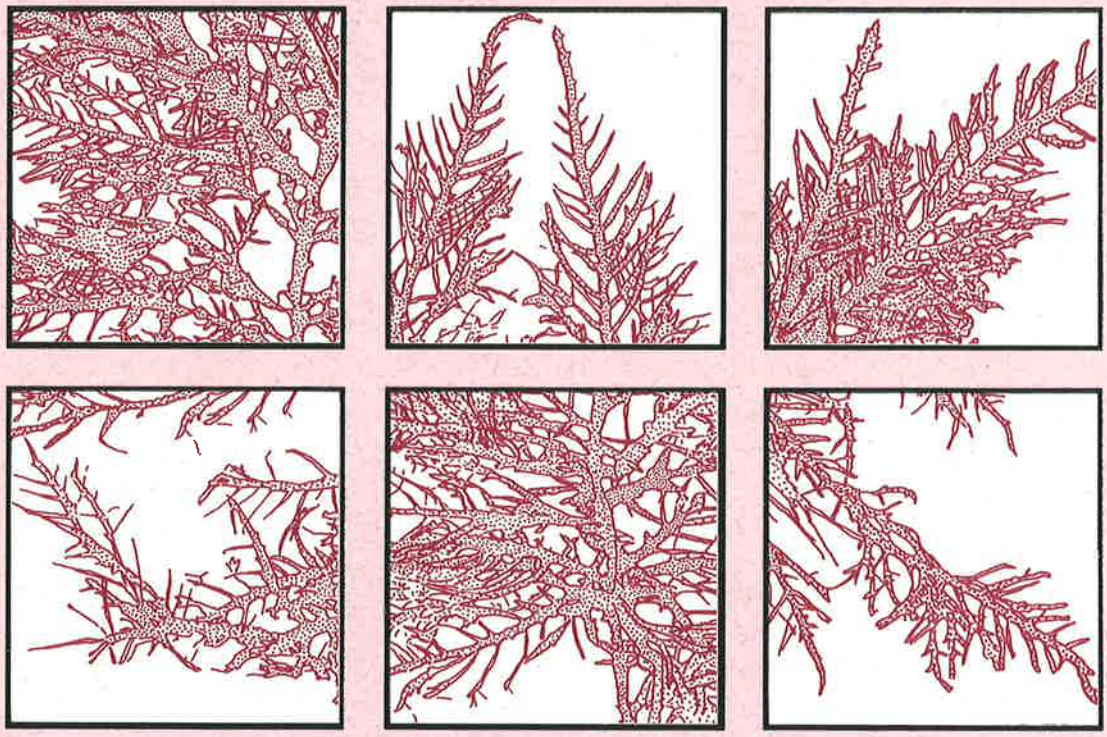
Handbook for stock assessment of agar seaweed *Pterocladia lucida*; with a comparison of survey techniques

M. I. McCormick



New Zealand Fisheries
Technical Report No. 24
ISSN 0113-2180
1990

MAF
MINISTRY OF AGRICULTURE AND FISHERIES
TE MANATU AHUWHENUA AHUMOANA

Handbook for stock assessment of agar seaweed *Pterocladia lucida;* with a comparison of survey techniques

M. I. McCormick

Present address:

Department of Marine Biology,
James Cook University,
Townsville, Queensland 4811, Australia

New Zealand Fisheries
Technical Report No. 24
1990

Published by MAF Fisheries
Wellington
1990

Inquiries to:
The Editor, MAF Fisheries Greta Point,
P.O. Box 297, Wellington,
New Zealand.

MAF Fisheries is the fisheries business group of the New Zealand Ministry of Agriculture and Fisheries. The name MAF Fisheries was formalised on 1 November 1989 and replaces MAFFish, which was established on 1 April 1987. MAFFish combined the functions of the old Fisheries Research Division and Fisheries Management Division and the fisheries functions of the old Economics Division.

The *New Zealand Fisheries Technical Report series* in part continues the *Fisheries Research Division Occasional Publication* series. The *New Zealand Fisheries Occasional Publication* series contains mainly conference proceedings and bibliographies.

Edited by S. J. Baird

Set in 10 on 11 Times Roman

Typeset by Challis Datacom

Printed by Madison Printing Company Ltd

Cover: *Pterocladia lucida.* (Drawn by A. M. Conroy)

ISBN 0–477–08284–X

Contents

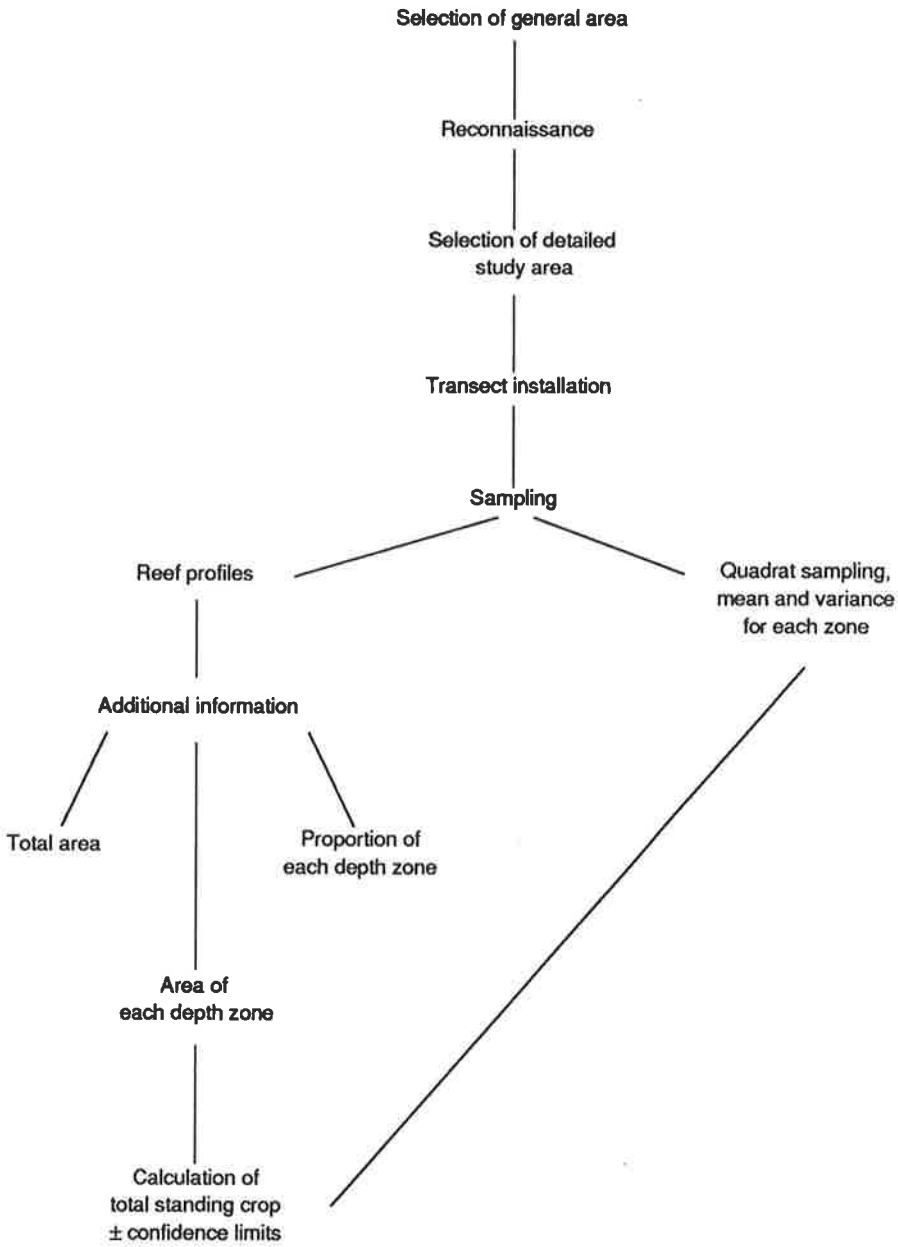


Figure 1: Recommended procedural steps for the method of assessing agar seaweed stocks.

Abstract

McCormick, M. I. 1990: Handbook for stock assessment of agar seaweed *Pterocladia lucida*; with a comparison of survey techniques. *N.Z. Fisheries Technical Report No. 24.* 36 p.

Survey designs were fieldtested to find the best method for assessing the total standing crop of the commercially harvested agar seaweed *Pterocladia lucida*. A two-stage sampling programme is recommended: an initial reconnaissance survey to identify areas of potential interest, followed by a more detailed survey to determine quality and quantity. For a detailed assessment of algal biomass a 0.25 m^2 quadrat was the most efficient sampling unit; it gave a 137% saving in time when compared with a 1 m^2 quadrat to obtain an arbitrary error of 10% of mean *P. lucida* biomass. Percentage cover within a quadrat was the most easily and consistently measured predictor of biomass. Broad biomass categories were designed for *P. lucida* abundance. Standing crop estimates were calculated for both these measures, and these were compared with results from harvested quadrats, but their general applicability was lessened by strict assumptions and a lack of statistical comparability between locations. A semirandom stratified survey design with sampling conducted in four microhabitat zones produced a more accurate standing crop estimate (32 980 kg ± 95% confidence limits of 5081 kg) than a semisystematic design with replicate quadrats sampled at fixed depths with regularly spaced sites (25 336 kg ± 9159). However, the latter design is recommended for *P. lucida* stock assessment as it was less time consuming and allowed statistical comparisons of biomass between depths, sample sites, and geographic locations as well as an acceptable ability to estimate standing crop.

Agar seaweed survey handbook

Introduction

Agar seaweed has been harvested in New Zealand since the early 1940s with almost no restrictions. Traditionally, agar has been collected as drift alga or by snorkel divers plucking the alga from shallow reefs. Recent renewed interest in the resource has led to the suggestion that more intensive methods (e.g., scuba) be used. Therefore, it is necessary to set realistic limits on the amount of agar seaweed harvested, so that neither the resource nor the environment is irreparably damaged.

For the commercial management of a seaweed it is necessary to know how much is present within an area (standing crop), and whether one area has more seaweed than another and whether this changes with time because of harvesting or natural fluctuations. The method of assessing agar seaweed stocks described in this handbook provides this information. It is a two-stage technique: areas of interest are identified by a broad survey (reconnaissance) and then are resampled more intensively. Procedural steps are shown in Figure 1.

The handbook is derived from the comparison of survey techniques. Sampling examples and calculations are taken from the comparison, but the depth zones used there differ from those recommended in this handbook.

The sampling methods have been designed to be simple in procedure and flexible in implementation because of problems such as adverse weather and sea conditions or changes in personnel. In addition, because the cost of subtidal research is high, the surveys have been designed to take as little time as possible. Three researchers should ideally take 2–3 days to assess in detail 3 km of coast.

The methods described require extensive use of scuba and the identification of dominant algal assemblages underwater. Therefore, it is imperative to train personnel in algal identification and the techniques used in this handbook so that accurate and repeatable results can be obtained.

Although agar seaweed is made up of two recognised species of red algae, *Pterocladia lucida* and *P. capillacea*, the detailed survey method described in this handbook refers only to the former. This species comprises over 95% of the algae harvested. Because of the differences in the distribution patterns of the two species, a separate technique would be required to obtain a good estimate of standing crop for *P. capillacea*. Thus, references to "agar" or "agar seaweed" in this handbook refer to *P. lucida* alone.

Reconnaissance surveys

The selection of areas of potential interest may be based on information from aerial photographs, harvest returns from the area, local knowledge, or simply be part of a random survey of the coast. If previous investigations have shown that the area possesses substantial quantities of agar seaweed, the reconnaissance part of the survey will be unnecessary.

Aerial photography at low tide on a calm day will define the shoreward boundary of the survey and indicate the topography of the shallow reef being assessed. From photographs a detailed map of relevant areas can be drawn at a scale of about 1 : 6000, and the sample stations or reconnaissance plots can be precisely recorded.

The objective of the reconnaissance survey is to rapidly describe algal coverage on large areas of reef. Therefore, areas of interest are identified for more detailed study, and the representativeness of these smaller areas can be assessed. These surveys should involve between 4 and 10 km of coast.

Sampling

A variable speed diver propulsion vehicle (DPV) (Figure 2) is recommended to obtain information such as reef morphology and algal assemblages, as well as more specific data about the distribution and abundance of agar seaweed. Underwater visibility of at least 3 m is required for the safe use of this vehicle.

A diver is towed by a DPV while being followed by a boat. The diver zigzags over the reef from as close inshore as conditions allow to the lower limit of the agar seaweed distribution, or no deeper than 10 m. After a distance of about 150 m has been traversed or an abrupt change in reef morphology encountered (e.g., sloping to drop-off), the diver returns to the boat and is debriefed by the boatperson. This involves the diver placing his observations into broad categories of reef type, dominant growth forms, and state of the agar seaweed stocks and recording them on a data sheet with explanatory notes (Appendix 1). The location of each of the surveyed parts of coast is recorded on a shoreline map of the area.

This reconnaissance technique should also identify the lower limit at which agar seaweed grows. When the reef is long and gradually sloping, a DPV can best be used by zigzagging perpendicularly to the shore at given intervals (*see* Figure 2). This is quicker than attempting to cover the whole reef. An area for more detailed assessment can then be chosen. A 3 km unit of coast is recommended for detailed surveys to allow the simple comparison of agar stocks between areas, and it has been established that this can be sampled in 2–3 days.

When a DPV is not available, a diver could make spot searches. If there is enough agar to harvest, it is likely to be present in most shallow exposed parts of the reef, particularly on outjutting points open to the direct action of wave surge. These are the most useful areas to determine the presence or absence of the algae.

Detailed surveys

The main aim of the detailed survey is to obtain an estimate of the amount of agar seaweed on the stretch of coast (i.e., the standing crop and its confidence limits). Thus, the following information is required: an estimate (with confidence limits) of the mean plant weight within the area and an estimate of the area of reef under study. The former is scaled up by the latter to produce the final estimate of standing crop.

Once the 3 km area to be studied in detail has been determined, sampling sites are regularly allocated. A minimum of six is recommended. Each site is a transect line along which samples are taken. Transect lines are laid to measure the variation of reef depth with distance offshore to obtain reef profiles and as a reference line from which quadrat samples are randomly harvested at fixed depths.

Each transect is a calibrated lead line fixed at low tide level by a grapnel and laid out perpendicularly to the shoreline by boat. The seaward end of the line is marked by a buoy for later reference and recovery. Lines should be stored on reels or in fish bins in 100 m lengths for ease of deployment. Each line should terminate in a blundell clip, to allow simple extension to any required length.

Sampling

Reef profiles are drawn from information obtained by a diver who has swum down the transect line and recorded the depth every 2–5 m and the boundaries of the various algal zones (e.g., *Carpophyllum* spp., *Lessonia* spp., *Ecklonia* spp.). The transects end at the lower

depth limit established during the reconnaissance survey. It is this lower depth limit which defines the seaward boundary of the survey area.

Quadrat sampling is conducted at five depths down the transect line. The five depths sampled depend on the lower depth limit of the agar seaweed distribution and have been divided into two categories (Table 1). All depths are calculated from mean low water (MLW). The diver first records the height of water above the bare rock to vegetation interface, then subtracts this measurement from subsequent depth gauge values. The diver then swims down the transect line from the shore and collects four random samples of agar seaweed as soon as each of the prescribed depths is reached. Two 0.25 m^2 (0.5 × 0.5 m) quadrats are laid either side of the transect line, with random numbers (1–10) giving the distance of the quadrat from the line in quadrat widths (Figure 3). Within each quadrat, all agar seaweed plants are plucked and placed into bags. The site, depth, and bag number of each sample are recorded. At the field station or laboratory, the contents of each bag are shaken dry, sorted, and wet weighed. Samples may be kept for the determination of measurements such as dry weights, size frequencies, and sex ratios as required.

Additional reef profiles are required to measure the distance from the shore to the outer depth limit of the survey (previously defined). The total survey area can then be calculated, and an accurate estimate of the amount of agar seaweed present in the area can be made. This additional profile sampling should be conducted in the areas between the six transect sites.

Table 1: The five depths at which sampling should be conducted, and the depth zones used in the calculation of a standing crop estimate, for two lower depth limits of agar seaweed distribution

Lower limit (m)	Sampling depths (m)	Depth zones (m)
6	0.5, 2, 3, 4, 5	0.0–1.5, 1.5–2.5, 2.5–3.5, 3.5–4.5, 4.5–6.0
8	1, 2, 4, 6, 8	0.0–1.5, 1.5–3.0, 3.0–5.0, 5.0–7.0, > 7.0

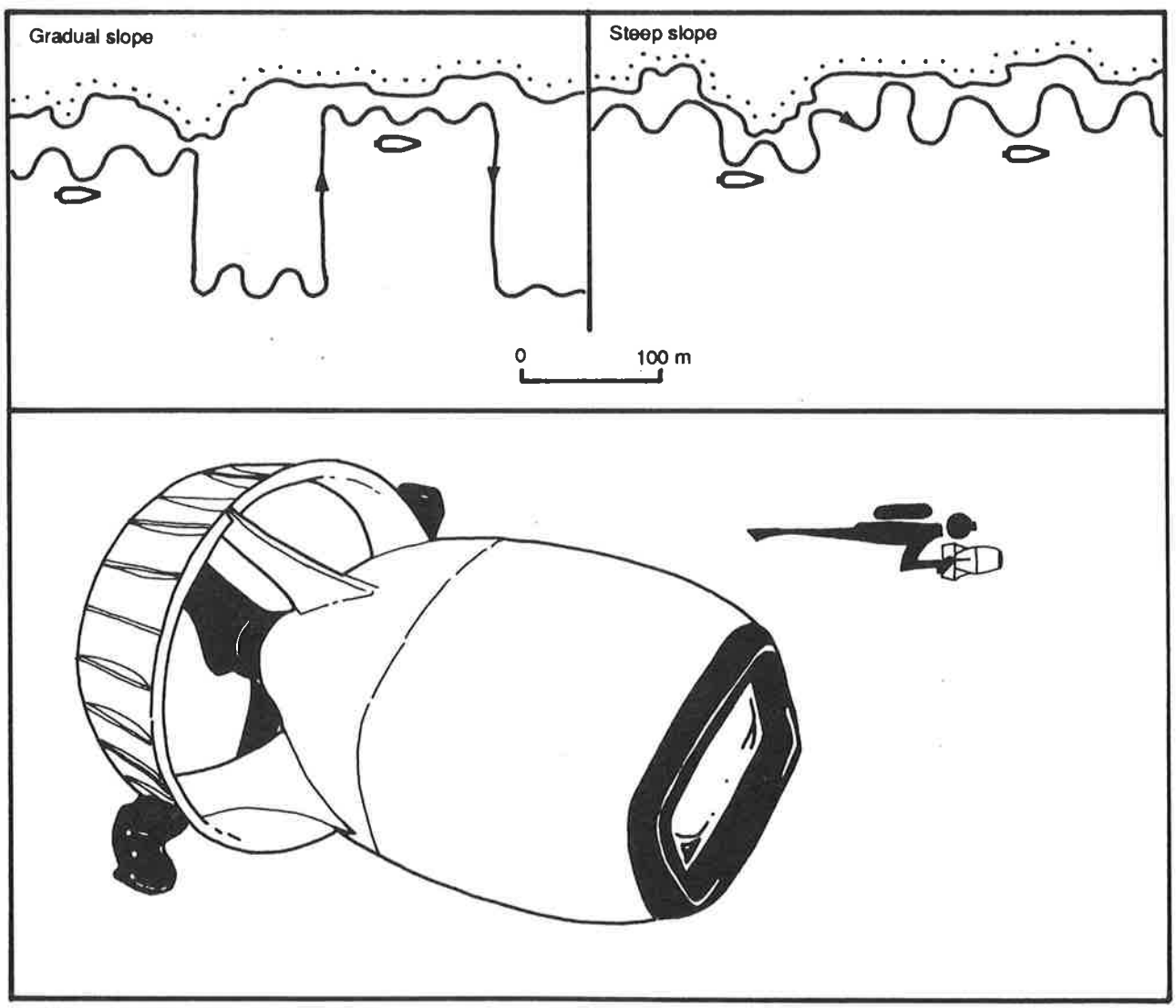


Figure 2: The use of a diver propulsion vehicle (boat shapes represent recording stations).

A rapid method of obtaining these supplementary depth profiles is by the combination of a DPV and a line transect. Once the line has been laid perpendicularly to the shore, a diver towed by a DPV can follow the line down to the prescribed depth limit. For every metre of depth, the distance along the transect line and depth are recorded. This is a particularly useful technique on gradually sloping long reefs.

Spot dives or observations over the side of the boat can also be used to obtain an idea of topography and reef slope. Areas can be described as "like transect 1", "like transect 2", and the respective depth profiles can be attributed to those additional areas.

Sample storage

Seaweed samples can be preserved in 3–5% commercial formalin in sea water for longterm storage. Seaweeds can be kept indefinitely in preservative, tied up in individually labelled plastic bags and stored in a large container. Formalin is an unpleasant chemical. Contact with the skin and inhalation should be avoided.

Large samples which require further examination can be stored for 1–2 days in sea water and kept in a cool dark container, which will slow decay. This may be necessary if time does not allow all the required measurements (e.g., size frequencies) to be done in the field.

Each sample should be individually identified with labels made from waterproof paper and written in soft pencil. Necessary information includes: date, location, site, depth, collector, and preliminary identification.

Survey area calculation

The outer depth boundary of the survey area must be defined accurately. Aerial photographs taken on a calm day at low tide, used with depth transects, are invaluable for estimating the position of the outer depth limit. In addition, hydrographic maps are available (Hydrographic

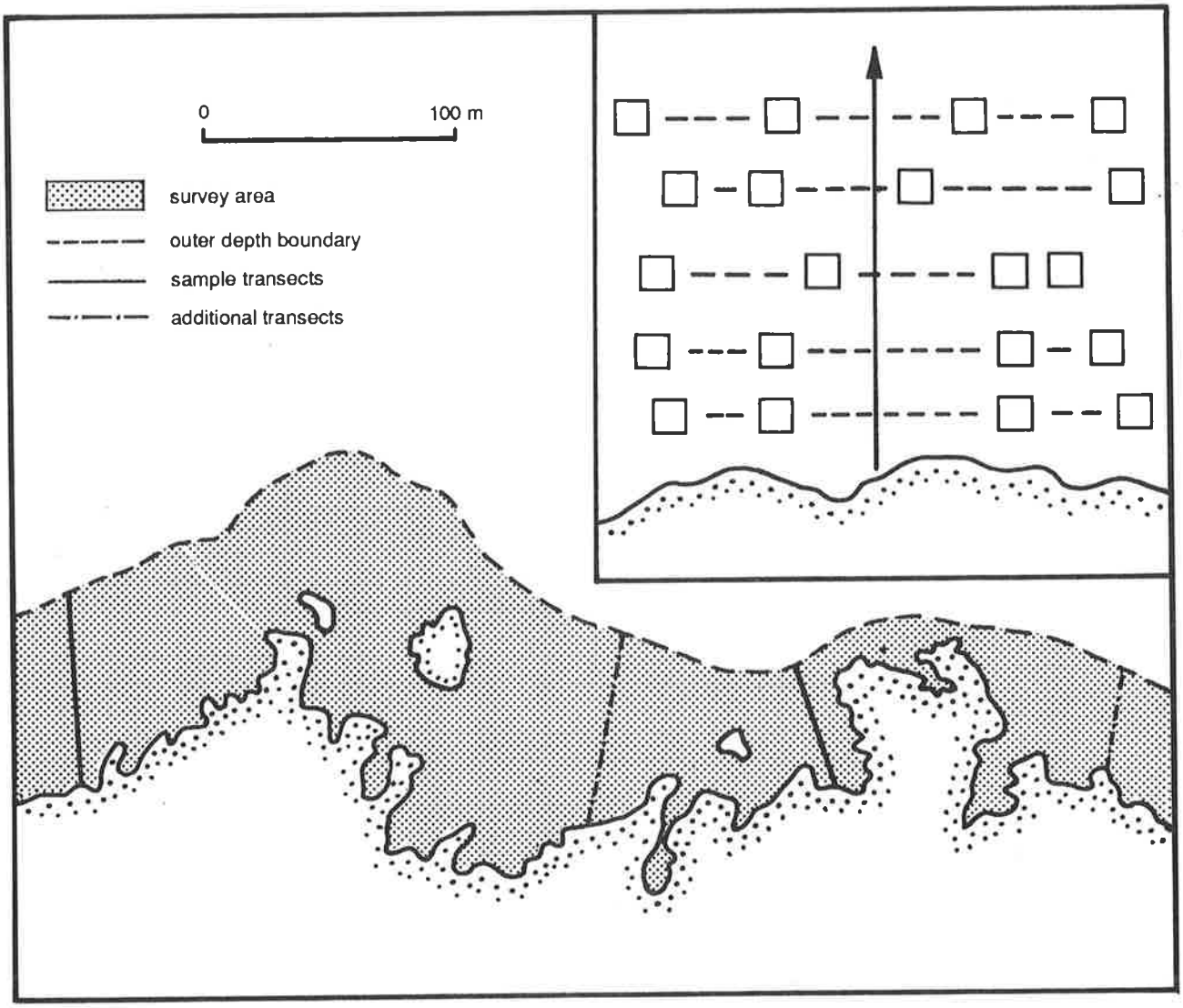


Figure 3: An example of the delimitation of the survey area. (Inset shows the allocation of quadrats down a transect line.)

Office of the Royal New Zealand Navy) for many localities. Observation from adjacent cliffs, local knowledge, and previous surveys may also help.

This information is drawn to scale on the detailed shoreline map of the survey area. The outer depth limit of the survey is then contoured (*see* Figure 3). The survey area (that between the shoreline and the designated outer depth limit) is calculated by use of a computer graphics tablet. The area should be determined twice and averaged.

Depth zone area calculation

The length along the habitat transect of each of the survey zones is tabulated from the reef profiles to calculate the area of each depth zone (Figure 4). The contribution of each zone to the total area is then expressed as a proportion for each transect and averaged over transects (Table 2). Finally, the mean proportion of each zone is multiplied by the total survey area to give an estimate of area for each zone.

Standing crop estimation

The total plant weight or standing crop is the sum of the mean plant weight per quadrat (over the six sample sites) for each of the five depths, each scaled up by the number of 0.25 m² sampling units which could fit into the area of each depth zone. That is:

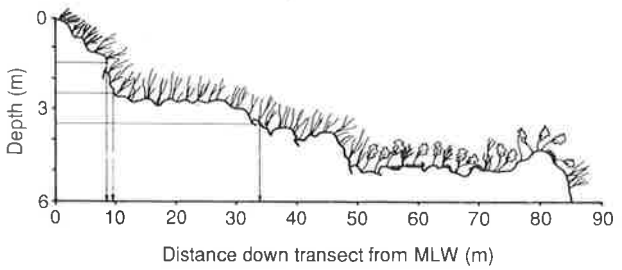
$$X = \sum_h N_h \bar{x}_h$$

where N_h is number of sampling units which will fit into the zone area (e.g., a zone which was estimated to occupy 100 m² would contain 400 possible quadrats), $\bar{x}_h$ is mean plant weight (grams per 0.25 m²) for each depth zone.

The variance of the overall mean plant weight used to obtain the final confidence limits is calculated from the following formula:

$$s^2_{\text{total}} = \sum_h \frac{W_h^2 s_h^2}{n_h}$$

where W_h is proportion the zone makes up of the total area, s_h^2 is variance of plant weight for that depth zone and n_h is number of sampling units taken from that depth zone.



	Depth zone (m)			
	0.0 – 1.5	1.5 – 2.5	2.5 – 3.5	3.5 – 6.0
Distance along transect	8	1.2	24	51.5
Proportion	0.094	0.015	0.283	0.608

Figure 4: An example of the calculation of proportional representation for each depth zone along a habitat transect (*see* Table 2).

The 95% confidence limits around the standing crop estimate are calculated from this variance by:

$$1.96N\sqrt{s^2_{\text{total}}}$$

where N is total number of sampling units which will fit into the survey area. An example of the calculations is given in Table 3. All computations should be repeated until consistent results are obtained.

Statistical analyses

The detailed survey is designed to allow a statistical comparison of the amount of agar seaweed present between the six sites and five depths over several survey localities, or at one locality over time. These comparisons are made by analysis of variance (ANOVA). Two examples of useful statistical models are given in Table 4. Worked examples are given in Appendix 2.

Table 2: An example of the calculation of the proportional contribution of each depth zone to the survey area (from "Comparison of survey techniques")*

	Length of depth zone down transect (m)				Depth zone proportion (m)			
Transect	0.0–1.5	1.5–2.5	2.5–3.5	3.5–6.0	0.0–1.5	1.5–2.5	2.5–3.5	3.5–6.0
1	8.0	1.2	24.0	51.5	0.09	0.02	0.28	0.61
2	2.5	4.0	5.5	38.0	0.05	0.08	0.11	0.76
3	1.0	1.0	9.0	9.0	0.05	0.05	0.45	0.45
4	2.1	1.9	2.0	3.5	0.22	0.20	0.21	0.37
5	2.3	1.5	2.0	4.5	0.22	0.15	0.20	0.43
6	7.5	3.3	2.5	10.0	0.32	0.14	0.11	0.43
7	9.0	7.0	15.0	27.5	0.15	0.12	0.26	0.47
8	1.5	1.5	1.7	3.6	0.18	0.18	0.21	0.43
9	3.5	15.0	9.5	12.0	0.09	0.38	0.24	0.30
Mean proportion					0.15	0.15	0.23	0.47

* Depth zones differ from those recommended in this handbook.

Table 3: An example of the calculation of the standing crop estimate (g) and confidence limits for the 3 km of coast between Goat Island and Cape Rodney in northeastern New Zealand (from "Comparison of survey techniques")*

Stratum depth (m)	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
0.0–1.5	0.153	14 700	58 798	28	63.39	4 366	3 727 205	3.65
1.5–2.5	0.146	14 027	56 108	28	188.36	64 355	10 568 503	48.99
2.5–3.5	0.229	22 001	88 005	28	61.04	14 230	5 371 825	26.65
3.5–6.0	0.472	45 347	181 389	28	31.25	8 618	5 668 406	68.57
			N = 384 300				25 335 940	147.86

s^2_{total} = 147.86 g => s_{total} = 12.16 g

Standing crop estimate: $X = \sum_h N_h\bar{x}_h$ = 25 336 kg

0.95% confidence limits: $X \pm t_{0.05}Ns_{total}$

$= 1.96 \times 384\ 300 \times 12.16$

$= 9\ 159$ kg

where W_h is proportion each depth zone is of the total area; Area is total area multiplied by W_h; N is total number of sampling units which can fit inside the survey area; N_h is number of sampling units which will fit into the zone area; n_h is number of sampling units taken from each depth zone; $\bar{x}_h$ is mean biomass (grams per 0.25 m^2) of agar seaweed for each zone; s_h^2 is variance of the biomass for each zone; s^2_{total} is variance of the total mean biomass; s_{total} is standard deviation of the total mean biomass.

* Depth zones differ from those recommended in this handbook.

Table 4: Balanced analysis of variance models for the statistical comparison of surveys

Example 1: Comparison of biomass samples from different depths (b levels) over a number of localities (a levels). (Survey design: two-way ANOVA.)

Source of variation	d.f.*	MS ratio for tests†
Localities (L)	$(a-1)$	MS_L / MS_{Res}
Depths (D)	$(b-1)$	MS_D / MS_{Res}
Locality x depth (LD)	$(a-1)(b-1)$	MS_{LD} / MS_{Res}
Residual (Res)	$ab(n-1)$	

Example 2: Comparison of the agar seaweed biomass from the same survey area over time (a times) at a number of sample depths (b depths) and sites (c sites). (Survey design: three-way ANOVA with one nested factor.)

Source of variation	d.f.	MS ratio for tests
Times (T)	$(a-1)$	$MS_T / MS_{S(T)}$
Depths (D)	$(b-1)$	MS_D / MS_{TD}
Times x depths (TD)	$(a-1)(b-1)$	$MS_{TD} / MS_{DS(T)}$
Sites (times) (S(T))	$a(c-1)$	$MS_{S(T)} / MS_{Res}$
Depths x sites (times) (DS(T))	$a(c-1)(b-1)$	$MS_{DS(T)} / MS_{Res}$
Residual (Res)	$abc(n-1)$	

* Degrees of freedom.

† MS ratios give the derivation of the F value used in the significance test.

Comparison of survey techniques

Introduction

The effective management of commercially important algal stocks requires a good knowledge of distribution and abundance and how these change with time. Information on standing crop and productivity can be used to set up quotas to ensure proper use of the resource. However, the precise measurement of these parameters is limited by the patchy distribution of algae and the resulting sampling errors. The size of the error is mainly a function of the survey design, and it is this which determines the usefulness of the resulting information. Therefore, it is important that, before a major sampling programme is undertaken, a preliminary study should be carried out to identify the sampling methodology which will give information of the type and precision required. Furthermore, the high cost of subtidal research may be reduced after such a preliminary examination.

This study examines sampling methods for agar seaweed *Pterocladia lucida*, a small (about 200 mm high), bushy red alga which has a patchy distribution and grows on shallow exposed reefs. Wild stocks have been commercially harvested in New Zealand since the early 1940s with little restriction, but little is known of the distribution patterns or standing crop of this species. Although agar seaweed comprises two species of red algae, *P. lucida* and *P. capillacea*, the survey methods examined in this study refer only to the former, which constitutes over 95% of agar harvested in New Zealand (W. A. Nelson pers. comm.). Because of the differences in distribution of the two species, a separate technique would be required to obtain a good estimate of standing crop for *P. capillacea* (author's unpublished data).

This study establishes the sampling problems peculiar to *P. lucida* and identifies the requirements of a survey to allow the appropriate management of *P. lucida* stocks. The designs of many of the currently-used methods for assessing algal stocks are evaluated and discussed in relation to *P. lucida*. A progression of survey techniques, from general reconnaissance to more detailed methods, is examined and the optimum sampling unit type, number, and allocation are investigated. The results from field tests of the different methods are then weighed by the quality and quantity of information required to determine the best generally applicable survey methodology for *P. lucida*.

Study areas

Sampling was conducted in the Cape Rodney-Okakari Point Marine Reserve (36° 16′ S, 174° 48′ E) (Leigh marine reserve), on the northeastern coast of New Zealand (Figure 5). The area has two main rock types, with Waitemata series sandstone west and greywacke basement rock east of Goat Island. Because of this, there is a diverse reef structure along this 5 km stretch of coast. The sandstone areas are characterised by long shallowly sloping terraced reefs, whereas the more structurally complex greywacke reefs are formed from large sheer-sided blocks, which rise into shallow water. Further information was obtained from the Wairarapa coast at Ngawihi, a particularly exposed coast composed of a gradually sloping (25 : 1) broken rock platform, with a dominant canopy cover of the fucoid *Carpophyllum maschalocarpum* and the laminarian *Lessonia variegata*. Two arbitrary sampling sites were selected about 250 m apart.

Literature summary

Quantitative surveys of the standing crop of many aquatic algal species have been made in various parts of the world. Although the methods used and the reliability of the results have varied substantially, most have a common underlying methodology. This can be summarised as: selection of areas for detailed survey; identification of the distribution or extent of the algal beds; sampling within these beds to obtain an estimate of average weight or density per unit area; and finally scaling up this average by the total survey area to calculate the total standing crop estimate. In this summary examples are given of the range of methods used to achieve each of these steps.

The area for detailed examination has often been determined by the goals of the survey; e.g., surveys to measure the biomass estimate for an area already known to have important commercial stocks (e.g., Roland 1984), or to determine the effects of a pollutant outflow on the biomass of an alga (e.g., Grace and Tilly 1976, Brown *et al.* 1980). However, area selection becomes an important consideration when the survey aim is to obtain a total standing crop estimate for an algal resource with a broad commercial distribution. In a review of the methods used in surveying *Laminaria* in the United Kingdom, all available information about the algal beds was used to select areas of commercial potential for more detailed study (Chapman 1944). Preliminary distribution data were obtained from boat and cliff observations, grapnel samples, drift weed concentrations, and local knowledge. The overview obtained allowed an assessment of the representativeness of the locations chosen for detailed study.

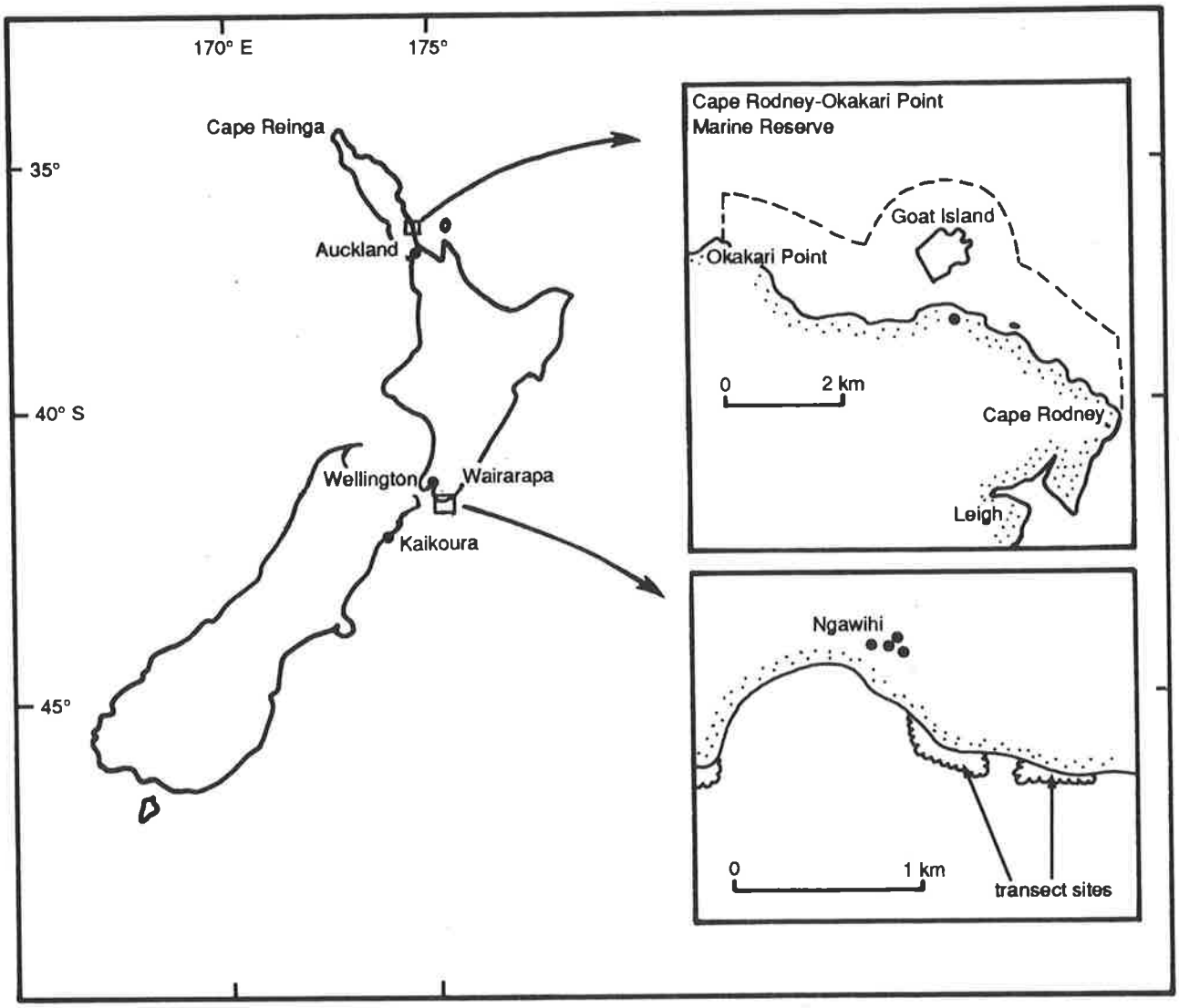


Figure 5: The two study areas and places mentioned in the text.

More recently, Grenager and Baardseth (1966) devised a method for estimating the biomass of the intertidal seaweed *Ascophyllum nodosum* in Norway. This method is applicable to all seaweed surveys and involves dividing the study area into squares of equal size and measuring a random selection of these. The biomass estimates for each selected square (obtained by quadrat sampling) can be scaled up to a total standing crop estimate for the whole region simply by the number of squares in the area. The main problem of this method is that the accuracy of the resulting estimate depended on how representative the squares were of the survey population, and this information is not obtained. A similar random selection of areas for intensive study was made by Topinka *et al.* (1981) for the intertidal macroalgae *Ascophyllum nodosum* and *Fucus*, and by Mann (1972) for the macrophytes of St. Margaret Bay, Nova Scotia.

Once the survey area has been delimited, the area of the algal bed to be sampled must be determined. Many techniques have been used to do this. Ward and Talbot (1984) mapped the distribution of aquatic macrophytes in Lake Alexandrina, New Zealand by use of scuba transects along echosounding traces, but did not calculate a total biomass estimate. Chapman (1944) used grapnel samples, with each sample located by a sextant, to map the distribution and density of *Laminaria*.

Recently, aerial photography has gained wide acceptance and is now the most commonly used technique. It has been used extensively for emergent subtidal species such as *Nereocystis* and *Macrocystis* off the North American coast (Foreman 1975, Coon and Field 1983), shallow lagoon or estuarine species (Brown *et al.* 1980, Critchley 1983, Thorne-Miller *et al.* 1983), and intertidal species (Brinkhuis 1976, Meulstee *et al.* 1986). In each study the use of aerial photography has been followed by some *in situ* examinations, whereby the characteristic patterns in the photographs were examined in representative and identifiable areas in the field. The choice of equipment was usually determined by the finance

available, and the merits of different types of film have been discussed extensively in the literature (e.g., Avery 1977).

Several techniques have been used to obtain biomass estimates. Direct harvest from random quadrats of known area was the most common method, though grabs (e.g., Unni 1977) and hooks (e.g., Bayley *et al.* 1978) have also been used. In a comparison of dredge sampling and scuba quadrat sampling, dredging was only 6% as efficient (Schneider and Searles 1979). These diver-remote techniques have been mainly superseded by the use of scuba, except where excessive depths or intense cold are prohibitive.

The plants within the quadrats have usually been harvested and weighed, but other plant characteristics have been used to predict biomass. Sheldon and Boylen (1978) assigned a series of 11 density categories to algal stands in the field to predict the biomass of 40 algal species. Meulstee *et al.* (1986) used the relationship between colour densities from false-colour aerial photographs and field samples to predict the biomass of 11 algal zones. One of the most elaborate methods was devised by Foreman (1975) for a largescale survey of the standing crop of the kelp genera *Macrocystis* and *Nereocystis* on the coast of British Columbia. This method used aerial photography to identify beds of the emergent kelps. Percentage cover was determined within each bed by means of a grid housed in a binocular microscope and superimposed over the aerial photographs. A comparison of percentage cover and field samples from the same region established the relationship ($r^2 = 0.440$) used to predict biomass for each grid sample and subsequently total standing crop of the photographed area.

Unfortunately, a common failing in these studies of total standing crop is the lack of any confidence limits on the estimate (e.g., Foreman 1975, Brown *et al.* 1980, Coon and Field 1983, McQuaid 1985). Some authors give the variance components of individual biomass values, but do not calculate the total variance associated with the final estimate (e.g., South and Hay 1981, Hay 1979). Others calculate the final confidence limits, but do not take into account highly influential sources of variability in biomass (e.g., Mann 1972, Roland 1984, Meulstee *et al.* 1986).

Few estimates of standing crop have been obtained for those macroalgae which occur beneath the depth limit of penetration by aerial photography (about 1 m with infra-red, false-colour photography), or for species which are small and occur under a canopy of larger macrophytes. This is due to the commercial emphasis on the larger and more accessible macroalgae. Because many of the benefits of aerial photography such as reconnaissance, algal bed determination, and the counting of plant densities are not available for these small algal species (which include *P. lucida*), more labour-intensive and diver-oriented survey methods must be used. Similarly, surveys for understorey algae should include a general reconnaissance study to identify relevant areas, followed by more detailed studies to assess the biomass.

Reconnaissance techniques

Introduction

The aim of a reconnaissance study is to provide a rapid general survey of large areas of reef, which then allows the representativeness of small areas under detailed study to be assessed. It is common practice to use aerial photography for algae studies, but this only gives inferences on potential areas of occurrence for subcanopy plants. These inferences may take the form of conspicuous algal bands under which the target species usually occurs, or reef structures on which it is generally found. However, because of the high cost of subtidal surveys, more information is required to plan a detailed survey in the area. A preliminary underwater study of the resource must be undertaken, to give some understanding of the distribution and abundance the target species.

A technique which has been used, particularly in tropical systems, to qualitatively assess subtidal community assemblages is the manta tow (Kenchington 1984). A diver holds onto a manta board, which is towed behind an outboard power boat at 1–2 kn. However, these boards are restricted to areas where the water depth is 3 m or more and to less heterogeneous habitats. A better method for the assessment of *P. lucida*, which usually occurs in shallow water, is a modification of the manta method, whereby a diver is towed by a diver propulsion vehicle (DPV). These vehicles have the advantage of being independent of a boat and allow access to areas close inshore which are not readily accessible to a manta tow. In this study the use of a DPV for the assessment of *P. lucida* stocks is investigated.

Methods

A variable-speed dive vehicle (Tekna DV-3) was used to obtain data on characteristics such as reef morphology, algal assemblages, and the state of *P. lucida*. Trials were conducted on the 5 km coast of the Cape Rodney-Okakari Point Marine Reserve.

A diver was towed by a DPV and followed by a boat (*see* Figure 2). The diver zigzagged over the reef from as close inshore as conditions allowed to depths of 6–8 m. Preliminary observations had found little *Pterocladia* below these depths. After about 150 m had been traversed, or there was an abrupt change in reef morphology, the diver returned to the boat and was debriefed. This involved the diver recording

his observations in broad categories of reef types, dominant growth forms, and state of the *Pterocladia* stocks. This information was recorded on a data sheet. The survey areas of coast were recorded on a shoreline map of the area.

Results and discussion

The reserve was divided into two areas based on reef topography, east and west of site M (Figure 6). The eastern reef area (towards Cape Rodney) dropped off to a bottom of cobbles and/or sand, whereas the western area (towards Okakari Point) comprised a stepped or sloping reef to a bottom of broken rock and rock flats. The broad categorical data are given in Appendix 1.

Pterocladia lucida was common over the reserve and was most abundant on sheer-sided outcrops. It formed a shallow band of varying density along the length of the coast and on pinnacle tops and also occurred on the seaward edge of shallow boulder tops. The distribution of *P. lucida* was patchy and, where abundant, there were continuous swards. However, all *P. lucida* stocks within the reserve were well covered by epiphytes and, therefore, of no use for agar manufacture. The less commercially important species, *P. capillacea*, was present in moderate densities on rock flats west of Goat Island, but was not considered easy to harvest, being small with few lateral branches.

The DPV method of reconnaissance was fast and effective in the identification of *Pterocladia* stocks in areas only otherwise accessible to a diver. Three dives (each 1.5 h) were necessary to traverse the 5 km stretch of coastline. This technique could be used to determine whether the stocks in an area were large enough to be harvested and warranted further investigation.

Detailed surveys

The primary aim of sampling to allow management of *P. lucida* stocks was to obtain biomass estimates which were sufficiently precise for comparisons between areas and over time. Other important aspects to the management of an exploited wild stock, which will influence the choice of survey design, involve the establishment of a baseline of general population data such as size-frequency distributions, variability in abundance between sites or locations (levels of patchiness), and trends with depth.

The survey design adopted is determined by the amount of relevant information obtained for a given cost. Subtidal research is expensive because of the need for costly equipment such as boats and scuba. Research is further constrained by weather and sea conditions, especially in a study of a shallow habitat alga such as *P. lucida*. Therefore, a good sampling programme must be simple and flexible.

The basic procedure for an estimation problem such as this is (*after* Höisaeter and Matthiesen 1979): the boundaries of the study area are defined; sampling sites on the reef are located by

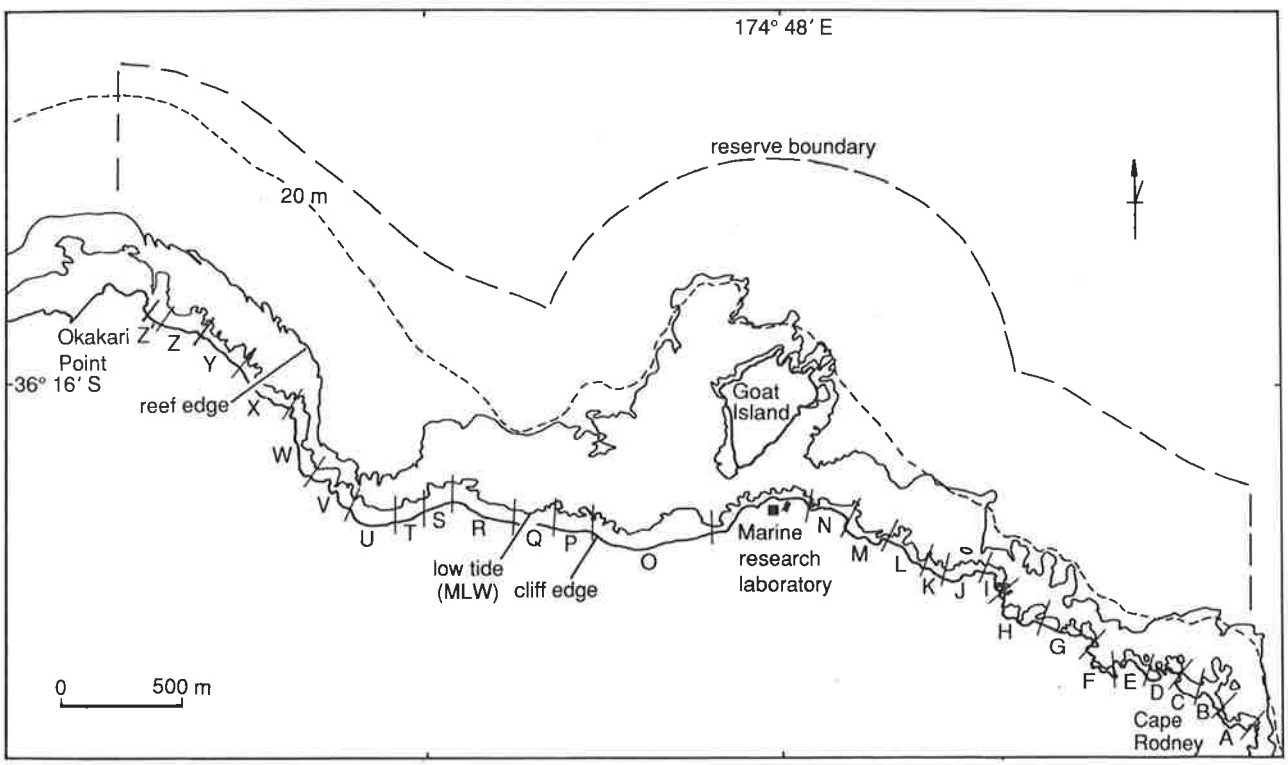


Figure 6: The diver vehicle reconnaissance survey divisions (A–Z′) in the Cape Rodney-Okakari Point Marine Reserve.

a rigidly defined procedure; a frame of a pre-selected size is placed on each of these sites; the target species is then collected (or a predictor of its occurrence recorded) from each frame; these samples are then weighed (or weights derived), and mean weight and variance per sampling plot are calculated. The total standing crop estimate is then calculated by multiplying the mean weight by the number of sampling plots which fit inside the sampling boundaries.

Within the confines of this procedure there is room for maximising sampling efficiency so that tight confidence limits are associated with the total biomass estimate. Questions raised include: what sampling unit is best, what should be measured, how many samples should be taken, and what is the most efficient placement of the sampling effort? In this study, emphasis was placed on the way in which sampling units were allocated, with respect to the distribution pattern of the plants. Stratified random sampling was compared with semisystematic and simple random sampling. The use of easily measured variables to predict plant weight is shown, and the importance of variance components in the calculation of confidence limits is stressed.

Sampling unit and size

Introduction

The most efficient sampling unit can be determined when a single species is surveyed. There are many ways of sampling the biomass or density of plants, and these can be divided into plotless and plot sampling techniques.

Although plotless techniques have often been used to survey corals (e.g., Loya 1978) and terrestrial vegetation (e.g., Mueller-Dombois and Ellenberg 1974), they have generally not been used in the assessment of marine algal stocks. Little use has been made of these methods in exact comparisons, because estimates of biomass or density cannot be readily compared (Grieg-Smith 1983). All plotless techniques require accurate measurement of the distances between individuals (single plants, corals, or patches), and this is impractical in shallow surge conditions. Similarly, all require that individuals and their centres are easily defined to ensure correct measurements are taken. Such constraints rule out their use on the morphologically diverse, often bushy, and highly patchy *P. lucida*.

Plot sampling (quadrat) techniques are generally used to measure algal populations. The most common shape is the square, though rectangles and circles have been used (Pringle 1984). Each shape has advantages and disadvantages, e.g., the rectangle has been suggested for clumped organisms because it is more likely to include both densely and sparsely populated areas and thus provide an estimate with a smaller variance (Grieg-Smith 1983). However, rectangular sampling units have an increased edge-effect and consistently include individuals that should be excluded or exclude those that should be included. Circular quadrats have the least boundary and, therefore, the least edge-effect of any shape for a given sampled area, but when closely packed they leave gaps which are theoretically inaccessible to sampling. This is not a problem when the sample area is large compared with the quadrat area. In most studies, reasons are not given for the choice of sampling unit size or shape (*see* Pringle 1984).

Square quadrats were chosen for this study for several reasons: ease of construction, simplification of quadrat size optimisation, ease of division into grids for assessment of percentage-cover, and simplification of the random sample allocation procedure (random numbers correspond to end-over-end turns of the quadrat).

In previous studies of aquatic macrophytes a wide range of sizes of square quadrats has been used. Downing and Anderson (1985) reported that from 240 studies which used quadrats the sizes ranged from 0.01 to greater than 4 m^2. Recent studies that have examined the efficiency of various quadrat sizes have shown that much time can be saved if these investigations are undertaken before beginning a large sampling programme. Pringle (1984), in a study of Irish moss (*Chondrus crispus*), found that for a given precision there was a 135% saving in time when a 0.25 m^2 rather than a 1 m^2 quadrat was used. A similar investigation of quadrat size was undertaken in this study to select the most cost-effective sampling unit for *P. lucida*.

Methods

The precision and cost of four sampling unit sizes were compared for a given total harvested area. The sizes of the square quadrats were: 0.25, 0.5, 1.0, and 1.5 m^2. Several *P. lucida* beds were randomly sampled in the Leigh marine reserve, under the constraint that sampling was concentrated in water shallower than 2 m mean low water (MLW). For each dive, the first quadrat of a bed was dropped from the surface by the diver. The position of subsequent quadrats was determined by random numbers, which corresponded to end-over-end turns of the quadrat along the shore. Each of the larger quadrats contained randomly placed, non-overlapping smaller sized quadrats (e.g., a 1.5 m^2 quadrat contained four 0.25 m^2 quadrats or one 0.5 m^2 quadrat). A total area of 10 m^2 for each quadrat size was used for comparison of sampling precision and cost. All *P. lucida* plants within each quadrat and every second plant found exactly on an edge were collected and placed into labelled plastic bags. The time taken to harvest each quadrat was also recorded. At the laboratory the contents of each bag were shaken dry and

weighed. They were then transferred to a drying oven at 70 °C for 48 h for dry weight determination.

The total time taken to harvest a quadrat and the precision of the biomass estimate were used to compare the efficiencies of the four quadrat sizes. In this study precision was defined as (*after* Andrew and Mapstone 1987): "the degree of concordance among a number of measurements or estimates for the same population". Precision of a particular sampling unit was approximated by a measure of the relative variability of the sample data (standard error in this study), standardised by the magnitude of the sample mean (*after* Snedecor and Cochran 1980). The harvesting time was taken as representative of the sampling cost of each quadrat size. The mean time was corrected for the biomass sampled to account for harvesting unequal biomasses. The number of sampling units (n) required to attain a certain precision (0.075, 0.10, and 0.15) for each sampling unit size was determined by this formula (Andrew and Mapstone 1987):

$$n = \left(\frac{s}{p\bar{x}}\right)^2$$

where s is standard deviation, $\bar{x}$ is mean biomass, and p is required precision.

Results and discussion

Downing and Anderson (1985) noted that "the major goal in designing a sampling program is to achieve an accurate measurement with high precision for the least effort". Many combinations of sampling unit size and number can give the same level of precision for a given sampled biomass (e.g., Pringle 1984, Downing and Anderson 1985). Once the required level of precision is established, either by experience or from the literature (often a level of 10% of the mean is acceptable (Southwood 1966)), two factors will determine the required sampling unit size: the relationship between the quadrat size and the spatial distribution patterns of the sampled individual (as measured by the precision) and the time taken to sample it.

When cost, in terms of time, was considered alone in the assessment of *P. lucida* biomass, a 1 m² sampling unit would be used, because it took 150 min to harvest a standardised biomass from a 10 m² area (Table 5). Compared with other sample units, this represented a saving in time ranging from 15.4% (for the 0.25 m² plot) to 41% (0.5 m²). However, the precision with which the various quadrats sampled the *P. lucida* distribution is also important; this ranged from 0.065 (0.25 m²) to 0.111 (1.0 m²) (Table 6).

A linear relationship was found between the sampling unit size and the number of sampling units required for the three levels of precision (0.075, 0.10, and 0.15) (Figure 7). Many small quadrats (e.g., 30 (0.25 m²) at p = 0.075) were required to attain the same precision as several large quadrats (e.g., 13 (1.5 m²) at p = 0.075).

A curvilinear relationship was found between the sampling unit size and the total time required to sample a standardised biomass from 10 m², for all levels of precision (Figure 8). The smallest quadrat (0.25 m²) was the most efficient, and the 1.0 m² quadrat was the most inefficient. Time saved by use of a 0.25 m² quadrat ranged from 194.0 to 27.6 min depending on the sampling precision required. This showed the importance of an investigation of sampling unit efficiency before large sampling programmes are undertaken. If an arbitrary quadrat size had been used, such as the common 1 m², sampling would have taken 136.6% longer to obtain an error of 10%, than for the 0.25 m² unit.

These results support the general conclusion that many small quadrats are more cost effective when sampling for an individual with a patchy distribution (Green 1979, Höisaeter and Matthiesen 1979, Pringle 1984, Downing and Anderson 1985, Andrew and Mapstone 1987).

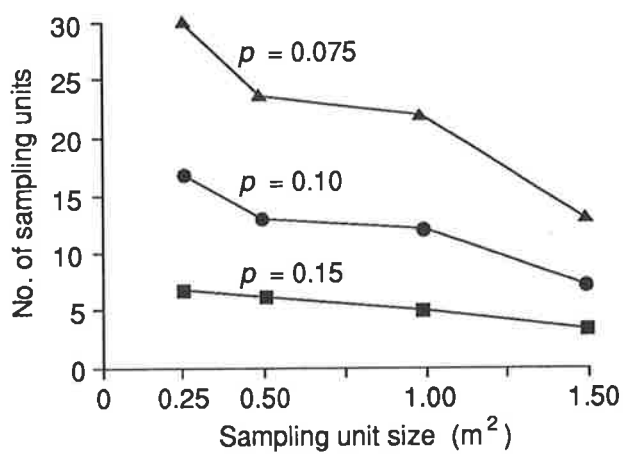


Figure 7: The relationship of sampling unit size and the number of sampling units for three levels of precision (p).

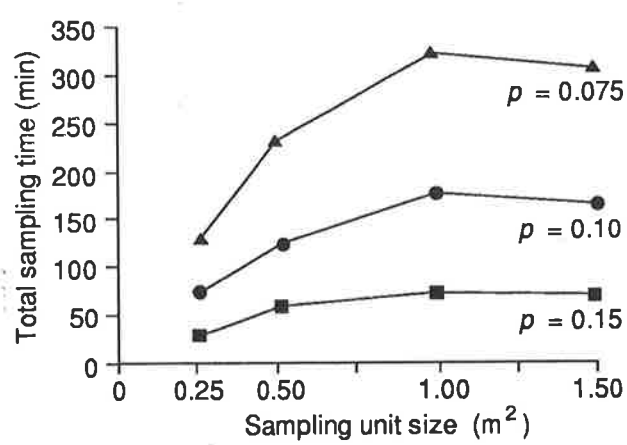


Figure 8: The relationship of sampling unit size and total time taken to sample a standardised biomass of *P. lucida* for three levels of precision (p).

Table 5: Time (min) taken to sample a standardised biomass* for the four sampling unit sizes

Sampling unit (m^2)	Sample No.	Sample area (m^2)	Total time	Mean time (per unit)	Standardised total time†	Biomass (g) Sample	Biomass (g) Corrected‡	Corrected time§
0.25	40	10	177.7	4.44	177.7	24 543	24 543	177.7
0.50	20	10	195.8	9.79	195.8	18 779	18 779	255.9
1.0	10	10	148.8	14.88	148.8	24 300	24 300	150.3
1.5	7	10.5	167.3	23.90	159.3	23 511	22 391	183.4

* Standardised for 10 m^2.
† The product of the number of samples, the mean time, and 0.1 of the sample area.
‡ The product of the sample biomass and 10 divided by the sample area.
§ The product of the total time to sample and 24 543 divided by the corrected sample biomass.

Table 6: Statistics for the four sampling unit sizes and the estimated number of sampling units and time taken to sample (min) for three levels of sampling efficiency (precision)

Sampling unit (m^2)	Sample No.	Mean biomass	Standard deviation	Precision	Estimate of sampling efficiency (Sample No. (time to sample))* 0.075	0.100	0.150
0.25	40	604.0	247.8	0.065	30 (133.2)	17 (75.5)	7 (31.1)
0.5	20	938.2	342.0	0.082	24 (235.0)	13 (127.3)	6 (58.7)
1.0	102	430.0	853.9	0.111	22 (327.4)	12 (178.6)	5 (74.4)
1.5	7	3 358.7	911.4	0.102	13 (310.7)	7 (167.3)	3 (71.7)

* Time to sample is the product of the sample number and the mean time taken to sample a quadrat.

Quadrat sizes smaller than 0.25 m^2 may have proved more efficient, but none were included in this analysis. However, as quadrat size decreases there is an increase in the error due to edge-effect. This problem can be partly alleviated by the exclusion of 50% of the individuals along the boundary from the quadrat, as has been done here. Grieg-Smith (1983) cautioned against the use of too small a quadrat, particularly for species (such as *P. lucida*) which have an ill-defined boundary at ground level. Therefore, the results of this study suggest a 0.25 m^2 quadrat size be used when sampling *P. lucida* or species of similar distribution.

There are many additional advantages in the use of a small quadrat size, such as 0.25 m^2. Large sample numbers increase the robustness of most statistical analyses to violations in their underlying assumptions (Green 1979). Also, the tightness of the confidence limits of the total biomass estimates is increased directly by increasing sample size (Cochran 1977). Other advantages of small quadrats are that they give samples which are more easily stored and transported, destroy less habitat, and are easier to process for dry weight measurements.

Predictors of biomass

Introduction

During subtidal surveys, relevant information should be obtained as quickly as possible because the underwater time of a diver is limited by physiological and monetary constraints.

As harvesting algae is time consuming, easily measured characteristics which are strongly correlated with biomass are often measured instead of plant weight (e.g., Foreman 1975, Meulstee *et al.* 1986). This has been particularly useful for large laminarian kelps such as *Macrocystis* and *Nereocystis* (Foreman 1975, Coon and Field 1983), where the bulk of individual plants prevents simple and rapid measurement of weight (lengths of 45 m are common for specimens of *Macrocystis* (Bold *et al.* 1980)). However, many studies which have used predictors of biomass to obtain standing crop estimates have lacked or had inadequate calculation of precision estimates (e.g., Foreman 1975, Coon and Field 1983).

During this survey, the correlation of various plant characteristics with the harvested weight of *P. lucida* was investigated to determine whether there was an easily measured nondestructive predictor of biomass. This was examined at the scale of both clumps of individual plant axes and for all plants in a 0.25 m^2 quadrat. Because *P. lucida* is often covered by lush growths of epibiota, coverage was considered when assessing predictors of plant biomass. Total standing crop estimates using these predictive methods are compared with estimates obtained from harvested quadrats in a later study (*see* "Comparison of estimation methods").

Methods

The growth pattern of *P. lucida* generally consists of small clumps containing a number of primary axes, joined by an anastomosing holdfast. One hundred and eighty-seven clumps were sampled and placed into labelled plastic bags. The variables recorded for each clump were: length of the largest axis (cm), girth halfway up the clump (cm), shaken wet weight (g), dry weight (g), and an estimate of epibiotic coverage recorded as low (0–10% coverage), medium (10–40%), and high (over 40%).

Similarly, within a 0.25 m² quadrat two measures of percentage cover and an estimate of plant size (length) were regressed to determine which character was the best predictor of the *P. lucida* biomass. Percentage cover of *P. lucida* thallus was determined by eye and by the number of occurrences under the intercepts of a 36-point grid (in a 0.25 m² quadrat). Individuals were then harvested from each quadrat and bagged for wet and dry weight determination. Plant size was estimated by the mean size of 10 plants. Size was the length measured from the base of the holdfast (where the erect portion meets the prostrate) to the end of the longest branch. A total of 139 quadrats was sampled for this study and for the larger study on methods of estimating total biomass (*see* "Comparison of estimation methods"). Because regression assumes linearity between variables, each relationship was checked by eye before analysis.

Results and discussion

"Area" (length by girth) of individual clumps of *P. lucida* was strongly predictive of wet weight (Table 7), especially when the clumps were separated according to epibiotic coverage. The group with medium coverage had a marginally stronger relationship than the clumps with high coverage. This was despite the diverse nature of the epibiota, which ranged from large sponges to filamentous red algae, with a range of densities and water retention properties. In addition, wet weight of the clumps was an excellent predictor of dry weight; this obviated the need for time consuming dry weighing.

However, the measurement of all individual clumps in a quadrat for biomass estimates would be prohibitively time consuming, and an easily measured predictor of *P. lucida* weight within a whole quadrat would be of more use. The variables of greatest predictive value are given in Table 8. Estimated percentage cover, true (grid) percentage cover, and rough estimates of plant "volume" (percentage cover, both estimated and true, multiplied by an estimate of plant length) were all good predictors of the biomass of *P. lucida*. Although estimated percentage cover would be the quickest variable to record in the field for each quadrat, it is also potentially the most subject to observer error. Percentage cover determined by a gridded quadrat was chosen as the easiest and most precise method of predicting biomass within a quadrat. This relationship was used in "Comparison of estimation methods" to predict the biomass within quadrats as if only percentage cover of *P. lucida* had been measured. Means and variance estimates were calculated and scaled up to predict standing crop estimates for a comparison with estimates obtained from surveys in which the quadrats were harvested.

Another quick method of evaluating *P. lucida* weight within a quadrat was to classify plant quantities by eye into broad biomass categories. A similar technique was used by Sheldon and Boylen (1978). Means and variances for *P. lucida* biomass (grams per 0.25 m²) were calculated from harvested quadrats classified into three categories of abundance and epibiotic coverage. These categories were based on percentage cover and represent an approximately even division of the sampled population into three groups: rare (0.1–10%), common (10–20%), and abundant (> 20%) (Table 9). Estimates for populations with low epibiota categories were obtained from

Table 7: Regression coefficients, equations, and mean square error (MSE) for various *P. lucida* patch characteristics with wet weight (g)

	r^2	Equation	MSE*
Combined epibiota categories			
Dependent v. independent			
Wet weight v. size x girth	0.794	$Y = -8.67 + 0.004x$	438.20
Dry weight v. wet weight	0.992	$Y = 0.116 + 0.316x$	1.95
Separated epiphyte categories			
High coverage			
Wet weight v. size x girth	0.869	$Y = -7.04 + 0.004x$	52.64
Wet weight v. girth	0.653	$Y = -14.09 + 0.59x$	139.73
Medium coverage			
Wet weight v. size x girth	0.911	$Y = -11.84 + 0.004x$	296.96
Wet weight v. girth	0.859	$Y = -38.99 + 1.09x$	469.19

* Used in the calculation of an estimate of variance for a regression prediction of biomass (*see* "Comparison of estimation methods").

Table 8: Regression coefficients, equations, and mean square error (MSE) for various *P. lucida* quadrat characteristics with wet weight (grams per 0.25 m²) and a correlation between estimated and grid percentage cover

	r^2	Equation	MSE*
Weight v. estimated %	0.760	$Y = 8.38x$	16759.4
Weight v. grid %	0.860	$Y = 9.30x$	9773.9
Weight v. (estimated % + grid %)/2	0.850	$Y = 9.27x$	10539.0
Weight v. estimated % x length	0.756	$Y = 0.059x$	17043.2
Weight v. grid % x length	0.867	$Y = 0.068x$	9270.5
Grid % v. estimated %	0.817	$Y = 0.866x$	127.5

* Used in the calculation of an estimate of variance for a regression prediction of biomass (*see* "Comparison of estimation methods").

a survey of *P. lucida* at Ngawihi on the Wairarapa coast and are included for comparison (Appendix 2). These broad biomass categories were also used to calculate a total standing crop estimate for comparison with results from harvested quadrats (*see* "Comparison of estimation methods").

Table 9: Epibiotic coverage biomass categories for *P. lucida*, means with variances (grams per 0.25 m²), and the number of quadrats used to obtain the estimates (*N*) are given

	Epibiotic coverage	
Abundance	Low	High
Rare (0.1–10%)	30.5 (± 1 060.1) *N* = 22	40.1 (± 1 150.4) *N* = 47
Common (10–20%)	94.1 (± 1 386.6) *N* = 19	173.9 (± 6 180.1) *N* = 46
Abundant (> 20%)	165.5 (± 9 601.0) *N* = 17	382.8 (± 44 160.9) *N* = 42

Determination of area

Introduction

The following information is required to obtain an estimate of the total biomass of a population through a subsampling technique: a mean biomass estimate and confidence limit within the area and an area estimate for the survey area. The former is scaled up by the latter to produce the final estimate of standing crop. Therefore, the determination of the total area of the survey and any sampling zones within it should be as accurate as possible.

In previous studies involving standing crop estimates on a broad scale, aerial photography has been used extensively to delimit the area of the algal beds. These studies involved either large emergent species (e.g., *Macrocystis* and *Nereocystis* (Foreman 1975)) or shallow and obvious subtidal species (e.g., *Caulerpa* (Brown *et al.* 1980)). Unfortunately, because *P. lucida* is a small red alga and is often found under a canopy of the fucoids *Cystophora* and *Carpophyllum,* it is inconspicuous to aerial photography. Therefore, other techniques must be used to identify the outer limits of distribution and to obtain an estimate of the survey area.

Methods and results

Although aerial photography cannot be used to map *P. lucida* distribution, it provides important information about reef morphology and defines the shoreward boundary of the survey region. A detailed map of the Goat Island to Cape Rodney survey area had been compiled from aerial photographs (Ayling 1978) which were used to define the low tide boundary of the survey.

Preliminary observations had shown that the main stocks of *P. lucida* within this area were above 6 m, and this depth was chosen as the outer limit of the survey. Some individuals occurred below this depth, and thus there was a small underestimate of the total standing crop. The area between the shore and 6 m was determined by transects perpendicular to the shore. These "habitat transects" were also used to define a set of reef profiles from which the proportion of each sampling zone (or stratum) for the surveys could be calculated. Two survey designs are compared in this study (and are discussed later): one in which sampling is allocated to subtidal habitat types and the other to depth zones. The four zones used in each survey are defined in Table 10.

Nine transects were evenly spaced along the coastline from Goat Island to Cape Rodney (Figure 9). The transect consisted of a calibrated lead line fixed at the low tide level by a grapnel and laid out perpendicularly to the shoreline from a boat. The seaward end of the line was marked by a buoy for subsequent reference and recovery. Reef profiles were obtained by a diver who swam down the transect line and recorded the depth every 2–5 m and the boundaries of the various microhabitats. Once the diver had reached below a depth of 6 m the transect was ended.

However, definition of the 6 m outer limit of the 3 km survey region by nine habitat transects will not give a very precise estimate of area. Therefore, information from other sources as well as habitat transects must be used to define the outer boundary of the survey area: aerial photographs taken on a calm day at low tide, spot observations over the side of the boat, hydrographic maps which show depth contours close inshore, observations from adjacent cliffs, local knowledge, and previous studies.

In this study habitat transects, spot observations, and approximate depth contours provided by the Leigh marine reserve maps (Ayling 1978) were used to define the outer boundary of the survey area. This area was then calculated twice by computer and averaged.

Table 10: Sampling zones used in the two survey designs

Stratified semirandom (within microhabitats)	Semisystematic (along fixed depths (m))
Cystophora — dominated by *Cystophora* spp.. occurring predictably just below MLW	0.0–1.5
Reds — composed of mainly red algae (predominantly *P. lucida*, also thick coralline turf and *Melanthalia* spp.) usually on vertical faces exposed to direct wave surge	1.5–2.5
Carpophyllum — *Carpophyllum* spp. form a canopy; no *Ecklonia radiata*	2.5–3.5
Mixed algae — *Ecklonia radiata* and *Carpophyllum* spp. common, *Sargassum* spp. and *Landsburgia* spp. are present; an understorey of coralline turf and paint	3.5–6.0

The length along the habitat transects of each of the survey zones was tabulated from the reef profiles (Figure 10). The contribution of each zone to the total area was then expressed as a proportion for each transect and averaged over transects (Table 11). The mean proportions of each zone were multiplied by the total survey area to give an estimate of area for each zone.

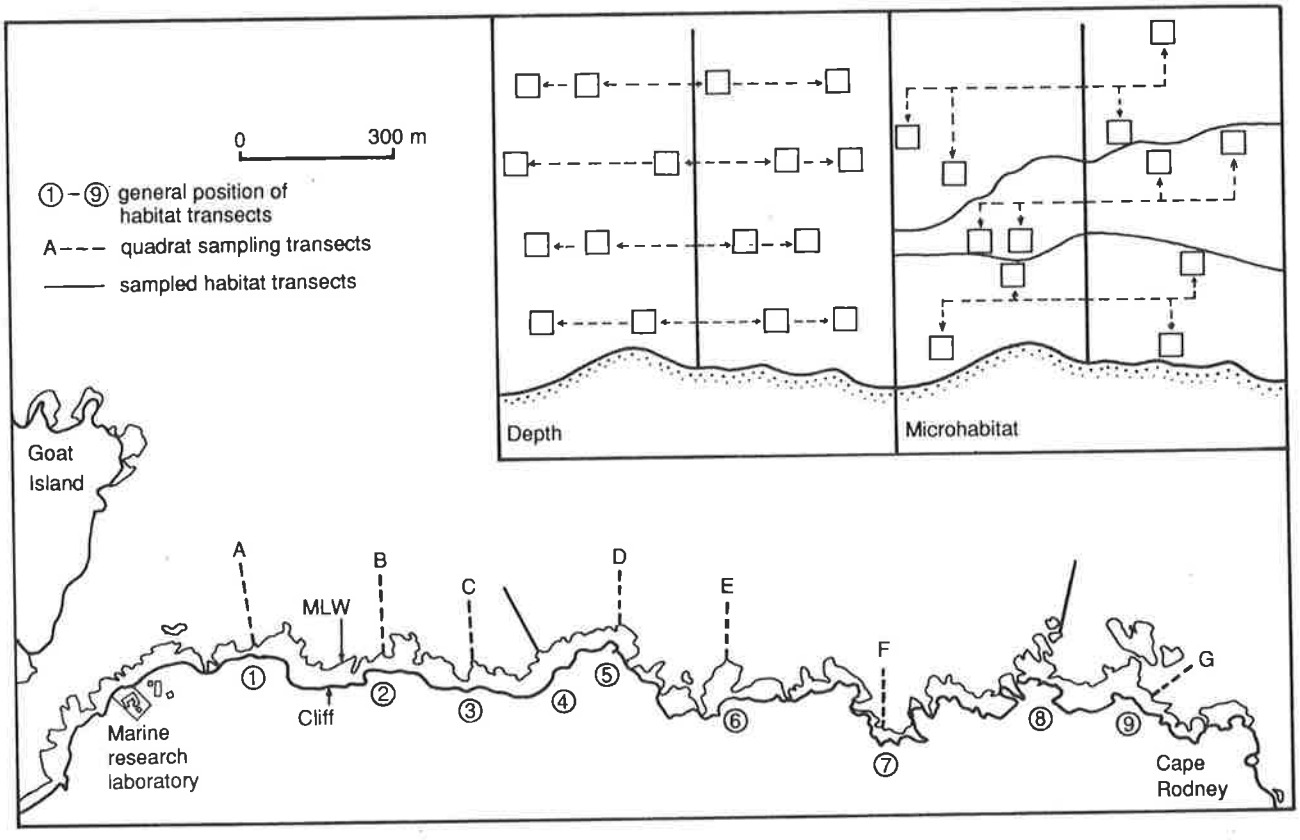


Figure 9: Map of Goat Island to Cape Rodney coastline for detailed *P. lucida* surveys. (Inset shows quadrat positions for stratified semirandom by microhabitat and semisystematic depth surveys.)

Table 11: The contribution of each microhabitat or stratum depth zone (m) to the total area expressed as a proportion of each habitat transect, mean proportions, and mean proportions corrected including those for the areas not included in the microhabitat definitions (i.e., "Others")

	Microhabitat zone					Stratum depth zone			
Transect	*Cystophora*	Red algae	*Carpophyllum*	Mixed algae	Others	0.0–1.5	1.5–2.5	2.5–3.5	3.5–6.0
1	0.06	0.00	0.50	0.44	0.00	0.09	0.02	0.28	0.61
2	0.01	0.00	0.09	0.10	0.80	0.05	0.08	0.11	0.76
3	0.07	0.05	0.14	0.44	0.32	0.05	0.05	0.45	0.45
4	0.17	0.00	0.72	0.11	0.00	0.22	0.20	0.21	0.37
5	0.15	0.24	0.00	0.07	0.54	0.22	0.15	0.20	0.43
6	0.09	0.27	0.14	0.50	0.00	0.32	0.14	0.11	0.43
7	0.03	0.01	0.38	0.37	0.22	0.15	0.12	0.26	0.47
8	0.12	0.24	0.47	0.17	0.00	0.18	0.18	0.21	0.43
9	0.03	0.00	0.30	0.10	0.57	0.09	0.38	0.24	0.30
Mean proportion	0.08	0.09	0.30	0.26	0.27	0.15	0.15	0.23	0.47
Corrected mean proportion	0.11	0.12	0.42	0.35					

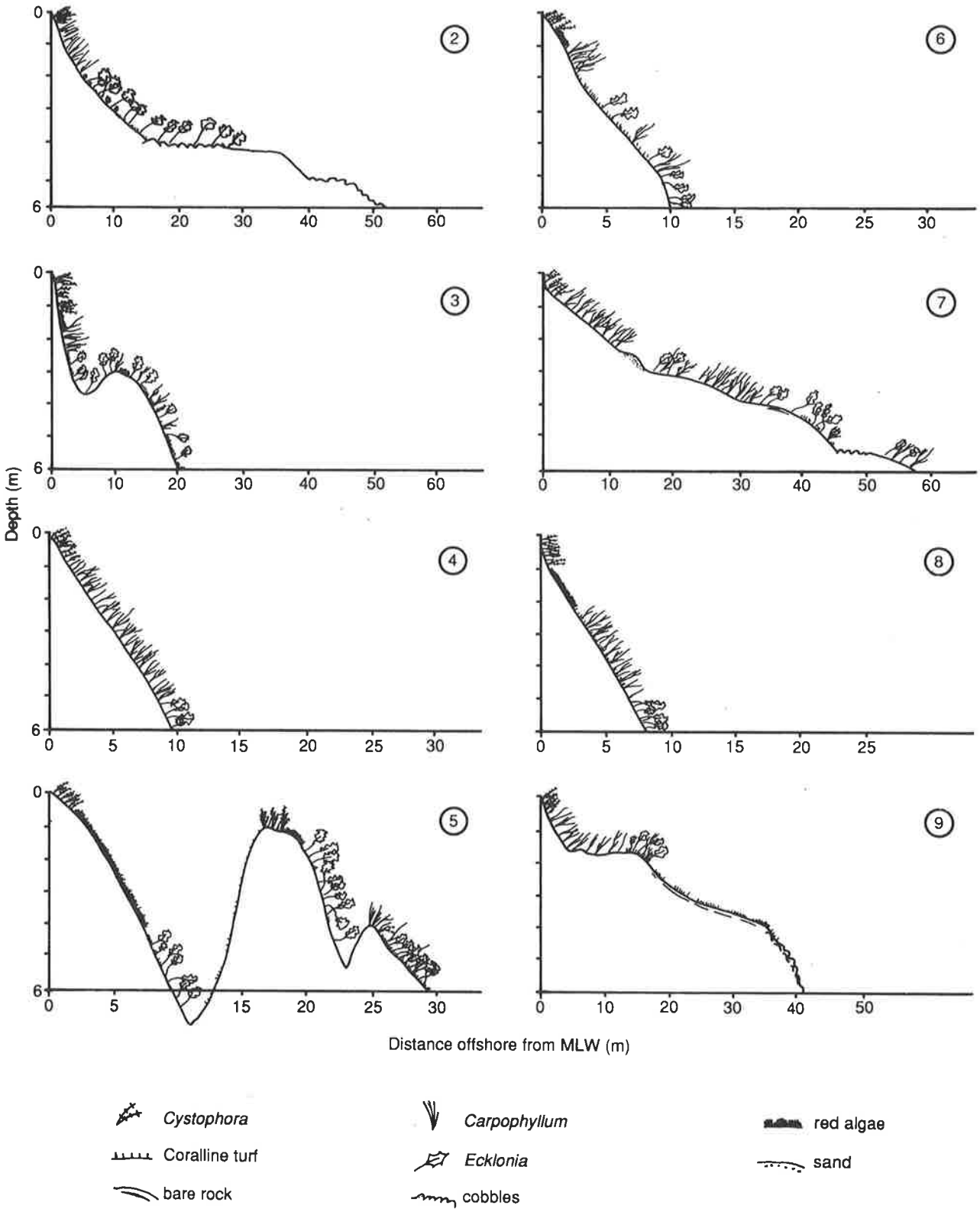


Figure 10: Reef profiles (*see* Figure 4 for profile 1).

Comparison of estimation methods

Introduction

There are three general categories of sampling designs which need to be considered in a survey to estimate standing crop: simple random sampling, systematic sampling, and stratified random sampling. The most appropriate design is the one which gives the quality and quantity of information required for the least cost.

Simple random sampling is the most common and has the advantage that precision can be easily calculated. Systematic (or grid) sampling allows samples to be more evenly distributed, and it is more time efficient because there is no need to generate and locate random points. However, systematic sampling is usually avoided because a reliable variance estimate cannot be calculated due to the lack of randomisation and the potential bias from sampling at the same time as fluctuations occur in the biological system (Snedecor and Cochran 1980). It should be noted that if the latter constraint is not fulfilled, an estimate of variance, even if calculated as random, will still be better than that obtained through simple random sampling (Cochran 1977). This estimate will always be an overestimate of the error. Variance can be estimated more precisely by pairing neighbouring points and calculating the stratified variance (Ripley 1981). This has been illustrated in a recent study of fine-scale density distribution of the cockle (*Chione stutchburyi*) in the soft sediments of the Ohiwa Harbour, New Zealand (McArdle and Blackwell 1989).

Stratified random sampling represents a compromise between the other two categories, because it is more precise than random sampling and allows this precision to be calculated. In stratified sampling a population with a patchy distribution is divided into several subpopulations within which similar biomasses (or abundances) occur, and between which different biomasses (or abundances) are found. The subpopulation or stratum limits are defined so that their average biomasses are as different as possible and their variances as small as possible. With good stratification, only a small sample is required from each stratum to obtain a confident estimate of biomass. The estimates can then be combined to form a precise estimate of standing crop for the whole area. Stratified random sampling requires the location of random points in the field within the sample area and each stratum. This can be time consuming and must be a consideration of survey design.

For a subtidal survey of a large section of coast, such as the 3 km investigated here, the randomisation procedure can be the most expensive part of the field sampling. The gear preparation and transportation of divers between the randomly located sites, each of which may only contain one or two samples, is time consuming. There is also the difficulty of finding random points in murky water. Therefore, an alternative procedure is necessary, and the two survey designs used in this study were neither wholly randomly stratified or wholly systematic, but combinations of both. In both designs sampling units were grouped into sites regularly spaced along the survey area of coastline. Within each site quadrats were randomly placed at various spatial scales (i.e., within fixed depths and throughout microhabitats). This designation of sampling sites minimised travelling time, but still retained randomisation. One survey was a stratified semirandom design on microhabitats; quadrats were randomly assigned within each site to four microhabitat strata which predicted different densities of *P. lucida*. The other survey was a semisystematic design replicated at depths; quadrats were randomly assigned along fixed depths. It is likely that the saving in time achieved through site allocation is only obtained at the expense of a small amount of precision.

Methods

Stratified semirandom design. The stratification which will achieve the smallest confidence limit around the estimate is one where the strata boundaries are based on the actual values of surveyed variable. This direct information is seldom available. Therefore, the boundaries are usually based on some habitat trait which is known or suspected to correlate with the biomass or density of the organism. In this survey microhabitat strata were defined from preliminary observations of *P. lucida* distribution from the reconnaissance survey. The four strata identified are listed in Table 10.

Once the strata within the population have been defined, sample sizes for each stratum must be chosen. This allocation of sampling effort may be proportional, in which sample allocation is in proportion to the area of each stratum, or optimum, in which there is more sampling effort in the more variable strata. The latter gives a more precise estimate of total biomass, especially when there are large differences between strata (Cochran 1977). Therefore, optimum stratification was chosen to estimate *P. lucida* standing crop.

A pilot study was necessary to estimate variability in plant biomass within the four microhabitats. This was done when the habitat transects were positioned (*see* "Determination of area"). Once the transect line had been laid, two or three 0.25 m^2 quadrats were placed in each of the four strata. Quadrats were positioned by random numbers which corresponded to end-over-end turns of the quadrat perpendicular to the transect line. The four microhabitats were not

present at all nine transect locations. Therefore, unequal numbers of quadrats were taken from each of the strata (n_h' in Table 12).

Table 12: Optimum allocation of sampling units for the stratified random design on microhabitats*

Stratum	W_h	s_h	$\bar{x}_h$	n_h'	n_h	No. per site
Cystophora	0.107	86.7	89.0	26	9	1–2
Red algae	0.121	193.1	499.1	9	23	3–4
Carpophyllum	0.419	196.8	189.4	25	80	11–12
Mixed algae	0.353	23.0	12.4	24	8	1–2
				84	120	

* Where W_h is proportion that stratum makes up of the total area; s_h is stratum standard deviation; $\bar{x}_h$ is mean of the stratum; n_h' is number of quadrats used to estimate stratum statistics; and n_h is optimum number of quadrats to use in the actual survey.

The standard deviations for each stratum from the pilot study were combined with the area of each stratum to determine how many of the total sampling units available should be allocated to each of the four strata (Neyman allocation, *see* Cochran 1977).

The number of quadrats used in the main study was decided by cost, rather than the number required for a given precision. The surveys were constrained by the number of fieldwork days that time, finance, and weather allowed. This was judged to be 3–4 days, of which 2 days were assigned to field sampling for the main study. Each quadrat was known to take 4–5 min to sample (*see* Table 5), which allowed a single diver to harvest at least 10 quadrats per dive. There were three dives a day because *P. lucida* occurs at shallow depths. Therefore, in 2 days two scuba divers could allocate 120 quadrats (*see* Table 12).

The strata allocations were divided into seven sites along the coastline for field sampling (*see* Figure 9). At each site a transect line was laid (as in "Determination of area") and used as a reference line from which quadrats were randomised within each of the four microhabitat strata. Each quadrat was positioned by a random co-ordinate: one digit (1–10) representing quadrat turns perpendicular to the transect line, the second digit (1–10) representing quadrat turns parallel to the line — numbers 1–5 inshore and 6–10 offshore of the line.

The percentage cover of *P. lucida* thallus in each quadrat was estimated by eye and then by a gridded quadrat. The algae were then harvested, placed into labelled bags, and brought back to the laboratory, where wet weights were recorded, the average length of 10 randomly selected plants calculated, and general epibiota coverage evaluated (low, medium, high) for all quadrats.

Semisystematic design. Quadrat sampling was conducted within sites, at four arbitrary depths (0.5, 2, 3, 4 m) which were chosen to correspond to the main *P. lucida* distribution zones identified from preliminary observations. The seven sites were the same as those used in the stratified random survey. If quadrats from that survey design were at the depths required for this survey, they were used in both designs.

Once the transect line had been laid, the diver swam down the line and took four random samples at each required depth. Two 0.25 m^2 quadrats were allocated either side of the transect line, with random numbers (1–10) giving the distance of the quadrat from the line in quadrat widths (*see* Figure 9). A total of 112 quadrats were sampled.

All depths were calculated from MLW. This was measured when the diver first entered the water and recorded the height of water above the bare rock to vegetation interface and then subtracted this measurement from subsequent depth gauge values. The harvest of *P. lucida* and the variables recorded within each quadrat were the same as for the stratified design.

Calculations. Three standing crop estimates for *P. lucida* in the 3 km survey area were calculated for each design. These three estimates and their confidence limits were derived from:

1. the harvest of quadrats, which gave a direct measure of *P. lucida* biomass in each quadrat;
2. the predicted quadrat biomass from a regression of *P. lucida* density (percentage cover) by weight;
3. the predicted quadrat biomass from broad biomass categories (absent, rare, common, and abundant).

In addition, whenever data had been obtained by stratified random sampling, it was possible to calculate the variance of the estimated standing crop which would have resulted if a simple random sample had been taken. This random variance was calculated for the stratified semirandom design from data from harvested quadrats and compared with the other six estimates of variance.

In the calculation of a total biomass estimate for the semisystematic depth design, quadrats were treated as random samples from these depth zones: 0.0–1.5, 1.5–2.5, 2.5–3.5, and 3.5–6.0 m. Therefore, total biomass estimates and confidence limits for all six surveys (three biomass variables from two designs) were calculated as for the stratified random samples (e.g., Cochran 1977). Calculations differed only in the method that strata means and variances were determined for those surveys which use predictor variables to estimate *P. lucida* biomass in each quadrat (as in methods 2 and 3 above).

Results: stratum mean and variance calculation

Regression estimate of weight per quadrat. Percentage cover was the most promising and easily measured characteristic of *P. lucida* vegetation which could be used to predict plant weight within each quadrat (*see* "Predictors of biomass"). The following regression equation was used:

$$\text{predicted wet weight (grams per 0.25 m}^2) = 9.3\ (\text{percentage cover})\ (r^2 = 0.860)$$

The mean used to calculate the total biomass estimate was the arithmetic mean of those predicted weights for each stratum.

The variance of the strata means comprised the sum of the simple variance of the predicted values of *P. lucida* weight and that variance which the regression equation did not predict. This unpredicted variance was estimated by the mean square error on the regression line, which was easily obtained from an ANOVA on the line:

$$\text{var}(y_h) = s^2(y_h) + s^2(e)$$

where $\text{var}(y_h)$ is variance of the predicted biomass from individual quadrats for a given stratum, $s^2(y_h)$ is simple variance of the predicted weights for a given stratum, $s^2(e)$ is mean square error (calculated from a pilot study).

Regression ANOVA of percentage cover by weight:

Source	d.f.	SS	MS	*F* value	Significance
Model	1	8 301 207	8 301 207	849.3	$p = 0.0001$
Error	138	1 348 804	9 774		
Total	139	9 650 011			

$$\text{var}(y_h) = s^2(y_h) + 9774$$

As an example, the strata means and variances for the semisystematic depth design are given in Table 13.

Broad biomass categories. The broad biomass categories were calculated so that, from a knowledge of general abundance (rare, common, or abundant) and epibiotic cover within a quadrat, it was possible to predict a weight of *P. lucida* within certain limits (*see* Table 9). A fourth category, "absent", was also used for quadrats which had no *P. lucida*. When such a predictor of biomass is used in a stratified survey to obtain a standing crop estimate, the frequency of occurrence of the four biomass categories within any particular stratum provides the data. Thus, when the mean of a stratum is calculated, the mean predicted biomass and frequency of all categories must be considered. Therefore, the grand mean of each stratum is the sum of the predicted means from the three categories, each weighted by the proportion of the total number of quadrats within that category:

$$\bar{\bar{Y}} = \sum_k \frac{n_k}{n} \bar{y}_k$$

where n_k is number of quadrats within a biomass category and stratum combination, n is total number of quadrats for the three categories for each stratum, and $\bar{y}_k$ is mean biomass for that category.

The variance component for each stratum is the sum of the variability predicted by the categories and the variability due to the difference in biomasses between categories:

$$\text{var(st)} = \sum_k \left(\frac{n_k (\bar{y}_k - \bar{\bar{Y}})^2}{n - 1} + \frac{n_k}{n} s_k^2 \right)$$

where s_k^2 is variance of each biomass category.

The derivation of this formula is given in Appendix 3. Calculations of the grand means and variances for each stratum are given for the semisystematic depth design in Table 14 as an example of the procedure.

Standing crop estimation. All six surveys were treated as stratified random samples in the calculation of the estimates of standing crop and their confidence limits. The example given here is for the stratified semirandom survey sampling by microhabitats by use of harvested quadrats (Table 15). The total biomass calculations for the remaining surveys are given in Appendix 4. Raw data for the 120 quadrats sampled are given in Appendix 5.

The total biomass is the sum of the mean biomasses of the strata, each scaled up by the number of 0.25 m² sampling units which could fit into the whole survey area. The variance of the total mean biomass used to obtain the final confidence limits is calculated by the following formula (Cochran 1977):

$$s^2(\bar{x}_{st}) = \sum_h \frac{W_h^2 s_h^2}{n_h} - \sum_h \frac{W_h^2 s_h^2}{N}$$

where W_h is proportion that stratum makes up of the total area, s_h^2 is variance within the stratum, n_h is number of sampling units taken from that stratum, and N is total number of sampling units which could fit into the total area.

The last term corrects for the effect of the finite population size. It is usual to ignore this factor when the sampling fraction is less than 5% (Höisaeter and Matthiesen 1979). In the survey it is about 0.04% (120/279 772).

Variance calculation as if sampled randomly. When data have been collected by stratified sampling it is possible to estimate the variance which would have been obtained if a simple random sample had been taken from the same

population. The following formula was used for estimating this variance (*after* Cochran 1953):

$$\text{var(ran)} = \frac{N - n}{nN}(\Sigma W_h s_h^2 + \Sigma W_h \bar{x}_h^2 - (\Sigma W_h \bar{x}_h)^2)$$

where n is total number of sampling units taken from all strata and $\bar{x}_h$ is mean sampled biomass from each stratum.

Data from the harvested quadrats of the stratified semirandom survey were used to calculate this variance (Table 16).

Discussion

For the management of a commercially important and harvested seaweed, one of the main requirements is a knowledge of how much is in an area, i.e., its standing crop. If the survey results were evaluated only on the ease of obtaining a precise total biomass estimate within an area, then a stratified semirandom design based on microhabitats would be used. This survey design produced a confidence limit of 15.4% of the mean standing crop when 0.25 m² quadrats were harvested, whereas the confidence limits of the random sample and the sample taken at fixed depths were 25.6 and 36.2%. This error may have been further reduced by the totally random allocation of quadrats to the strata. The allocation to sites potentially biases the sample in that once the first site has been selected, the location of subsequent sites is predetermined and the adjoining areas are theoretically inaccessible to sampling. However, the increased precision through randomisation could only have been achieved at a large increase in cost.

It can be assumed that the microhabitat stratified design was also more accurate than the semisystematic design because sampling was directly related to the actual amount of *P. lucida* present, rather than an arbitrary environmental factor (i.e., depth) suspected to correlate with the amount of *P. lucida* present. The standing crop estimate of the depth survey was outside the lower confidence limit of the microhabitat survey (Table 17), which suggested the former represented an underestimate of the standing crop. The raw data and reef profiles showed that the "red" zone, from which 42.8% of the microhabitat standing crop estimate was derived, was inadequately sampled by the depth design. This red zone occurred as a thin band between the upper fringe of *Cystophora* spp. and lower sward of *Carpophyllum* spp., often between the 0.5 and 2 m fixed depth samples and, therefore, was seldom sampled.

Table 13: Percentage cover of *P. lucida*, predicted biomass, and variance estimates for the semisystematic depth design*

	Depth stratum (m)							
	0.0–1.5		1.5–2.5		2.5–3.5		3.5–6.0	
Variable†	%	y	%	y	%	y	%	y
1	5.6	52.1	13.9	129.3	13.9	129.3	5.6	52.1
2	8.3	77.2	11.1	103.2	22.2	206.5	30.6	284.6
3	8.3	77.2	5.6	52.1	22.2	206.5	19.4	180.4
4	2.8	26.0	16.7	155.3	13.9	129.3	13.9	129.3
5	55.5	516.2	88.9	826.8	11.1	103.2	5.6	52.1
6	44.4	412.9	13.9	129.3	8.3	77.2	2.8	26.0
7	33.3	309.7	19.4	180.4	2.8	26.0	0	0
8	2.8	26.0	2.8	26.0	2.8	26.0	0	0
9	27.8	258.5	2.8	26.0	2.8	26.0	0	0
10	13.9	129.3	5.6	52.1	2.8	26.0	0	0
11	8.3	77.2	2.8	26.0	0	0	0	0
12	19.4	180.4	5.6	52.1	0	0	0	0
13	16.7	155.3	52.8	491.0	0	0	0	0
14	2.8	26.0	61.1	568.2	0	0	0	0
15	8.3	77.2	75.0	697.5	0	0	0	0
16	8.3	77.2	11.1	103.2	0	0	0	0
17	2.8	26.0	22.2	206.5	0	0	0	0
18	2.8	26.0	8.3	77.2	0	0	0	0
19	8.3	77.2	22.2	206.5	0	0	0	0
20	2.8	26.0	19.4	180.4	0	0	0	0
21	5.6	52.1	5.6	52.1	0	0	0	0
22	13.9	129.3	5.6	52.1	0	0	0	0
23	30.6	284.6	13.9	129.3	0	0	0	0
24	2.8	26.0	11.1	103.2	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
$\bar{y}_h$		111.63		169.82		34.14		25.87
$s^2(y_h)$		173 233		45 236		3 902		4 356
var(y_h)		27 097		55 010		13 676		14 130

* Strata means and variances were calculated for the predicted values in each depth stratum: where $\bar{y}_h$ is mean predicted weight for a given stratum, $s^2(y_h)$ is simple variance of y_h, var(y_h) is variance of the predicted biomass from individual quadrats for a given stratum.

† 1–28 quadrats within each of the depth zones.

Table 14: Calculation of the strata grand means and variances by use of biomass categories for the semisystematic depth design*

Stratum depth (m)	Category	n_k	$n_k \frac{(\bar{y}_k - \bar{\bar{Y}})^2}{n-1}$		$\frac{n_k}{n} s_k^2$		Grand means and variances
0.0–1.5	Rare	15	3 092		616		$\bar{\bar{Y}}_{st1}$ = 15/28(40.1)
	Common	4	519		883		+ 4/28(173.9)
	Abundant	5	13 311		7 886		+ 5/28(382.8)
	Absent	4	1 949				+ 4/28(0) = 114.7
		28	18 871	+	9 385	=	var_{st1} = 28 256
1.5–2.5	Rare	10	4 648		411		$\bar{\bar{Y}}_{st2}$ = 10/28(40.1)
	Common	9	156		1 987		+ 9/28(173.9)
	Abundant	6	11 813		9 463		+ 6/28(382.8)
	Absent	3	2 575				+ 3/28(0) = 152.24
		28	19 192	+	11 861	=	var_{st2} = 31 053
2.5–3.5	Rare	6	15		247		$\bar{\bar{Y}}_{st3}$ = 6/28(40.1)
	Common	2	1 167		441		+ 2/28(173.9)
	Abundant	2	8 283		3 154		+ 2/28(382.8)
	Absent	18	1 562				+ 18/28(0) = 48.4
		28	11 027	+	3 842	+	var_{st3} = 14 869
3.5–6.0	Rare	3	11		123		$\bar{\bar{Y}}_{st4}$ = 3/28(40.1)
	Common	2	1 526		441		+ 2/28(173.9)
	Abundant	1	4 602		1 577		+ 1/28(382.8)
	Absent	22	753				+ 22/28(0) = 30.39
		28	6 891	+	2 142	+	var_{st4} = 9 033

* Means and variances for the biomass categories are: rare, 40.1 ± 1 150.4; common, 173.9 ± 6 180.1; abundant, 382.8 ± 44 160.9.

Table 15: Calculation of the standing crop estimate (g) and confidence limits for the stratified semirandom sampling by microhabitats

Stratum	W_h	Area (m²)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
Cystophora	0.107	7 484	29 936	9	50.56	1 339.8	1 513 564	1.70
Red algae	0.121	8 463	33 852	23	416.70	41 047.0	14 106 128	26.13
Carpophyllum	0.419	29 306	117 224	80	129.35	20 507.6	15 162 924	45.00
Mixed algae	0.353	24 690	98 760	8	22.25	836.8	2 197 410	13.03
			N = 279 772				32 980 026	85.86

$s^2(\bar{x}_{st})$ = 85.86 g => $s(\bar{x}_{st})$ = 9.27

Standing crop estimate: $X = \sum_h N_h\bar{x}_h$ = 32 980 kg

0.95% confidence limits: $X \pm t_{0.05} N s(\bar{x}_{st})$

= 1.96 × 279 772 × 9.27

= 5 083 kg

where W_h is proportion that stratum is of the total area; Area is estimated total area of the stratum in the 3 km coastline; N is total number of possible sampling units (0.25 m²) that can be fitted into the whole area; N_h is number of possible sampling units (0.25 m²) that can be fitted into each stratum; n_h is number of sampling units actually taken from each stratum; n is total number of sampling units taken from all strata; $\bar{x}_h$ is mean sampled biomass from each stratum; s_h^2 is variance around the mean biomass within each stratum; $s^2(\bar{x}_{st})$ is variance of the total stratified mean biomass.

Part of the large confidence limit on the fixed depth estimate compared with the microhabitat stratified estimate, was due to the division of the reef slope into depth zones. The last depth zone (3.5–6 m) contained 47.2% of the total area of reef shallower than 6 m, and it was responsible for a large amount of the total variability. Although this depth zone had the second smallest variance component, this was scaled up by area to represent 46.4% of the total variation around the standing crop estimate. With a general trend of decreasing biomass (and corresponding variability) with depth, the division of this zone into two would lower the confidence limit to at least below that from a simple random sample. It should also be noted that the calculated simple random confidence limit is an underestimate of variability due to the samples being grouped into regular sites.

A comparison of a design in which quadrats were randomly allocated within depth zones and the fixed depth design would probably have resulted in an abundance estimate between the two estimates compared in this study. There would have been less work than for the stratified semirandom survey on microhabitats, but more than for the semisystematic depth survey.

The use of predictive regressions and biomass categories to obtain an estimate of the total biomass showed the potential usefulness of easily and rapidly measured plant characteristics to predict *P. lucida* weight. The means and variances of the sampled population were reconstructed well by both methods, as shown by the closeness of their means and variances to that obtained from harvested quadrats when both designs were used (*see* Table 17). However, the usefulness and

Table 16: Calculation of simple random sample variance (a continuation of Table 15)

Stratum	$W_h s_h^2$	$W_h \bar{x}_h^2$	$W_h \bar{x}_h$
Cystophora	143.36	273.53	5.41
Red algae	4 966.69	21 010.30	50.42
Carpophyllum	8 592.68	7 010.47	54.20
Mixed algae	295.39	174.76	7.85
	13 998.12	28 469.06	117.88

$$\text{var(ran)} = \frac{279\,772 - 120}{279\,772(120)}(13\,998.1 + 28\,469.1 - (117.9)^2)$$

$$= 238.0\,\text{g}$$

general applicability of these methods is limited by two assumptions: that sampling is from the same population used to construct the initial biomass categories or regression line, and that the relationship of the characteristics used as a predictor to plant biomass is the same for the pilot and newly sampled populations. To obtain a confident estimate, these assumptions require that a pilot study be undertaken within each particular study area. This would involve sampling a substantial number of harvested quadrats to establish the relationship between the predictor variables (percentage cover) and biomass for each study area. It may be that a general relationship between the easily measured predictor and weight can be determined. However, this will only be known after many sites from many different locations have been sampled. Where a general (i.e., repeatable) relationship can be defined, the regression and biomass category methods are rapid and useful methods of estimating the total standing crop of *P. lucida*.

Although there are important assumptions for the use of predictive regressions, Foreman (1975), in a general methods manual for assessing the standing crops of floating kelps, recommended the use of such a regression technique (*see* "Literature summary"). Unfortunately, the relationship (in the survey between percentage cover and density) was calculated for a single locality and time and used few plants. The regression was then used to calculate total standing crop over a wide geographic range and some years. Furthermore, no confidence limits were calculated on the final standing crop estimates. However, because the fit of the regression line was not particularly good ($r^2 = 0.44$) it is suspected that they were at least three times the mean.

It should be noted that the estimation of both the total area of reef involved in the survey and the area of each stratum (depth or microhabitat) also involved measurement error. This error was not accounted for. Consequently, the standing crop estimates obtained by this method warrant cautious use. Further work must determine the accuracy and precision of the "habitat transect" method of defining and measuring thin strips of reef area, and/or find rapid and cost efficient alternatives to the method. All information available, e.g., hydrographic maps, spot observations, and diver vehicle surveys, must be used to define the zones to be subsequently sampled.

Table 17: A summary of the estimates (kilograms wet weight) of the total standing crop with 95% confidence limits for *P. lucida*, from the 3 km Goat Island to Cape Rodney coastline*

	Variables			
Design	Harvested quadrats	Random	Regression	Biomass categories
Stratified by microhabitats	32 980 ± 5 081	± 8 460	32 753 ± 8 413	33 602 ± 6 302
Semisystematic depth samples	25 336 ± 9 159		23 789 ± 10 718	25 057 ± 9 107

* Estimates were calculated for two survey designs by use of three different variables which related to plant biomass: plant weight from harvested 0.25 m² quadrats, predicted biomass from a regression of percentage cover by wet weight, and biomass predicted from broad biomass categories based on plant abundance categories. A 95% confidence limit for the standing crop estimate as if sampled randomly is also calculated.

Other considerations

An algal resource cannot be managed effectively with standing crop information alone. Knowledge of the biology of the species and how it will respond to a harvesting regime, information about the population structure, its abundance and distribution with respect to major environmental gradients (such as depth) and how such patterns vary geographically, are also important. Therefore, in the design of a general survey to assess stock state, it is necessary to incorporate as many of these features as possible while still retaining the ability to obtain a good estimate of standing crop.

The use of easily measured variables to predict the biomass of *P. lucida* within a quadrat, instead of the more time consuming harvesting and weighing, restricted the range of information which could be obtained. Since no specimens were collected in the main study, additional information (e.g., on size structure and reproductive state) cannot be readily obtained. Furthermore, any statistical exploration of the data was either restricted (as with the regression method) or not possible (as with biomass categories). Given these constraints, it is recommended that harvested quadrats are used for general surveys to assess algal stocks.

The optimum stratified semirandom sampling design provided an estimate of standing crop with tight confidence limits. In addition, size frequencies for *P. lucida* could be obtained for each microhabitat or, if depth were also recorded for each quadrat, down a depth gradient. However, because a different number of sampling units was taken from each stratum the design cannot rigorously test how the variability in

P. lucida biomass was distributed spatially, or statistically determine whether there have been changes over time, or if there are differences in biomass between areas, without many samples being collected.

These statistical capabilities are important if the survey is to be used as a baseline of general population information on which subsequent changes will be judged. Most statistical texts recommend three design constraints: replicate sampling units, a balanced design (equal numbers of sampling units at each level of sampling), and randomisation at the replicate level (e.g., Cochran 1977, Green 1979, Grieg-Smith 1983).

Sampling should be allocated in the same way over the whole range of locations which are to be compared, so that differences in biomass between locations can be tested. Surveys for *Pterocladia* should be conducted over its whole distributional range in New Zealand (Cape Reinga to Kaikoura). This encompasses a wide range of reef types, exposures, and temperature and salinity conditions, which can be expected to affect the distribution of *P. lucida*. For example, at Ngawihi on the exposed Wairarapa coast, the reef is long and shallow sloping, reaching a depth of 6 m about 250 m offshore. Here there is no distinct zonation of macrophytes (with the exception of the bullkelp *Durvillaea* spp.), but subtle changes in the relative abundances of the dominant algae: *Carpophyllum maschalocarpum, Lessonia variegata, Ecklonia radiata,* and the sea rimu *Caulerpa brownii.* At Ngawihi *P. lucida* is evenly distributed over the whole reef, whereas on the steeply sloping reefs at Leigh there is distinct zonation (*see* Appendix 2). Therefore, a survey design which requires sampling in microhabitats is unsuitable because zones where *P. lucida* predictably occur cannot be standardised across locations. A more generally applicable method is to sample in relation to depth.

The semisystematic depth survey has the advantage of a balanced design and reduces the level of randomisation, thereby saving time while still retaining a random element. Therefore, it is more flexible, simple, and yields the widest range of both useful and important information. The standing crop estimate is not as precise as that obtained from the microhabitat stratification design. However, when used with reef profiles to show how sampling was positioned in respect to any habitat zones, an idea of where the true value of standing crop lies within the confidence limits can be obtained. More accurate results can be expected when assessing stocks which do not have distinct zonal distributions (e.g., much of the Wairarapa coast). The use of sampling within sites at fixed depths in an investigation of the variability of *Pterocladia* biomass in a sampled area is shown in Appendix 2, for the Goat Island to Cape Rodney data.

Thus, the survey based on quadrat sampling at fixed depths within regularly allocated gives information at an adequate level of accuracy and precision for the effective management of *P. lucida* stocks.

Acknowledgments

This work was based at the University of Auckland Goat Island Marine Laboratory and supported by contract funds from the Fisheries Management Division, N.Z. Ministry of Agriculture and Fisheries. Logistic support was provided by the Goat Island Marine Laboratory. I am indebted to J. H. Choat for his advice and criticism of the manuscript and to B. H. McArdle who gave statistical advice enthusiastically throughout the course of this study. I thank W. A. Nelson, M. J. Kingsford, D. R. T. Schiel, and R. G. Creese for their discussions and contributions. Thanks to I. J. Doonan for advice on the statistics behind the methodology, to B. A. Kerrigan for encouragement, and to C. M. Petherick and R. E. Maulder for their field assistance.

References

Andrew, N. L. and Mapstone, B. D. 1987: Sampling and the description of spatial pattern in marine ecology. *Oceanography and marine biology, an annual review, 25*: 39–90.

Avery, T. E. 1977: "Interpretation of Aerial Photographs", third edition. Burgess Publishing Co., Minneapolis. 392 p. and 6 plates.

Ayling, A. M. 1978: Okakari Point to Cape Rodney Marine Reserve Survey. *Leigh Lab. Bulletin No. 3.* 98 p.

Bayley, S., Stotts, V. D., Springer, P. F., and Steenis, J. 1978: Changes in submerged aquatic macrophyte populations at the head of Chesapeake Bay, 1958–1975. *Estuaries 1*: 171–182.

Bold, H. C., Alexopoulos, C. J., and Delevoryas, T. 1980: "Morphology of Plants and Fungi", fourth edition. Harper and Row Publishers, New York. 819 p.

Brinkhuis, B. H. 1976: The ecology of temperate salt-marsh fucoids. 1. Occurrence and distribution of *Ascophyllum nodosum* Ecads. *Marine Biology 34*: 325–338.

Brown, V. B., Rowan, K. S., and Ducker, S. C. 1980: The effects of sewage effluent on the macrophytes off Werribee, Port Phillip Bay. *Ministry for Conservation, Victoria. Environmental Studies Program, Task Report No. 273.* 238 p.

Chapman, V. J. 1944: Methods of surveying *Laminaria* beds. *Journal of the Marine Biological Association of the U.K. 26*: 37–60.

Cochran, W. G. 1953: "Sampling Techniques", second edition. John Wiley & Sons, New York. 413 p.

Cochran, W. G. 1977: "Sampling Techniques", third edition. John Wiley & Sons, New York. 428 p.

Coon, L. M., Field, E. J., and Canadian Benthic Ltd. 1983: Nootka Sound Kelp Inventory, 1975. *British Columbia Marine Resources Branch Fisheries Management Report No. 2.* 27 p.

Critchley, A. T. 1983: The establishment and increase of *Sargassum muticum* (Yendo) Fensholt populations within the Solent area of Southern Britain. II. An investigation of the increase in canopy cover of the alga at low water. *Botanica Marina 26*: 547–552.

Downing, J. A. and Anderson, M. R. 1985: Estimating the standing biomass of aquatic macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences 42*: 1860–1869.

Foreman, R. E. 1975: KIM-1. A method for inventory of floating kelps and its application to selected areas of kelp license area 12. Final report, file No. 5506–81–131–1–72. BERP report 75–1. Report to Federal Fisheries and Marine Service and Provincial Marine Resources Branch.

Grace, J. B. and Tilly, L. J. 1976: Distribution and abundance of submerged macrophytes, including *Myriophyllum spicatum* L. (Angiospermae), in a reactor cooling reservoir. *Archiv für Hydrobiologie 77*: 475–487.

Green, R. H. 1979: "Sampling Design and Statistical Methods for Experimental Biologists". John Wiley & Sons, New York. 257 p.

Greig-Smith, P. 1983: "Quantitative Plant Ecology", third edition. Blackwell Scientific Publications, Oxford. 359 p.

Grenager, B. and Baardseth, E. 1966: A two-stage sampling method of estimating seaweed quantities. *In* Young, E. G. and McLachlan, J. L. (Eds.), Proceedings of the 5th International Seaweed Symposium, pp. 129–140. Pergamon Press, London.

Hay, C. H. 1979: Growth, mortality, longevity and standing crop of *Durvillaea antarctica* (Phaeophyceae) in New Zealand. *In* Jensen, A. and Stein, J. R. (Eds.), Proceedings of the 9th International Seaweed Symposium, pp. 97–104. Science Press, Princeton.

Höisaeter, T. and Matthiesen, A. 1979: Report on some statistical aspects of marine biological sampling based on a UNESCO-sponsored training course in sampling design for marine biologists. San Carlos Publications, Cebu City, Philippines.

Kenchington, R. A. 1984: Large area surveys of coral reefs. *In* "Comparing coral reef survey methods." *UNESCO Reports in Marine Science No. 21*: 92–103.

Loya, Y. 1978: Plotless and transect methods. *In* Stoddart, D. R. and Johannes, R. E (Eds.), "Coral Reefs: Research Methods". *UNESCO Monographs on Oceanographic Methodology No. 5*: 197–217.

Mann, K. H. 1972: Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. I. Zonation and biomass of seaweeds. *Marine Biology 12*: 1–10.

McArdle, B. H. and Blackwell, R. G. 1989: Measurement of density variability in the bivalve *Chione stutchburyi* using spatial autocorrelation. *Marine Ecology Progress Series 52*: 245–252.

Meulstee, C., Nienhuis, P. H., and Van Stokkom, H. T. C. 1986: Biomass assessment of estuarine macrophytobenthos using aerial photography. *Marine Biology 91*: 331–335.

McQuaid, C. D. 1985: Seasonal variation in biomass and zonation of nine intertidal algae in relation to changes in radiation, sea temperature and tidal regime. *Botanica Marina 28*: 539–544.

Mueller-Dombois, D. and Ellenberg, H. E. 1974: "Aims and Methods of Vegetation Ecology", John Wiley & Sons, New York. 547 p.

Pringle, J. D. 1984: Efficiency estimates for various quadrat sizes used in benthic sampling. *Canadian Journal of Fisheries and Aquatic Sciences 41*: 1485–1489.

Ripley, B. D. 1981: "Spatial Statistics". John Wiley & Sons, New York. 252 p.

Roland, W. G. 1984: Resource management biology for the edible kelp *Cymathere triplicata. Canadian Journal of Fisheries and Aquatic Sciences 41*: 271–277.

Schneider, C. W. and Searles, R. B. 1979: Standing crop of benthic seaweeds on the Carolina continental shelf. *In* Jensen, A. and Stein, J. R. (Eds.), Proceedings of the 9th International Seaweed Symposium, pp. 293–301. Science Press, Princeton.

Sheldon, R. B. and Boylen, C. W. 1978: An underwater survey method for estimating submerged macrophyte population density and biomass. *Aquatic Botany 4*: 65–72.

Snedecor, G. W. and Cochran, W. G. 1980: "Statistical Methods", seventh edition. Iowa State University Press. 507 p.

South, G. R. and Hay, C. H. 1981: Variation in morphology and standing crop in New Zealand *Durvillaea antarctica* (Chamisso) Hariot in relation to exposure and latitude. *In* Fogg, G. E. and Jones, W. E. (Eds.), Proceedings of the 8th International Seaweed Symposium, pp. 489–498. Marine Science Laboratory, Menai Bridge.

Southwood, T. R. E. 1966: "Ecological Methods with particular reference to the study of insect populations". Chapman & Hall, London. 391 p.

Thorne-Miller, B., Harlin, M. M., Thursby, G. B., Brady-Campbell, M. M., and Dworetzky, B. A. 1983: Variations in the distribution and biomass of submerged macrophytes in five coastal lagoons in Rhode Island, U.S.A. *Botanica Marina 26*: 231–242.

Topinka, J., Tucker, L., and Korjeff, W. 1981: The distribution of fucoid macroalgal biomass along central coastal Maine. *Botanica Marina 24*: 311–319.

Unni, K. S. 1977: The distribution and production of macrophytes in Lunz Mittersee and Lunz Untersee. *Hydrobiologia 56*: 89–94.

Ward, J. and Talbot, J. 1984: Distribution of aquatic macrophytes in Lake Alexandrina, New Zealand. *N.Z. Journal of Marine and Freshwater Research 18*: 211–220.

Winer, B. J. 1971: "Statistical Principles in Experimental Design", second edition. McGraw-Hill Kogakuska, Tokyo. 907 p.

Appendix 1

Diver vehicle reconnaissance data*

Location†	A	B	C	D	E	F	G	H	I	J	K	L	M
Reef form	3	3	1	3	3	1	3	3	3	2	3	3	1
Bottom type	2	2	2	2	3	1	2/3	2/3	2	1/2	2	2	1
Aspect	6	6	2	6	5/6	2	5/6	5–2	5	3/6	5	5	2
Major algae													
P. lucida	C–R	A–C	R	R	C	R	A–C	C	A–C	C	C	C	C
P. capillacea	–	–	–	–	R	–	–	–	–	–	–	–	R
Cystophora	A	C	C	C	R	R	C	C	C	R	C	R	C
Carpophyllum	A	A	C	A	A	A	A	A	A	A	A	A	A
Ecklonia	R	A–C	R	C	C	C	C	C	C	C	C	C	C
Lessonia	–	–	–	–	–	–	–	–	–	–	–	–	–
Others‡	–	Xip	Xip	Xip	–	–	–	–	Cor	Vid	Vid Gig	Vid	Sar
Position													
P. lucida	1/4	1/4	2	2	2	2	1/4	1/4	1/4	1/4	1	1	1/2
P. capillacea	–	–	2	–	1	–	–	–	–	–	–	–	3
Size													
P. lucida	2	1–2	1	2	1–2	2	1	1–2	2	2	1	2	2
P. capillacea	–	–	1	–	1	–	–	–	–	–	–	–	1
Distribution													
P. lucida	2	3/4	1	1	2	1	3	1–4	3/4	1/2	2/3	2/3	2
P. capillacea	–	–	2	–	3	–	–	–	–	–	–	–	2
Epibiota													
P. lucida	H	H	H	H	H	H	H–L	H–M	H	H	H	H	H
P. capillacea	–	–	L	–	L	–	–	–	–	–	–	–	L

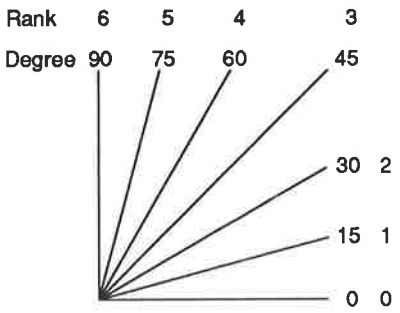
Location†	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Z′
Reef form	1	1	1	2	2	2	2	2	2	2	2	2	2	2
Bottom type	1	1	2	1	1	1	1/4	1/4	1/4	1	2	1/4	1	2
Aspect	2	1	2	2	1/2	1	1	1	2	2	2	2	2	2
Major algae														
P. lucida	C	R	R	R	C–R	C	R	R	C	R	R	C	C	A–C
P. capillacea	–	C	C	R	R	R	C	A–C	A–C	R	–	–	R	–
Cystophora	C	C	C	C	C	C	C	C	C	R	R	R	R	R
Carpophyllum	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lessonia	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Others	Sar	–	–	Cor	Vid	Vid	–	Vid	Vid	Zon	–	Vid	Vid	Vid
Position														
P. lucida	2	1	2	1–2	1	2	1	1	1	1	1	1	1	1
P. capillacea	–	3	2	2	2	2	2	2	1	1	–	–	2	–
Size														
P. lucida	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P. capillacea	–	1	1	1	1	1	1	1	1	1	–	–	1	–
Distribution														
P. lucida	2/3	1	1	2	2	3	2	2	3	1	1	2	2	2
P. capillacea	–	3/4	3	3	2	1	3	3	3	2	–	–	2	–
Epibiota														
P. lucida	H	H	H	H	H	H	H	H	H	H	H	H	H	H
P. capillacea	–	L	L	L	L	L	L	L	L	L	–	–	L	–

* Explanatory notes are given on page 31.
† Locations correspond to positions on Figure 6.
‡ Xip = *Xiphophora* spp., Cor = Coralline turf, Vid = *Vidalia* spp., Gig = *Gigartina* spp., Sar = *Sargassum* spp., Zon = *Zonaria* spp.

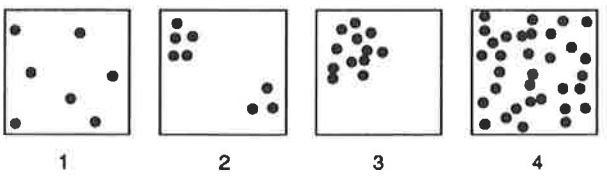
Appendix 1 — *continued*

Agar seaweed survey sheet — explanatory notes

Reef form	
Form	1 sloping; 2 stepped (sharp drop to less than 2 m depth); 3 drop-off
Bottom type	1 broken rock; 2 cobbles; 3 sand; 4 rockflats; 5 plateaus or gutters
Aspect	0–6



Major algae present	A, abundant; C, common; R, rare
Pterocladia lucida	
P. capillacea	Notation:
Carpophyllum spp.	
Ecklonia spp.	A–R Category A through to R
Other	A/R Category A and R
Position of agar	1 sub-littoral skirt; 2 boulder tops; 3 rock flats; 4 pinnacle tops; 5 other
Size (agar)	
P. lucida	1, < 20 cm; 2, > 20 cm
P. capillacea	1, < 10 cm; 2, > 10 cm
Plant distribution levels	
P. lucida	1 isolated; 2 forming patches; 3 large single patch;
P. capillacea	4 continuous sward



Epibiota coverage	H high (> 40%); M medium (40–10%); L low (< 10%)

Appendix 2

An analysis of the distribution and abundance patterns of *Pterocladia lucida*

An analysis of the Leigh marine reserve and Ngawihi semisystematic depth surveys is presented here. The two sites sampled at Ngawihi on the exposed Wairarapa coast are shown in Figure 5.

A two-factor analysis of variance testing for differences in *P. lucida* biomass between four depths at seven locations from Goat Island to Cape Rodney is given below (transformed $\log_{10}(x + 1)$). Percentage of the total variation explained by each term is given (%) (Winer 1971). The two factors are location (A-G) and depth (0.5, 2, 3, 4 m).

Source	d.f.	SS	MS	*F* value	Significance	%
Depth	3	172.07	57.36	23.47	$p < 0.001$	31.0
Site	6	120.38	20.06	8.21	$p < 0.001$	17.4
Depth x site	18	103.39	5.77	2.35	$p = 0.005$	13.0
Residual	84	205.29	2.44			38.6

Interpretation

The biomass of *P. lucida* was highly variable both along and down the reef from Goat Island to Cape Rodney. This was shown by the high significance of all terms in the above two-way ANOVA. Much of the total variation was explained by differences between the four depths down the reef (31%). However, the major portion was due to differences in *P. lucida* biomass between quadrats (residual 38%). Thus, there was a general depth trend in biomass, but the distribution was patchy at each depth.

This is in contrast to the distribution of *P. lucida* at Ngawihi. The influence of site and depth on *P. lucida* biomass is given below. Mean biomass (grams per 0.25 $m^2 \pm 1$ s.e.) are given for each site. A two-way ANOVA showed no significant differences in biomass between the five depths or two sites ($n = 4$ quadrats per depth per site; $\log_{10}(x + 1)$). Percentage of the total variation explained by each term is given (%).

	Depth (m)				
Site	1	2	4	6	8
1	176.5	56.5	91.3	20.0	99.5
	(86.5)	(32.9)	(28.0)	(8.7)	(12.7)
2	104.5	162.8	105.5	167.5	73.5
	(37.3)	(25.7)	(31.5)	(76.3)	(36.8)

Source	d.f.	SS	MS	*F* value	Significance	%
Depth	4	7.95	1.99	1.17	$p = 0.345$	1.4
Site	1	6.88	6.88	4.04	$p = 0.054$	9.8
Depth x site	4	17.13	4.28	2.51	$p = 0.062$	24.4
Residual	30	755.68	1.70			64.4

Much of the total variability in biomass was attributable to differences between quadrats (residual 64%). Most of the remaining variability was explained by differences in biomass between the individual site and depth combinations. Thus, no depth trend in biomass was found, and *P. lucida* distribution was patchy over the surveyed reef.

These differences in *P. lucida* distribution between the Leigh marine reserve and Ngawihi are at least partly due to differing reef topography. Reefs in the Leigh marine reserve are short and steeply sloping, whereas on the Wairarapa coast reefs are characteristically long and gradually sloping. These differences can be expected to effect the environmental factors which influence the distribution of algal species (e.g., wave exposure and light).

Appendix 3

Derivation of the total variance for an estimate of standing crop from predictive regression and biomass categories

In "Comparison of estimation methods" biomass information was collected in the form of variables which predict plant biomass (percentage cover), and these were subsequently used to determine standing crop. The two predictive methods used were a regression of percentage cover by weight and a series of biomass categories constructed on the basis of abundance (rare, common, abundant) and epibiota coverage. The total variance components obtained from both these methods are composed of the same components, though their calculation differs:

$$\text{Let} \quad y = a + bx_j + e_j \qquad j = 1, \ldots n$$
$$= y_j + e_j$$

where e_j has mean 0, variance var(e_j), and the y_j biomass samples are drawn from a population mean μ.

This gives $\quad \text{var}(y) = \text{var}(y) + \text{var}(e) + \text{cov}(y.e_j)$

Usually take e_j to be uncorrelated with y_j, so covariance is zero.

This gives $\quad \text{var}(y) = \text{var}(y) + \text{var}(e)$

Regression

The sample version of var(y) is $s^2(y_h)$ where y_h are predicted values of biomass from the regression, and var(e) is estimated to be the mean square error on the regression (9774, *see* page 24).

Therefore, $\text{var}(y_h) = s^2(y_h) + 9774$

Biomass category

Here y_j can be $\bar{y}_1$, $\bar{y}_2$ or $\bar{y}_3$, depending on if they are rare, common, or abundant.

The sample version of

$$\text{var}(y) = E((\bar{y}_j - \mu)^2) = \sum_k \frac{n_k(\bar{y}_k - \bar{\bar{Y}})^2}{n-1}$$

The sample version of var(e_j) can be s_1^2, s_2^2 or s_3^2, depending on k (R, C, or A) and is the pooled estimate of var(e):

$$\text{var}(e_j) = \sum_k \frac{n_k}{n} s_k^2 \qquad \text{where } n = \Sigma n_k$$

$$\text{Thus, var}(y) = \sum_k \frac{n_k(\bar{y}_k - \bar{\bar{Y}})^2}{\text{n} - 1} + \frac{n_k}{n} s_k^2)$$

Appendix 4

Continuation of survey analyses

Calculation of the standing crop estimate (g) and confidence limits for the stratified semirandom survey by microhabitat, by use of regression estimates, is given below.

Stratum	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
Cystophora	0.107	7 484	29 936	9	61.75	9 451	1 848 548	12.02
Red algae	0.121	8 463	33 852	23	340.80	42 396	11 536 762	26.99
Carpophyllum	0.419	29 306	117 224	80	137.50	27 537	16 118 300	60.43
Mixed algae	0.353	24 690	98 760	8	32.90	8 730	3 249 204	135.97
			$N =$ 279 772				32 752 814	235.41

$s^2(\bar{x}_{st}) = 235.41$ g => $s(\bar{x}_{st}) = 15.34$

Standing crop estimate: $X = \Sigma N_h\bar{x}_h = 32\ 753$ kg

0.95% confidence limits: $X \pm t_{0.05}Ns(\bar{x}_{st})$
$= 1.96 \times 279\ 772 \times 15.34$
$= 8\ 413$ kg

where W_h is proportion that stratum is of the total area; Area is estimated total area of the stratum in the 3 km coastline; N is total number of possible sampling units (0.25 m^2) that can be fitted into the whole area; N_h is number of possible sampling units (0.25 m^2) that can be fitted into each stratum; n_h is number of sampling units actually taken from each stratum; n is total number of sampling units taken from each stratum; $\bar{x}_h$ is mean sampled biomass from each stratum; s_h^2 is variance around the mean biomass within each stratum; $s^2(\bar{x}_{st})$ is variance of the total stratified mean biomass.

Calculation of the standing crop estimate (g) and confidence limits for the stratified semirandom survey by microhabitat, by use of biomass categories, is given below.

Stratum	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
Cystophora	0.107	7 484	29 936	9	50.50	3 898	1 511 768	4.96
Red algae	0.121	8 463	33 852	23	328.30	43 050	11 113 612	27.40
Carpophyllum	0.419	29 306	117 224	80	157.80	37 277	18 497 947	81.80
Mixed algae	0.353	24 690	98 760	8	25.10	1 150	2 478 874	17.91
			$N =$ 279 772				33 602 203	132.10

$s^2(\bar{x}_{st}) = 132.10$ g => $s(\bar{x}_{st}) = 11.49$

Standing crop estimate: $X = \Sigma N_h\bar{x}_h = 33\ 602$ kg

0.95% confidence limits: $X \pm t_{0.05}Ns(\bar{x}_{st})$
$= 1.96 \times 279\ 772 \times 11.49$
$= 6\ 302$ kg

Calculation of the standing crop estimate (g) and confidence limits for the semisystematic depth design, by use of regression estimates, is given below.

Stratum depth (m)	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
0.0–1.5	0.153	14 700	58 798	28	111.63	27 097	6 563 621	22.65
1.5–2.5	0.146	14 027	56 108	28	169.82	55 010	9 528 261	41.88
2.5–3.5	0.229	22 001	88 005	28	34.14	13 676	3 004 491	25.61
3.5–6.0	0.472	45 347	181 389	28	25.87	14 130	4 692 533	112.42
			$N =$ 384 300				23 788 906	202.56

$s^2(\bar{x}_{st}) = 202.6$ g => $s(\bar{x}_{st}) = 14.23$

Standing crop estimate: $X = \Sigma N_h\bar{x}_h = 23\ 789$ kg

0.95% confidence limits: $X \pm t_{0.05}Ns(\bar{x}_{st})$
$= 1.96 \times 384\ 300 \times 14.23$
$= 10\ 718$ kg

Appendix 4 — *continued*

Calculation of the standing crop estimate (g) and confidence limits for the semisystematic depth design, by use of biomass categories, is given below.

Stratum depth (m)	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
0.0–1.5	0.153	14 700	58 798	28	114.68	28 256	6 742 955	23.62
1.5–2.5	0.146	14 027	56 108	28	152.24	31 063	8 541 882	23.65
2.5–3.5	0.229	22 001	88 005	28	48.40	14 869	4 259 442	27.11
3.5–6.0	0.472	45 347	181 389	28	30.39	9 033	5 512 412	71.87
			$N =$ 384 300				24 056 691	146.25

$s^2(\bar{x}_{st}) = 146.25$ g => $s(\bar{x}_{st}) = 12.09$

Standing crop estimate: $X = \Sigma N_h\bar{x}_h = 25\ 057$ kg

0.95% confidence limits: $X \pm t_{0.05}Ns(\bar{x}_{st})$

$= 1.96 \times 384\ 300 \times 12.09$

$= 9\ 107$ kg

Calculation of the standing crop estimate (g) and confidence limits for the semisystematic depth design, by use of harvested quadrats.

Stratum depth (m)	W_h	Area (m^2)	N_h	n_h	$\bar{x}_h$	s_h^2	$N_h\bar{x}_h$	$\frac{W_h^2 s_h^2}{n_h}$
0.0–1.5	0.153	14 700	58 798	28	63.39	4 366	3 727 205	3.65
1.5–2.5	0.146	14 027	56 108	28	188.36	64 355	10 568 503	48.99
2.5–3.5	0.229	22 001	88 005	28	61.04	14 230	5 371 825	26.65
3.5–6.0	0.472	45 347	181 389	28	31.25	8 618	5 668 406	68.57
			$N =$ 384 300				25 335 940	147.86

$s^2(\bar{x}_{st}) = 147.86$ g => $s(\bar{x}_{st}) = 12.16$ g

Standing crop estimate: $X = \Sigma N_h\bar{x}_h = 25\ 336$ kg

0.95% confidence limits: $X \pm t_{0.05}Ns(\bar{x}_{st})$

$= 1.96 \times 384\ 300 \times 12.16$

$= 9\ 159$ kg

N in the microhabitat surveys differs from that in the depth surveys because of the removal of an "other" miscellaneous category from the total area estimate: 384 300 − (384 300 x 0.272) (*see* Table 11).

Appendix 5

Stratified microhabitat and semisystematic survey data*

Raw data from the stratified microhabit at survey by transect (A–G):

A				B				C				D			
Cys	Red	Car	Mix†	Cys	Red	Car	Mix	Cys	Red	Car	Mix	Cys	Red	Car	Mix
106	155	146	88	50	463	85	0	0	777	273	0	59	324	76	19
31	341	23	23	98	300	6	0	–‡	601	170	0	–	244	300	–
–	225	137	–	–	485	56	–	–	986	315	–	–	429	91	–
–	519	116	–	–	–	18	–	–	–	335	–	–	–	216	–
–	237	371	–	–	–	49	–	–	–	148	–	–	–	46	–
–	–	352	–	–	–	42	–	–	–	277	–	–	–	215	–
–	–	21	–	–	–	0	–	–	–	147	–	–	–	38	–
–	–	197	–	–	–	0	–	–	–	407	–	–	–	211	–
–	–	605	–	–	–	0	–	–	–	141	–	–	–	429	–
–	–	77	–	–	–	0	–	–	–	271	–	–	–	389	–
–	–	44	–	–	–	0	–	–	–	195	–	–	–	195	–
–	–	259	–	–	–	0	–	–	–	0	–	–	–	–	–

E				F				G			
Cys	Red	Car	Mix	Cys	Red	Car	Mix	Cys	Red	Car	Mix
71	230	306	28	13	410	69	20	27	283	23	0
–	175	298	–	–	400	79	–	–	429	37	–
–	689	40	–	–	353	31	–	–	530	12	–
–	–	585	–	–	–	31	–	–	–	240	–
–	–	248	–	–	–	13	–	–	–	143	–
–	–	211	–	–	–	97	–	–	–	59	–
–	–	5	–	–	–	8	–	–	–	0	–
–	–	0	–	–	–	210	–	–	–	0	–
–	–	0	–	–	–	38	–	–	–	0	–
–	–	0	–	–	–	0	–	–	–	0	–
–	–	0	–	–	–	0	–	–	–	0	–
–	–	–	–	–	–	–	–	–	–	–	–

Raw data from the semisystematic depth survey:

	Depth stratum (m)															
	0.0–1.5				1.5–2.5				2.5–3.5				3.5–6.0			
Transect	1	2	3	4§	1	2	3	4	1	2	3	4	1	2	3	4
A	106	31	68	37	259	180	146	23	429	389	195	10	407	271	141	0
B	98	88	74	50	89	6	56	18	0	0	0	0	0	0	0	0
C	190	80	19	0	195	777	601	986	273	0	0	0	0	0	0	0
D	59	280	23	0	76	300	91	216	0	101	40	16	17	19	0	0
E	71	111	164	123	585	248	5	230	28	0	0	0	0	0	0	0
F	13	4	28	20	17	120	8	15	0	0	0	85	20	0	0	0
G	27	0	0	11	27	0	0	0	0	0	0	143	0	0	0	0

* Values are biomass of *P. lucida* (grams per 0.25 m^2).
† *Cystophora*, red algae, *Carpophyllum*, mixed algae.
‡ No sample.
§ Quadrats.

NEW ZEALAND FISHERIES TECHNICAL REPORTS

(This series in part continues the *Fisheries Research Division Occasional Publication* series.
Prices do not include GST. New Zealand purchasers please add GST at current rate.)

TR1. HICKMAN, R. W. 1987: Growth, settlement, and mortality in experimental farming of dredge oysters in New Zealand waters. 18 p. $20.00

TR2. UNWIN, M. J., LUCAS, D. H., and GOUGH, T. 1987: Coded-wire tagging of juvenile chinook salmon (*Oncorhynchus tshawytscha*) in New Zealand, 1977–86. 24 p. $19.00

TR3. HURST, R. J. and BAGLEY, N. W. 1987: Results of a trawl survey of barracouta and associated finfish near the Chatham Islands, New Zealand, December 1984. 44 p. $25.00

TR4. UOZUMI, Y., YATSU, A., and ROBERTSON, D. A. 1987: Japan-New Zealand trawl survey off southern New Zealand, April 1983. 52 p. $22.00

TR5. HURST, R. J. 1988: The barracouta, *Thyrsites atun*, fishery around New Zealand: historical trends to 1984. 43 p. $25.00

TR6. BREEN, P. A., BOOTH, J. D., and TYSON, P. J. 1988: Feasibility of a minimum size limit based on tail width for the New Zealand red rock lobster, *Jasus edwardsii*. 16 p. $14.00

TR7. FRANCIS, M. P. and SMITH, D. W. 1988: The New Zealand rig fishery: catch statistics and composition, 1974–85. 30 p. $18.00

TR8. MASSEY, B. R. 1989: The fishery for rig, *Mustelus lenticulatus*, in Pegasus Bay, New Zealand, 1982–83. 19 p. $21.00

TR9. HATANAKA, H., UOZUMI, Y., FUKUI, J., AIZAWA, M., and HURST, R. J. 1989: Japan-New Zealand trawl survey off southern New Zealand, October-November 1983. 52 p. $28.00

TR10. UNWIN, M. J., FIELD-DODGSON, M. S., LUCAS, D. H., and HAWKE, S. P. 1989: Experimental releases of coded-wire tagged juvenile chinook salmon (*Oncorhynchus tshawytscha*) from the Glenariffe Salmon Research Station, 1982–83 to 1984–85. 22 p. $22.00

TR11. CLARK, M. R. and KING, K. J. 1989: Deepwater fish resources off the North Island, New Zealand: results of a trawl survey, May 1985 to June 1986. 56 p. $28.00

TR12. FENAUGHTY, J. M. and UOZUMI, Y. 1989: A survey of demersal fish stocks on the Chatham Rise, New Zealand, March 1983. 42 p. $28.00

TR13. BENSON, P. G. and SMITH, P. J. 1989: A manual of techniques for electrophoretic analysis of fish and shellfish tissues. 32 p. $28.00

TR14. ZELDIS, J. R. 1989: A fishery for *Munida gregaria* in New Zealand: ecological considerations. 11 p. $16.00

TR15. HORN, P. L. and MASSEY, B. R. 1989: Biology and abundance of alfonsino and bluenose off the lower east coast North Island, New Zealand. 32 p. $30.00

TR16. HORN, P. L. 1989: An evaluation of the technique of tagging alfonsino and bluenose with detachable hook tags. 15 p. $16.00

TR17. HATANAKA, H., UOZUMI, Y., FUKUI, J., AIZAWA, M., and LIVINGSTON, M. E. 1989: Trawl survey of hoki and other slope fish on the Chatham Rise, New Zealand, November-December 1983. 31 p. $28.00

TR18. HURST, R. J., BAGLEY, N. W., and UOZUMI, Y. 1990: New Zealand-Japan trawl survey of shelf and upper slope species off southern New Zealand, June 1986. 50 p. $20.00

TR19. WOOD, B. A., BRADSTOCK, M. A., and JAMES, G. D. 1990: Tagging of kahawai, *Arripis trutta*, in New Zealand, 1981–84. 15 p. $15.00

TR20. NELSON, W. A., O'HALLORAN, S. M. L., CONROY, A. M., and JORGENSEN, M. A., 1990: Phenology of the red seaweed *Porphyra* (karengo) at Kaikoura, South Island, New Zealand. 23 p. $15.00

TR21. MICHAEL, K. P., OLSEN, G. P., HVID, B. T., and CRANFIELD, J. H. 1990: Design and performance of two hydraulic subtidal clam dredges in New Zealand. 15 p. $15.00

TR22. TRACEY, D. M., McMILLAN, P. J., ARMSTRONG, J. H., and BANKS, D. A. 1990: Orange roughy trawl survey: Challenger Plateau and west coast South Island, 1983. 34 p. $30.00

TR23. JONES, J. B. 1990: Jack mackerels (*Trachurus* spp.) in New Zealand waters. 28 p. $27.00