Status of the introduced brown seaweed *Undaria* in New Zealand

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Contents

1. Summary

1.1 Project and Client

The Nelson/ Marlborough Conservancy of the Department of Conservation is concerned about the likely spread of the brown seaweed *Undaria pinnatifida* from its present very localised distribution in marinas and harbours to other areas of New Zealand's rocky coastline, and the effect this will have on natural community structure and function. There is also a general concern about the environmental effects resulting from farming of *Undaria* in New Zealand waters.

1.2 Objectives

To consider the environmental implications of the proposal to cultivate *Undaria* in New Zealand waters, with the following specific objectives:

- To describe the seaweed *Undaria pinnatifida.*
- To illustrate the life history of this brown alga.
- To establish factors important in the growth of *Undaria* in New Zealand waters.
- To describe the algal communities in which *Undaria* grows in New Zealand.
- To comment on control of the spread of *Undaria.*
- To comment on the introduction of seaweds into New Zealand.
- To answer 12 questions asked by the Department.
- To compile a bibliography of references on *Undaria.*

1.3 Methods

Literature searches involved the reprint collection of the author, the library of Manaaki Whenua - Landcare Research, Lincoln, electronic searches in CAB (Commonwealth Agricultural Bureaux) and Current Contents to 18 August 1994 for anything relevant to *Undaria,* and interloaning if possible. Specimens in the CHR Herbarium, Landcare Research, Lincoln, were examined and a small sample was collected from the marina at Lyttelton. A bibliography of the references found was compiled.

1.4 Results and Conclusions

The brown alga *Undaria pinnatifida* was accidentally introduced into New Zealand waters from Japan sometime before 1987. To date it has been found at Wellington, Lyttelton, Timaru, Oamaru, Picton, Porirua, Otago harbour, and Port Chalmers, apparently spread by shipping.

Undaria pinnatifida looks like the kelp *Ecklonia* but is thinner, membranous, and mucilaginous. Its life history is typical for a laminarian kelp, with a large sporophyte and microscopic filamentous male and female gametophytes. The sporophyte grows rapidly from winter to spring and degenerates in late summer and autumn, although in New Zealand sporophytes are always present. *Undaria* is found on rock and immersed artificial substrates (wooden and concrete wharf piles, mooring ropes, steel cables, hulls of boats). It grows with a wide variety of other seaweeds from the mid low water neap (MLWN) tide mark down to 15 m depth and occasionally to 18 m,

depending on the light conditions.

Temperature is the most important environmental factor influencing the spread of *Undaria* in New Zealand waters. In time this seaweed will probably become established in most New Zealand ports, having been spread by coastal shipping. It is believed that *Undaria* will become part of the natural community of marine organisms, and will not displace any other species completely. It is not possible to control the spread of *Undaria* in the marine environment.

Care should be taken not to introduce deliberately any other marine species or new strains of species into New Zealand waters for any reason.

1.6 Recommendations

- It is not feasible now to attempt to remove *Undaria* from any area where it has become established.
- Marinas and pleasure boat harbours or anchorages, the main areas of infestation, should be regularly monitored for signs of the presence of *Undaria.*
- Marine farming experiments involving *Undaria* should be carried out only in areas where the kelp is already found.
- It is not appropriate to deliberately introduce any new marine algal species of any kind, or new strains of currently naturalised marine species, into New Zealand waters.
- Only the genotypes of seaweeds at present in New Zealand should be used for aquaculture.

2. Abstract

Undaria pinnatifida (Phaeophyceae, Laminariales) was accidentally introduced into New Zealand waters from Japan sometime before 1987. To date it has been found in the harbours of Wellington, Lyttelton, Timaru, Oamaru, Picton, Porirua, Otago, and Port Chalmers, apparently spread by shipping. A description of *U. pinnatifida* and details of its life history are given. Information is provided on the size of the plants in New Zealand and their seasonality, which differs somewhat from that seen in Asia. Substrate preferences and the depth of growth are summarised. Temperature is the most important environmental factor influencing the spread of *Undaria* in New Zealand waters. In time this seaweed will probably become established in most New Zealand ports, having been spread by coastal shipping. It is believed that *Undaria* will integrate into the natural community of marine organisms and not displace any other species completely. It is not possible to control the spread of *Undaria* in the marine environment. Care should be taken not to introduce any other new species or strains of species of marine algae into New Zealand waters.

3. Introduction

Undaria pinnatifida (Harvey) Suringar (Phaeophyceae, Laminariales), a brown marine alga of considerable commercial importance in Asia, was accidentally introduced into New Zealand waters from Asia (probably Japan) sometime before 1987, when it was first recorded in Wellington Harbour. The Department of Conservation is concerned about the likely spread of *U. pinnatifida* from its present very localised distribution in marinas and harbours to other areas of New Zealand's rocky coastline, and the effect this will have on natural community structure and function. There is also a general concern about environmental effects resulting from farming of *Undaria* in New Zealand waters.

4. Objectives

To answer the questions on *Undaria pinnatifida* posed by the Nelson/Marlborough Conservancy, Department of Conservation.

To consider the environmental implications of the proposal to cultivate *Undaria* in New Zealand waters, with the following specific objectives:

- To describe the seaweed *Undaria pinnatifida.*
- To illustrate the life history of this brown alga.
- To establish factors important in the growth of *Undaria* in New Zealand waters.

- To describe the algal communities in which *Undaria* grows in New Zealand.
- To comment on control of the spread of *Undaria*.
- To comment on the introduction of seaweeds into New Zealand.
- To answer 12 questions asked by the Department.
- To compile a bibliography of references on *Undaria*.

The 12 specific questions and their answers are given in the Conclusions.

5. Methods

Literature searches involved the reprint collection of the author, the library of Manaaki Whenua - Landcare Research, Lincoln, electronic searches in CAB (Commonwealth Agricultural Bureaux) and Current Contents to 18 August 1994 for anything relevant to *Undaria,* and interloaning if possible. Specimens in the CHR Herbarium, Landcare Research, Lincoln, were examined and a small sample was obtained from the marina at Lyttelton. A bibliography of the references found was compiled.

6. Results

6.1 General comments on *Undaria*

The brown algal genus *Undaria* (Phaeophyceae, Order Laminariales, Family Alariaceae), a laminarian kelp, has three species: *U. pinnatifida* (Hare.) Suringar, *U. undarioides* (Yendo) Okamura, and *U. peterseniana* (Kjellm.) Okamura. All species are used fresh or dried for food in Asia, but *U. pinnatifida* is commercially the most important species; consequently it is extensively cultivated (Saito 1975). This genus is indigenous to the temperate regions of Japan, China, and Korea in the northwest Pacific (Ohno & Matsuoka 1993). *U. pinnatifida* is the only species of *Undaria* known to be present in New Zealand waters (Adams 1994).

In recent years *U. pinnatifida* (Fig. 1) has been found growing in New Zealand in marinas and ports - Wellington (the first record for the Southern Hemisphere; Hay & Luckens 1987), Lyttelton (Hay 1990), Timaru (Hay 1990, Brown & Lamare 1994), Oamaru (Hay 1990), Picton (Nelson *et al.* 1992, Brown & Lamare 1994), Porirua (Hay & Villouta 1993), Otago harbour and Port Chalmers (Hay & Villouta 1993, Brown & Lamare 1994, Anon. 1994) - and also in Tasmania (Sanderson 1988, 1990), apparently spread by shipping. Hay and Villouta (1993) suggest that this kelp has been introduced by international shipping to the ports of Wellington and Timaru, and spread by coastal shipping to other harbours and marinas in New Zealand.

Undaria pinnatifida was discovered in 1971 on the Mediterranean coast of France where it was probably introduced accidentally with oyster spat (Boudouresque *et al.* 1985). In 1983 this *Undaria* was transplanted for commercial purposes to the French Atlantic coast off Brittany by the French Institute for Exploitation of the Sea (IFREMER)

(Boudouresque *et al.* 1985, Hay & Villouta 1993). It is now becoming established as part of the algal flora of the Atlantic coast of France (Castric-Fey et *al.* 1993).

6.2 Description of *Undaria pinnatifida*

Sporophyte large (Fig. 1), up to 2 (3) m in length. Main stipe or stem flattened, 1-3 cm wide, elliptical in cross-section, extending to the top of the blade as a wide midrib. Blade *Ecklonia*-like, with numerous lateral lobes 50-80 cm long lying in one plane; thinner than *Ecklonia,* membranous and mucilaginous, surface smooth not corrugated, with scattered hair pits or cryptostomata and microscopic clear or darkened 'gland' cells, margin smooth without teeth. Holdfast of dichotomously branched, slender, root-like haptera. Colour golden brown, glossy; texture firm and pliable, but blade easily torn compared with *Ecklonia.*

Reproduction: unilocular sporangia on thickened, sinuous, lobed sporophylls originating from the edge of the stipe but becoming folded and interleaved so as to appear spiral around the stipe.

Gametophyte microscopic, filamentous, and dioecious.

6.3 Life history

The life history of *U. pinnatifida* (Fig. 2) is typical for a laminarian kelp, with a large, usually annual sporophyte (Fig. 1) producing swimming zoospores which give rise to microscopic filamentous male and female gametophytes. The male gametophytes produce swimming spermatozoids, which fertilise the egg or oospore that develops and remains on the female gametophyte. The sporophyte develops in situ from the fertilised oospore (Ohno & Matsuoka 1993, Floc'h *et al.* 1991).

6.4 Plant size

A maximum length of 3 m is recorded for *U. pinnatifida* in Japan (Akiyama & Kurogi 1982). New Zealand plants have been recorded to about 56 cm long in Wellington Harbour. On average plants from Timaru and Oamaru grew to be some four times longer, to about 135 cm. A full analysis is given in Hay and Villouta (1993). At Timaru Brown and Lamare (1994) found that *Undaria* ranged from 10 to 80 cm in length, with no significant variation in plant size with depth. Towards the harbour entrance larger plants were found, suggesting that an increase in the degree of turbulence and concomitant increase in nutrient exchange may in part be responsible (Brown & Lamare 1994). In a study of different *U. pinnatifida* populations in Matsushima Bay on the Pacific coast of Honshu Island, Taniguchi *et al.* (1981) found that plants from the outer bay were larger than those from the inner part of the bay, and that morphology and phenology also varied at different sites.

6.5 Seasonality

The main growth period of the sporophyte is in the spring (Saito 1975, Koh & Shin 1990). In Asia the fronds (sporophytes) of *U. pinnatifida* grow rapidly from winter to spring and degenerate in late summer and autumn, and there is a period, during the coldest temperatures, when sporophytes are not present. Although exposed to a relatively narrow annual temperature range and to cooler summer temperatures, *Undaria* sporophytes in New Zealand have an annual growth cycle similar in some ways to that of Asian populations, but in New Zealand sporophytes are always present (Hay & Villouta 1993), as the temperatures are presumably not cold enough for growth to cease altogether. Mature *Undaria* sporophytes were found throughout the year in Wellington Harbour. At Timaru and Oamaru sporophytes persist through summer and autumn, when degenerating remnants and newly recruited sporelings occur simultaneously (Hay & Villouta 1993).

6.6 Regeneration of sporophyte

Under laboratory conditions, explants taken from the meristem, midrib, and stipe of immature sporophyte fronds all formed callus tissue, but only the explants from the meristem regenerated small entire fronds (Kawashima and Tokuda 1993). Regeneration of the sporophyte from any meristematic part of the blade has not been observed under field conditions.

6.7 Substrate preference of *Undaria*

Undaria is found predominantly on rock and immersed artificial substrates such as wooden and concrete wharf piles, mooring ropes, steel cables, and hulls of boats. The tendency for plants to colonise immersed artificial substrates is well documented (Hay 1990, Floc'h *et al.* 1991, Brown & Lamare 1994). This may be related to the selection of these plants in Japan and Korea for rope cultivation and 'stone planting' Brown & Lamare 1994). In Wellington Harbour *Undaria* grows on cobbles and bare areas of sea floor (Hay & Villouta 1993). At Timaru harbour plants were found growing on rocks ranging in size from over 1 m down to 5-10 cm in diameter. This may be the lower size limit, as an area of pebbles 3-5 cm in diameter had no visible plant cover, while a steel cable running across the area supported healthy plants (Brown & Lamare 1994). This is probably related to the frequency of movement or turning over of the pebbles.

6.8 Depth

Undaria has been found from the low intertidal down to 15 m (Saito 1975), or as far as 18 m (Floc'h *et al.* 1991). Where suitable substrate is available the prevailing light conditions, often influenced by the sediment load, will determine the lower limit for growth. In Wellington Harbour *Undaria* grows from just above mid low water neap (MLWN) tide level to the bottom of the Container Wharf retaining wall at 7-9 m depth. At one location in the industrial harbour at Wellington plants were growing at 18 m depth (Hay & Villouta 1993). Maximum depth in Timaru Harbour was 5 m below mean low water, with the majority of plants occurring in the upper 2 m (Brown & Lamare 1994). In Tasmania *Undaria* grows to a depth of 15 m in a wide range of wave exposures, especially in areas newly bared by sea urchin grazing, by the die-off of *Macrocystis* and by the action of loose boulders (Sanderson & Barrett 1989, Hay 1990).

6.9 Temperature tolerances

Water temperature is considered to be the most important environmental factor influencing the life history and ecology of *U. pinnatifida* (Saito 1975). In Japan *Undaria* completes its annual life cycle in areas where the annual range in sea surface temperature is from 0°C (during winter in NW Hokkaido) to 27°C (during summer in SW Kyushu) (Funahashi 1974). Sporophyll formation appears not to be under temperature control but zoospore release begins when the 10-day average water temperature rises above 14°C (Saito 1975).

Table 1. Temperature tolerances and optima (°C) for the sporophytic and gametophytic generations of *Undaria pinnatifida* (Sanderson 1990)

	Sporophyte	Gametophyte
Lethal temperatures	<0°, >25°	<-1°, >30°
Growth boundaries	3.5° to 20°	10° to 24°
Reproductive boundaries	<7°, >23°	<10°, >24°

(From Akiyama 1965, Aldyama & Kurogi 1982, Arasaki & Arasaki 1983, Saito 1975, and Zhang *et al.* 1984)

6.10 Associated species and competition

At the Container Terminal in Wellington Harbour *Undaria* is growing in association with the following seaweed flora: *Codium dichotomum* (Huds.) S.F.Gray, *Ulva* sp., *Cutleria multifida* (Smith) Grev., and species of *Aeodes, Gigartina, Kallymenia, Plocamium,* and *Grateloupia.* Here there are no large brown algae. By contrast, near the Freyberg marina there is a relatively sparse seaweed flora but with scattered specimens of large, brown, perennial seaweeds including *Carpophyllum flexuosum* (Esper) Grev., *C. maschalocarpum* (Turn.) Grev., and *Sargassum sinclairii* Hook.f et Harv. (Hay & Villouta 1993).

Recently *Undaria* in Wellington Harbour has spread to semi-sheltered rocky reefs supporting thick fringing beds of *Carpophyllum maschalocarpum* growing near the MLWN tide mark, and small beds of *C. flexuosum* growing in the shallows down to about 3-4 m depth. There is no obvious sign of *Undaria* displacing either *Carpophyllum* species. It colonises bare low intertidal rock and tidal pools above the *C. maschalocarpum* zone and below a mid-intertidal band of the blue mussel *Mytilus edulis aoteanus* Powell. Below the *C. maschalocarpum* zone it grows on cobbles and bare areas where there is little competition from the perennial brown seaweeds. Similarly it colonises cobbles and bare areas that separate the small beds of *C. fkxuosum,* instead of the beds themselves (Hay & Villouta 1993).

By shading and covering much of the substrate, *Undaria* is potentially able to exclude smaller seaweeds. However, at the Container Wharf, Wellington, there is a very high diversity of native seaweeds growing amongst the *Undaria,* even in spring when the biomass of the kelp is highest (Hay & Villouta 1993).

If *Undaria* spreads to the open Wellington coast facing Cook Strait, it must compete with dense populations of a variety of perennial brown (fucalean) algae including *Carpophyllum maschalocarpum, Cystophora scalaris, Sargassum sinclairii, Marginariella* spp., *Landsburgia quercifolia* (Hook.f. et Harv.) Harv., and the laminarians *Ecklonia radiata* (C.Ag.) J.Ag. and *Lessonia variegata* J.Ag. In very exposed places there is also a fringing band of *Durvillaea antarctica* (Cham.) Hariot. Its effect on these species is not known. Hay and Villouta (1993) considered it unlikely, however, that *Undaria* could displace either *Durvillaea, Lessonia,* or *Marginariella boryana* (A.Rich.) Tandy, because of the strong wave action those species prefer.

At Oamaru mature sporophytes were found growing intertwined with *Macrocystis pyrifera* (Linnaeus) C.Agardh and masses of stalked tunicates or sea tulip (*Pyura pachydermatina* Herdman) on five wharf piles (Hay & Villouta 1993).

At the slipway at Timaru, Undaria has replaced a band of algae growing near MLWN level comprising mainly smaller foliose red and green algae (mainly species of *Ulva*, *Scytosiphon*, *Gigartina*, *Iridaea*, *Schizoseris*, *Grateloupia*, *Myriogramme*, *Rhodophyllis*, and *Plocamium*). There were relatively few large brown algae at the slipway (Hay & Villouta 1993). Along the inside of the North Mole at Timaru, Hay and Villouta (1993) reported that *Undaria* coexists with large brown algae such as *Macrocystis pyrifera*, *Sargassum sinclairii*, *Cystophora scalaris* J. Ag., and *Desmarestia ligulata* (Stack.) Lamx. There was a fringing band of *Macrocystis pyrifera* (L.) C.Ag., attached mainly at 2-3 m depth, and *Sargassum sinclairii* was common in the shallows. On the outside of the North Mole, where the biomass of these large brown seaweeds was higher and wave action was stronger, there was comparatively little *Undaria*, and the sporophytes that occurred there were on average much smaller than inside the Mole (Hay & Villouta 1993).

In Tasmania *Undaria* also grows completely intertwined with the juvenile sporophytes of native kelps such as *Ecklonia radiata* (J. Ag.) C. Ag. (Hay 1990).

Although most large brown seaweeds in New Zealand are perennial, in the long term *Undaria* may invade their habitat when areas are cleared by storms, urchin grazing, abrasion by gravel or sand, and perhaps by pollution. Areas cleared in summer or autumn will be quickly colonised by *Undaria* because most large brown algae in New Zealand are fertile in winter. On areas cleared in winter, recruiting native seaweeds would have to compete with *Undaria* sporelings which may have a relatively faster growth rate. However, if the native plants survive amongst the *Undaria* holdfasts until summer, they may be advantaged by the autumnal decline of the adventive species (Hay & Villouta 1993).

The intricately branched rias of the Marlborough Sounds are characteristically barren of seaweeds. If *Undaria* spreads from Picton near the head of Queen Charlotte Sound, and forms fringing kelp beds similar to those inside Wellington Harbour, then it may cause major ecological change (Hay & Villouta 1993).

6.11 Eradication

Undaria is now well established in Timaru Harbour, where it is thriving, and any attempt to eradicate it would be futile (Brown & Lamare 1994). In Tasmania it is believed that eradication of this alga is out of the question owing to the elusive, microscopic gametophyte stage of the alga and the extent of colonisation (Sanderson 1990).

6.12 Deliberate importation

The deliberate importation of any new species or new variety of seaweed, or any new genetic strain of an already well established adventive species, should be considered with great caution. Transplanting living organisms from an ecosystem where they have developed naturally in competition with other organisms into another system where they may not have any competition, and where they may behave quite differently, is fraught with problems. On land, where observation is easy and control can be exercised for the most part, transplants can often cause problems and become weeds of some economic consequence. When similar transplants occur in marine habitats further spread by tides, currents, and coastal shipping cannot be prevented, and since the behaviour of the organisms under water cannot readily be observed, the problems increase by enormous proportions.

Sargassum muticum was accidentally introduced into the English Channel sometime before 1973, probably with Japanese oysters that were imported into France (Boalch 1985). By 1985 this seaweed had spread along both sides of the Channel and up into the North Sea to the. Danish coast. In Europe this alga grows larger and faster than in its native habitat. Some subtidal areas that were free of large seaweds were occupied in 1985 by dense growths of this *Sargassum* (Boalch 1985).

The French action of transplanting *Undaria* for commercial purposes from the Mediterranean coast of France to the Atlantic coast off Brittany, where it is now becoming established as part of the algal flora, is considered by some researchers to be irresponsible (Kain & Dawes 1987). In 1987 the cultivation of *Undaria* off France was suspended pending the outcome of an enquiry into the advisability of growing this exotic alga in the open sea. It was already too late; cultivated *Undaria* plants had reproduced *in situ*, and numerous sporophytes had colonised the nearby bay. The estimated potential range of this species extends northwards to Scotland and Norway, and its competitive ability in European waters is unknown (Kain 1991). Kain (1991) suggests that this case should serve as a warning to would-be importers of exotic species. When *Undaria* was originally transferred to Brittany it was claimed that local summer sea temperatures were too low to allow reproduction (International Council for the Exploration of the Sea 1984; see Kain 1991). It was already known, however, that gametophytes could grow and sporophytes could be formed at temperatures well within the range experienced in the sea off Brittany (Akiyama 1965). Any introduction of an exotic species should be preceded by a thorough investigation, both of the literature and of the biology of the species Main 1991).

Generally it is not possible to predict the changes that introduction of a new alga will make to the ecosystem. The question that we should be asking is whether the risk of such changes can be justified by the benefits from the introduction.

7. Conclusions

General question:
What are the environmental issues associated with the proposal to cultivate *Undaria* in New Zealand waters?

Related questions:

1. What are the ecological tolerances of *Undaria?* Temperature, depth, light, exposure/shelter.

Water temperature is considered to be the most important environmental factor influencing the life history and ecology of *U. pinnatifida* (Saito 1975). In Japan *Undaria* completes its annual life cycle within the annual range in sea surface temperature from 0°C to 27°C (Funahashi 1974).

In New Zealand *Undaria* grows from low intertidal level down to 5-9 m with the majority of plants occurring in the upper 2 m of this range. At one location in the industrial harbour, Wellington, plants grow at 18 m depth (Hay & Villouta 1993). Where suitable substrate is available the prevailing light conditions, often influenced by the sediment load, will determine the lower limit for growth.

At present *Undaria* is associated with marinas, harbours, and relatively calm situations in New Zealand. From my initial observations it appears that *Undaria* has a preference for relatively well lit situations, rather than continuous shade. The only known place where *Undaria* grows on an exposed New Zealand shore is the outside of the North Mole at Timaru. Here, growing with the large brown seaweeds *Macrocystis pyrifera, Sargassum sinclairii, Cystophora scalaris,* and possibly Carpophyllum maschalocarpum and *Marginariella* sp., the comparatively few *Undaria* plants were on average much smaller than those on the inside of the Mole (Hay & Villouta 1993). It is not known how readily or aggressively *Undaria* will grow on exposed New Zealand shores. Likely areas in New Zealand should be monitored.

2. Over what geographical range could *Undaria* establish itself in New Zealand waters? Where in the Marlborough Sounds would it be likely to establish?

All New Zealand ports and harbours lie well within the annual range in sea surface temperature of 0°C to 27°C. In southern New Zealand, long-term monthly mean temperatures range from about 7°C in July to 16-17°C in February. At Tauranga and Auckland in the north, monthly mean sea surface temperatures range from 13°C in winter to 20°C (Tauranga) and 23°C (Auckland) (Greig *et al.* 1988). As a consequence it is very probable that populations of *Undaria* will eventually become established in most New Zealand ports. There will no doubt be many areas with solid substrates in the Marlborough Sounds that might be colonised by *Undaria.* This is likely to spread out from permanent marinas near Picton into suitable areas where contaminated pleasure craft are moored for any length of time. In my opinion ships that are constantly on the move, such as the interisland ferries, are unlikely to contribute to the dispersal of *Undaria*. Hay and Villouta (1993) mention that the intricately branched rias of the Marlborough Sounds in the northern South Island are characteristically barren of seaweeds. They suggest that if *Undaria* spreads from Picton near the head of Queen Charlotte Sound, and forms fringing kelp beds similar to those inside Wellington Harbour, then it may cause major ecological change.

3. What natural habitats/communities are at risk from Undaria? and

4. Does *Undaria* have the potential to displace native seaweeds in New Zealand waters? What species would be at risk?

Undaria has been found growing with a mixed algal community from the low intertidal zone down to several metres below low water. The algae in this community include *Ulva, Gigartina, Schizoseris* and other leafy red algae, and the brown algae *Macrocystis*, *Ecklonia, Sargassum*, and *Carpophyllum*. On floating objects *Undaria* grows usually with *Macrocystis*, *Ecklonia*, and *Ulva*. Although *Undaria* will compete for space with the algae in this community, it does not seem to date to have occupied any natural communities to the exclusion of other species. The native brown algae with which *Undaria* competes for space are perennial, living usually for some years. In Asia *Undaria* is an annual. Here in New Zealand it appears as if the basal portion of the *Undaria* sporophyte will persist for up to a year, although the upper, leafy part of the frond dies back. It is not known if the base will produce a second upper leafy frond in the next growing season. I believe that *Undaria* will not displace completely any other species of seaweed, but further observations are required.

5. *Undaria* seems to be confined at present to 'disturbed' habitats (piles, seawalls, floats, etc). Is this merely a reflection of its current dispersal by way of coastal shipping, or is it likely that native species (seaweeds, sponges, etc.) can out-compete *Undaria* in a natural setting?

When *Undaria* is first introduced into a harbour area it appears to be confined to 'disturbed' habitats, as these provide a ready surface for zoospore and gametophyte settlement. Such surfaces are also the closest to the moorings of the pleasure craft that seem to be distributing this seaweed around New Zealand. Since the initial introduction of the sporophyte, plants of *Undaria* have become part of the natural community of algae and marine animals in nearby habitats, successfully maintaining themselves without excluding any particular native species.

6. Following on from the above, would shoreline stability be a critical factor in the successful settlement and growth of *Undaria*? For example, would the Boulder Bank at Nelson (where boulders are regularly overturned by storm events, thus creating new surfaces for colonisation) be more prone to *Undaria* colonisation than the more stable rock surfaces of the Kaikoura coast?

Undaria is found predominantly on rock, immersed artificial substrates (wooden and concrete wharf piles, mooring ropes, steel cables, and hulls of boats). In Wellington Harbour and at Timaru it grows on cobbles on the sea floor. It is possible that the newly exposed surfaces on the Boulder Bank at Nelson would provide a substrate for settlement of *Undaria*. This would depend on the exposure of these boulders to wave action and the frequency of storm events that would turn the boulders over. The *Undaria* plants growing in marinas appear to be of a more fragile texture than the perennial, rather tough, native brown algal species such as *Carpophyllum*. This suggests that *Undaria* would not readily grow in the conditions favoured by *Carpophyllum* on the Boulder Bank; however, a definite statement cannot be made at this time.

7. Are drifting plants reproductively viable?

Undaria has no flotation organs, bladders, or air sacs, so it does not drift as easily as seaweeds which have these, such as *Macrocystis*. The parts of the blade of *Undaria* that are readily torn off do not contain any reproductive tissue. It is not known how long whole plants would continue to produce zoospores should they float free. Drift is not likely to be a factor in the spread of *Undaria* in New Zealand waters.

8. Does *Undaria* reproduce vegetatively? E.g., cysts.

Undaria does not reproduce vegetatively. It does not produce cysts or resting stages. It has a large sporophyte generation (2N) that produces zoospores (N). These give rise to filamentous, male and female gametophytes (N) which produce sperm and eggs respectively. After fertilisation the zygote (2N) develops in situ into the large sporophyte.

9. Would it be possible to control the spread of *Undaria* from existing sites, for example by removing individual plants?

It would be possible to remove the first crop of the large sporophytes from a site, but as these sporophytes develop from microscopic filamentous gametophytes, it is likely that these sporophytes would be rapidly replaced by others already present but too small to be seen.

10. Following from Question 9:

(a) What methods could be used to remove *Undaria* plants?

Whole plants should be pulled or cut off as low to the base as possible. The reproductive tissue is located along the edge of the stipe or stem, so the stipe must be removed to prevent further zoospore production. Any remaining fragments of the holdfast would rot away quickly or be eaten by grazing marine animals such as sea urchins or molluscs.

(b) Does *Undaria* regrow from a cut stipe or from a holdfast left attached to a rock surface?

Experimental evidence suggests that the sporophyte of *Undaria* will not regrow from the holdfast. As the sporogenous or reproductive tissue develops on the edge of the stipe, this should be removed to ensure that the sporogenous tissue is removed. There is no evidence to suggest that a cut stipe would regenerate a new blade under field conditions, but as the upper part of the stipe is meristematic it might be possible. Laboratory experiments in Japan are inconclusive on this point.

(c) What attempts, if any, have been made to remove *Undaria* from areas in New Zealand?

To my knowledge, none. Moreover, I believe that attempts to do this, after sufficient plants are present to bring them to notice, would be futile. The microscopic gametophytes can neither be seen easily nor removed.

11. What are the risks associated with land-based culture of *Undaria*? Could systems be established to ensure that there is absolutely no chance of *Undaria* spreading from a shore-based facility? Could sterilisation techniques (e.g., heat, chemical, ultraviolet light) be effective? Filtration? For experimental study, could a totally secure/enclosed water system be designed to preclude release into the wild?

There is a risk that land-based culture of *Undaria* could become a source of spores and gametophytes, which might establish *Undaria* in new areas if sterilisation of the effluent was inadequate. In an experimental study it would be appropriate for all water that is used in culturing *Undaria* to be carefully filtered, and sterilised with ultraviolet light before returning it to the sea. Sterilisation with heat or chemicals would pollute the immediate environment of any outfall to the sea. The technique of sterilisation or filtration, and all equipment used, should be carefully and regularly monitored to ensure that it is effective. For some initial experimental situations a totally secure or enclosed seawater system could be designed. However, later farming experiments would need to be carried out in open sea areas where *Undaria* is already established.

12. What other environmental questions/issues need to be addressed before *Undaria* is considered for marine farming in New Zealand waters?

Undaria pinnatifida has become part of our introduced seaweed flora, and will continue to slowly spread around our shores. Marinas and pleasure boat harbours or anchorages should be regularly monitored for signs of its presence. It is appropriate that marine farming experiments be carried out only in areas where the kelp is already found, rather than risk spreading it further. It is not appropriate to deliberately introduce any new marine algal species, or new strains of currently naturalised species, into New Zealand to enhance marine farming or aquaculture in any way. Only the genotypes of seaweeds at present in New Zealand should be used for aquaculture.

8. References

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9. Appendix

A short supplementary bibliography of *Undaria*

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* Not available as a serial in New Zealand.

Figure 1. Sporopiayte of *Undaria pinnatifida.* Scale: 10 mm. Reproduced from Adams (1994), Seaweeds of New Zealand, plate 34.

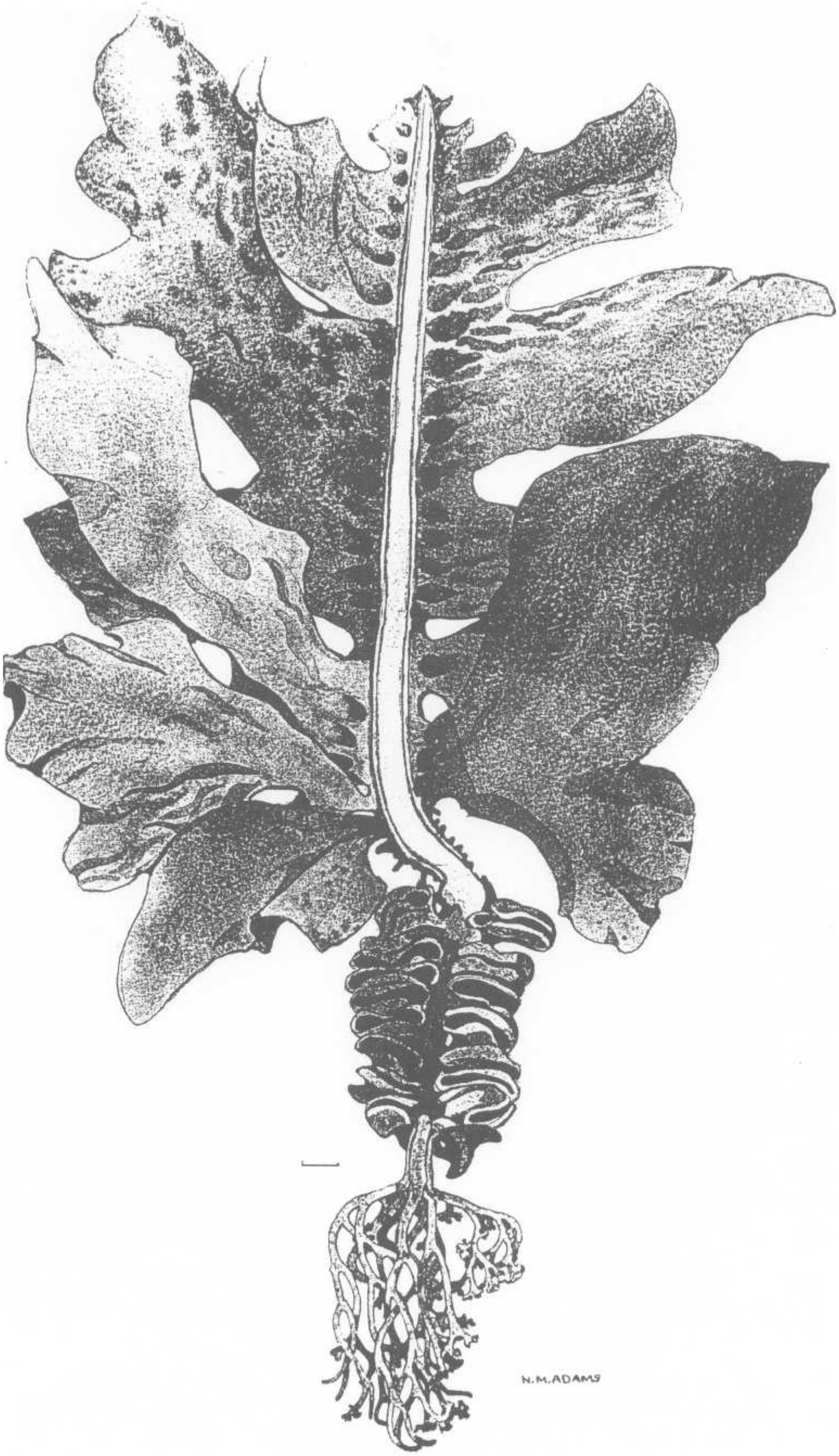

Figure 2. Life history of *Undaria:*

1. zoospore (n);
2-4, germination;
5,6, male gametophyte generation (n) (c, spermatozoid);
7-9, female gametophyte generation (n) (a, oogonium; b, oospore);
10, fertilised oospore (2n);
11, germination of sporophyte generation (2n) (d, rhizoid);
12, plumule of juvenile sporophyte;
13, adult sporophyte with sporophylls (e).

Reproduced from Ohno & Matsuoka (1993), figure 2.