanopy of *Carpophyllum flexuosum*. *Scutus breviculus* was abundant, with its greatest density near shore and decreasing density along the groyne and into deeper water. At depths of 10–15 m, at the end of the groyne, *Desmarestia ligulata* and *Pugetia delicatissima, Cladophora feredayi,* and *Ulva* sp. were found together with numerous sponges (pers. obs. Dec. 1994).

Algal assemblages at Aquarium Point, Otago Harbour were recorded by Batham (1956b). The lower mid-littoral zone was dominated by *Hormosira banksii* and *Ulva* sp. with associated *Polysiphonia* spp., articulate coralline algae and *Gigartina decipiens*, and seasonal appearances of *Colpomenia sinuosa*, *Leathesia difformis* and *Scytosiphon lomentaria*. *Cystophora torulosa* occupies the upper sublittoral fringe. The sublittoral zone was dominated by *Macrocystis pyrifera* with a subcanopy of *C. retroflexa* and occasional *Carpophyllum flexuosum* and *Cystophora scalaris*. *Desmarestia ligulata* was probably seasonally abundant. *Ecklonia radiata* formed small beds of stunted sporophytes in the sublittoral zone (Batham 1956b; Morton & Miller 1968; pers. obs. Dec. 1994). *Xiphophora gladiata* occured at parts of Quarantine Island, but was not present at Aquarium Point (Batham 1956a).

### 3.2.2 Algal assemblages associated with Undaria in harbour environments

As Undaria prefers artificial substrates in sheltered harbours (Parsons 1994; Floc'h et al. 1996), associated algal assemblages comprise species that have a similar preference. Filamentous and small foliose algae such as *Mediothamnion lyalli*, *Ulva rigida*, *Rhodymenia* spp., *Griffthsia crassicula*, *Gigartina* spp. and *Phycodrys quercifolia* associate with Undaria on wharf piles in Otago Harbour (Stuart 1997). Likewise, species of *Ulva*, *Scytosiphon*, *Gigartina*, *Iridaea*, *Schizoseris*, *Grateloupia*, *Myriogramme*, *Rhodophyllis* and *Plocamium* associate with Undaria on the slipway at Timaru (Hay & Villouta 1993). In other harbour areas Undaria associates with canopy-forming seaweeds occupying a narrow band from < 1 to 15 m depth in sheltered regions subject to a strong tidal currents (Hay & Villouta 1993; pers. obs. 1997). In Wellington Harbour, Undaria colonises bare rock in the low intertidal zone, above the *Carpophyllum maschalocarpum* zone, as well as cobbles and bare areas between stands of *C. maschalocarpum* and *C. flexuosum*. Undaria was also associated with *Codium dichotomum*, *Ulva* sp., *Culteria multifida*, *Aeodes* sp., *Gigartina* sp., *Kallymenia* sp., *Plocamium* sp. and *Grateloupia* sp.; in Timaru Harbour Undaria co-habits with *Sargassum sinclairii*, *Macrocystis pyrifera*, *Cystophora scalaris* and *Desmarestia ligulata* (Hay & Villouta 1993).

At Aquarium Point, Otago Harbour, Undaria grows on rocky substrate and on boulders within softer substrates just below m.l.w.n. (mean low water neap), but is densest about m.l.w. (mean low water) amongst assemblages of *Hormosira banksii*, *Cystophora torulosa* and *Codium fragile* (pers. obs. Jul. 1997). Colonies of Undaria were found growing on rocky substrate and boulders. The density of Undaria was greatest (15–25 plants/m$^2$) on the rock reef extending into the channel and where associated with the sea squirt *Pyura pachydermatina*, the oyster *Crassostrea gigas* and *Ulva lactuca*. Clumps of Undaria were observed within the zone inhabited by *Ulva lactuca* and *Polysiphonia* sp. and individual sporophytes were also observed in slightly deeper water, growing upon boulders under a canopy of *Macrocystis pyrifera* (pers. obs. Jul. 1997).

### 3.2.3 Otago coast

Extensive accumulation of sand on beaches and sandspits is a notable coastal feature of the Otago coast, where rocky shoreline usually exists only as a narrow band that disappears into sand over short distances (Fyfe 1992). Subtidal reefs support relatively diverse algal assemblages where volcanic formations form promontories along the Otago coastline, and sandstone terraces extend to depths of 15–20 m north of Cornish Head and Pleasant River (pers. obs.). Such assemblages comprise a dense canopy of *M. pyrifera* near the shore with a subcanopy of *Ecklonia radiata* and *Carpophyllum flexuosum* and undercanopy of *Xiphophora gladiata*, *Cystophora scalaris*, *Desmarestia ligulata* and *Margineriella boryana* (Fyfe 1992; pers. obs., Jan. and Mar. 1995). In slightly deeper water, the canopy of *M. pyrifera* is less dense. *Ecklonia radiata* and *C. flexuosum* are more dominant and individuals of *Landsburgia quercifolia* are also present. Rock outcrops occur in places which support a diverse algal flora including *Anotrichum crinitum*, *Antithamnionella adnata*, *Antithamnion applicatum*, *Arthrocardia corymbosa*, *Ceramium* sp., *Hymenena durvillaei*, *Plocamium costatum*, *Plocamium augustum*, *P. microcladioides*, *Rhodophyllis membranacea* and *Sarcodia flabellata* (pers. obs. Jan. 1995 and Mar. 1995).

Outcrops of the Katiki formation at Shag Point were interspersed with patches of shell gravel and colonised by *Euptilota formossisima*, *Hymenena durvillaei* and *Plocamium* sp. (Fyfe 1992). A similar formation exits along the coastline north of Cornish Head. At depths of 5–10 m, rock terraces were colonised by *Caulerpa brownii*, *Rhodophyllis membranacea*, *Xiphophora gladiata*, *Marginariella boryana*, *Desmarestia ligulata*, *Halopteris funicularis*, *Microzonia velutina*, *Hymenena durvillaei*, *Anotrichium crinitum*, *Craspedocarpus erosus*, *Dasya collabens*, *Cladhymenia coronata*, *Plocamium augustum*, *Anthrocardia corymbosa* and *Microzonia velutina* (pers. obs. Dec. 1994 and Feb. 1995). The terrace descended to depths approaching 10 m, where it gave way to flat regions of rock interspersed with boulder fields and rock outcrops. The boulder fields were colonised by stands of *Macrocystis pyrifera* and a subcanopy of *Ecklonia radiata*, while regions of flat rock were colonised by scattered *E. radiata* and *Landsburgia quercifolia*. Areas of deeper subtidal reef (10–20 m) were colonised by crustose coralline algae and scattered *M. pyrifera,* with a subcanopy of *E. radiata* and *D. ligulata*, and intermittent *Landsburgia quercifolia*. Undercanopy algae comprised *Anotrichum crinitum*, *Antithamnionella adnata*, *Antithamnion applicitum*, *Halopteris novae-zelandiae*, *Hymenena* sp., *Sarcodia flabellata* and *Spatoglossum chapmanii* (pers. obs. Dec. 1994 and Jan. 1995). *Microzonia velutina* covered the tops of some rock outcrops, whereas *Rhodophyllis gunni* and *Plocamium* spp. formed clumps on the tops and sides of rock outcrops, with *Rhodophyllis acanthocarpa* being epiphytic upon *Halopteris funicularis* (pers. obs. Feb. 1995).

Sandstone terraces occur at 10–15 m depth at Pleasant River and were colonised by extensive stands of *Macrocystis pyrifera* bisected by depressions filled with sand and shell, and intermittent boulders. *Rhodophyllis gunnii*, *Plocamium* sp., *Landsburgia quercifolia*, *Hymenena palmata*, *Ptilopogon botryocladus* and *Halopteris* sp. occur at edges of the kelp forest that open onto sand (pers. obs. Jan. 1995). A subcanopy of *Desmarestia ligulata* may develop in summer, particularly after canopy removal resulting from periodic storm events. Other regions at Pleasant River contained more irregular substrate of sand, broken rock, and boulders with less abundant or diverse algae, including intermittent *Ecklonia radiata*. (pers. obs. Nov. 1995).

The exposed coastline of the Otago Peninsula comprises volcanic basalt formations emerging from a sand substrate. *Durvillaea antarctica* and *D. willana* were conspicuous inhabitants of exposed coastline, where *D. antarctica* dominated the sublittoral fringe, giving way to *D. willana* in the sublittoral zone (Batham 1956a). Subtidal assemblages were dominated by *Marginariella boryana* and *Lessonia variegata* growing on a mixed substrate of crustose and articulated coralline algae, with associated *Xiphophora gladiata, Cystophora scalaris, C. distenta* and *Hymenena durvillaei*. *Desmarestia ligulata* and *Glossophora kunthii* appeared seasonally (Batham 1956a; pers. obs. Nov. 2002). Rock walls contained a diverse assemblage of foliose and filamentous red seaweeds including *Plocamium costatum*, *Euptilota formosissima*, *Cladymenia* spp., *Rhodophyllis* spp., and *Callophyllis* spp., giving way to sand colonised by *Gracilaria secundata*, *Gymnogrongrus humulis*, *Lenormandia chauvanii* and numerous filamentous red algae (Fyfe 1992; pers. obs. Nov. 2002). The exposed shoreline at Karitane contained a similar sublittoral fringe of *Durvillaea antarctica* and *D. willana* with a subcanopy of *Xiphophora gladiata* and *Margineriella boryana* (pers. obs. Jan. 1995).

Observations of algal assemblages at the artificial breakwater at the entrance to Otago Harbour have been made by the author, before and after it was extensively colonised by Undaria. These suggest that the development of a dense canopy of Undaria results in a reduction in algal abundance through the exclusion of canopy-forming and undercanopy algae. Observations made before colonisation by Undaria indicated a dense stand of *Macrocystis pyrifera* in relatively shallow water (5 m), with abundant *Xiphophora gladiata* at the upper sublittoral fringe (pers. obs. May 1995). The subcanopy was dominated by *Streblocladia glomerulata* and *Desmarestia ligulata*, with an undercanopy of *Hymenena durvillaea*, *H. palmata*, *Spatoglossum chapmanii*, *Plocamium costatum*, *Curdiea flabellata*, *Schizoseris grifflhsia*, *S. dichotoma*, *Glossophora kunthii*, *Ulva rigida*, and *Gigartina* spp. (pers. obs. Mar. 1998). Sand / gravel beds at the base of the sea-wall were colonised by *Gigartina apoda*, *G. lanceata*, *G. circumcincta*, *Gracilaria truncata, Liangia hookeri*, *Sargassum sinclairii*, *Hymenena durvillaea*, *Rhodymenia dichotoma*, *Rhodophyllis gunnii*, *Phycodrys quercifolia* and *Epimenia wilsonis* (pers. obs. May 1995). Undaria was discovered at the Aramoana breakwater in December 1997 as three isolated sporophytes growing amongst a dense subcanopy of red and brown algae, comprising predominantly *Streblocladia glomerculata* and *Desmarestia ligulata*. A further two specimens were collected from under the kelp canopy in March 1998 (pers. obs.).

Five years after this initial discovery, a dense canopy of Undaria had colonised a region at the Aromoana breakwater from e.l.w.n. (extreme low water neap) to the lower edge of the *Macrocystis pyrifera* canopy at 5.5 m depth (pers. obs. Dec. 2002). From e.l.w.n. to the upper edge of the *M. pyrifera* canopy at 3 m depth was colonised by a mosaic of patches dominated by *Ulva* sp. or Undaria. Patches of *Ulva* sp. also contained *Desmarestia ligulata*, *Streblocladia glomerculata*, *Spatoglossum chapmanii*, *Glossophora kunthii*, *Hymenena durvillaea*, *Curdaea flabellata*, *Gigartina* spp. (foliose and branched) and small *M. pyrifera* sporophytes. However, patches of Undaria formed a dense canopy over substrate covered by crustose and articulated coralline algae with intermittant subcanopy species such as *S. chapmanii*, *Curdaea coriacea*, *Halopteris funicularis*, *D. ligulata*, *Ulva* sp. and small *M. pyrifera* sporophytes. The canopy of Undaria was densest at a margin with kelp forest where a monospecific sub-canopy of Undaria formed under a canopy of *M. pyrifera* and extended from 3 m depth to 5.5 m. Undercanopy species comprised intermittent individuals of *Curdaea coriacea*, *D. ligulata*, *Craspedocarpus erosus*, *Rhodophyllis gunnii* and *S. chapmanii* over substrate covered by both crustose and articulated coralline algae. At this point the rock breakwater gave way to cobble / sand substrate. Undaria was also observed growing on this (haptera adhering to pebbles / cobbles). Associated algae comprised a diverse assemblage of seaweeds including *S. glomerculata*, *D. ligulata*, *Schizoseris davidsii*, *Callophyllis hombroniana*, *Gigartina* spp., *Grateloupia stipata*, *Liangia hookeri*, small *M. pyrifera*, *R. gunnii*, *Plocamium costata* and *Ulva* sp. Boulders, resting on cobble / sand substrate, supported Undaria along with *H. durvillaea*, *P. costata*, *L. hookeri*, *C. flabellata*, *M. pyrifera* and crustose coralline algae.

### 3.2.4 Banks Peninsula

Schiel & Hickford (2001) remarked that Banks Peninsula was differentiated from other regions by a dominance of sessile invertebrates, including an extreme abundance of sea tulips (*Pyura pachydermatina*) and a rich understorey of bryozoans, mussels, ascidians and sponges. At Godley Head, *Macrocystis pyrifera* occurred at 3–6 m depth, with an understorey of *Carpophyllum maschalocarpum* and *Landsburgia quercifolia*. *Ecklonia radiata* dominated at 9–12 m depth. In contrast, *C. maschalocarpum* dominated at 5 m depth at Taylors Mistake, with mixed stands of *Marginariella* spp., *Landsburgia quercifolia*, *C. maschalocarpum*, *E. radiata* and *Lessonia variegata* from 6 m to 9 m.

Two distinct hard-shore habitats, each dominated by crustose coralline algae and foliose brown macroalgae, occur along the southern coastline of Banks Peninsula, east of Akaroa Harbour (Davidson et al. 2001). Crustose coralline algae habitat was most widespread, and characterised by a sublittoral fringe of *Durvillaea antarctica* and / or *D. willana*, above expansive subtidal areas dominated by crustose coralline algae, where brown macroalgae, such as *Ecklonia radiata*, were few or absent. Habitats dominated by foliose macroalgae comprise a sublittoral fringe of *Durvillaea antarctica* and / or *D. willana*, above subtidal areas often dominated by tall stands of *Carpophyllum flexuosum* and associated species such as *Ecklonia radiata*, *Macrocystis pyrifera*, *C. maschalocarpum* and *Lessonia variegata*.

### 3.2.5 Kaikoura Coast

Extensive collections and observations of marine algae where made by South & Adams (1976), who note the absence of sheltered inlets or estuaries, and presence of sandy beaches along 30% of the Kaikoura coast. A variety of rock substrates include greywacke, limestone and siltstone (mudstone) and support a diverse flora comprising 324 algal species. General descriptions of species' distributions indicate that *Durvillaea antarctica* is widespread and common at l.w.s. (low water spring) in exposed regions, with *D. willana* occupying the sublittoral fringe below *D. antarctica* in regions of extreme exposure. The sublittoral fringe is colonised by *Marginariella boryana* in exposed regions (South & Adams 1976). In more sheltered areas, the sublittoral fringe is dominated by *Carpophyllum maschalocarpum*, with *Cystophora torulosa* and *C. scalaris* occurring in the littoral zone above *C. retroflexa* (Morton & Miller 1968; South & Adams 1976). *Cystophora congesta* occurs in the lower littoral in areas of moderate shelter and *C. retroflexa* in the lower littoral zone in deeper channels and pools (South & Adams 1976). *Macrocytis pyrifera* is common but does not form extensive beds, whereas *Lessonia variegata* and *Ecklonia radiata* are abundant in the sublittoral zone in exposed areas (South & Adams 1976).

The greywacke substrate and off-shore reefs south of Kahutari are similar to those occurring north of the Kaikoura Peninsula and were colonised by *Durvillaea* spp., *Lessonia variegata*, *Hymenena curdieana*, *H. multipartita*, *H. palmata*, *H. durvillaei* and *Hymenocladia sanguinea*. The sublittoral fringe may contain abundant *Laurencia thysifera*, *Chondria macrocarpa*, *Plocamium angustum*, *Grateloupia intestinalis* and *Curdiea flabellata*. Extensive alternating beds of *Durvillaea antarctica* and *D. willana* colonise a series of raised barriers, affording considerable protection to extensive beds of *Gigartina* spp. between e.h.w.n. (extreme high water neap) and e.l.w.s. (exteme low water spring). Sublittoral assemblages comprise abundant *Cystophora scalaris*, *C. torulosa*, *Cladymenia oblongifolia*, foliose *Gigartina* spp., *Streblocladia glomerulata*, *Lenormandia augustifolia*, *Laurencia thyrsifera*, *Ballia hirsuta*, with epiphytic *Chaetomopha coliformis*, *Lophurella hookeriana* and *Grateloupia stipitata*.

The Kaikoura Peninsula is bounded on both sides by sand beaches and presents three distinct aspects to the sea with its eastern extremity close to very deep water. Along the northeast and southwest faces, the substrate comprised an alternation between rough broken and folded limestone, and relatively level platforms of siltstone (mudstone) that have been eroded smooth. This combination of variable substrate and exposure led to diverse algal assemblages. The sublittoral fringe of sheltered limestone outcrops supported a narrow band of *Durvillaea antarctica* with sublittoral stands dominated by *Marginariella boryana* and *Landsburgia quercifolia*. In deeper and slightly more exposed sites, such as St Kilda, limestone substrate supported a dense forest of *Marginariella urvilleana*, with an undercanopy of small red algae. Large areas of limestone bedrock at 8–15 m supported diverse assemblages containing *Hymenena* spp., *Phycodrys quercifolia*, *Schizoseris dichotoma*, *Plocamium* spp., *Delesia elegans*, *Ptilonia willana*, *Rhizopogonia asperata, Spatoglossum chapmanii* and *Champia chathamensis*.

Sheltered siltstone (mudstone) substrates supported a diverse and varied assemblage of subtidal seaweeds dominated by *Ecklonia radiata*, *Sargassum sinclairii*, *Macrocystis pyrifera*, *Cladymenia oblongifolia*, *Craspedocarpus erosus*, *Plocamium* spp., *Asparagopsis armata* and *Euptilota formosissima*. *Margineriella boryana* was the dominant canopy-forming seaweed in the sublittoral zone (South & Adams 1976). *Caulerpa brownii* was the dominant cover on gentle slopes where sediments accumulate, and the sublittoral fringe was colonised by *Sargassum sinclairii*, *Carpophyllum maschalocarpum* and *Landsburgia quercifolia*—almost to the exclusion of smaller undercanopy species. *Durvillaea antarctica* dominated this zone in more exposed sites, with a diverse undercanopy of *Bryocladia ericoides*, *Plocamium augustum*, *Caulerpa brownii* and *Lophurella hookeriana* (South & Adams 1976).

## 3.3 POTENTIAL IMPACTS OF UNDARIA

New Zealand seaweed assemblages are dominated by large perennial fucoid seaweeds which may be susceptible to invasion by Undaria, as explained below. Hay & Villouta (1993) postulated that Undaria would invade stands of perennial seaweeds when areas are cleared by storms, urchin grazing, pollution, or abrasion by gravel and sand. Such clearances occur periodically. Moderate grazing pressure and intermittent storm clearance would result in the periodic clearance of established perennial kelp stands without removing the underlying gametophyte stage. This may favour colonisation by Undaria in a similar manner as regular disturbance by sea-urchin grazing promotes colonisation by annual seaweeds in the northern hemisphere (Paine & Vadas 1969; Duggins 1980; Cowen et al. 1982; Leinaas & Christie 1996). In such cases the gametophyte stage of laminarian kelps such as Undaria acts as a 'seed bank' and enables them to smother fucalean competitors in cleared areas. However, the larger size, advanced development and higher survival rates of fucalean germlings may give fucalean seaweeds a competitive advantage over laminarian seaweeds when colonising bare substrate (Schiel 1988). Hence, intensive sea-urchin grazing would remove the gametophyte stage of Undaria and may favour colonisation by the germlings of fucalean species.

Research indicates that Undaria requires the clearance of an intact canopy to become established, and suggests that the persistence of the sporophyte stage or regeneration of indigenous algal assemblages depends on the magnitude and frequency of the disturbance events (Valentine & Johnson 2003). In Europe, grazing of Undaria sporophytes and gametophytes by sea-urchins (*Paracentrotus lividus*, *Evichinus esculentus* and *Psammechinus miliaris*) and the abalone, *Haliotis tuberculata*, is suggested to have a negative effect on Undaria abundance (Floc'h et al. 1991; Castric-Fey et al. 1993). Grazing pressure therefore appears to be high enough to remove the gametophyte generation and thereby inhibit the regeneration of the sporophyte stage following sporophyte removal. However, Sanderson (1990) found that a patchy but dense cover of Undaria in the Mercury Passage, Tasmania, coincided with the presence of the echinoid *Heliocidaris erythrogramma*. The distribution of the echinoid was correlated with wave exposure, such that sheltered regions had more echinoids, more bare substrata, and were colonised exclusively by Undaria, whereas wave-exposed regions had a greater abundance of native seaweeds, fewer echinoids, and isolated individuals of Undaria. This suggests that a moderate level of echinoid grazing may have a positive effect of the establishment and maintenance of Undaria, through regular clearance of patches for colonisation by the sporophyte stage. More recent studies have indicated that large monospecific stands of Undaria in the Mercury Passage are associated with urchin barrens, leading to a similar suggestion that increased grazing pressure has facilitated the establishment of dense Undaria stands by reducing native algal cover (Valentine & Johnson 2003).

The most intensive study of the impacts of Undaria is a 3-year study of low-shore assemblages in a sheltered New Zealand Harbour (Lyttelton) undertaken by the Cawthron Institute (Forrest & Taylor 2002). This study did not provide any evidence of displacement of the native canopy by Undaria. However, this lack of evidence was suggested to reflect the fact that, in the studied areas, there was already an assemblage of canopy-forming species to which Undaria was an addition, but not to such an extent as to form an enclosed canopy. It must be emphasised that the study was conducted in a sheltered harbour environment where a low frequency and intensity of disturbance may have allowed Undaria to establish only as localised patches within an otherwise homogenous canopy of indigenous species.

In New Zealand, the removal of different-sized areas of monospecific stands of *Carpophyllum* has been shown to stimulate the immediate recruitment of Undaria sporophytes within the cleared areas, with no recruitment within uncleared control plots (Thompson 2002). Regeneration of indigenous seaweeds occurred after 10 months in the smaller clearances (5 cm), but Undaria was still present in the larger cleared areas (25 cm and 50 cm), indicating that, as in Tasmania, the scale of disturbance is important to the persistence of the sporophyte stage.

Colonisation by Undaria can result in an increase in biodiversity in areas otherwise devoid of diverse indigenous seaweed assemblages, but can also result in a decrease in biodiversity in other regions where it displaces species or results in a loss of spatial heterogenity. Studies in Giudecca, Venice, have shown that Undaria competes with indigenous seaweeds for space, resulting in reduced biodiversity and reduced surface cover of *Rhodymenia ardissonei*, *Gracillaria verrucosa*, *Ulva rigida* and *Enteromorpha* spp. (Curiel et al. 1998). Colonisation by Undaria in New Zealand has been shown to increase biodiversity in some areas, such as the Marlborough Sounds, that are otherwise devoid of diverse indigenous seaweed. The increase in biodiversity is attributed to an increase in habitat complexity (Battershill et al. 1998). This same study found that subcanopy assemblages under stands of *Carpophyllum* spp. comprised a patchy mosaic of turfing and bushy seaweeds (e.g. *Ulva*, *Dictyota*, *Gigartina* and *Gelidium* spp.) together with encrusting and articulate coralline algae and bryozoans. As the density of Undaria increased, however, this community appeared to be displaced by solitary sea-squirts, tube worms and hydroids. While this may appear to indicate significant impacts, this study does not have the benefit of observations made before the seaweed beds were invaded by Undaria. Hence, there is an assumption that *Carpophyllum* spp. once inhabited patches where Undaria was present. This may not have been the case, and it is equally possible that the observed distribution of species reflected pre-existing factors unrelated to the presence or absence of Undaria. Similar studies conducted in the Mercury Passage, Tasmania found a reduction in the diversity and abundance of fauna associated with a canopy of Undaria compared with an adjacent canopy of indigenous species (TAFI 2000).

The observations made by the author at Aramoana breakwater (section 3.2.3 above) were compelling and highlight the impacts of Undaria. The visual impact of Undaria was particularly striking within stands of *Macrocystis pyrifera*, where a dense subcanopy obscured much of the underlying substrate and undercanopy seaweeds and a reduction in algal abundance was clearly evident. Previously dominant subcanopy algae, such as *Streblocladia glomerculata* and *Desmarestia ligulata*, and previously abundant undercanopy species, were only present as intermittent individuals under a dense canopy of Undaria. The impact of Undaria from e.l.w.n. to 3 m appeared to be mitigated by the heterogeneous environment provided by patches of Undaria and indigenous algae. However, long-term impacts could not be discounted, particularly on perennial fucoid species such as *Xiphophora gladiata*. Undaria grew on sand / cobble substrate and boulders beyond the breakwater, but associated algae did not appear to be any less abundant or diverse than they were prior to the Undaria invasion.

It has been suggested that Undaria may have positive impacts through increased production and benefits to fauna resulting from improved food availability in regions with little native seaweed growth (Hay 1992). Undaria may indeed enhance populations of grazers and filter-feeders by improving food availability, but increased grazing pressure on indigenous seaweeds is likely to occur once Undaria disappears in late summer to early autumn. This could have a substantial impact on alternative food algae that would be grazed in the absence of Undaria. In areas otherwise devoid of significant algal cover, such as the Marlborough Sounds, the seasonal occurrence of Undaria may seasonally benefit faunal populations. However, the disappearance of Undaria sporophytes over autumn and winter would leave faunal populations without an adequate food source and would likely result in population decline.

Sustained benefit to commercially important species, such as paua (*Haliotis iris*), is also unlikely, as the contribution of Undaria to the diet of paua is likely to be insignificant in all but the densest of infestations. Paua feed predominantly on drift algae and only feed actively when food availability is limited (Poore 1972). The contribution of Undaria to algal drift would therefore depend on the relative proportion of other drift algae, and would only be significant when Undaria was so abundant as to exclude most other algae. Furthermore, Undaria has been shown to be of inferior nutritive value compared with indigenous seaweeds, and to produce slower rates of growth (Redfearn 1994). Hence, the seasonal occurrence of Undaria sporophytes is unlikely to provide any sustained benefit to faunal populations and may, in fact, have a detrimental effect on indigenous algae through increased grazing pressure when Undaria dies back. Undaria is also unlikely to enhance the growth of paua, because of the preference of paua for feeding on drift algae, and the low nutritive value of Undaria compared with indigenous seaweeds.

## 3.4 CONCLUSION

The impact of Undaria on the eastern coast of the South Island will be variable and mostly confined to localised areas of rock substrate along a coastline that largely comprises sand and boulder / cobble beaches.

- Where it does establish, its impact could be profound, particularly where moderate levels of grazing pressure or regular storm events promote its establishment and persistence.

- Undaria may colonise substrates that do not otherwise contain a dense canopy of seaweed, or it may exclude seaweeds from established algal assemblages by forming a dense cover in cleared regions, thereby preventing the recruitment of ephemeral or canopy-forming species.
- Regular disturbance of the seabed or substrates may allow patches of Undaria to persist within stands of fucoid algae (*Carpophyllum flexuosum* and *Cystophora* spp.) or under a canopy of *Macrocystis pyrifera*.
- Colonisation by Undaria has been shown to result in increased biodiversity in areas otherwise devoid of diverse indigenous seaweed assemblages, but could also result in reduced biodiversity in regions where Undaria displaces species or results in a loss of spatial heterogenity.
- Impacts of Undaria are, therefore, most likely along the eastern coastline of the South Island in areas where the frequency and magnitude of storm events result in the periodic removal of indigenous algae.
- Impacts of Undaria will be particularly evident when canopy removal corresponds with the seasonal appearance of Undaria over spring and early summer.

Observations by the author (1995–2002) indicate that the establishment of Undaria has excluded indigenous subcanopy and undercanopy algae from the Aramoana breakwater. Similar impacts could be expected within extensive stands of *Macrocystis pyrifera* along the eastern coast of the South Island where the availability of rock substrate and a level of exposure may facilitate the establishment and persistence of Undaria, e.g. Karitane, Pleasant River, Shag Point, Moeraki, Kakanui, and Akaroa Harbour. The exclusion of dominant canopy-forming species, such as *Hormosira banksii*, *Carpophyllum flexuosum* and *Cystophora* spp., from the sublittoral fringe is possible in Otago, Lyttelton and Akaroa Harbours, as is the persistence of Undaria within stands of *C. flexuosum* and *M. pyrifera* that fringe Otago Harbour. Impacts of Undaria on the open coastline and bays about Banks Peninsula will largely depend on the level of exposure and grazing pressure, but the exclusion of algae could be expected in coastal embayments where there are established stands of *C. flexuosum* and *M. pyrifera.*

The diversity of substrate type and exposure about the Kaikoura Peninsula is likely to result in variable impacts of Undaria.

- Impacts will most probably be greatest on sheltered siltstone (mudstone) substrate. These are presently colonised by *Ecklonia radiata*, *Sargassum sinclairii*, *Macrocystis pyrifera*, *Cladymenia oblongifolia*, *Craspedocarpus erosus*, *Plocamium* spp., *Asparagopsis armata* and *Euptilota formosissima*.
- Fucoid algal species colonising the sublittoral fringe may be particularly vulnerable to displacement by Undaria. These include *S. sinclarii*, *Carpophyllum maschalocarpum*, *Landsburgia quercifolia* and *Cystophora torulosa*.
- Protected beds of *Gigartina* spp. and protected sublittoral assemblages at Kahutari may also be vulnerable to the impacts of Undaria.
- Wave exposure is likely to mitigate the impacts of Undaria in the most exposed regions of the Kaikoura coastline.

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# Appendix 1

## REPORTS FROM RESEARCH PROGRAMMES

Listed here are reports from the research programmes summarised in Section 2 (grouped under research institution). Some entries are repeated as regular references (in Section 4), and in the bibliography (Appendix 2).

### Department of Conservation

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. *British Phycological Journal 25*: 301–313.

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## National Institute of Water and Atmospheric Research (NIWA)

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# Appendix 2

## BIBLIOGRAPHY

### Published reports

Literature documenting the distribution and spread of *Undaria pinnatifida*, including dispersal mechanisms, potential impacts, pest management, and control methods.


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## Dissertations and theses


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## Erratum

**Stuart, M.D. 2004: Review of research on *Undaria pinnatifida* in New Zealand and its potential impacts on the eastern coast of the South Island. *DOC Science Internal Series 166*. Department of Conservation, Wellington. 40 p.**

This publication contains, on page 24, a reference to an unpublished report:

"Undaria has been shown to be of inferior nutritive value compared with indigenous seaweeds, and to produce slower rates of growth (Redfearn 1994)".

It has been pointed out to the publisher that a more precise representation is:

"Undaria has been shown to be of inferior nutritive value compared with the indigenous seaweed *Gracilaria chilensis* (Redfearn 1994)".