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The distribution of *Undaria pinnatifida* (Harvey) Suringer within Timaru harbour, New Zealand

Murray T. Brown* and Miles D. Lamare

Botany Department, University of Otago, P.O. Box 56, Dunedin, New Zealand

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A quantitative survey of the *Undaria pinnatifida* (Harvey) Suringer population in Timaru harbour, New Zealand, was undertaken during the summer of 1989–90. Information on the distribution, abundance, size and reproductive status of plants was obtained. An extensive population was found throughout the harbour attached to a variety of substrates. Plants were found down to a depth of 5 m below MLW, the lower limit being set by the quantity of available light. The maximum density of plants was 22 per 0.5 m^2 and there was a general reduction with depth in most parts of the harbour. Size of the population was estimated to be over 70,000 plants. Plants found at the entrance to the harbour were larger than those at more sheltered sites within the harbour. There was little variation in size with depth at any site. Over 90% of the population was reproductive at the time of the survey. Over the period of the study the lengths of individual plants decreased and by late February only the basal sporophylls remained. The majority of the population had disappeared completely by late summer.

Key Index Words: abundance—distribution—New Zealand—*Undaria pinnatifida*.

Undaria pinnatifida (Harvey) Suringer, a native brown seaweed of Japan and Korea and commonly found along parts of the Chinese coastline (Zhang *et al.* 1984), in the Okhotsk Sea and near Vladivostok in the former USSR (Zinova 1954; Funahashi 1966), has most recently been discovered in Europe and Australasia. In 1971 *U. pinnatifida* was identified in the Étang de Thau on the Mediterranean coast of France near the town of Sète (Boudouresque *et al.* 1985), having been accidentally introduced to the area with spat of the Pacific Oyster. It has since spread to other parts of the Mediterranean coast, and was intentionally introduced to the French Atlantic coast with the view to farming (Pérez *et al.* 1984). Seeded ropes were transplanted to three sites on the Brittany coast but all but one of these original sites, Ile d'Oussant near Brest, were eventually abandoned (Floc'h *et al.* 1991). It was thought that the cultured populations would be fully controllable and unlikely to spread from the cultivation sites since the species would be unable to reproduce *in situ* in the colder waters of NW France. However, the results of a study carried out by Floc'h *et al.* (1991) in the Bai de Lampaul, Ouessant suggest the contrary; they concluded that the whole reproductive life cycle could be completed within the vicinity of the farm site. Additional evidence for the opinion that *U. pinnatifida* can reproduce *in situ* in northern France comes from the observations of luxuriant growth of sporophytes on an anchored rope at an abandoned farm site near Portsall (Brown and Floc'h pers. obs. 1991).

The first report of the species presence in Australasia was in 1987 from Wellington Harbour, New Zealand (Hay and Luckens 1987). Since then it has been discovered in several harbours in the South Island (Lyttleton, Timaru, Oamaru) and most recently has been found in Otago harbour, Dunedin (pers.

* Present address and address for correspondence: Department of Biological Sciences University of Phymouth Phymouth PLH 8AA Devon, United Kingdom.

obs.) and Picton (Hay pers. com.). The initial introduction is thought to have occurred as gametophytes in the ballast water of fishing boats and its subsequent spread apparently via coastal shipping (Hay 1990). In 1988 *U. pinnatifida* was identified on the east coast of Tasmania, Australia (Sanderson 1990). Ballast water from cargo ships transporting woodchips from Tasmania to Japan is considered the most likely source of the introduction.

Despite the interest shown in *U. pinnatifida* and concern about its possible spread, there is little quantitative data about the ecology of the species in its new biotopes. Pérez *et al.* (1981, 1984) have reported that in Étang de Thau its biology is similar to that in Korea and Japan, Floc'h *et al.* (1991) have provided some information about population distribution and structure adjacent to the cultivation site in the Bai de Lampaul, Ile d'Ouessant and Hay (1992) has provided information on its seasonality in New Zealand.

Here we report on a preliminary quantitative survey of the population from Timaru harbour on the east coast of South Island, New Zealand (Fig. 1), which was first recorded in 1988 (Hay 1990). Timaru is a medium sized port supporting a local fishing fleet, servicing coastal shipping and visited regularly by Japanese fishing boats. We provide information on its vertical and horizontal distribution, abundance, size and reproductive status.

Materials and Methods

The main survey of the harbour was carried out by divers in the first week of December 1989. The harbour was divided into 8 sites (shorelength 200–400 m) based on substrate type, degree of exposure and location (Fig. 1).

The predominant rocky substrate consists of large (>1 m) basalt boulders, which have been used in the harbour's construction (sites 1, 2, 3, 5, 8). The substrate at sites 6 and 7 consists of wooden piles used to support large wooden wharves while at site 4 both wooden and concrete piles are present supporting a large wharf. Except for a gently sloping pebble bed along site 5 the remainder of the harbour bottom consists of a muddy substrate. The average depth of the water column is about 11 m at MLW.

At each site a minimum of three randomly selected transects were run out perpendicular to the shoreline. Contiguous sampling down the transect line using a 1×0.5 m quadrat provided a 1 m wide profile of the population with depth. Within each quadrat the number of plants and the lengths of individual plants were recorded and the reproductive status of each noted.

The subsurface water temperature was recorded, and a photon flux density (PFD)/depth profile was obtained outside the seaweed canopy, using a Li-Cor underwater spherical quantum sensor (Li 193SB) and integrator (Li 188B), at each of the sites. The degree of exposure at each site was estimated using plaster balls as described by Muus (1968).

Additional dives were carried out at site 7 at approximately monthly intervals until March 1990. On each of these visits the lengths of 20 randomly selected plants were measured and recorded.

Analyses of variance were carried out on the data and significance ($p < 0.5$) of differences between means was calculated by Duncans New Multiple Range Test.

Results and Discussion

U. pinnatifida is widely distributed within Timaru harbour. It occurs on a variety of substrates, predominately on rock but also on wooden and concrete wharf piles, on mooring ropes and hulls of boats. Plants were found growing on rocks ranging in size from over one metre down to 5–10 cm in diameter. This may be the lower size limit as an area of small pebbles (3–5 cm in diameter) at site 3 had no visible plant cover while a steel cable running across the area supported healthy plants. This tendancy for plants to colonize immersed artificial substrates is well documented (e.g. Hay 1990, Floc'h *et al.*

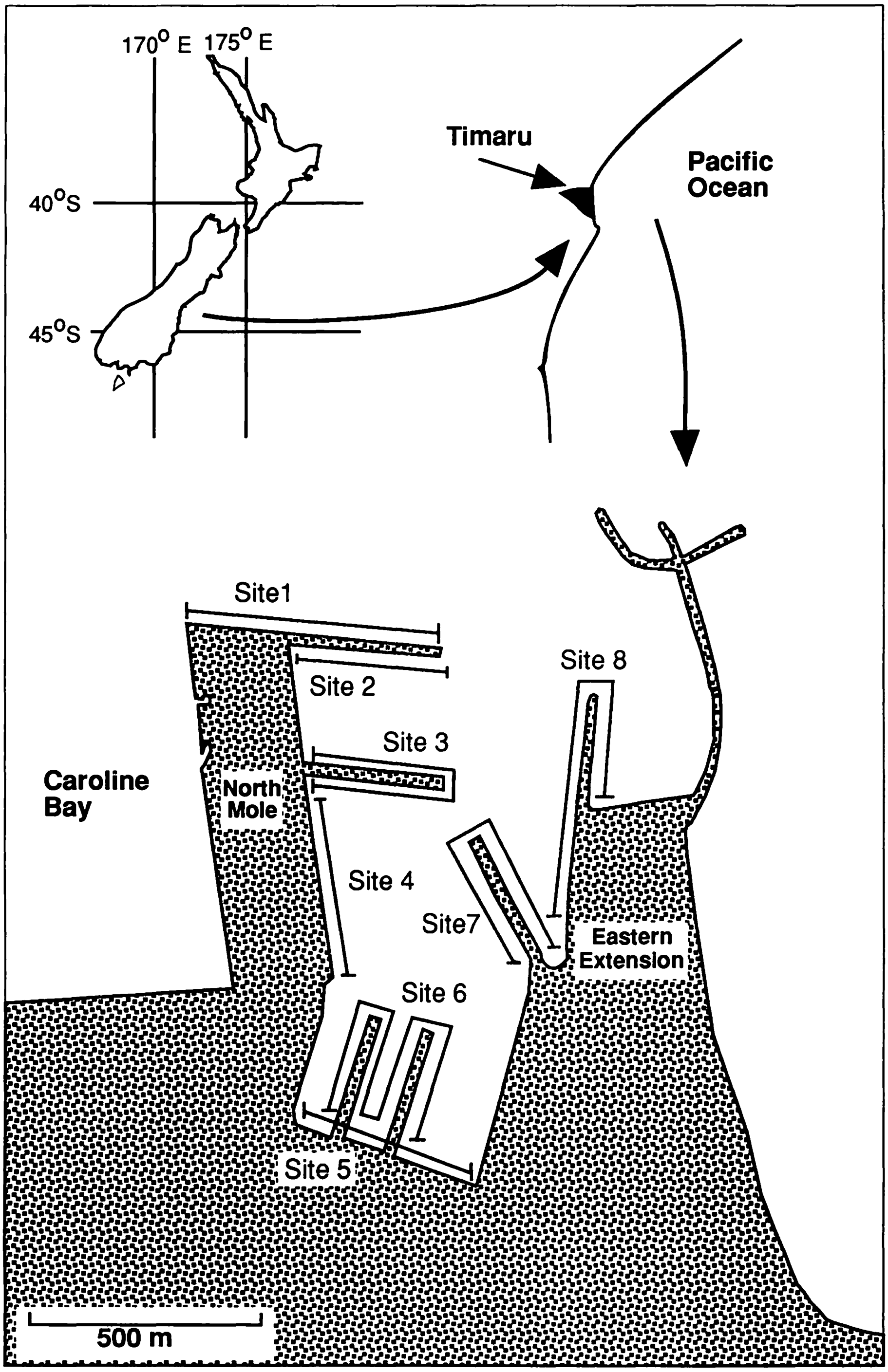

Fig. 1. The location of Timaru, New Zealand and map showing the sampling sites within Timaru harbour.

1991) and may be related to their selection for rope cultivation and 'stone planting' in Japan and Korea (Mathieson 1975).

The depth range for the species is usually considered to be from the low intertidal down to 15 m (Saito 1975) although Floc'h *et al.*

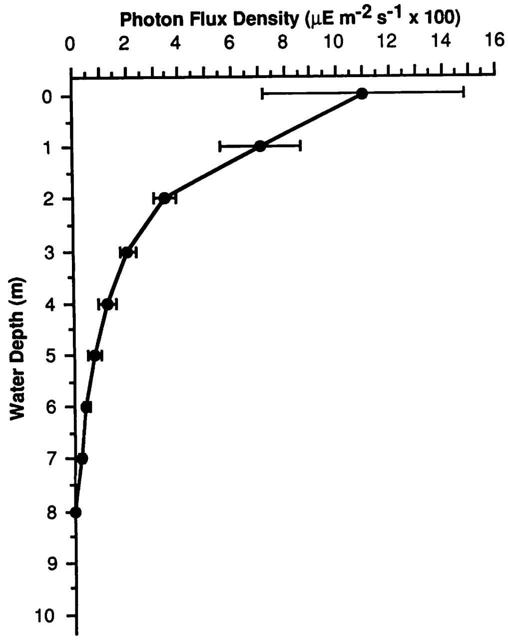

Fig. 2. Change in PAR with depth at site 7 within Timaru harbour (mean and standard error of readings taken on three consecutive days in the first week of December 1989).

(1991) found sporophytes growing on rocks at 18 m in the Bai de Lampaul, Ile d'Ouessant. Where suitable substrate is available the prevailing light conditions will determine the lower limit for growth. In Timaru harbour PAR is reduced rapidly with approximately 70% of surface light attenuated by 2 m and more than 95% by 6 m. These results obtained at site 7 (Fig. 2) are typical of the harbour as a whole. The maximum depth at which plants were found growing was 5 m below MLW despite the presence of suitable substrate below this depth.

The vertical distribution of *U. pinnatifida* varied in different parts of the harbour. The majority of plants occurred in the upper 2 m of the water column with the maximum density of approximately 22 plants per 0.5 m^2 being found at MLW at site 6 (Fig. 3). At most sites (2, 5, 6, 7, 8) the maximum number of plants occurred at the surface or within the top metre of the water column with density decreasing with depth (Fig. 3). At sites 1 and 3, density was significantly lower at the surface than at an intermediate depth of between 1.5 and 2 m. The distribution of *Undaria* plants at Site 4 is different from all other areas sampled in having an absence of plants at the water surface (Fig. 3). Maximum density occurred at 2 m depth and decreased thereafter. Because of the preliminary nature of this survey it is not possible, at this juncture, to provide definitive explanations for these different distributional patterns. A number of factors can affect the vertical distribution including substrate suitability, turbidity, grazing, competition, and turbulence. Zoospore attachment of *U. pinnatifida* has been shown to be adversely affected by currents above 8 cms^{-1} and its cultivation is more suitable under moderate to low wave action (Saito 1975). The degree of exposure decreased from the outer harbour (Site 1) to the inner harbour (sites 5 and 6) and therefore turbulence may be a contributory factor to the observed differences in distribution with depth found in Timaru harbour. At the more sheltered sites (2, 5, 6, 7) maximum density was found at the surface whereas at the more exposed sites towards the harbour entrance (sites 1 and 3), significantly fewer plants were found in surface waters. Sanderson (1990) also noted a relationship between plant numbers and wave action in his survey of the east coast of Tasmania. Site 4 is the main container wharf, and the low density of plants in the upper metre of the water column may be due to the greater amount of boat traffic preventing establishment of individuals.

Based on the number of individual plants encountered at each of the sampling sites we have estimated the total size of the population in Timaru harbour to be 77,600±5,600 plants. These data indicate that *Undaria* is now well established and thriving within this southern harbour and any attempt to eradicate it would be futile.

The size of individual *U. pinnatifida* plants ranged from 10–80 cm in length (Fig. 4). This is well within the known range for plant length recorded from other parts of the world which typically attain a maximum length of 3 m (e.g. Pérez *et al.* 1981, Akiyama & Kurogi

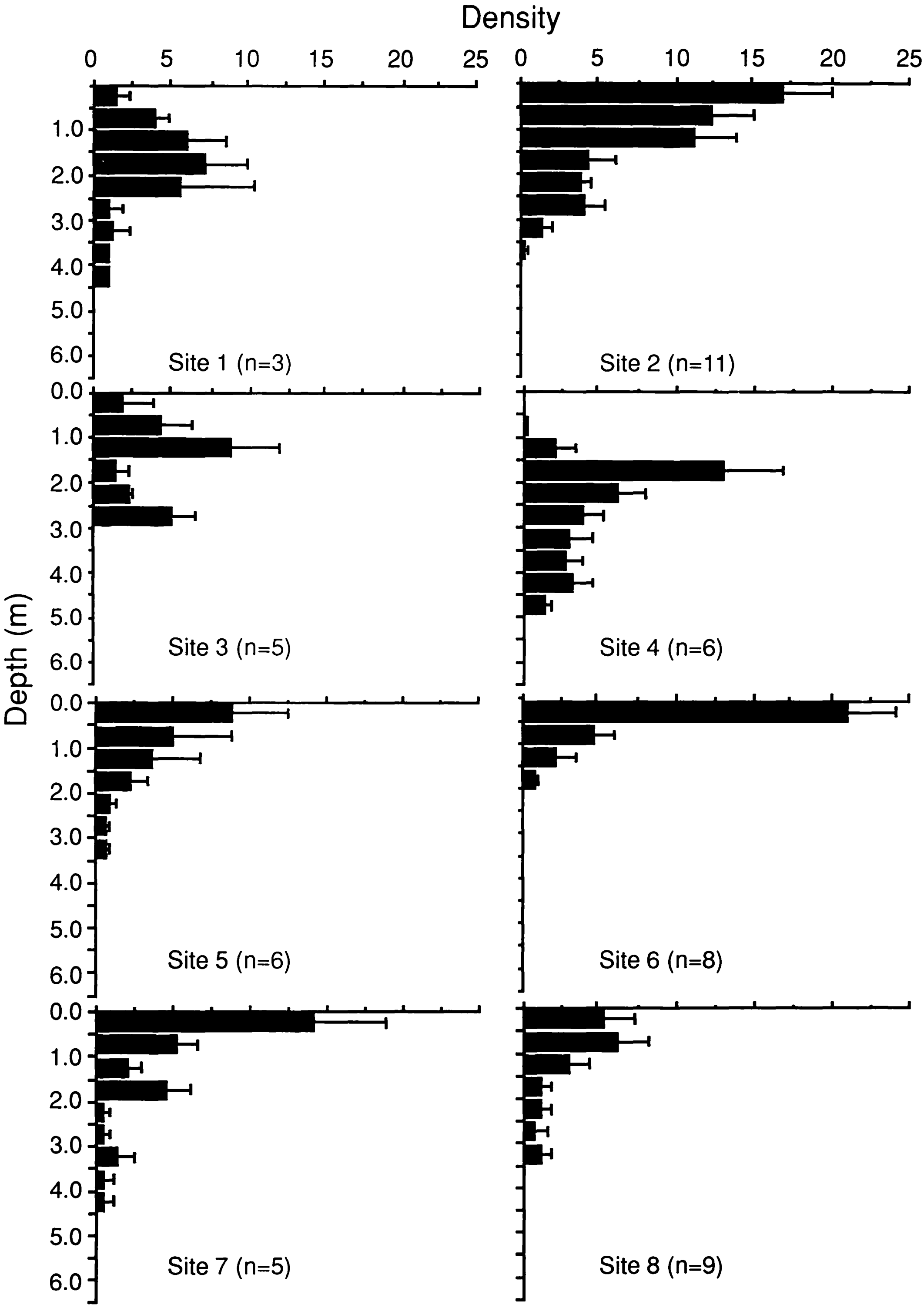

Fig. 3. Depth profile of plant density (number per 0.5 m^2) of *Undaria pinnatifida* at 8 sampling sites within Timaru harbour (n = number of transects; bars indicate standard error of mean) recorded during the first week of December 1989.

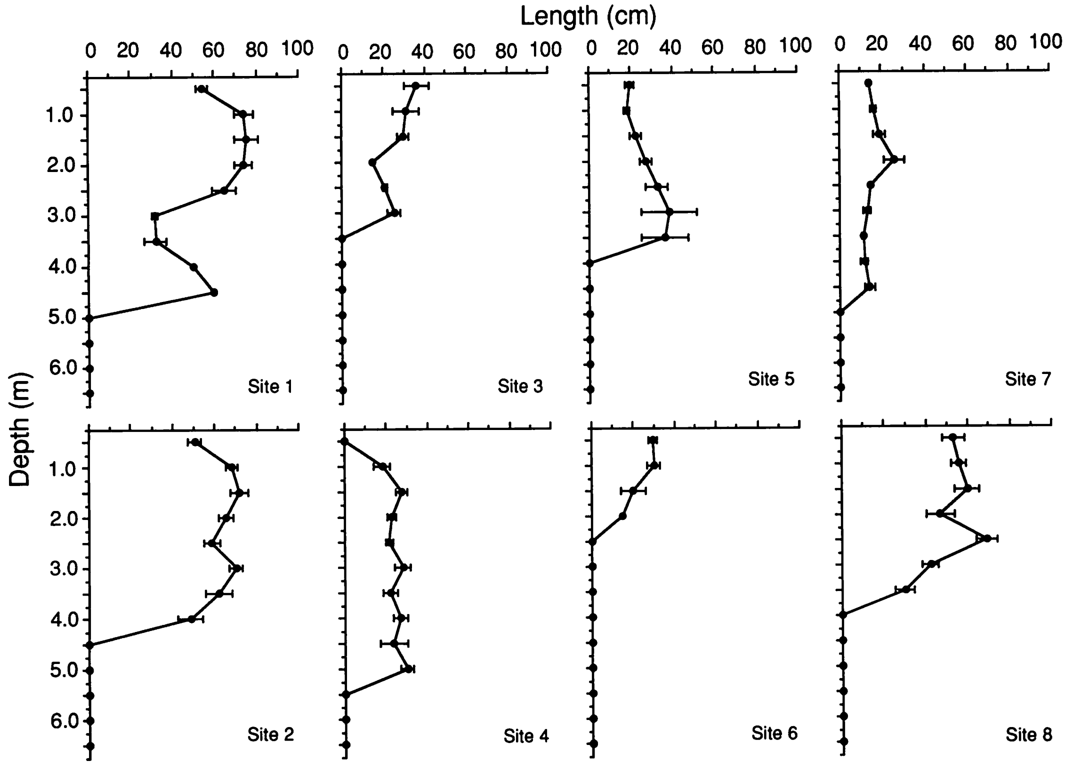

Fig. 4. Depth profile of mean length of individual *Undaria pinnatifida* plants at 8 sampling sites within Timaru harbour (bars indicate standard error of mean) recorded during the first week of December 1989.

1982, Sanderson 1990, Koh & Shin 1990, Floc'h *et al.* 1991). At most of the study sites there is no significant variation in plant size with depth (Fig. 4) and the size range of plants encountered is small. However at sites 1, 2, and 8 towards the harbour entrance significantly larger plants were found (Fig. 4). Degree of turbulence and concomitant increase in nutrient exchange, may in part, be responsible for this observation. 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 differed at the different sites.

Water temperature is considered to be the most important environmental factor influencing the life history and ecology of *U. pinnatifida* (Saito 1975). The temperature in Timaru harbour at the time of sampling was 16°C and the long-term mean monthly sea surface temperature ranges from 8°C in July to 18°C in February (Greig *et al.* 1988) and is thus well within the range for completing its life history (Funahashi 1974). The period of maximum growth for sporophytes is spring (Saito 1975, Pérez *et al.* 1981, Koh and Shin 1990) and therefore by the time of this survey in December, the growth rate would have already declined and thallus decay is likely to have begun (Koh and Shin 1990). Saito (1975) has reported that while sporophyll formation does not appear to be under temperature control zoospore release is, and begins when the 10-day average water temperature rises above 14°C. Similar results have been reported by Pérez *et al.* (1981, 1984) who found that sporophylls were mature during summer (May to July). More than 90% of the plants encountered during this study were reproductive and therefore it is highly likely that they had already reached maturity with zoospores

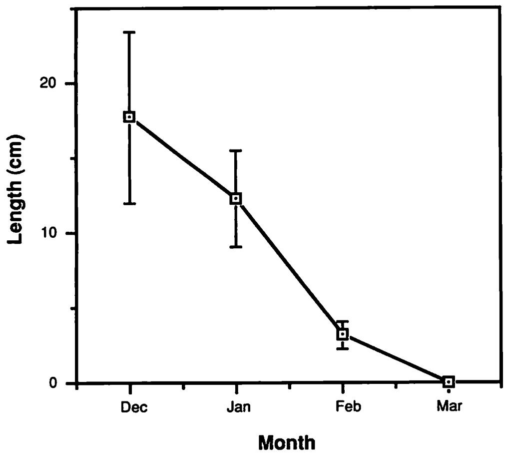

Fig. 5. The change in mean plant length over time at site 7 within Timaru harbour (bars indicate standard error of mean).

being discharged.

During subsequent dives, at approximately monthly intervals, a significant decline in the size of plants was observed (Fig. 5). Dieback occurs as a result of erosion of the apical portions of plants, and by late February only basal sporophylls remained. By the end of March the majority of sporophytes had disappeared completely from site 7 (Fig. 5) and from the harbour as a whole. This sequence and eventual disappearance by late summer, follows a similar pattern to that observed in Japan (Saito 1975), Korea (Koh and Shin 1990) and in the Mediterranean Sea (Pérez *et al.* 1984) but differs from the situation on the French Atlantic coast where sporophytes can be found all year round (Floc'h *et al.* 1991). Hay (1990), too has observed several successive generations throughout a year in Wellington harbour, New Zealand but didn't state whether the sporophytes are present all year round. More detailed studies are required to ascertain the annual cycle of events in the southerly populations.

U. pinnatifida is often considered to be an opportunistic species, colonizing disturbed and sparsely covered surfaces (Sanderson 1990, Floc'h *et al.* 1991) but lacks other attributes associated with opportunists such as several generations per year, high fecundity and high net primary productivity (Littler and Littler 1980). The low competitive ability of the species is implied by low abundance among large seaweeds or sessile macrofauna although it has been suggested that it may possibly compete with other annual species which have periodic recruitment (Floc'h *et al.* 1990). The sublittoral flora of New Zealand has no large brown annual species similar to *Saccorhiza polyschides* (Lightfoot) Batters from the north Atlantic but it may compete with smaller brown fucalean seaweeds such as *Sargassum, Cystophora* and *Carpophyllum*. In Timaru harbour the diversity and abundance of macroalgae associated with *U. pinnatifida* was relatively low but at the present time we do not know whether or not the presence of this newly established dense kelp canopy has had any impact on the native seaweed community.

This study provides a preliminary quantitative analysis of the vertical and horizontal distribution of *U. pinnatifida* in a southern New Zealand harbour. The data indicates that since first being encountered in 1988 the species has become well established and a thriving population now exists. The number of plants generally decreases with depth but significant differences were found between sites with different degrees of exposure as assessed by the use of plaster balls. The size of plants found at sites close to the harbour entrance is significantly larger than those encountered at more sheltered sites within the harbour but there was very little variation in size with depth. The annual cycle of growth observed in Japan and in the Mediterranean Sea also appears to occur here with sporophytes disappearing by late summer.

Interest has been expressed in farming *U. pinnatifida* in New Zealand using similar technology to that developed in France. While the species is now clearly well established and is unlikely to be eradicated from New Zealand waters, proliferation of kelp farms would undoubtedly lead to further spread of the species. Until more is known about the potential ecological impact on the native flora this would be an unwise move. It may be more appropriate to harvest wild populations from unpolluted waters. Under suitable management regimes this may keep its spread in check and at the same time provide a sustainable resource for the development of an industry based on the species.

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Brown, M. T. and Lamare, M. D.：ニュージーランド，チィマール港におけるワカメの分布

ニュージーランド，チィマール港におけるワカメの分布，現存量，サイズ，成熟状態を1989–90年の夏期に測定した。ワカメは港全体のさまざまな基質上に，低潮線下 5 m までの範囲で広く分布していた。最大密度は22個体/0.5 m² であり，港の多くの場所で水深に伴い減少した。個体群の大きさは港全体で70,000個体と見積もられた。港の入り口付近に生育する個体は港奥部のものに比べ大きく，また水深によっても大きさに若干の違いが見られた。測定時には90%以上の個体が成熟していた。測定期間中に藻体長は徐々に短くなり，2月下旬には基部を残すのみとなった。個体群の大部分は夏の終わりには消滅した。

(Botany Department, University of Otago, P.O. Box 56, Dunedin, New Zealand)