INVERTEBRATE WORKING PAPERS REVIEWED BY THE PACIFIC STOCK ASSESSMENT REVIEW COMMITTEE (PSARC) IN 1995. PART 2. ECHINODERMS.

B.J. Waddell, G.E. Gillespie and L.C. Walthers (Editors)

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INVERTEBRATE WORKING PAPERS REVIEWED BY THE PACIFIC STOCK ASSESSMENT REVIEW COMMITTEE (PSARC) IN 1995

PART 2. ECHINODERMS.

by

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ABSTRACT

Waddell, B.J., G.E. Gillespie and L.C. Walthers [eds.]. 1998. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215: 169 p.

Working Papers prepared in 1995 by Fisheries and Oceans Canada staff, First Nations and industry representatives that were reviewed by the Pacific Stock Assessment Review Committee (PSARC) are presented. These documents form the basis of biological advice given to managers for the development of fishing plans for 1996. Topics included: three surveys for red sea urchins (*Strongylocentrotus franciscanus*) conducted in 1994; reanalysis of four red sea urchin surveys conducted in 1993; protocols for sea urchin surveys; quota estimates for the 1996 red sea urchin fishery; quota recommendations for the 1995/96 green sea urchin (*Strongylocentrotus droebachiensis*) fishery; and quota options for the sea cucumber (*Parastichopus californicus*) fishery.

RESUME

Waddell, B.J., G.E. Gillespie and L.C. Walthers [eds.]. 1998. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215: 169 p.

Nous présentons les documents de travail, préparés en 1995 par les membres du ministère des Pêches et des Océans, les Premières Nations et les représentants de l'industrie, qui ont été examinés par le Comité d'examen de l'évaluation des stocks du Pacifique (PSARC). Ces documents constituent la base des avis biologiques fournis aux gestionnaires pour l'élaboration des plans de pêche de 1996. Les sujets traités sont : trois relevés sur l'oursin rouge (*Strongylocentrotus fransciscanus*) menés en 1994; une nouvelle analyse de quatre relevés sur l'oursin rouge menés en 1993; des protocoles pour les relevés sur les oursins; des estimations de quotas pour la pêche de l'oursin rouge en 1996; des recommandations de quotas pour la pêche de l'oursin vert (*Strongylocentrotus droebachiensis*) en 1995-1996; enfin, des options de quotas pour la pêche de l'holothurie (*Parastichopus californicus*).

INTRODUCTION

The Invertebrate Working Papers contained in this document were prepared by Fisheries and Oceans Canada (DFO) staff of the Stock Assessment Division of Science Branch; and the North Coast, South Coast and Fraser River Divisions of Operations Branch, Fisheries and Oceans Canada and other collaborators. The Working Papers were assigned reviewers by the Subcommittee Chair, and written comments were provided to the authors prior to the Subcommittee meeting. Assessments and advice to managers were then reviewed by the Invertebrate Subcommittee of the Pacific Stock Assessment Review Committee (PSARC) as a whole, which included representatives from Science Branch, Operations Branch, Program, Planning and Economics Branch, and the B.C. Provincial Government. The Subcommittee was required to reach consensus on any recommendation before it was submitted to the PSARC Steering Committee. Subcommittee recommendations were reviewed by the Regional Management Executive Committee, then used by the Shellfish Working Group to formulate management plans for industry review.

PSARC Working Papers document the scientific basis for fisheries management advice in the Pacific Region. As such, they provide one component of the stock assessment process and are not intended as comprehensive treatments of stock management.

The Invertebrate Subcommittee met twice in Nanaimo in 1995: January 24-25 and September 12-14. These meetings addressed advice and recommendations for management of invertebrate fisheries in British Columbia in 1996 and identified concerns and future research needs. An overview of British Columbia invertebrate fisheries, summaries of the Working Papers, reviewers' comments and Invertebrate Subcommittee discussions are included in the 1995 PSARC annual report (Rice *et al.* 1996). Commercial fishery updates for 1995 have been collected and will be published elsewhere.

This report is part of a series which document Working Papers which have been reviewed and accepted by the Invertebrate Subcommittee. Previous reports include Hand and Waddell (1996), Thomas (1990, 1992), Harbo and Jamieson (1987), Jamieson (1984, 1985) and Bernard (1982). This report presents Working Papers directed at red (*Strongylocentrotus franciscanus*) and green (*S. droebachiensis*) sea urchins and sea cucumbers (*Parastichopus californicus*). A companion volume (Waddell *et al.* 1998) presents Working Papers directed at intertidal clams (*Tapes philippinarum*, *Protothaca staminea* and *Saxidomus giganteus*) and geoducks (*Panopea abrupta*).

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Waddell, B.J., G.E. Gillespie and L.C. Walthers. [eds.]. 1998. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 1. Bivalves. Can. Tech. Rep. Fish. Aquat. Sci. 2214: 434 p.

Analysis of the 1994 Red Sea Urchin Survey Conducted in Haida Gwaii, Pacific Fishery Management Area 1

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ABSTRACT

Jamieson, G.S., R. Jones, G. Martel, C.J. Schwarz, C. Taylor, and R. Routledge. 1998. Analysis of the 1994 red sea urchin survey conducted in Haida Gwaii, Pacific Fishery Management Area 1. pp. 3-18. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Collaborative red sea urchin surveys were conducted in 1994 by Fisheries and Oceans Canada, the Pacific Underwater Harvesters Association and the Haida Fisheries Program. A broad-brush survey was carried out in Pacific Fishery Management Area 1, subareas 1, 2, 3 and 7 (Wiah Point westward to Fleurieu Point) in June 1994. By subarea, estimated densities ranged from 0.80-5.86 urchins/m^2, and the estimated total number of legal-sized urchins was 94 million in 76.3 km^2. Analyses of data using revised 1993 procedures indicated that the previous methodology overestimated densities relative to those produced with the 1994 analytical methods. It was noted that the total number of legal-sized urchins present does not represent the number of urchins available to the fishery, since only urchins in densities greater than an unknown threshold level may be economically exploited. Many legal-size urchins may be at such a low density that it may not be economical to harvest them.

INTRODUCTION

A survey was conducted in Pacific Fishery Management Area (PFMA) 1 on the coast of British Columbia in 1994 to estimate the abundance of the red sea urchin (*Strongylocentrotus franciscanus*) in the 0-10 m below Chart Datum in areas identified to be of particular interest. These surveys were conducted under informal partnership agreements between Fisheries and Oceans Canada (DFO), the Pacific Urchin Harvesters Association (PUHA), and the Haida Fisheries Program (HFP).

A broad-brush survey designed to cover a relatively large area was undertaken, as there were no prior data on sea urchin occurrence in this area.

The survey protocol for the 1994 survey was modified from that used in 1993 because of concerns expressed over the way in which the data were collected (G.S. Jamieson, unpublished manuscript). The 1994 survey protocol is reviewed in detail in Jamieson and Schwarz (1998).

Briefly, the 1994 survey protocol was conducted by selecting a systematic sample (with a random start location) of positions along the shoreline in areas identified as potential harvesting areas. A strip transect was then surveyed, starting at Chart Datum and running perpendicular to shore. Divers rolled a 1 m square quadrat along the ocean floor from 0 m to 10 m below Chart Datum, counting the number of urchins within each quadrat. Finally, on a randomly selected quadrat in every 2 m of depth surveyed (five samples per transect), the diameters of all urchins in the quadrat were measured.

Areas, in square kilometers, between Chart Datum and 10 m below Chart Datum were estimated from digitizing the largest scale hydrographic charts available.

This report evaluates the data and gives a summary of PFMA 1 observations by subarea.

METHODOLOGY

SURVEY PROCEDURES

In June, 1994, the HFP and PUHA jointly conducted a 12 day red sea urchin survey. Survey design and procedures were developed by Biological Sciences Branch, DFO, with the assistance of the Department of Mathematics and Statistics, Simon Fraser University. Locations for 59 randomly located transects in PFMA 1 were identified *a priori* (Fig. 1), with sites approximately equidistant between Tian Head north to Lepas Bay (2.4 km apart), then around the west, south, and east sides of Langara Island, and east to Wiah Point (3.63 km apart). Because of the large area between 0-10 m depth in Virago Sound, stations there were located with a different procedure, described below.

Three boats serving two dive teams were involved in the survey: BOLD SPIRITS, HESQUIAT FREEDOM and TERROR POINT. The first two were dive boats and the last was for living accommodations. Each dive team consisted of one HFP diver, one PUHA diver and a biologist from Triton Environmental Consultants.

During 9 days of diving, 44 of the 61 transects identified were surveyed, with the remaining ones (Fig. 1) not surveyed because: 1) seas were too rough to permit safe diving (sites 11-22, 30 and 31 south of Fleurieu Point on the west side of Graham Island); or 2) areas were too dangerous (kelp beds and large rocks) for the boats (sites 6, 26, and 40). All transects except those in Virago Sound were linear transects, starting at Chart Datum and running perpendicular to shore to a depth of 10 m below Chart Datum. In Virago Sound, the area was divided into east-west rows 100 m apart, with transects perpendicular to the rows, *i.e.*, north-south, randomly located in both rows and along the length of a row.

Divers swam along each transect, recording sea urchin, abalone (*Haliotus kamschatkana*) and macrophyte numbers by species in each 1 m^2 quadrat. Depth was also recorded for each quadrat. The quadrat was rolled along the bottom, so total quadrat number in each transect gives surveyed transect length. Distance from diver start and end locations was also estimated by either towing a current meter from a boat while it cruised this distance (if kelp beds were not in the way) or from the vessel's radar image.

In at least one randomly selected quadrat (Table 1) in each 2 m depth range (0-2, 2-4, 4-6, 6-8, and 8-10 m depth), the test diameters of all urchins were measured.

RESULTS

ANALYSIS OF 1994 DATA USING REVISED 1993 ANALYTICAL PROCEDURES

Density estimates, obtained by using only the part of the transect extending from Chart Datum down until three consecutive quadrats has zero urchins (Jamieson *et al.* 1998), were larger than those obtained from using all the transect (Table 2). This was not unexpected because urchin densities are thought to be higher nearer the kelp line. This shows the overestimation bias of using this revised 1993 analytical procedure (Jamieson *et al.* 1998) in density estimation, *i.e.*, of not including urchin counts in the lower part of the transect.

Density estimates obtained by using counts in the lower part of the transect, but setting them to zero, were smaller than the densities obtained from using all of the transects. Again, this was not unexpected, because some urchins occur in the second half of transects. This indicates that this 1993 reanalysis procedure (Jamieson *et al.* 1998) produces underestimates of the true density.

SUMMARY OF 1994 OBSERVATIONS

By subarea, mean density (count per square meter) ranged from 0.8-5.86 in the subareas surveyed. Plots of density change with depth were estimated for the overall area surveyed and for each constituent subarea (Figs. 2a-2f). Unfortunately, depth of each quadrat was not recorded, so an interpolated depth had to be computed. This was done by assuming that the first quadrat of a transect occurred at 0 m below Chart Datum and that the last quadrat occurred at 10 m below Chart Datum. A straight line interpolation was then used to assign a depth to each quadrat.

A smoothed curve was fit to the densities using a spline smoother. This will track the approximate mean density at each interpolated depth. Minor fluctuations in the curves may be artifacts of the smoothing process. Also, if there are few data points at an interpolated depth, this may affect the curve, as the curve is very sensitive to outliers.

Highest densities appeared to be near 0 m Chart Datum, with suggestion of another mode around 3-5 m depth. This may reflect the average transition depth from rock to sand because of a reduction in wave action.

Box plots of size distributions (Fig. 3) are given for the entire survey area and for each constituent subarea. Fig. 4 shows the size distribution by 10 mm groupings for the entire survey area.

The proportion of urchins above 100 mm in diameter was estimated based upon the following samples of urchins measured in each subarea (Table 3). All subareas had sufficient urchins measured that imprecision in proportion above 100 mm is small relative to that induced by sampling transects.

From the above data, Table 4 provides overall biomass estimates by subarea. However, density of legal-sized urchins ultimately determines their availability to a fishery, and since these data are limited, actual availability of legal-size urchins is not estimated.

DISCUSSION

This past year was only the second year in which red sea urchin surveys have been conducted in the North Coast. PFMA 1, the Haida Traditional Territory surveyed in this study, as with the previous year's survey (G.S. Jamieson *et al.*, unpublished manuscript), has never been previously surveyed, and so this report presents the first data characterizing urchins in this area. Survey work is quite time consuming, with only 44 transects done in a two week period. Given that each transect is only 1 m wide, this means that only 44 m of the estimated 90 km of shoreline surveyed was sampled. While the locations chosen were randomized, habitat variability and the contagious distribution of urchins both ensure that although the best data currently available, the data presented here should be treated with considerable caution. Not only are they a snapshot in time, but the sparsity of data suggests that biomass estimates are only crude at best.

The analysis presented here is only a preliminary step in a process which will ultimately provide rationalization for annual red sea urchin quotas in the area. Production data, where growth and mortality rates are used to estimate yields, and better definition of areas logistically capable of being exploited by fishers, are required for determination of sustainable annual yield.

One data component not adequately considered in data collected to date is the availability of legal-sized urchins in concentrations which make them profitable to exploit. There may be a large biomass of legal-sized urchins in an area, but if their density is too low, then few may be operationally exploitable. To provide these data, both total urchin number and legal-size number will be recorded by depth for each quadrat in future surveys. In this survey, only five size frequency counts were made per transect, giving only 220 size frequencies for the whole survey. Given the depth range covered (only 44 size frequencies in each 2 m depth interval), an inadequate amount of data is considered to be currently available to extrapolate sustainable, exploitable legal-size biomass with acceptable accuracy.

ACKNOWLEDGEMENTS

We wish to thank all First Nation, industry and DFO employees who participated and assisted in data collection, editing and analysis. The success of this project depended on the enthusiastic and conscientious participation of a wide diversity of people, all primarily interested in conserving our urchin resources so that sustainable use of them can be maintained into the future.

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Table 1. Number of size frequency counts by transect.

# Quadrats/ Transect	# Transects	Percent	# Quadrats
1	3	7.3	3
3	7	17.1	21
4	4	9.8	16
5	5	12.2	25
6	7	17.1	42
7	2	4.9	14
8	3	7.3	24
9	2	4.9	18
10	1	2.4	10
12	2	4.9	24
13	2	4.9	26
17	1	2.4	17
20	1	2.4	20
26	1	2.4	26
Total	41	100	285

Table 2. Mean density estimates using all 1994 data. Only the first half of the transects, and assuming quadrats in the last half of the transects have zero urchin counts.

	Mean Urchin Density Estimates (number/m^2)		
PFMA and Subarea	All data	Shallowest Half	Last Half = 0
1-1	3.48	4.91	2.44
1-2	5.86	8.73	4.64
1-3	1.58	2.19	1.11
1-7	0.80	0.80	0.40

Table 3. Proportion of red sea urchins above 100 mm test diameter by subarea.

PFMA and Subarea	Urchins Measured	Prop. over 100 mm
1-1	198	0.41
1-2	1,048	0.47
1-3	547	0.69

Table 4. Red sea urchin biomass estimates by PFMA and subarea.

PFMA and Subarea	Number of Transects	Total Urchins	Number of Quadrats	Estimated Density (#/m^2)	Estimated SE of Density (#/m^2)	Estimated Area of Harvesting (km^2)	Estimated Total Urchins (10^6)	Prop. >100 mm	Estimated Urchins >100 mm (10^6)	Estimated SE of Urchins >100 mm (10^6)
1-1	5	2,674	769	3.48	0.82	24.84	86.44	0.41	35.44	8.35
1-2	15	10,605	1,810	5.86	1.02	7.45	43.66	0.47	20.42	3.57
1-3	16	2,877	1,826	1.58	0.41	25.11	39.37	0.69	27.37	7.10
1-7	9	2,298	2,880	0.80	0.31	18.91	15.13	0.69	10.44	4.10
Total	45	18,454	7,285			76.31	184.90		93.77	12.22

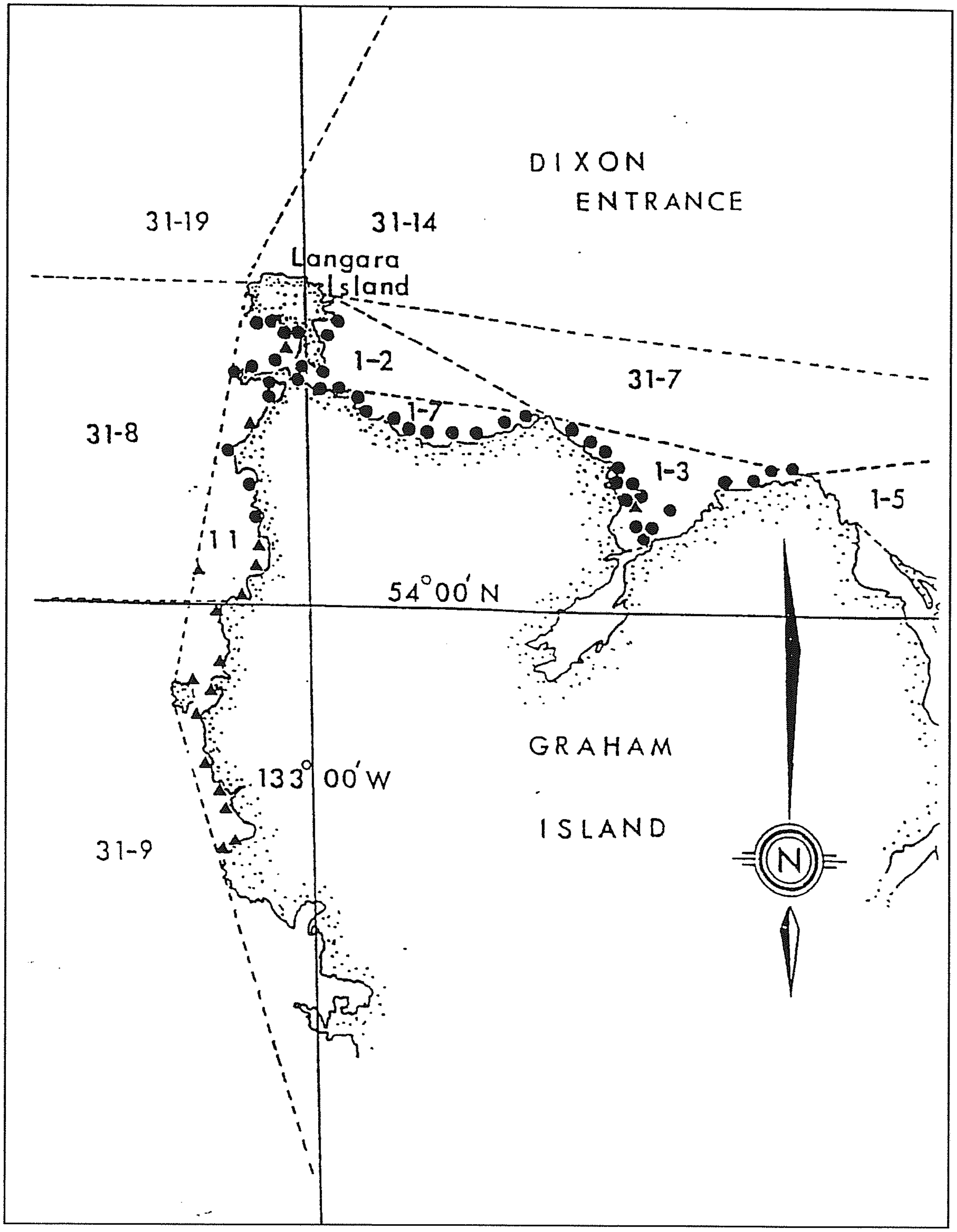


Fig. 1. Map showing area surveyed. Dots = transects surveyed; triangles = transects not surveyed because of unfavourable conditions.

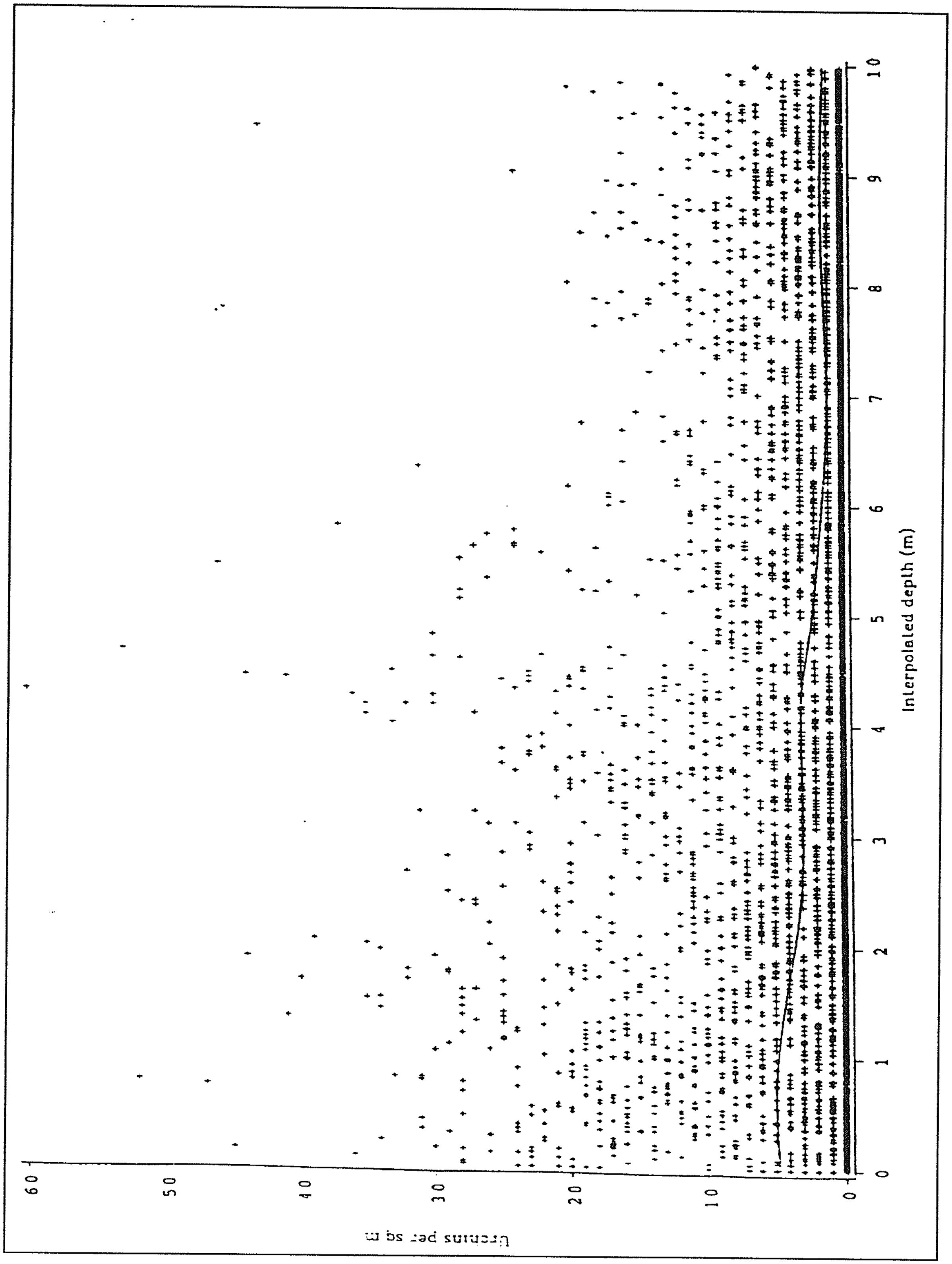


Fig. 2a. Plots of urchin count by interpolated depth (meters below Chart Datum) for the entire plot surveyed.

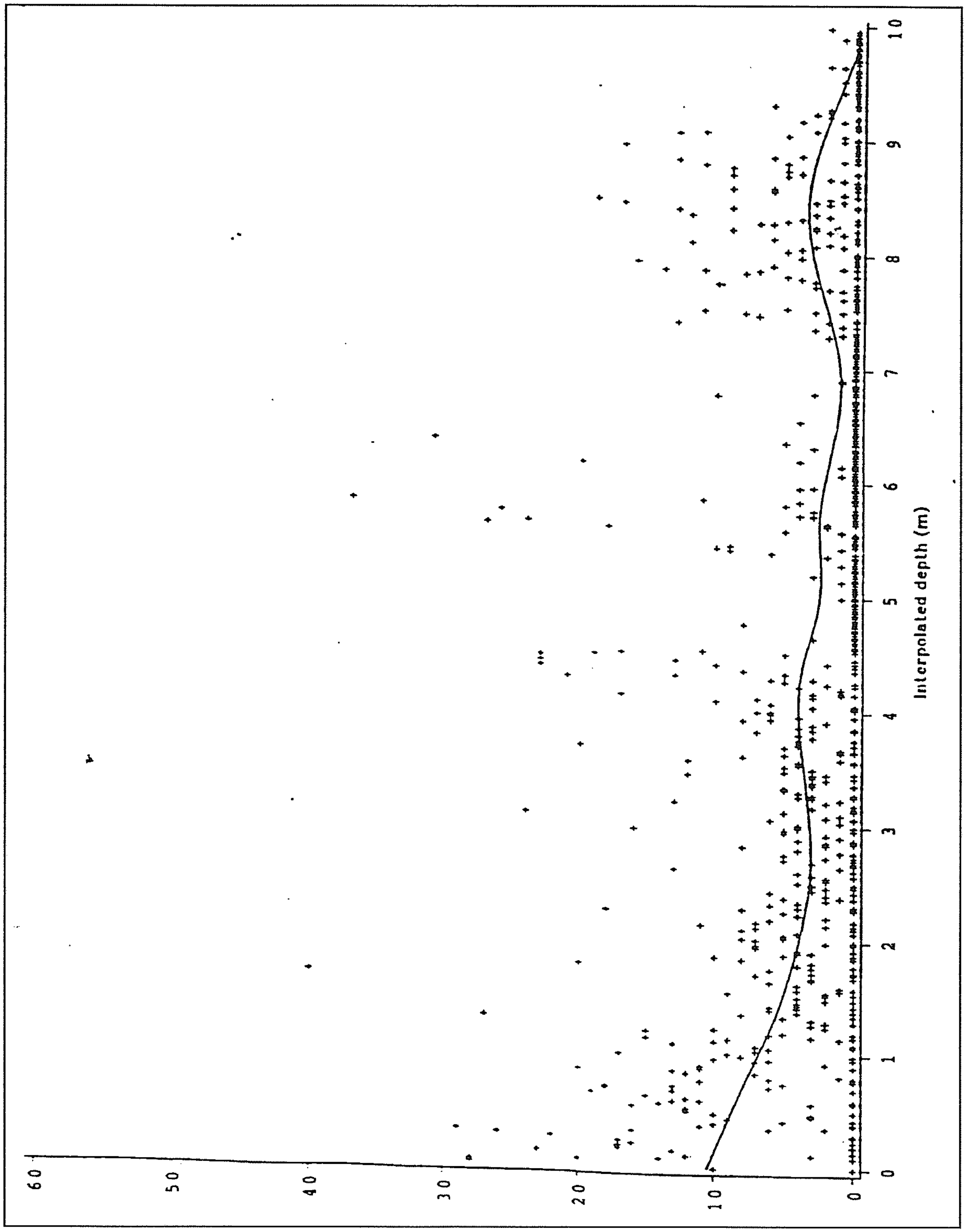


Fig. 2b. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 1-1.

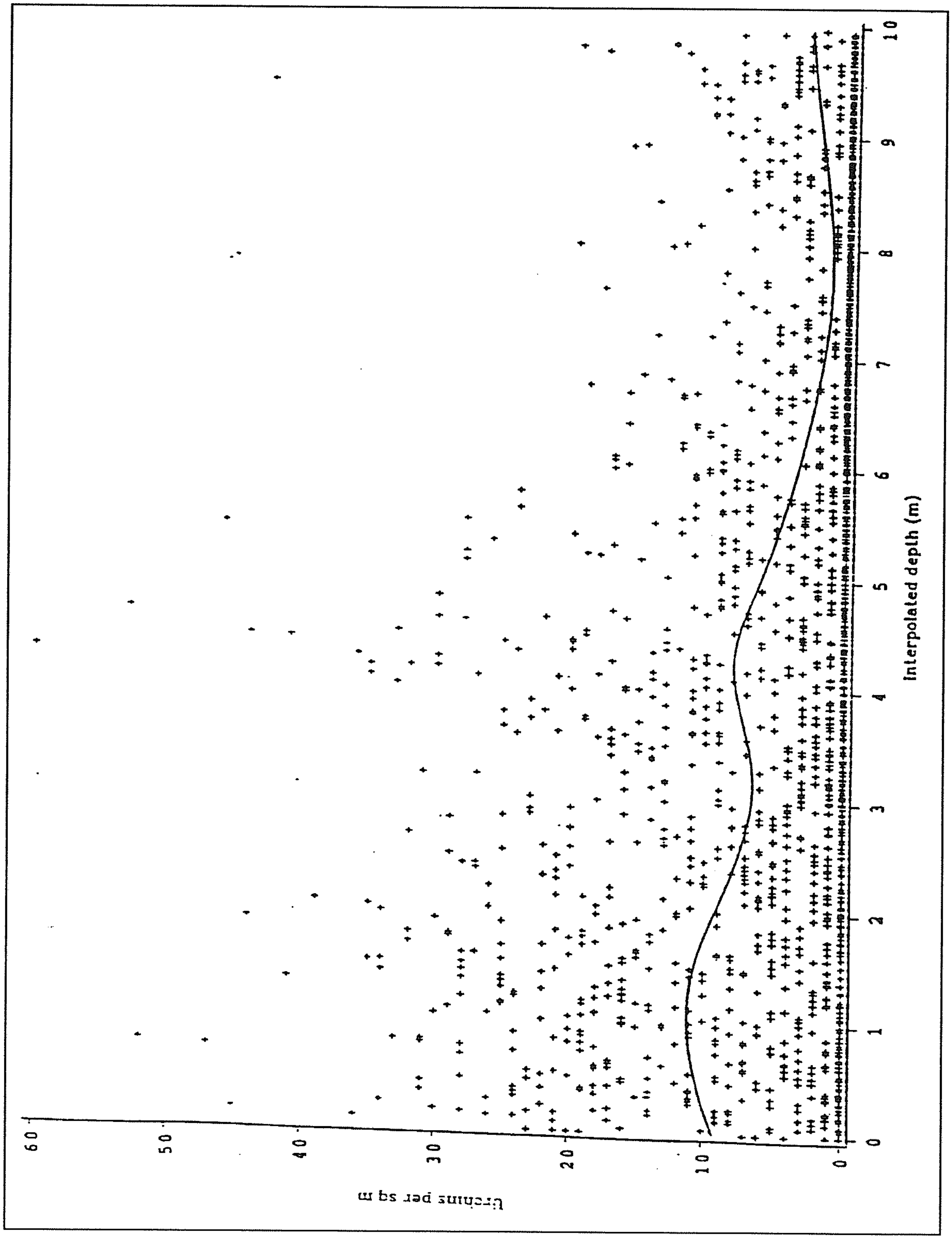


Fig. 2c. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 1-2.

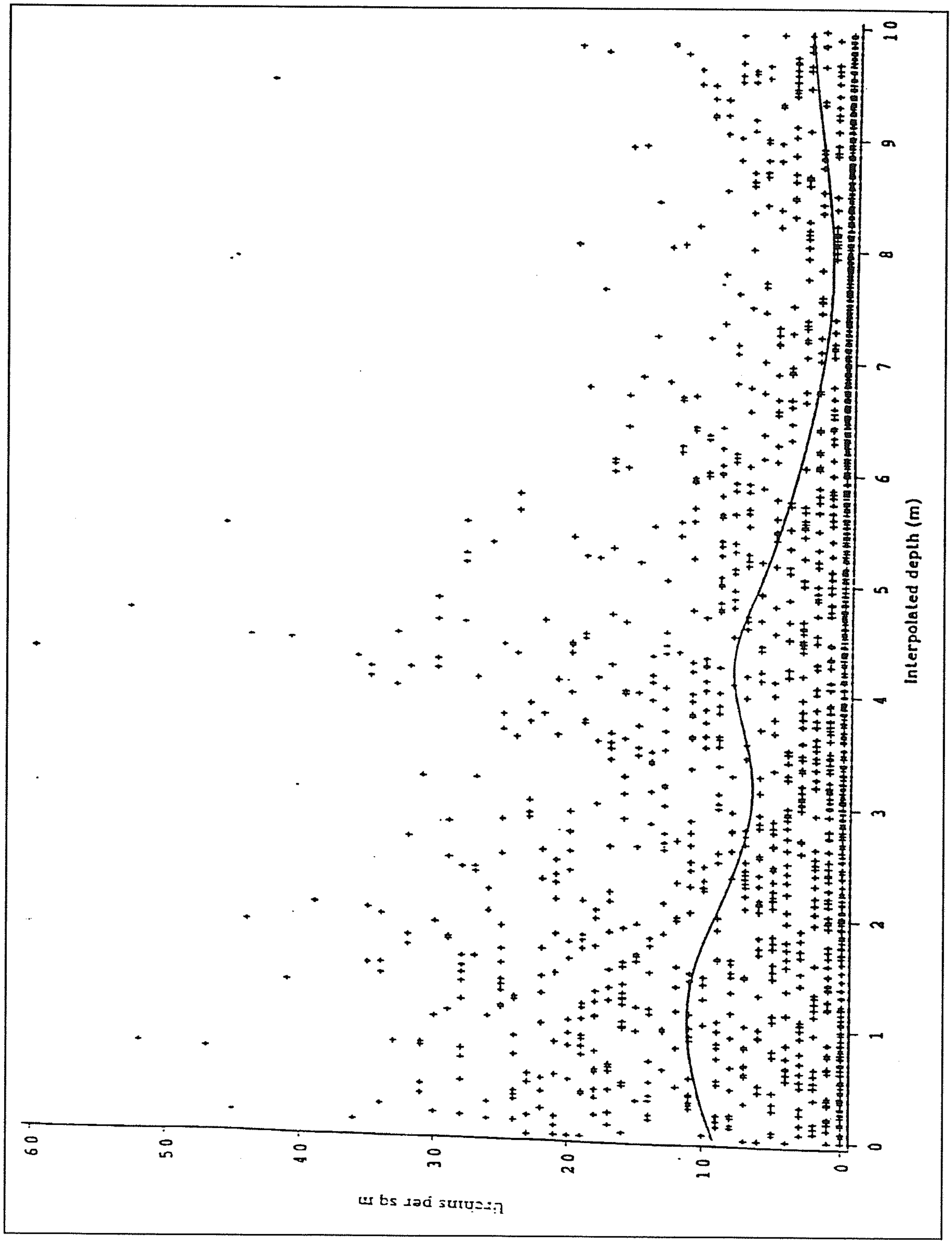


Fig. 2d. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 1-3.

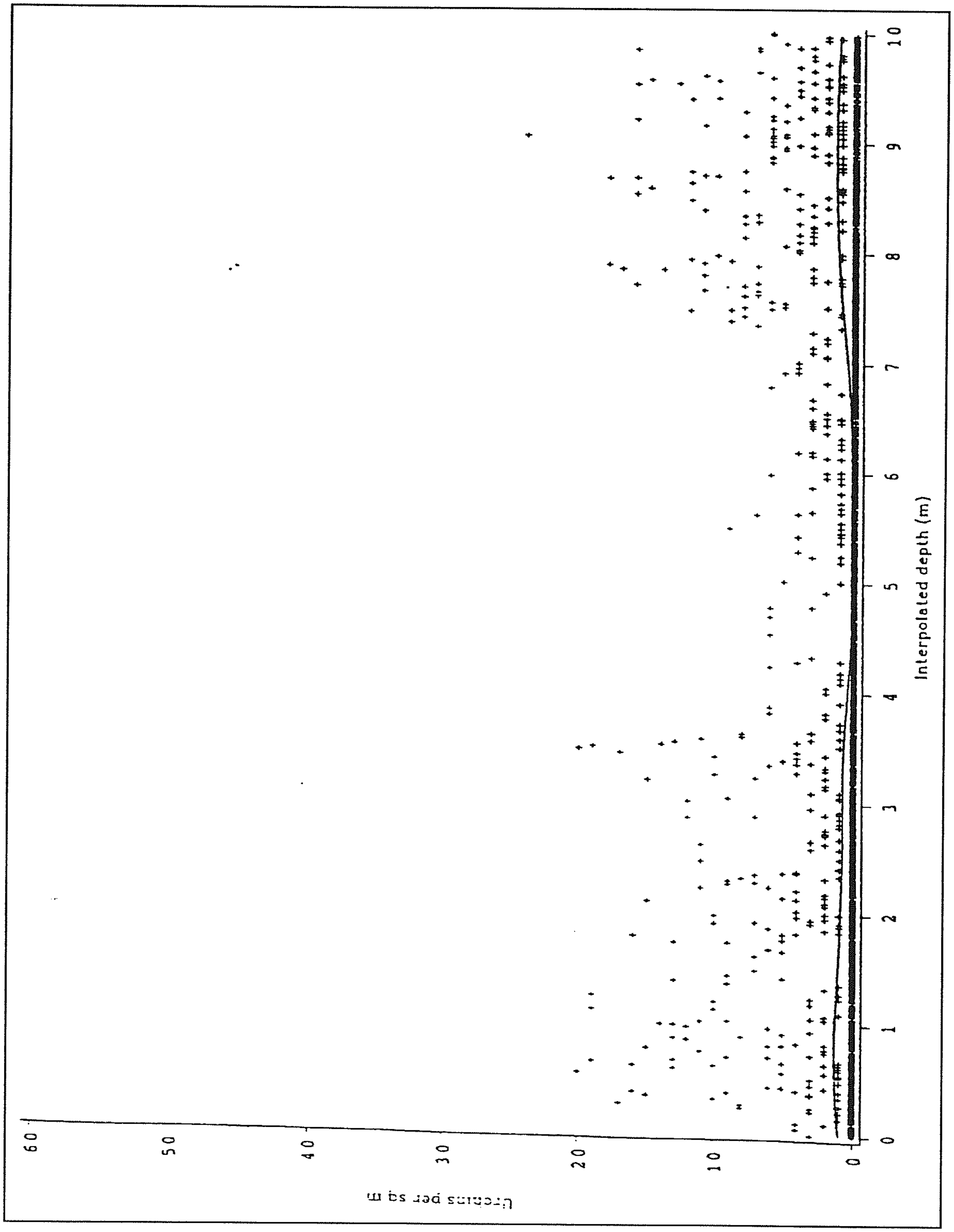


Fig. 2e. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 1-7.

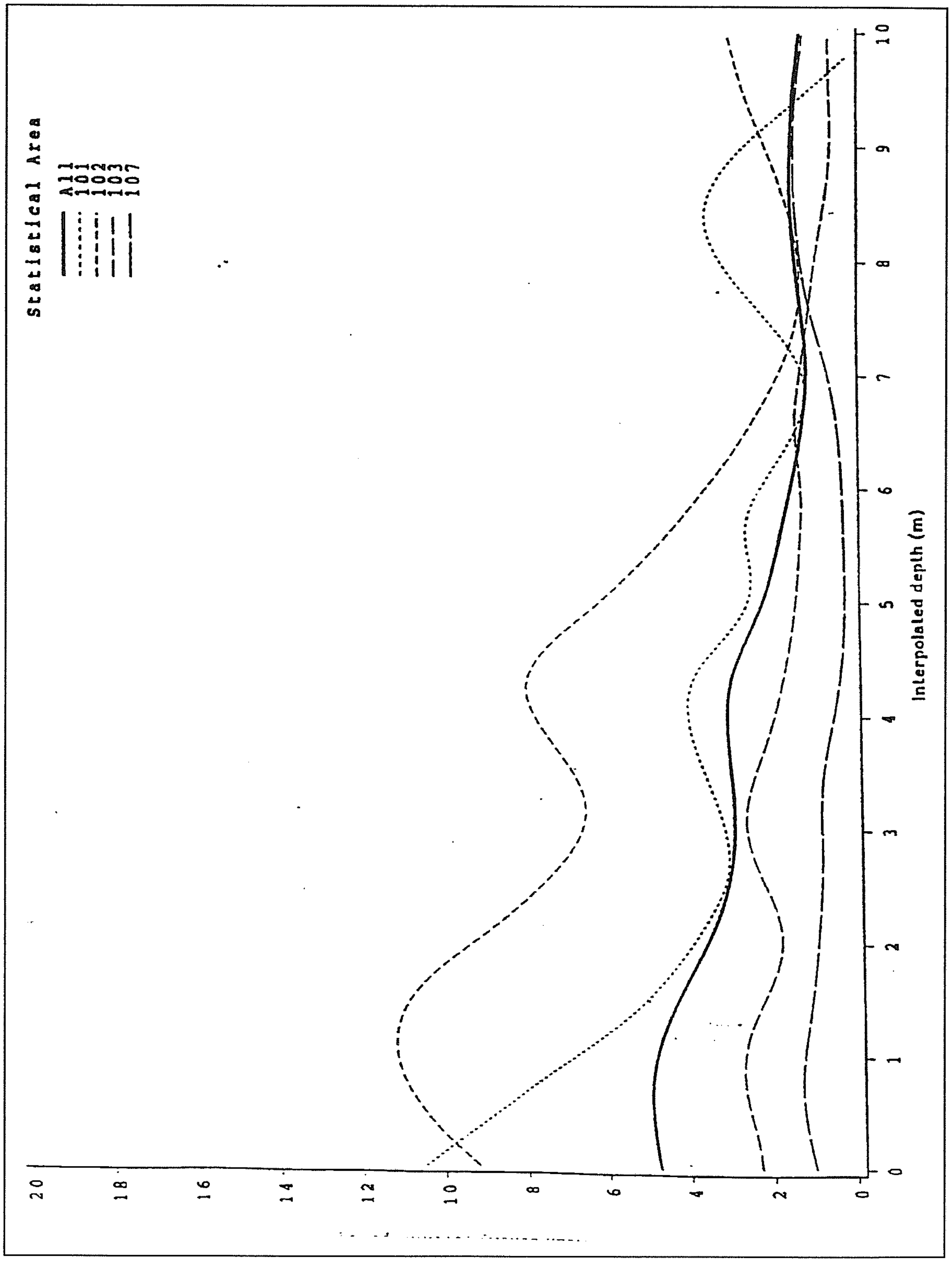


Fig. 2f. A comparison of all smoothed curves presented in Figs. 2a to 2e.

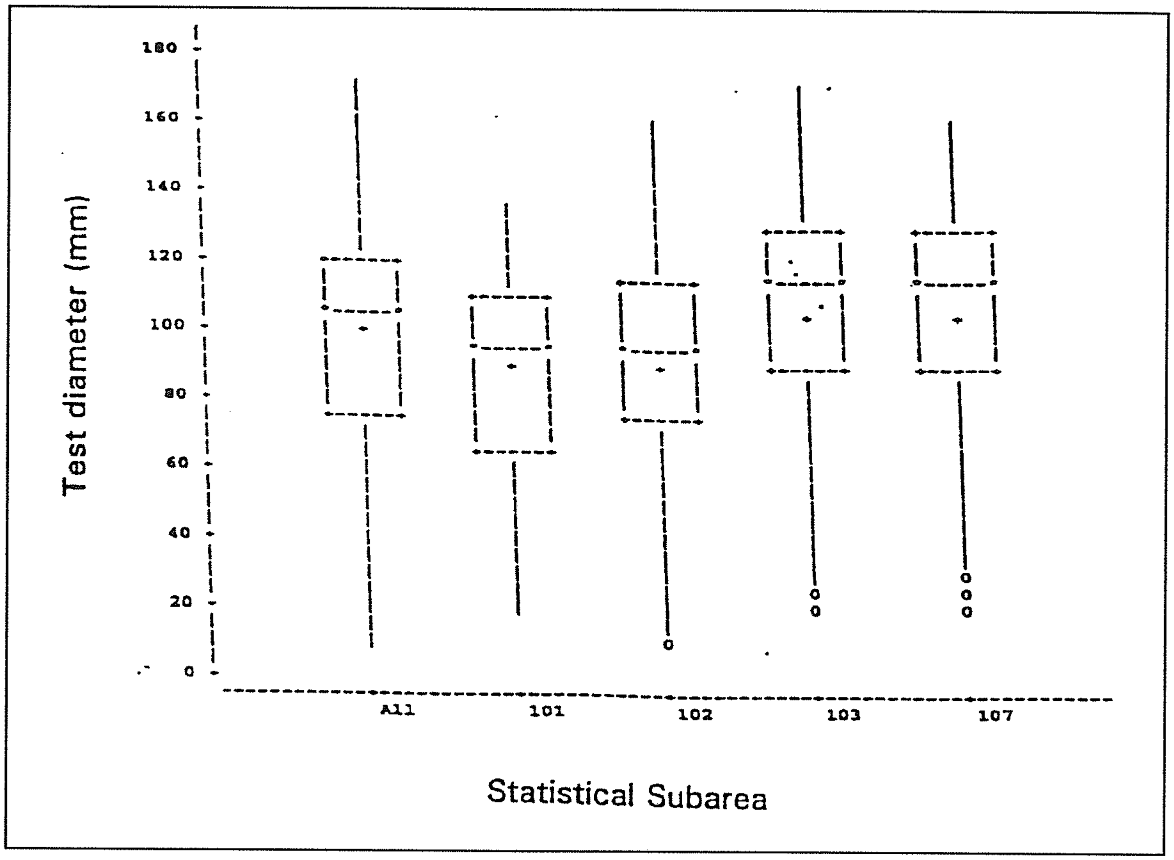
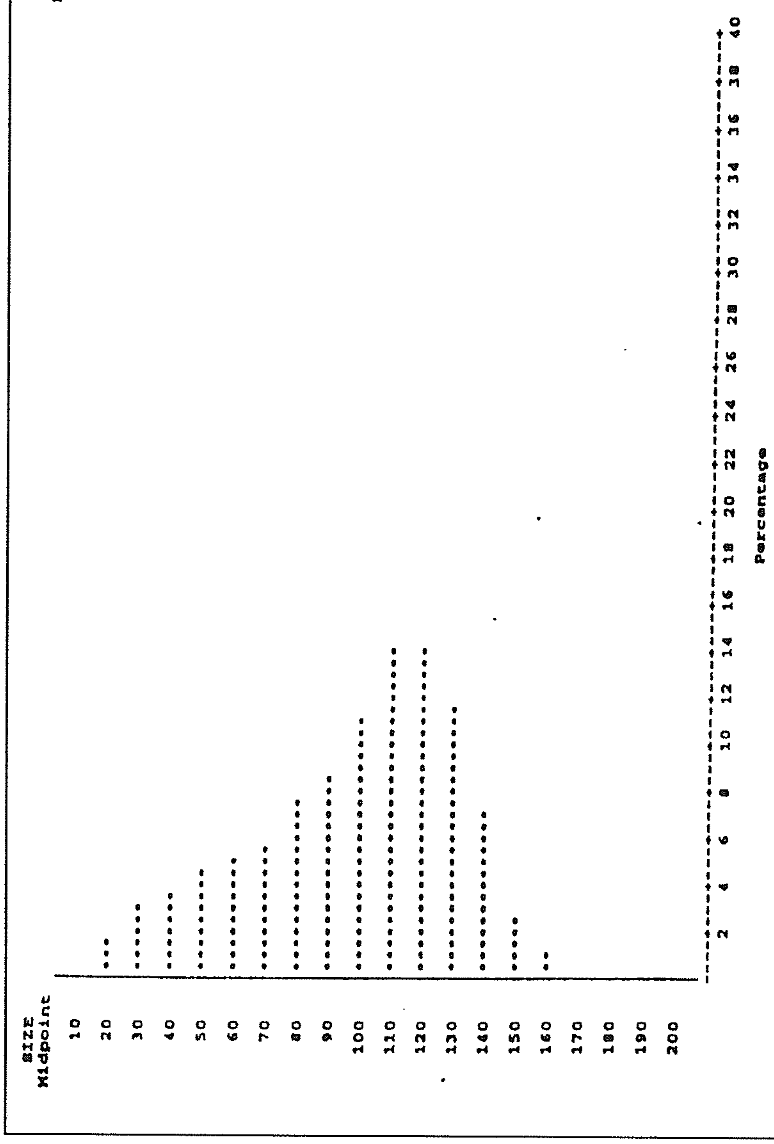


Fig. 3. Side-by-side box plots of size distributions by subarea. The solid line shows the approximate size range of the 95% of urchins, assuming a normal distribution (O's are the outliers); the bottom, mid-line and top lines of the box plot show the 25, 50, and 75% quantiles (i.e., 50% of the urchins are within the box, by count); and the "+" shows the mean size value. (Statistical subareas: 101 = PFMA 1-1; 102 = PFMA 1-2; 103 = PFMA 1-3; 107 = PFMA 1-7).



SIZE Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
10	5	5	0.22	0.22
20	33	38	1.48	1.70
30	68	106	3.05	4.75
40	83	189	3.72	8.47
50	96	285	4.30	12.77
60	108	393	4.84	17.61
70	125	518	5.60	23.21
80	163	681	7.30	30.51
90	194	875	8.69	39.20
100	250	1125	11.20	50.40
110	314	1439	14.07	64.47
120	309	1748	13.84	78.32
130	253	2001	11.34	89.65
140	152	2153	6.81	96.46
150	52	2205	2.33	98.79
160	24	2229	1.08	99.87
170	3	2232	0.13	100.00
180	0	2232	0.00	100.00
190	0	2232	0.00	100.00
200	0	2232	0.00	100.00

Fig. 4. Size frequency distribution for all urchins measured in this survey.

Analysis of 1994 Red Sea Urchin Surveys Conducted in Heiltsuk Traditional Territory, Pacific Fishery Management Area 7, Subareas 18 and 25

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ABSTRACT

Jamieson, G.S., W. Sandoval, C.J. Schwarz, C. Taylor, and R. Routledge. 1998. Analysis of 1994 red sea urchin surveys conducted in Heiltsuk Traditional Territory, Pacific Fishery Management Area 7, subareas 18 and 15. pp. 19-31. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Collaborative red sea urchin surveys were conducted in 1994 by Fisheries and Oceans Canada, the Pacific Underwater Harvesters Association and the Heiltsuk Fisheries Program. A broad-brush survey was carried out in Pacific Fishery Management Area 7, subareas 18 and 25. By subarea, estimated densities ranged from 2.84-3.25 urchins/m^2, and the estimated total number of legal-sized urchins was 28.4 million in 27.3 km^2. Analyses of data using revised 1993 procedures indicated that the previous methodology overestimated densities relative to those produced with the 1994 analytical methods. It was noted that the total number of legal-sized urchins present does not represent the number of urchins available to the fishery, since only urchins in densities greater than an unknown threshold level may be economically exploited. Many legal-sized urchins may be at such a low density that it may not be economical to harvest them.

INTRODUCTION

A survey was conducted in Pacific Fishery Management Area (PFMA) 7 on the coast of British Columbia in 1994 to estimate the abundance of the red sea urchin (*Strongylocentrotus franciscanus*) in the 0-10 m below Chart Datum in areas identified to be of particular interest. These surveys were conducted under informal partnership agreements between Fisheries and Oceans Canada (DFO), the Pacific Urchin Harvesters Association (PUHA), and the Heiltsuk Fisheries Program (HFP).

An intensive survey was designed to cover an area identified from the 1993 survey to have an abundance of red sea urchins.

The survey protocol for the 1994 survey was modified from that used in 1993 because of concerns expressed over the way in which the data were collected (G.S. Jamieson, unpublished manuscript). The 1994 survey protocol is reviewed in more detail in Jamieson and Schwarz (1998).

Briefly, the 1994 survey protocol was conducted by selecting a systematic sample (with a random start location) of positions along the shoreline in areas identified as potential harvesting areas. A strip transect was then surveyed, starting at Chart Datum and running perpendicular to shore. Divers rolled a 1 m^2 quadrat along the ocean floor from 0 m to 10 m below Chart Datum, counting the number of urchins within each quadrat. Finally, on a randomly selected quadrat in every 2 m of depth surveyed (five samples per transect), the diameters of all urchins in the quadrat were measured.

Areas, in square kilometers, between Chart Datum and 10 m below Chart Datum were estimated from digitizing the largest scale hydrographic charts available.

This report evaluates the data and gives a summary of PFMA 7 observations by subarea.

METHODOLOGY

SURVEY PROCEDURES

In August-September, 1994, the HFP and PUHA jointly conducted a 12 day red sea urchin survey. Survey design and procedures were developed by Biological Sciences Branch, DFO, with the assistance of the Department of Mathematics and Statistics, Simon Fraser University. Locations for 84, randomly located transects in PFMA's 7-18 and 7-25 were identified *a priori* (Fig. 1), with 65 sites approximately equidistant around the shorelines of islands from the northwest corner of Stryker Island to Cultus Sound, including the Goose Island Group. Because of the large area between 0-10 m depth around the Gosling Rocks and the McMullin Group, the additional 19 stations at these two locations were selected with a different procedure, described below.

Three boats serving two dive teams were involved in the survey: KING CLAM (PUHA), TWILIGHT DAWN (HFP) and the jetboat COLUMBIA RANGER (HFP). The first two were live-aboard dive boats and the last was only for diving. One dive team consisted of one HFP diver and one PUHA diver, while the other dive team consisted of two HFP divers, including a biologist from the HFP. At the end of each day, the biologist ensured that that all sampling and data recording was properly completed.

During 9 days of diving, 54 of the 84 transects identified were surveyed, with the remaining ones not surveyed because: 1) seas were too rough to permit safe diving; or 2) there was insufficient time available. Excluded sites were mostly around Goose Island (3 of 9 transects surveyed) and the Gosling rocks (0 of 10 transects surveyed). All transects except those in the McMullin Group and Gosling Islands were linear transects, starting at Chart Datum and running perpendicular to shore to a depth of 10 m below Chart Datum. In the McMullin Group and Gosling Rocks, the areas were divided into east-west rows 100 m apart, with transects perpendicular to the rows, *i.e.,* north-south, randomly located in both rows and along the length of a row.

Divers swam along each transect, recording sea urchin and abalone (*Haliotus kamschatkana*) numbers by species in each 1 m^2 quadrat. Depth was also recorded for each quadrat. The quadrat was rolled along the bottom, so total quadrat number in each transect gives surveyed transect length. Distance from diver start and end locations was also estimated by either towing a current meter from a boat while it cruised this distance (if kelp beds were not in the way) or from the vessel's radar image.

RESULTS

ANALYSIS OF 1994 DATA USING REVISED 1993 ANALYTICAL PROCEDURES

Density estimates, obtained by using only the first half of the transect extending from Chart Datum down until three consecutive quadrats had zero urchins (Jamieson *et al.* 1998a), were larger than those obtained from using all the transect (Table 1). This was not unexpected because urchin densities are thought to be higher nearer the kelp line. This shows the overestimation bias of using the revised 1993 analytical procedures (Jamieson *et al.* 1998a) in density estimation, *i.e.*, of not including urchin counts in the lower part of the transect.

Density estimates obtained by using counts in the lower part of the transect, but setting them to zero, were smaller than the densities obtained from using all of the transects. Again, this was not unexpected, because some urchins occur in the second half of transects. This indicates that this 1993 reanalysis procedure (Jamieson *et al.* 1998a) produces underestimates of the true density.

SUMMARY OF 1994 OBSERVATIONS

Mean density was 3.45 and 2.84 urchins/m^2 in PFMA's 7-18 and 7-25, respectively. Plots of density change with depth were estimated for the overall area surveyed and for each constituent subarea (Figs. 2a-2d). Unfortunately, depth of each quadrat was not recorded, so an interpolated depth had to be computed. This was done by assuming that the first quadrat of a transect occurred at 0 m below Chart Datum and that the last quadrat occurred at 10 m below Chart Datum. A straight line interpolation was then used to assign a depth to each quadrat.

A smoothed curve was fitted to the densities using a spline smoother. This tracked the approximate mean density at each interpolated depth. Minor fluctuations in the curves may be artifacts of the smoothing process. Also, if there are few data points at an interpolated depth, this may affect the curve, as the curve is very sensitive to outliers.

Highest densities appeared to be near 0 m Chart Datum, with suggestion of another mode around 3-6 m depth. This may reflect the average transition depth from rock to sand because of a reduction in wave action.

Box plots of size distributions (Fig. 3) are given for the entire survey area and for each constituent subarea. Fig. 4 shows the size distribution by 10 mm groupings for the entire survey area. In contrast to PFMA 1 (Jamieson *et al.* 1998b), average size was well below 100 mm, which could be either the result of larger recent settlements of a removal of larger urchins by the fishery. Comparison of size frequencies between the areas surveyed in 1994 in PFMA 1 (Jamieson *et al.* 1998b) and PFMA 7 (Fig. 4) suggest that this reduction in mean size is a result of the fishery, since urchins above 100 mm test diameter seem disproportionately represented in the population at the largest sizes.

The proportion of urchins above 100 mm in diameter was estimated based upon samples of urchins measured in each subarea (Table 2). All subareas had sufficient urchins measured that imprecision in proportion above 100 mm is small relative to that induced by sampling transects.

From the above data, Table 3 provides overall biomass estimates by subarea. However, density of legal-sized urchins ultimately determines their availability to a fishery, and since these data are limited, actual availability of legal-sized urchins is not estimated.

DISCUSSION

This past year was only the second year in which red sea urchin surveys have been conducted in the North Coast. PFMA's 7-18 and 7-25, the Heiltsuk Traditional Territory surveyed in this study, was previously surveyed as part of a larger broad-brush survey (G.S Jamieson and W. Sandoval, unpublished manuscript). This report presents a more intensive survey of the subareas indicated, which had been shown in the 1993 survey to have significant red sea urchin concentrations. However, survey work is quite time consuming, and while a much smaller area was surveyed in 1994, the area was still large. Estimated shoreline distances were 88.4 and 139.8 km in each subarea, respectively, with additional areas of 9.76 and 21.9 km^2 in the McMullin Group and Gosling Rocks, respectively. Transects were thus still quite far apart, being 4.91 and 5.18 km apart in PFMA's 7-18 and 7-25, respectively. With only 54 transects done in a two week period, and with each transect 1 m wide, this means that only 54 m of the estimated 228.2 km of shoreline was surveyed. While the locations chosen were randomized, habitat variability and the contagious distribution of urchins both ensure that although the best data currently available, the data presented here should be treated with considerable caution. Not only are they a snapshot in time, but the sparsity of data suggests that biomass estimates are only crude at best.

The analysis presented here is only a preliminary step in a process which will ultimately provide rationalization for annual red sea urchin quotas in the area. Production data, where growth and mortality rates are used to estimate yields, and better definition of areas logistically capable of being exploited by fishers, are required for determination of sustainable annual yield.

One data component not adequately considered in data collected to date is the availability of legal-sized urchins in concentrations which make them profitable to exploit. There may be a large biomass of legal-sized urchins in an area, but if their density is too low, then few may be operationally exploitable. To provide these data, both total urchin number and legal-size number will be recorded by depth for each quadrat in future surveys. In this survey, only five size frequency counts were made per transect, giving only 270 size frequencies for the whole survey. Given the depth range covered (only 54 size frequencies in each 2 m depth interval), an inadequate amount of data is considered to be currently available to extrapolate sustainable, exploitable legal-size biomass with acceptable accuracy.

ACKNOWLEDGEMENTS

We wish to thank all First Nation, industry and DFO employees who participated and assisted in data collection, editing and analysis. The success of this project depended on the enthusiastic and conscientious participation of a wide diversity of people, all primarily interested in conserving our urchin resources so that sustainable use of them can be maintained into the future.

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Jamieson, G.S. and C.J. Schwarz. 1998. Survey protocol considerations for 1995 sea urchin surveys. pp. 69-81. *In*: B.J. Waddell, G.E. Gillespie and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Table 1. Mean density estimates using all 1994 data. Only the first half of the transects, and assuming quadrats in the last half of the transects half zero urchin counts.

PFMA and Subarea	Mean Urchin Density Estimates (number/m^2)		
	All data	Shallowest Half	Last Half = 0
7-18	3.45	4.69	2.37
7-25	2.84	3.25	1.64

Table 2. Proportion of red sea urchins above 100 mm test diameter by subarea.

PFMA and Subarea	Urchins Measured	Prop. over 100 mm
7-18	765	.29
7-25	631	.40

Table 3. Red sea urchin biomass estimates by subarea.

PFMA and Subarea	# Trans	Total # Urchins	Total # Quad.	Est. Density (m^2)	Est. se of Density (m^{-2})	Area of Harvesting (km^2)	Est. Total Urchins (10^6)	Prop > 100 mm	Est. # Urchins >100 mm (10^6)	Est. se of # Urchins >100 mm (10^6)
7-18	25	4988	1520	3.28	0.79	14.06	46.1	.29	13.4	3.2
7-25	26	3726	1311	2.84	0.62	13.27	37.7	.40	15.1	3.3
Total	53	8714	2831				83.8		28.4	4.6

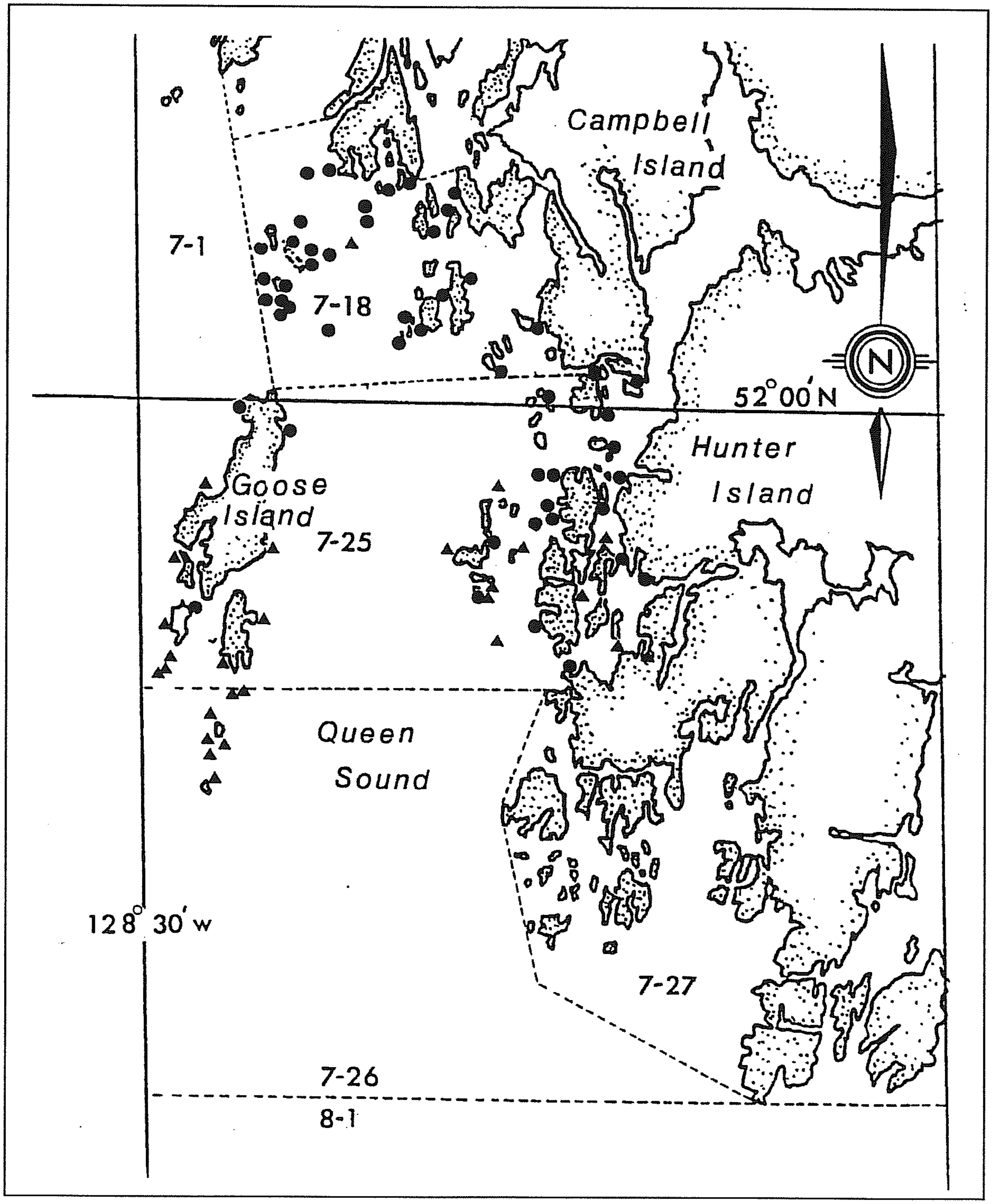


Fig. 1. Map showing area surveyed. Dots = transects surveyed; triangles = transects not surveyed because of unfavourable conditions.

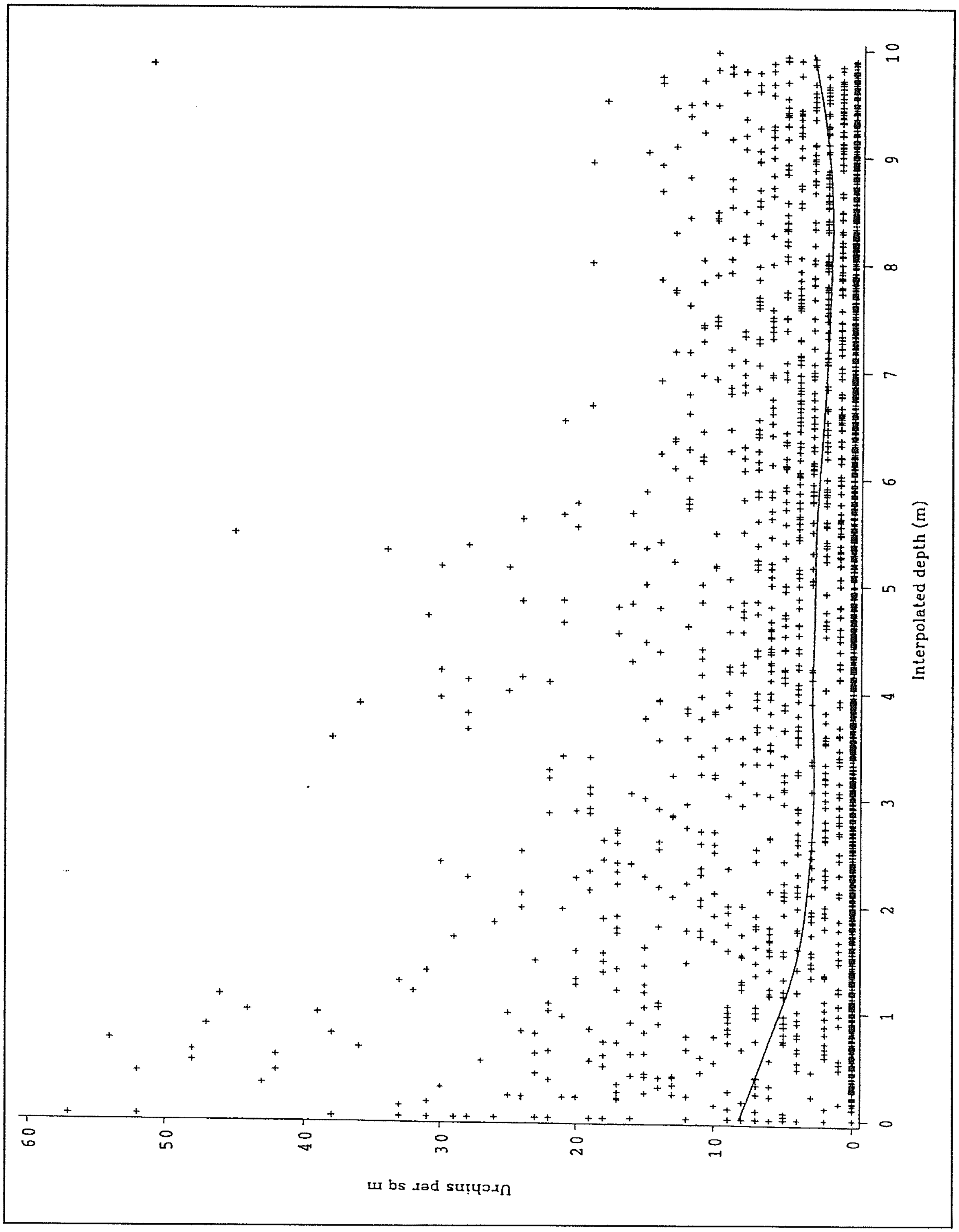


Fig. 2a. Plot of urchin count by interpolated depth (meters below Chart Datum) for the entire area surveyed (pooled).

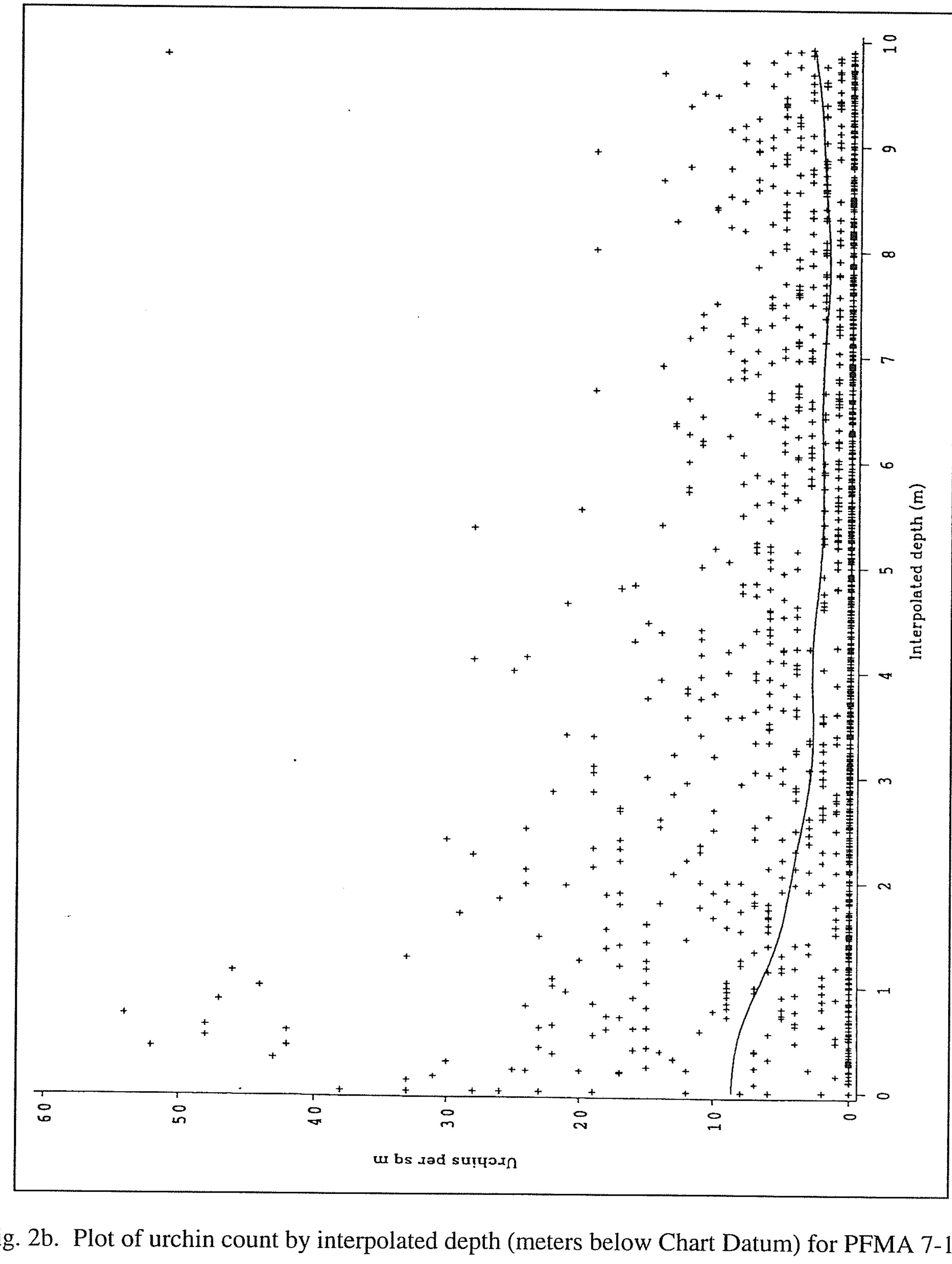


Fig. 2b. Plot of urchin count by interpolated depth (meters below Chart Datum) for PFMA 7-18.

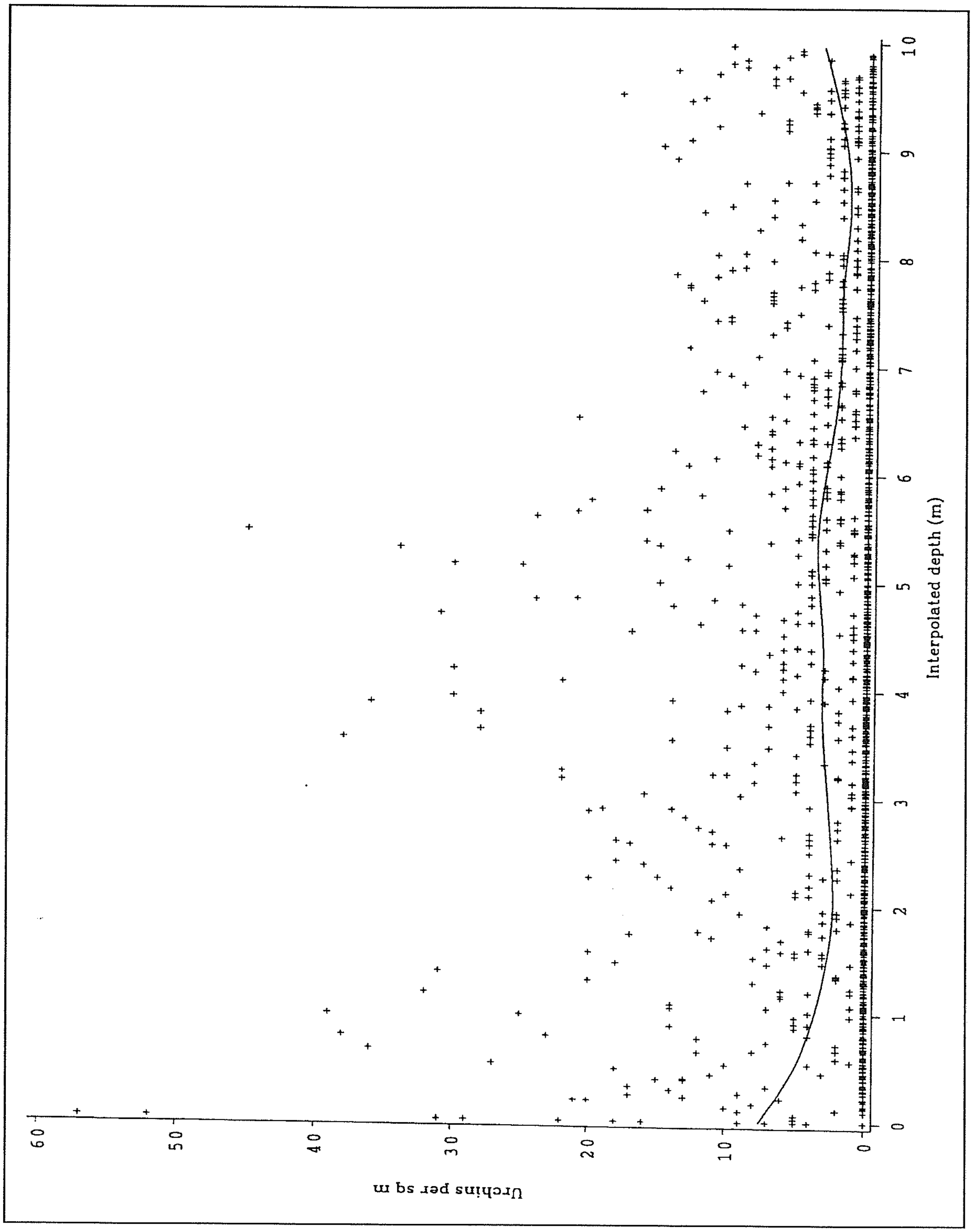


Fig. 2c. Plot of urchin count by interpolated depth (meters below Chart Datum) for PFMA 7-25.

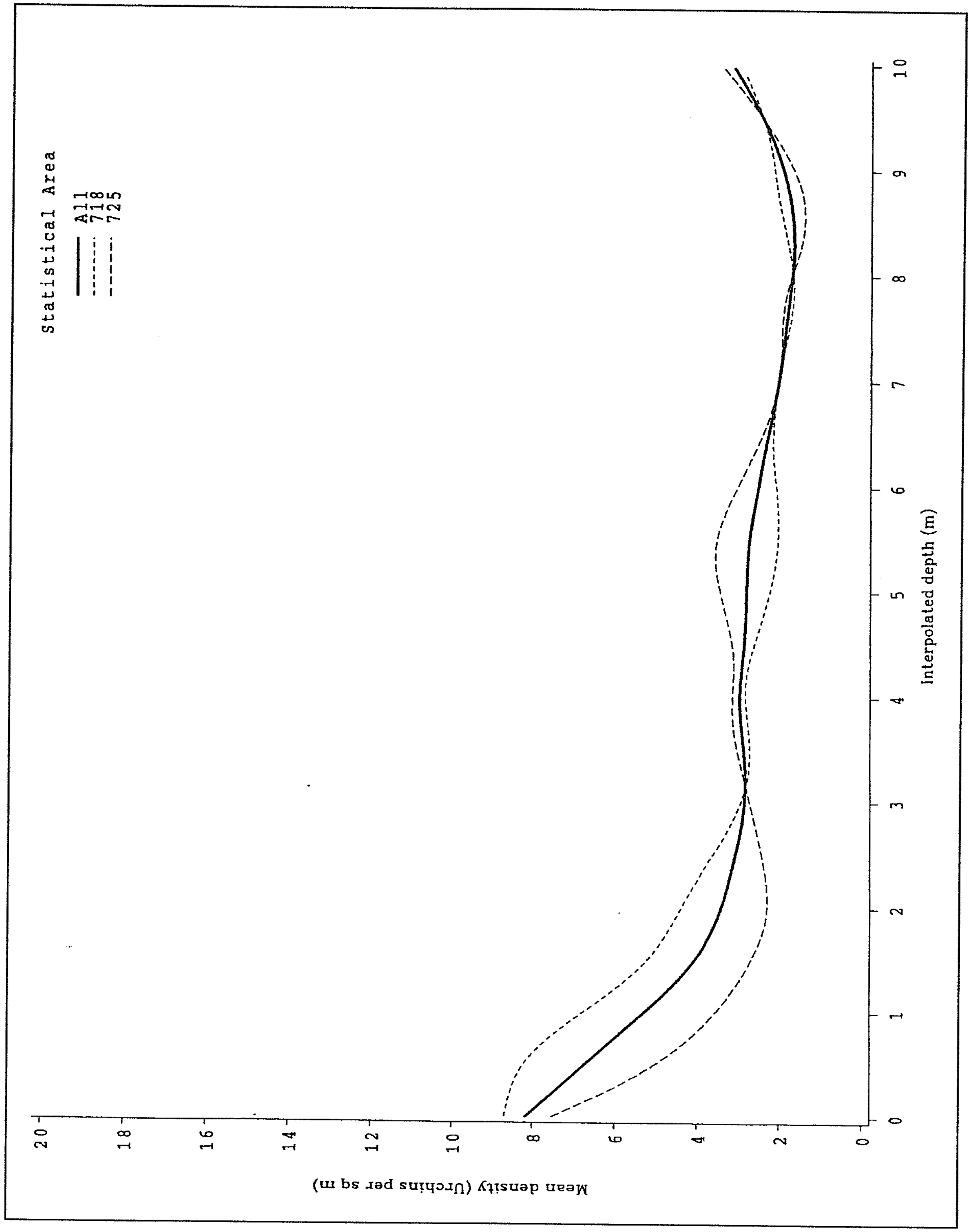


Fig. 2d. A comparison of all smoothed curves presented in Figs. 2a to 2c (mean).

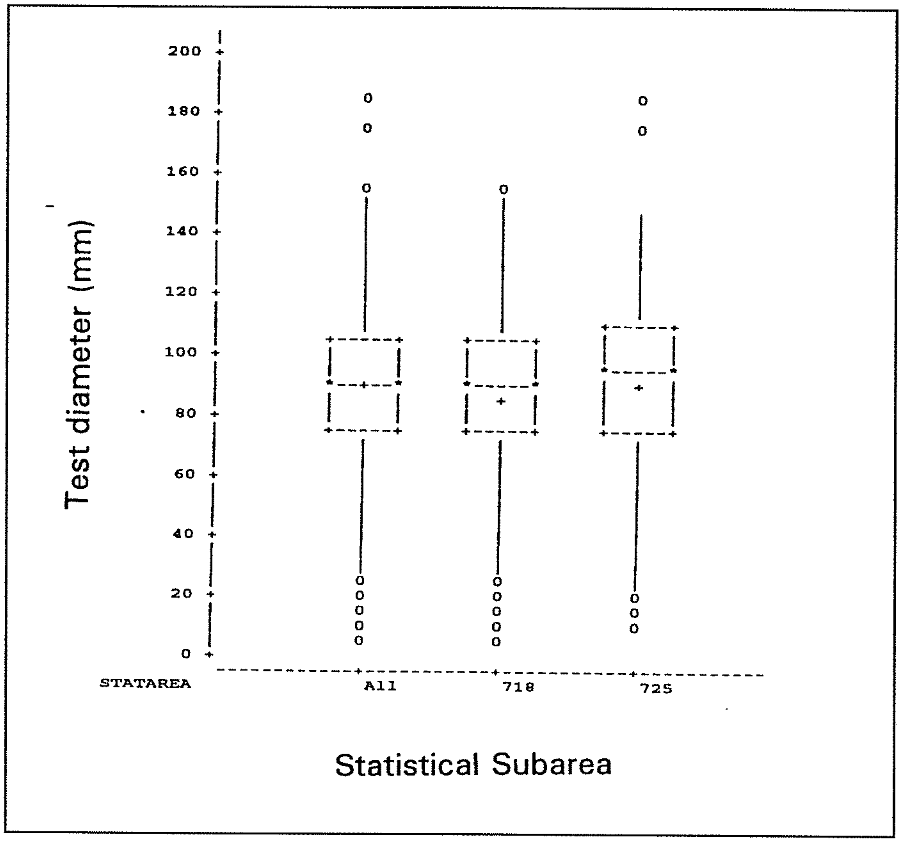
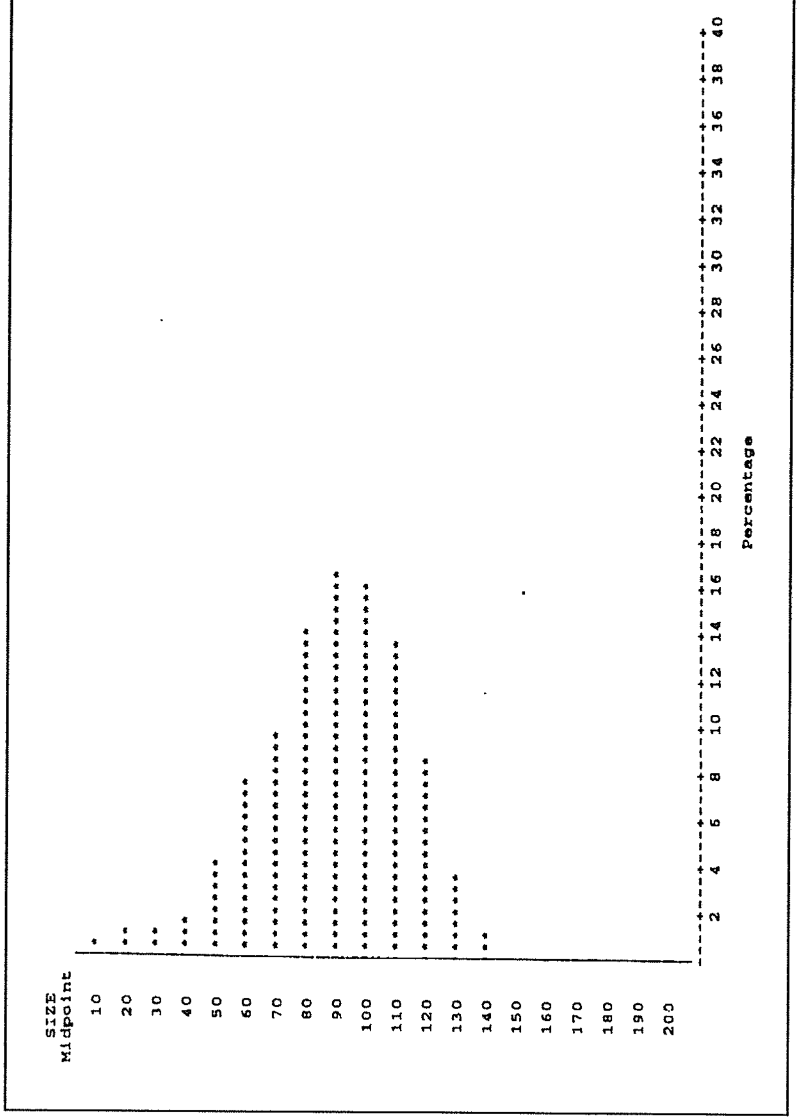


Fig. 3. Side-by-side box plots of size distributions by subarea. The solid line shows the approximate size range of 95% of urchins, assuming a normal distribution (O's are outliers); the bottom, mid-line and top lines of the box plot show the 25, 50 and 75% quantiles (i.e., 50% of the urchins are within the box, by count); and the "+" shows the mean size value. (Statistical Subareas: 718 = PFMA 7-18; 725 = PFMA 7-25).



SIZE Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
10	10	10	0.72	0.72
20	16	26	1.15	1.86
30	15	41	1.07	2.94
40	24	65	1.72	4.66
50	54	119	3.87	8.52
60	108	227	7.74	16.26
70	136	363	9.74	26.00
80	197	560	14.11	40.11
90	229	789	16.40	56.52
100	226	1015	16.19	72.71
110	190	1205	13.61	86.32
120	121	1326	8.67	94.99
130	46	1372	3.30	98.28
140	17	1389	1.22	99.50
150	3	1392	0.21	99.71
160	1	1393	0.07	99.79
170	2	1395	0.14	99.93
180	0	1395	0.00	99.93
190	1	1396	0.07	100.00
200	0	1396	0.00	100.00

Fig. 4. Size frequency distribution for all urchins measured in this survey.

Analysis of 1994 Red Sea Urchin Surveys Conducted in Aweena K'ola Traditional Territory, Subareas of Pacific Fishery Management Area 12

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ABSTRACT

Jamieson, G.S., G. Scharf, C.J. Schwarz, C.Taylor, and R. Routledge. 1998. Analysis of 1994 red sea urchin surveys conducted in Aweena K'ola Traditional Territory, subareas of Pacific Fishery Management Area 12. pp. 33-56. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Collaborative red sea urchin surveys were conducted in 1994 by Fisheries and Oceans Canada, the Pacific Underwater Harvesters Association and the Aweena K'ola Fisheries Program. A broad-brush survey was carried out in subareas of Pacific Fishery Management Area 12. By subarea, estimated densities ranged from 0.07-6.25 urchins/m^2, and the estimated total number of legal-sized urchins was 47.9 million in 89.9 km^2. It was noted that the total number of legal-sized urchins present does not represent the number of urchins available to the fishery, since only urchins in densities greater than an unknown threshold level may be economically exploited. Many legal-sized urchins may be at such a low density that it may not be economical to harvest them.

INTRODUCTION

A survey was conducted in Pacific Fishery Management Area (PFMA) 12 on the coast of British Columbia in 1994 to estimate the abundance of red sea urchins (*Strongylocentrotus franciscanus*) in the 0-10 m below Chart Datum in areas considered to have commercial fishery potential. This survey was conducted under informal partnership agreement between Fisheries and Oceans Canada (DFO), the Pacific Urchin Harvesters Association (PUHA), and the Aweena k'ola Fisheries Program (AFP). However, in this instance, PUHA was unable to participate because a commercial fishery was on-going at the time.

A broad-brush survey designed to cover a relatively large area was undertaken, as there were no prior data on sea urchin occurrence in this area.

The survey protocol for the 1994 survey was modified from that used in 1993 because of concerns expressed over the way in which the data were collected (G.S. Jamieson, unpublished manuscript). The 1994 survey protocol is reviewed in more detail in Jamieson and Schwarz (1998).

Briefly, the 1994 survey protocol was conducted by selecting a systematic sample (with a random start location) of positions along the shoreline in areas identified as potential harvesting areas. A strip transect was then surveyed, starting at Chart Datum and running perpendicular to shore. Divers rolled a 1 m^2 quadrat along the ocean floor from 0 to 10 m below Chart Datum, counting the number of urchins within each quadrat. Finally, on a randomly selected quadrat in every 2 m of depth surveyed (five samples per transect), the diameters of all urchins in the quadrat were measured.

Areas, in square kilometers, between Chart Datum and 10 m below Chart Datum were estimated from digitizing the largest scale hydrographic charts available.

This report evaluates the data and gives a summary of PFMA 12 observations by subarea.

METHODOLOGY

SURVEY PROCEDURES

In January-February, 1994, the AFP conducted a broad-brush red sea urchin survey. Survey design and procedures were developed by Biological Sciences Branch, DFO. Locations for 119 randomly located transects in 17 subareas in PFMA 12 were identified *a priori* by the Aweena k'ola, with sites approximately equidistant (1-2 nautical mile intervals) from the southeast portion of Johnstone Strait (east of Robson Bight) moving northeast on both sides of Queen Charlotte Strait to the Buckle Group (Fig. 1).

Three AFP boats serving two dive teams were involved in the survey: GALUDA II and two skiffs. There were two dive teams, with but initially, only one diver, a biologist, was experienced in SCUBA surveys. Consequently, a short training session was held by DFO to train divers in methodology prior to the survey. At the end of each day of surveying, the biologist ensured that all sampling and data recording was properly completed.

Survey procedures were slightly different from the others conducted in 1994 (Jamieson *et al.* 1998b, 1998c), since a full revision of the 1993 survey protocol had not yet been conducted. However, the protocol used was significantly improved from that used in 1993. Procedures were briefly as follows. After randomly selecting a location, divers either started at 15.4 m (50 ft) (regardless of tide and Chart Datum) or at Chart Datum and measured continuous quadrats along a transect perpendicular to depth isopleths. Divers recorded sea urchin and abalone (*Haliotus kamschatkana*) numbers by species in each 1 m^2 quadrat. Depth was also recorded for each quadrat. The quadrat was rolled along the bottom, so total quadrat number in each transect gives surveyed transect length. At every fifth quadrat, test diameters of all urchins in the quadrat were measured and data recorded (Table 1).

RESULTS

Analysis of 1994 Data Using Revised 1993 Analytical Procedures

Density estimates, obtained by using only the part of the transect extending from Chart Datum down until three consecutive quadrats had zero urchins (Jamieson *et al.* 1998a), were larger than those obtained from using all the transect (Table 2). This was not unexpected because urchin densities are thought to be higher nearer the kelp line. This shows the overestimation bias of using this revised 1993 analytical procedure (Jamieson *et al.* 1998a) in density estimation, *i.e.*, of not including urchin counts in the lower part of the transect.

Density estimates obtained by using counts in the lower part of the transect, but setting them to zero, were smaller than the densities obtained from using all of the transects. Again, this was not unexpected, because some urchins occur in the second half of transects. This indicates that this 1993 reanalysis procedure (Jamieson *et al.* 1998a) produces underestimates of the true density.

Summary of 1994 Observations

The overall geographical area surveyed in PFMA 12 (Fig. 1) consisted of many subareas which were either relatively small or which only had a portion of their areas considered to be habitat occupied by red sea urchins. Although a total of 17 subareas were sampled, many subareas had only a few transects in them. Consequently, for both statistical analysis and geographical proximity reasons, subareas were pooled (Table 2) to give a total of 9 pooled subareas (Table 3), including those subareas which only had transects directly from that subarea.

Area estimate measures in other 1993 and 1994 surveys (Jamieson *et al.* 1998b, 1998c; Jamieson and Schwarz 1998) were only of areas indicated by industry to be urchin habitat. In contrast, hydrographic charts of Area 12 had previously been digitized, and so initial area estimates (Table 4) from each chart were for the entire area between 0 to 10 m below Chart Datum by subarea. This included many inlets felt unlikely to have urchin habitat, and so a percentage of each subarea considered to be suitable for urchins was estimated (Table 4) by visual observation of the charts in relation to the areas surveyed by the Aweena k'ola.

By subarea, mean density ranged from 0.07-6.25 urchins/m^2 in the subareas surveyed. Plots of density change with depth were estimated for the overall area surveyed and for each constituent pooled subarea (Figs. 2a-2k). Unfortunately, depth of each quadrat was not recorded, so an interpolated depth had to be computed. This was done by assuming that the first quadrat of a transect occurred at 0 m below Chart Datum and that the last quadrat occurred at 10 m below Chart Datum. A straight line interpolation was then used to assign a depth to each quadrat.

A smoothed curve was fit to the densities using a spline smoother. This will track the approximate mean density at each interpolated depth. Minor fluctuations in the curves may be artifacts of the smoothing process. Also, if there are few data points at an interpolated depth, this may affect the curve, as the curve is very sensitive to outliers.

Except for PFMA 12, subarea 12, (PFMA 12-12) there was little evidence of a change in average urchin density with depth, in contrast to the Haida and Heiltsuk surveys (Jamieson *et al.* 1998b, 1998c, respectively). In PFMA 12-12, highest density was between 1 to 2 m below Chart Datum.

Box plots of size distributions (Fig. 3) are given for the entire survey area and for each constituent subarea. Figs. 4 and 5 give the size distributions by 10 mm groupings for the entire survey area and by depth (2 m groupings), respectively.

The proportion of urchins above 100 mm in diameter was estimated based upon the following samples of urchins measured in each subarea (Table 3). All subareas had sufficient urchins measured that imprecision in proportion above 100 mm is small relative to that induced by sampling transects.

From the above data, Table 5 provides overall biomass estimates by subarea. However, density of legal-sized urchins ultimately determines their availability to a fishery, and since these data are limited, actual availability of legal-sized urchins is not estimated.

DISCUSSION

This past year was only the second year in which red sea urchin surveys have been conducted in the North Coast. PFMA 12, the Aweena k'ola Traditional Territory surveyed in this study, has never been previously surveyed, and so this report presents the first data characterizing urchins in this area. Survey work is quite time consuming, with only 119 transects done in a two month period. Given that a total of 7,093 quadrats were sampled, this means that only 0.000079% m of the estimated 90 km^2 of area surveyed was sampled. While the locations chosen were randomized, habitat variability and the contagious distribution of urchins both ensure that although the best data currently available, the data presented here should be treated with considerable caution. Not only are they a snapshot in time, but the sparsity of data suggests that biomass estimates are only crude at best.

The analysis presented here is only a preliminary step in a process which will ultimately provide rationalization for annual red sea urchin quotas in the area. Production data, where growth and mortality rates are used to estimate yields, and better definition of areas logistically capable of being exploited by fishers, are required for determination of sustainable annual yield.

One data component not adequately considered in data collected to date is the availability of legal-sized urchins in concentrations which make them profitable to exploit. There may be a large biomass of legal-sized urchins in an area, but if their density is too low, then few may be operationally exploitable. To provide these data, both total urchin number and legal-size number will be recorded by depth for each quadrat in future surveys. In this survey, urchin size frequencies from 1,419 quadrats were measured, about 6 to 7 times the number measured in other 1994 surveys.

ACKNOWLEDGEMENTS

We wish to thank all First Nation, industry and DFO employees who participated and assisted in data collection, editing and analysis. The success of this project depended on the enthusiastic and conscientious participation of a wide diversity of people, all primarily interested in conserving our urchin resources so that sustainable use of them can be maintained into the future.

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Table 1. Number of size frequency counts by transect.

# Quadrats/Transect	# Transects	Percent	# Quadrats
1	13	16.7	13
2	10	12.8	20
3	17	21.8	51
4	10	12.8	40
5	15	19.2	75
6	10	12.8	60
7	1	1.3	7
9	1	1.3	9
10	1	1.3	10
Total	78	100	285

Table 2. Groupings of subareas to increase numbers of transects per subarea (transect totals by subarea in brackets).

Nominal PFMA and Subarea	Subreas Pooled
12-5	12-5 (10), 12-20 (2), 12-21 (2), 12-26 (1)
12-8	12-8 (4), 12-17 (2)
12-11	12-11 (15), 12-12 (1)
12-12	12-12 (2), 12-15 (2)
12-18	12-18 (18), 12-19 (3), 12-4 (1)

Table 3. Proportion of red sea urchins above 100 mm test diameter by pooled subarea (see Table 2).

PFMA and Subarea	Urchins Measured	Prop. over 100 mm
12-3	130	0.79
12-5	205	0.86
12-6	118	0.77
12-8	37	0.51
12-11	429	0.37
12-12	164	0.30
12-16	121	0.63
12-18	394	0.60
12-39	5	1.00

Table 4. Measured total chart area (square kilometers) between 0 to 10 m below Chart Datum and estimated area of each subarea inhabited by red sea urchins.

PFMA and Subarea	Total area from 0-10 m below Datum (km^2)	Estimated % suitable for urchins	Estimated area suitable for urchins (km^2)
12-3	2.64	60	1.59
12-4	0.79	100	0.79
12-5	3.29	100	3.29
12-6	18.82	100	18.82
12-8	7.39	100	7.39
12-11	8.04	40	3.22
12-12	6.39	45	2.87
12-15	13.40	10	1.34
12-16	12.03	93	11.19
12-17	3.41	100	3.41
12-18	9.70	100	9.70
12-19	7.78	100	7.78
12-20	0.62	100	0.62
12-21	0.79	100	0.79
12-39	12.38	100	17.10
Total	107.47		89.90

Table 5. Red sea urchin biomass estimates by subarea.

PFMA and Subarea	# Trans.	Total # Urchins	Total # Quad.	Est. Density (m^{-2})	Est. se of Density (m^{-2})	Area of Harvesting (km^2)	Est. Total Urchins (10^{-6})	Prop. >100 mm	Est. # Urchins >100 mm (10^{-6})	Est. se of Urchins >100 mm (10^{-6})
12-3	8	591	277	2.13	0.69	1.59	3.38	0.80	2.70	0.88
12-5	15	1,015	695	1.48	0.29	4.70	6.86	0.86	5.90	1.17
12-6	17	522	1,380	0.38	0.13	18.82	7.12	0.77	5.48	1.88
12-8	6	356	928	0.38	0.27	10.80	4.14	0.51	2.11	1.49
12-11	16	2,303	583	3.95	0.72	3.22	12.71	0.39	4.96	0.88
12-12	4	788	126	6.25	2.38	4.21	26.35	0.30	7.91	3.01
12-16	19	706	1,194	0.50	0.24	11.19	6.62	0.63	4.17	1.69
12-18	22	1,561	1,265	1.23	0.31	18.26	22.54	0.60	13.52	3.40
12-39	11	45	645	0.07	0.06	17.10	1.19	1.00	1.19	1.03
Total	118	7,093	7,093			89.89	90.91		47.94	5.76

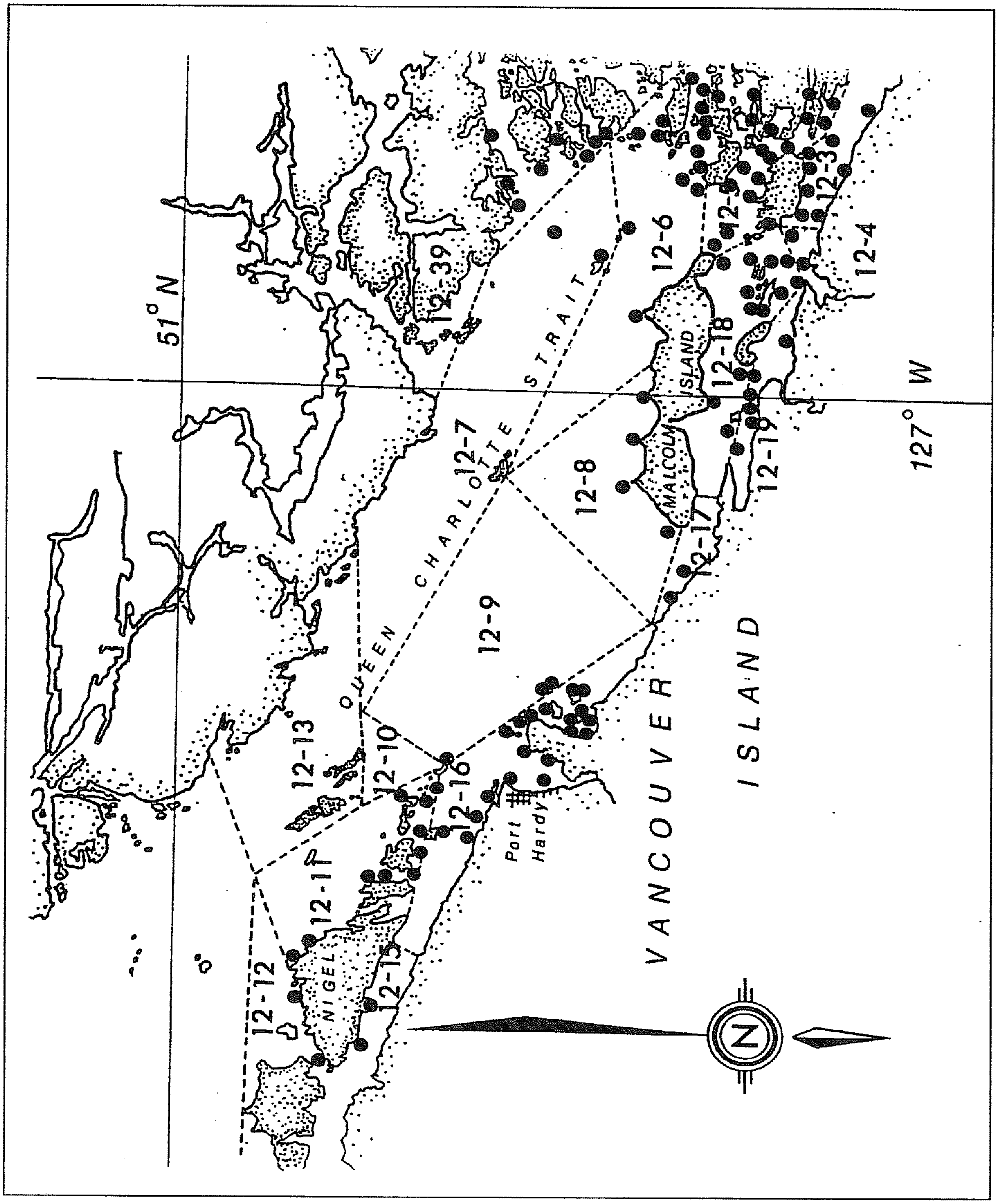


Fig. 1. Map showing area surveyed. Dots = transects surveyed; triangles = transects not surveyed because of unfavourable conditions.

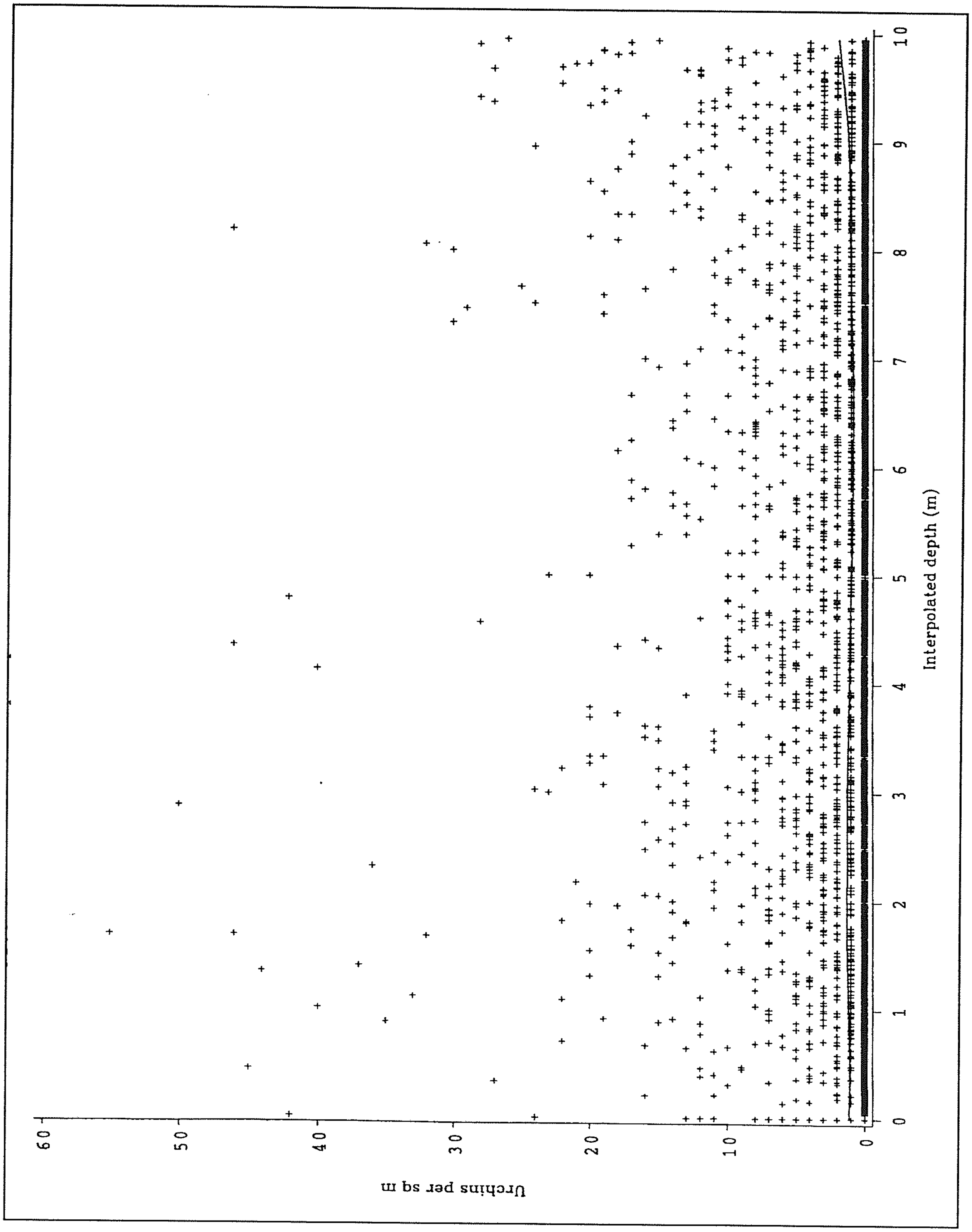


Fig. 2a. Plots of urchin count by interpolated depth (meters below Chart Datum) for the entire area surveyed (pooled).

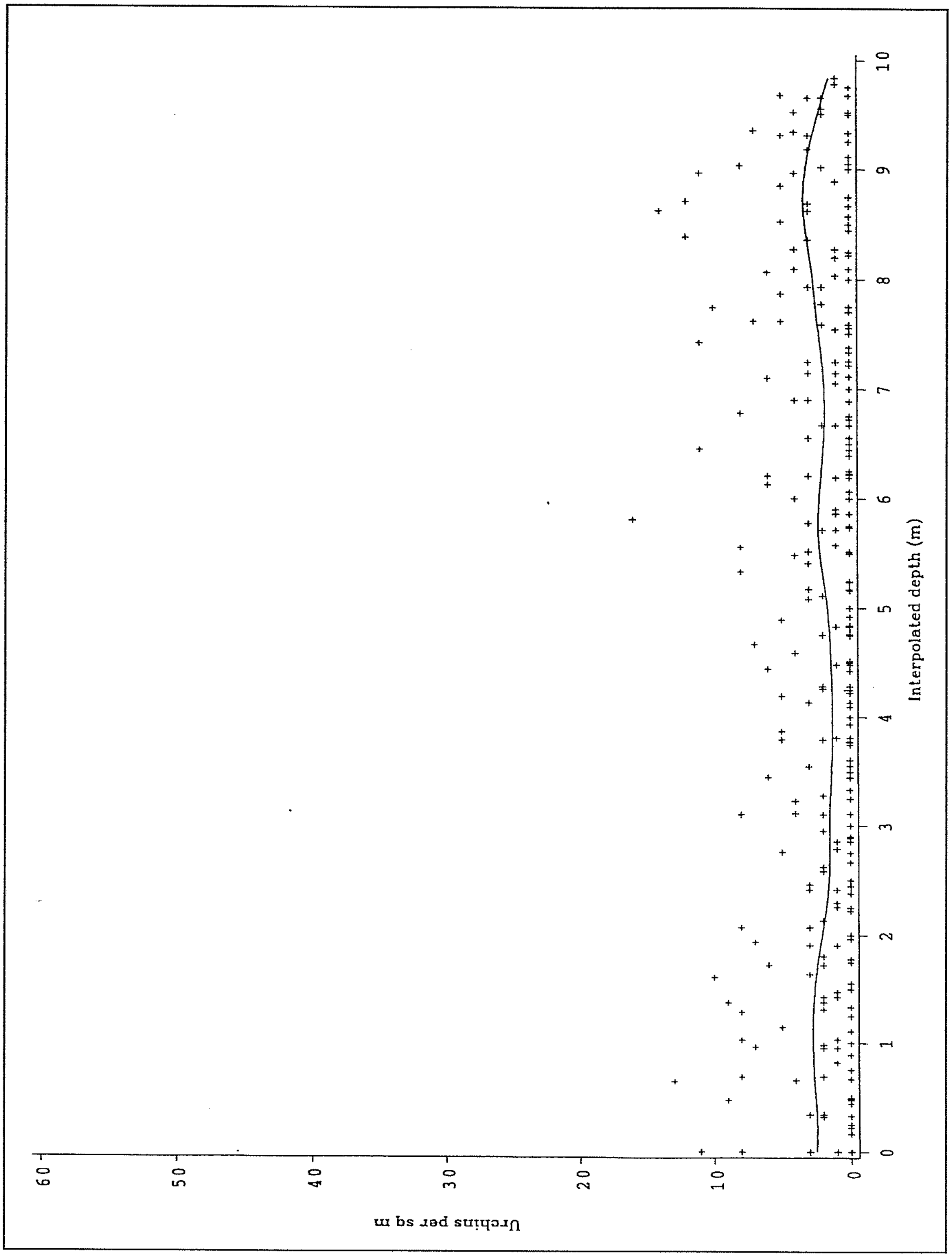


Fig. 2b. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-3.

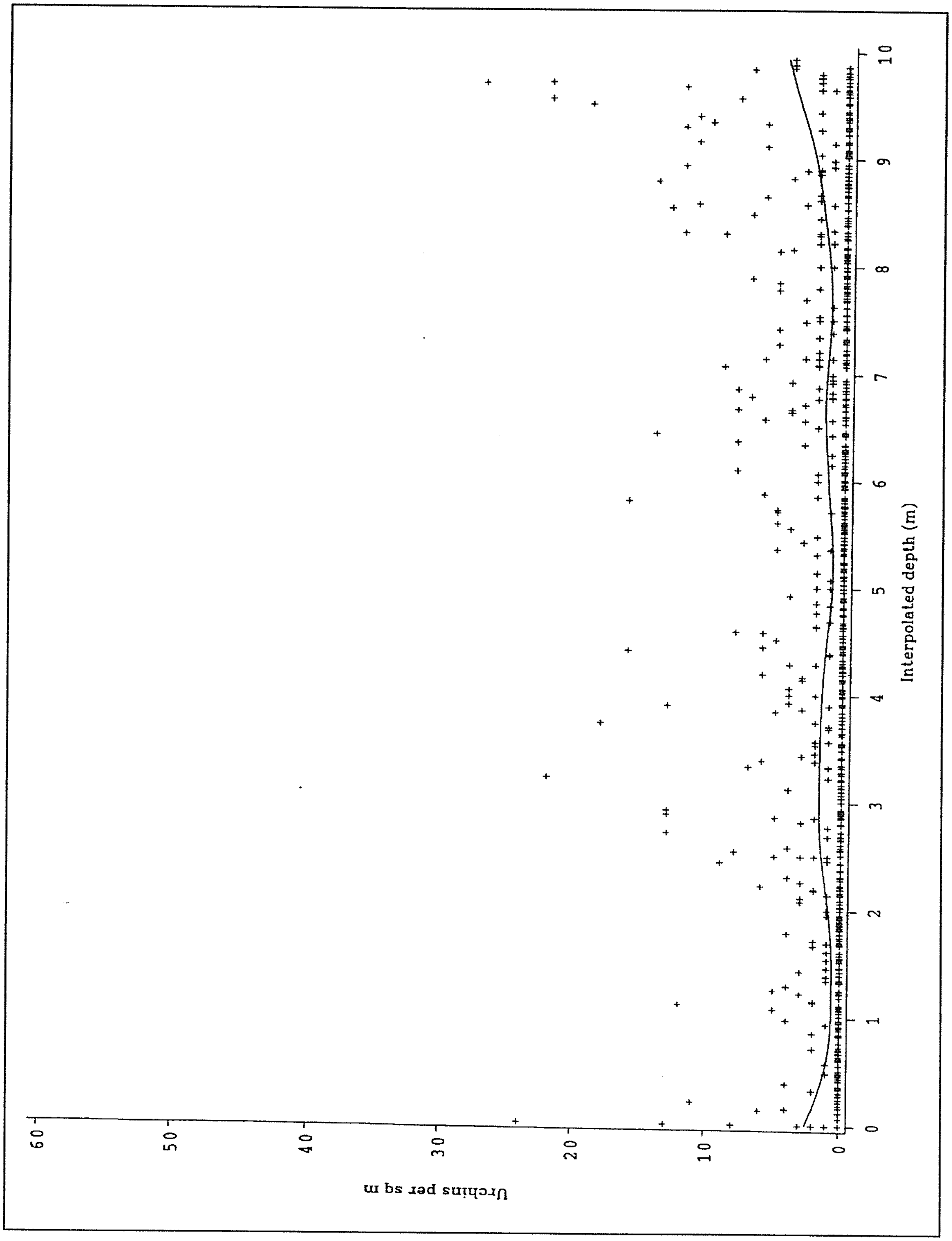


Fig. 2c. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-5.

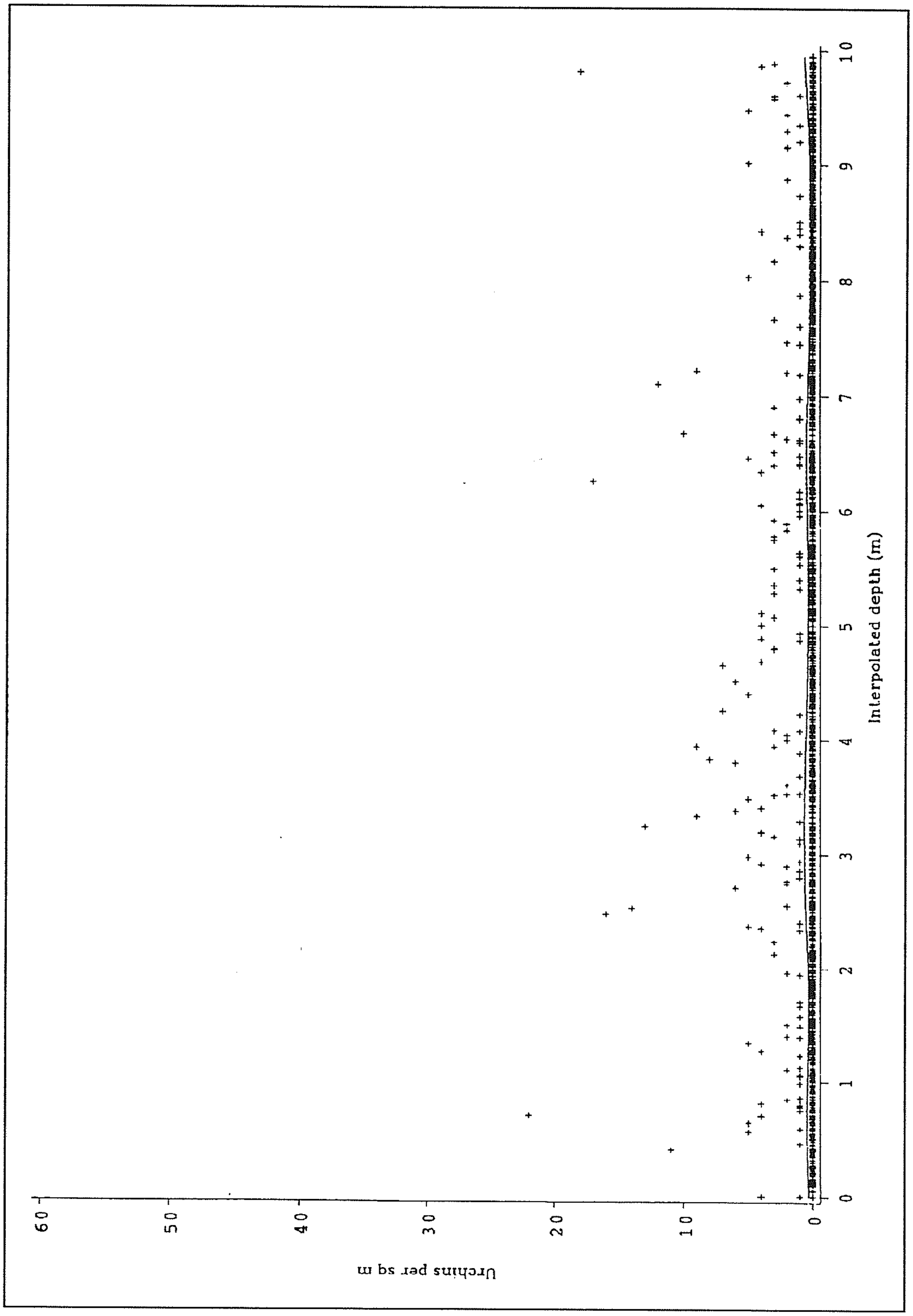


Fig. 2d. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-6.

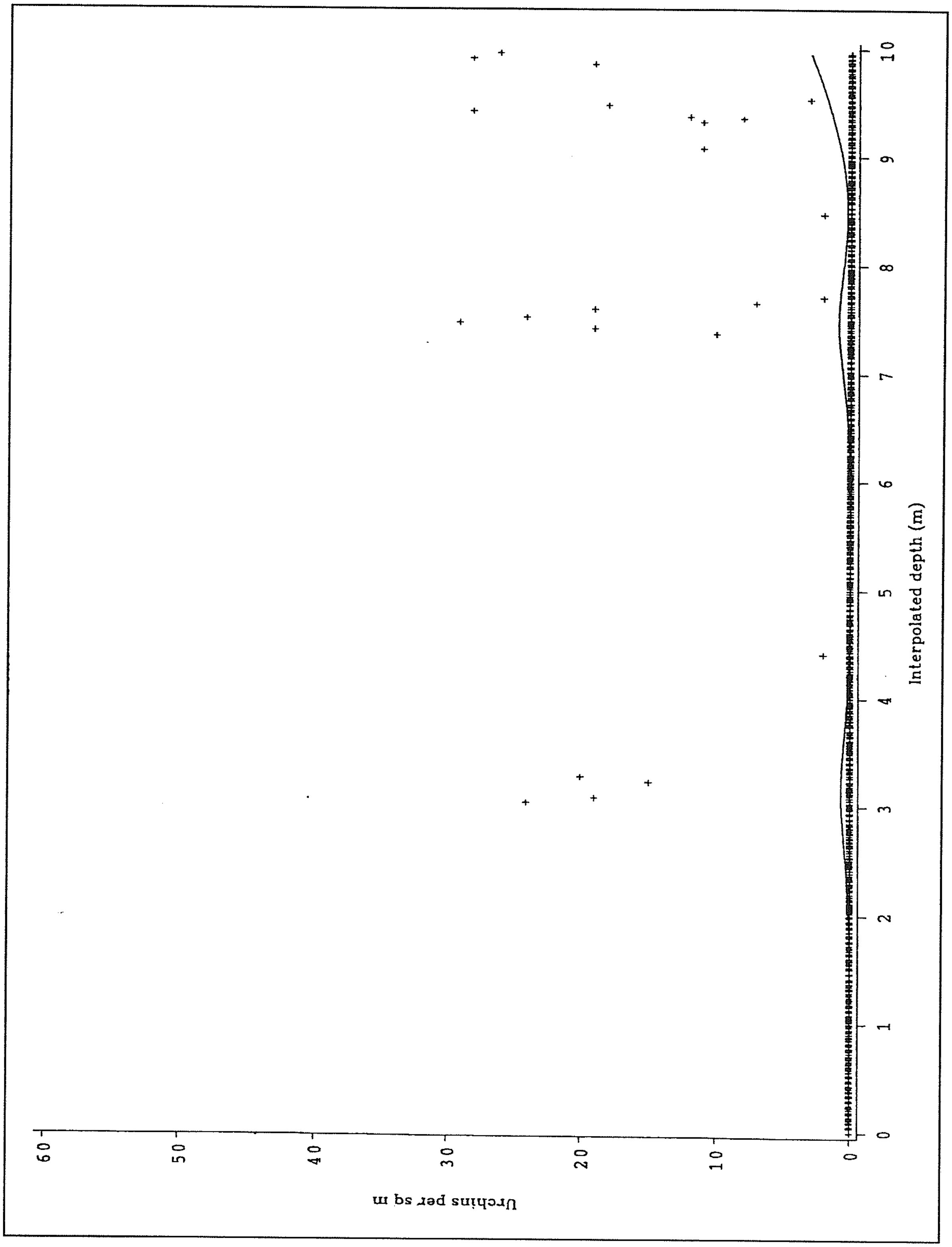


Fig. 2e. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-8.

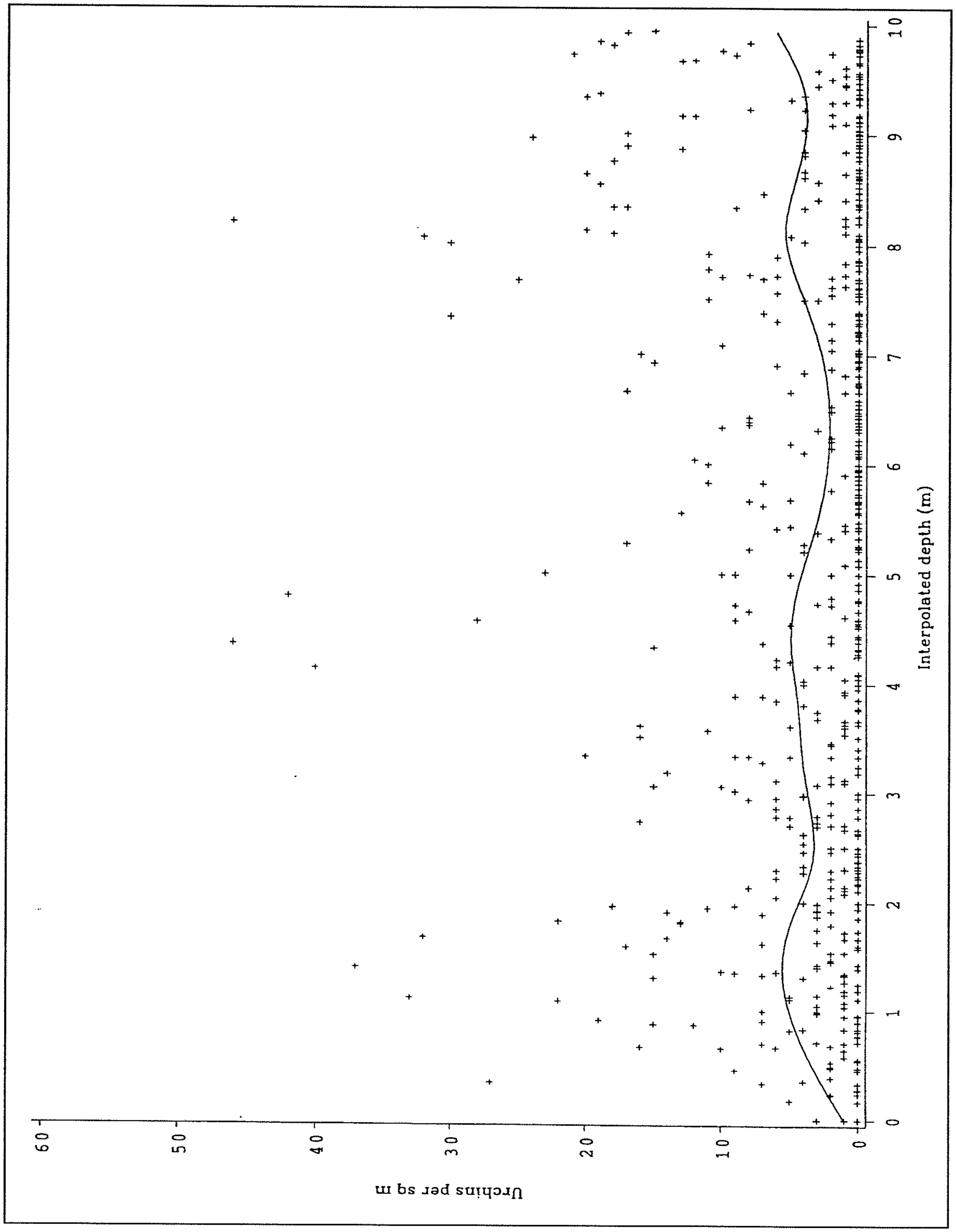


Fig. 2f. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-11.

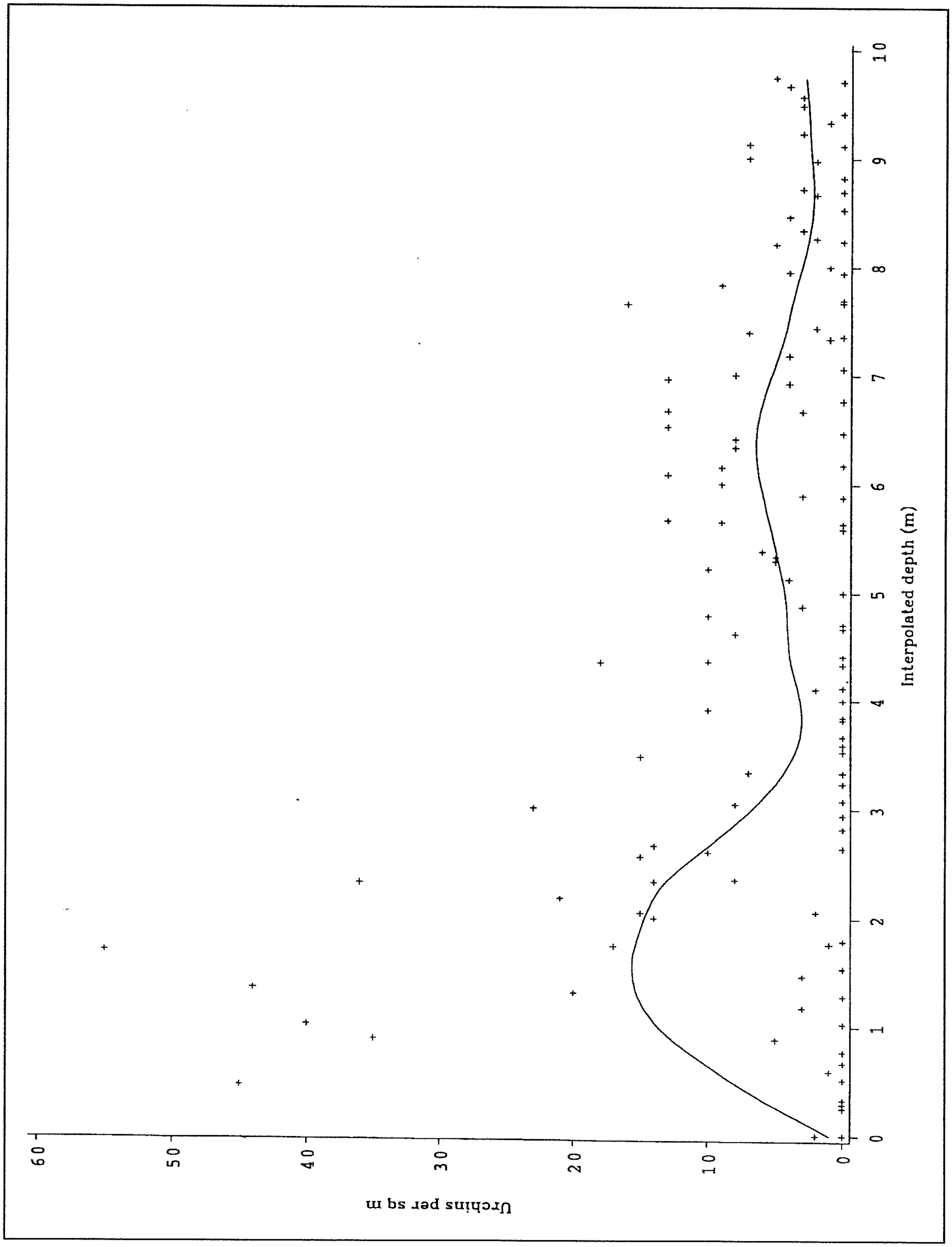


Fig. 2g. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-12.

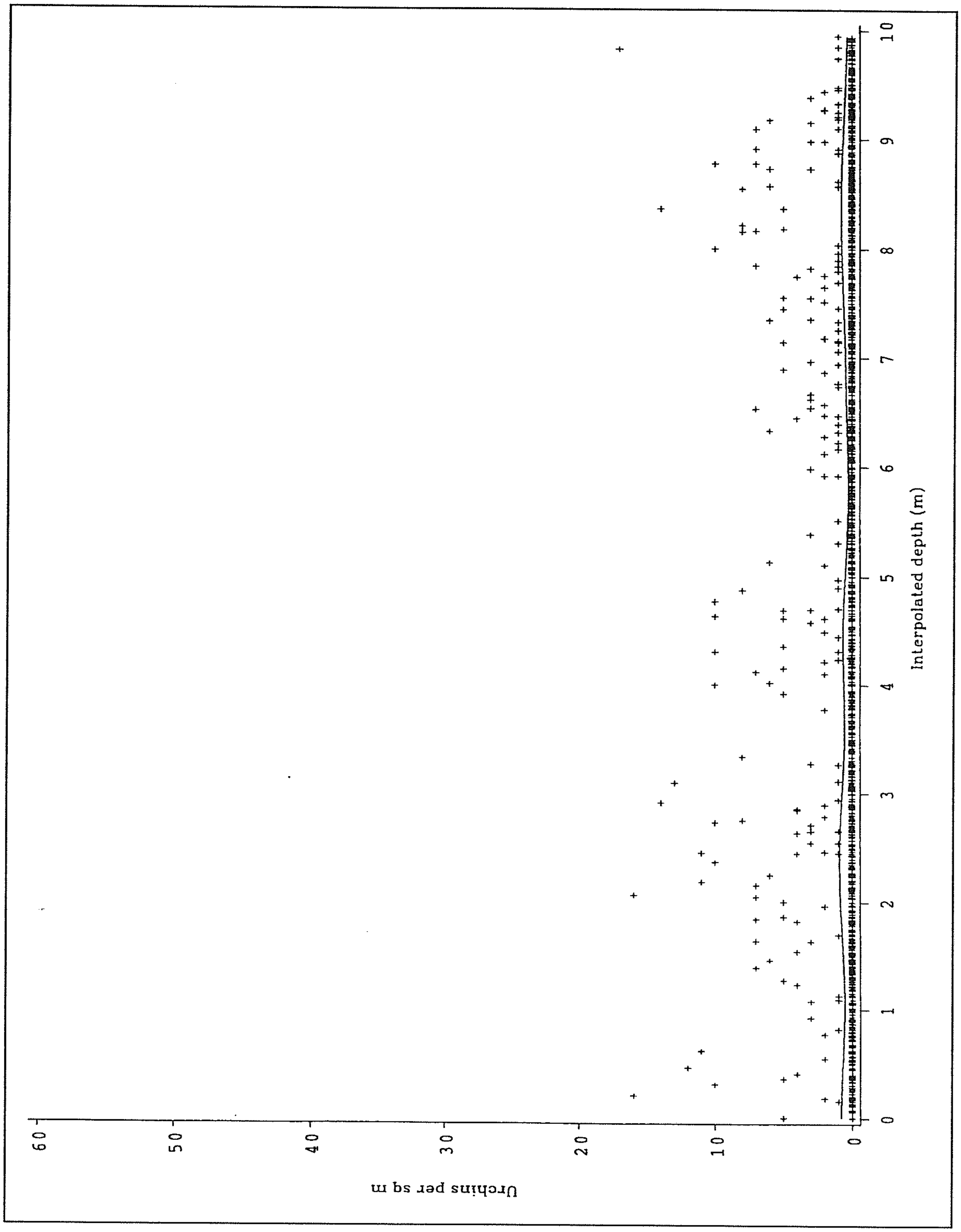


Fig. 2h. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-16.

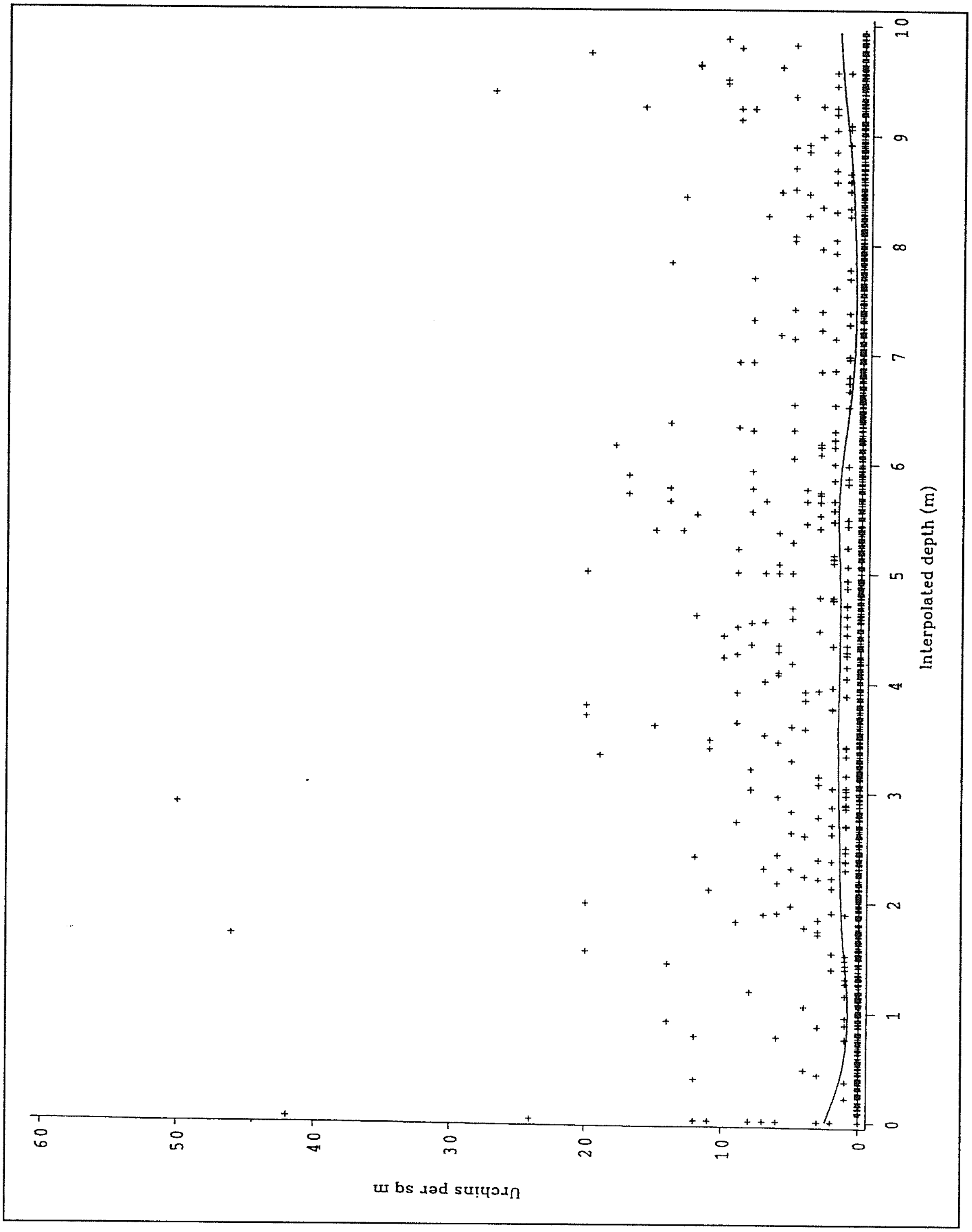


Fig. 2i. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-18.

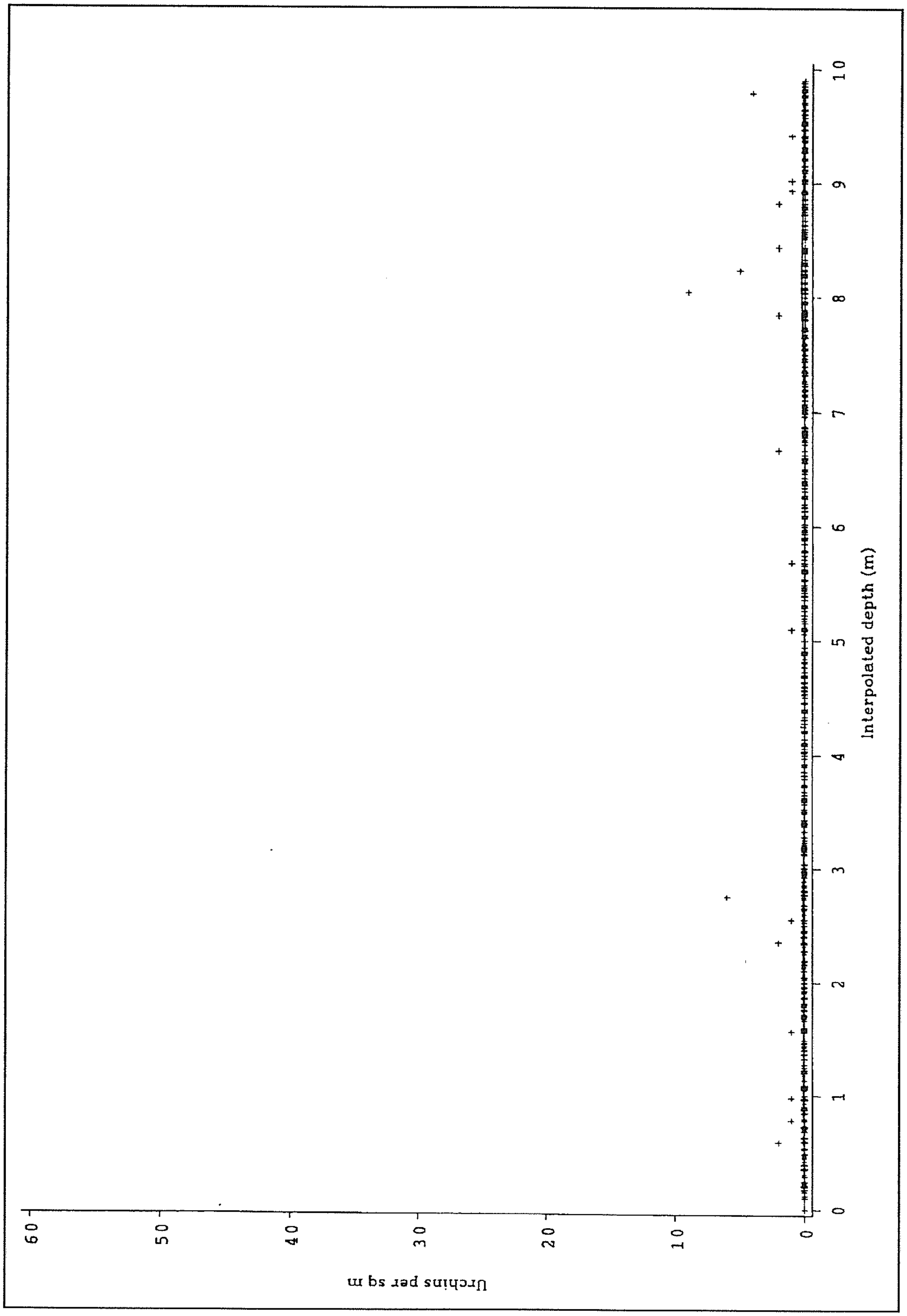


Fig. 2j. Plots of urchin count by interpolated depth (meters below Chart Datum) for PFMA 12-39.

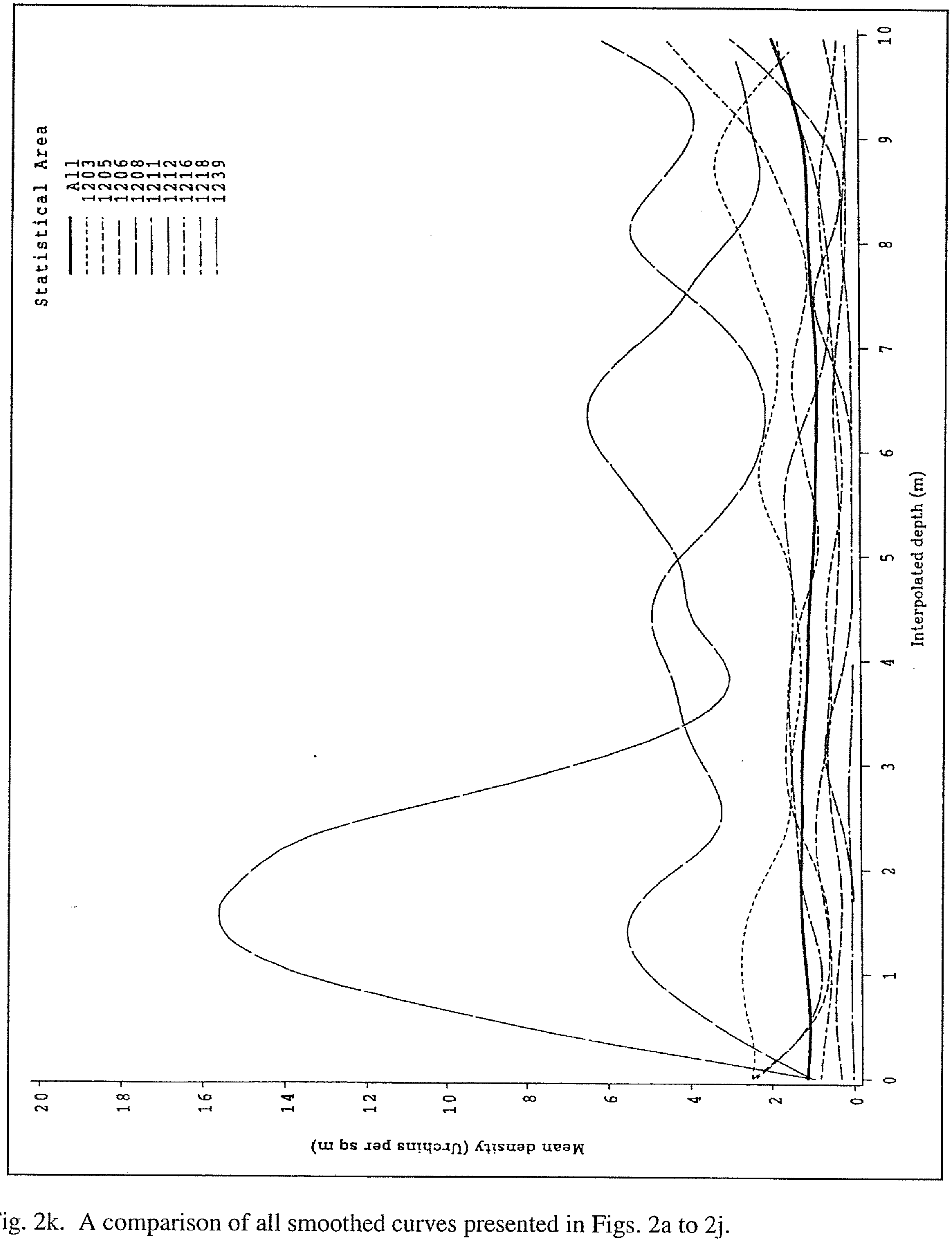


Fig. 2k. A comparison of all smoothed curves presented in Figs. 2a to 2j.

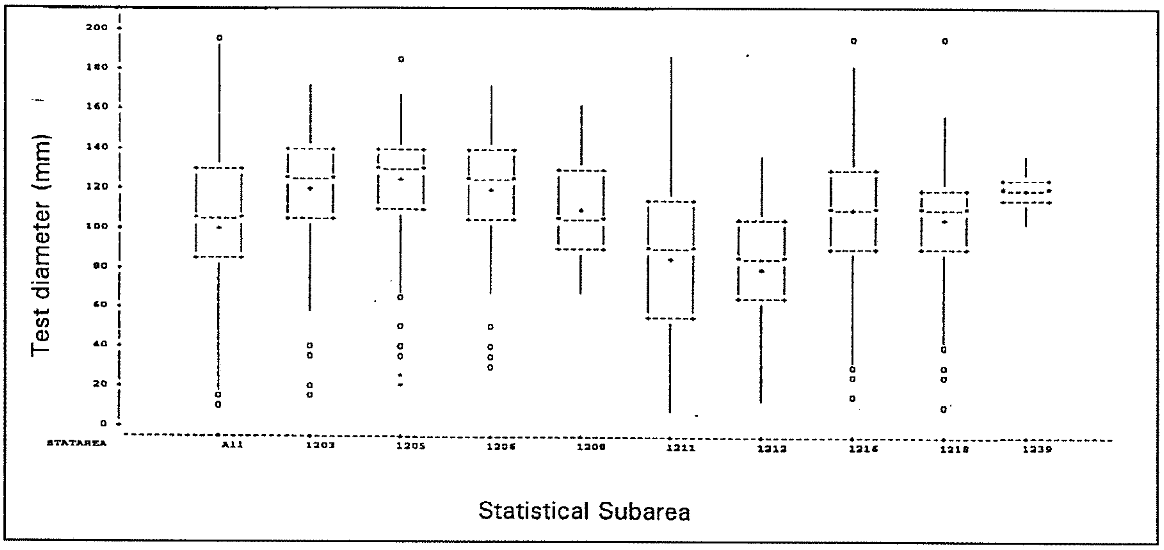
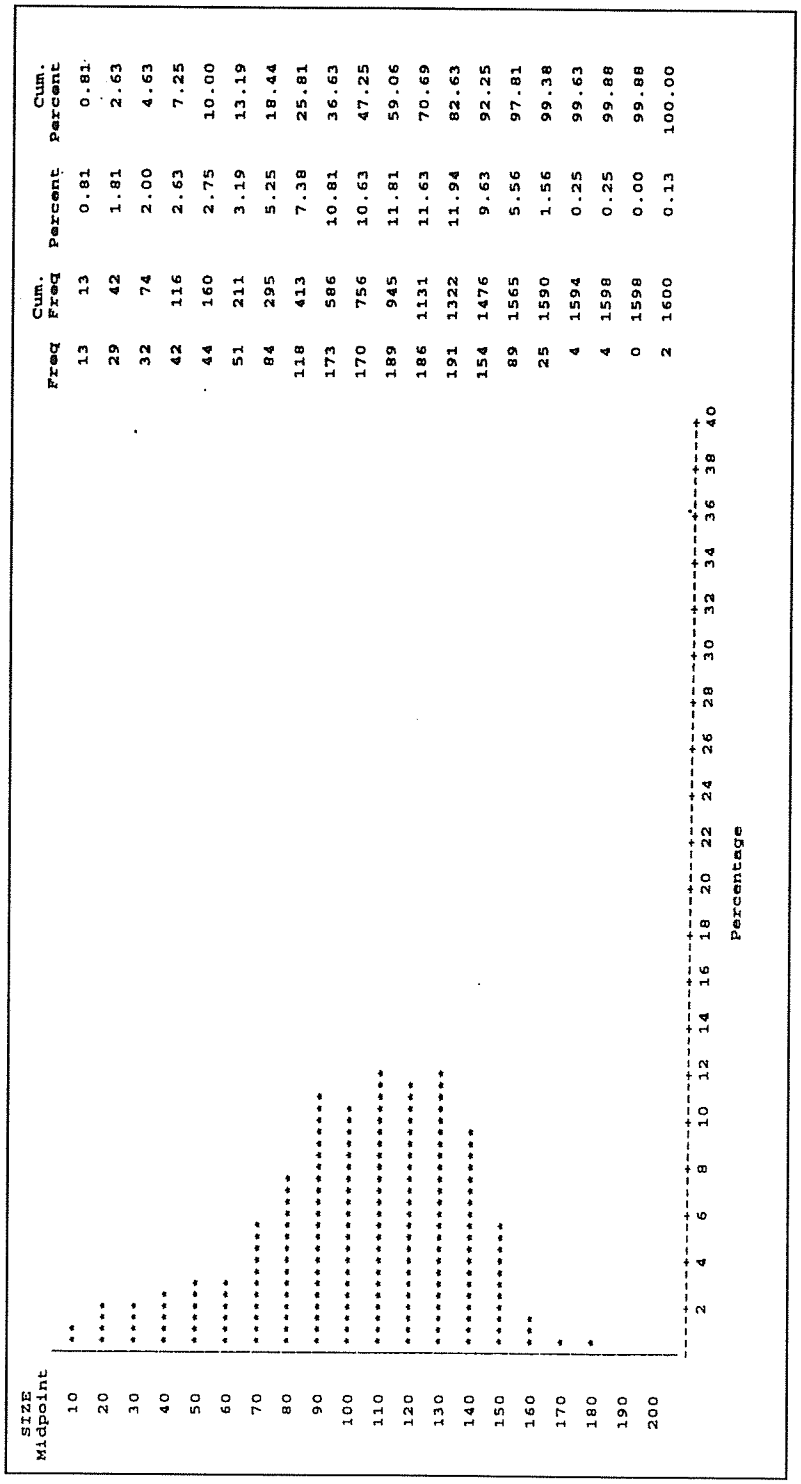


Fig. 3. Side-by-side box plots of size distributions by area. The solid line shows the approximate size range of 95% of urchins, assuming a normal distribution (O's are outliers); the bottom, mid-line and top lines of the box plot show the 25, 50 and 75% quantiles (*i.e.*, 50% of the urchins are within the box, by count); and the "+" shows the mean size value. (Statistical Subarea: 1203 = PFMA 12-3; 1205 = PFMA 12-5; etc.).



SIZE Midpoint	Freq	Cum. Freq	Percent	Cum. Percent
10	13	13	0.81	0.81
20	29	42	1.81	2.63
30	32	74	2.00	4.63
40	42	116	2.63	7.25
50	44	160	2.75	10.00
60	51	211	3.19	13.19
70	84	295	5.25	18.44
80	118	413	7.38	25.81
90	173	586	10.81	36.63
100	170	756	10.63	47.25
110	189	945	11.81	59.06
120	186	1131	11.63	70.69
130	191	1322	11.94	82.63
140	154	1476	9.63	92.25
150	89	1565	5.56	97.81
160	25	1590	1.56	99.38
170	4	1594	0.25	99.63
180	4	1598	0.25	99.88
190	0	1598	0.00	99.88
200	2	1600	0.13	100.00

Fig. 4. Size frequency distribution for all urchins measured in this survey.

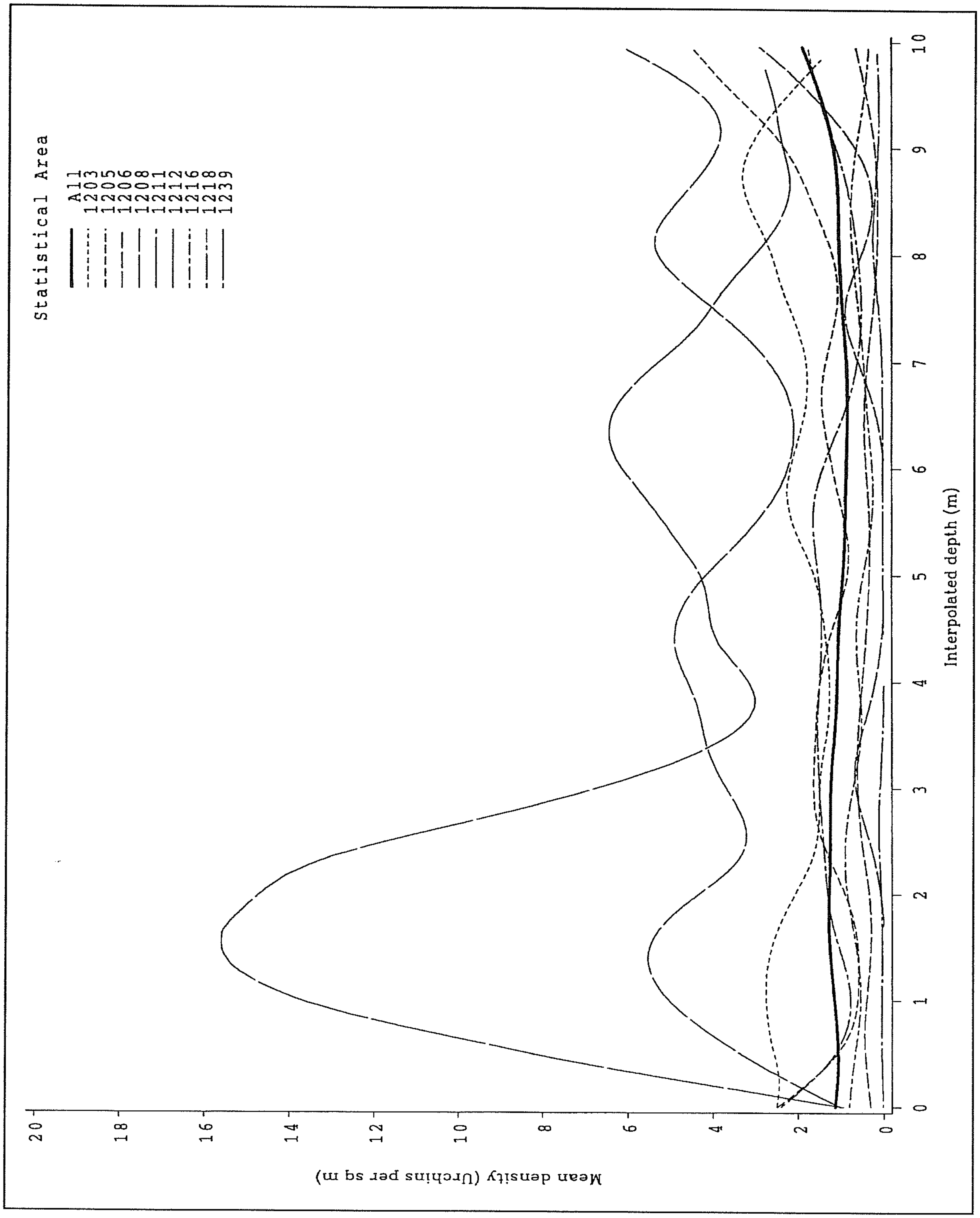


Fig. 5. Size frequency distributions by depth (2 m groupings) below Chart Datum. (Statistical Area: 1203 = PFMA 12-3; 1205 = PFMA 12-5; etc.).

Reanalyses of 1993 Red Sea Urchin Surveys Conducted in Haida, Heiltsuk, Kitasoo and Tsimshian Traditional Territories

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ABSTRACT

Jamieson, G.S., K. Cripps, M. Gijssen, L. Greba, R. Jones, G. Martel, W. Sandoval, C.J. Schwarz, C. Taylor, and R. Routledge. 1998. Reanalyses of 1993 red sea urchin surveys conducted in Haida, Heiltsuk, Kitasoo and Tsimshian Traditional Territories. pp. 57-68. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Collaborative red sea urchin surveys were conducted in 1993 by Fisheries and Oceans Canada, the Pacific Underwater Harvesters Association and four First Nation (Haida, Heiltsuk, Kitasoo and Tsimshian) Fisheries Programs. Broad-brush surveys were carried out, but being the first year of survey, little was known about sea urchin spatial distribution and the logistics of how best to sample them. Consequently, a number of problems were encountered in subsequent data analysis, and in particular relating to the 180° changes in transect direction which was supposed to occur after three quadrates with zero urchins in them were encountered. Here, we reanalyze the 1993 survey data, assuming that each transect had zero urchins after the first switch in direction until the 10 m below Chart Datum point was reached. Analyses of data using revised 1993 procedures indicated that the previous methodology overestimated densities relative to those produced with the 1994 analytical methods. It was noted that the total number of legal-sized urchins estimated does not represent the number of urchins available to the fishery, since only urchins in densities greater than an unknown threshold level may be economically exploited. Many legal-sized urchins may be at such a low density that it may not be economical to harvest them.

INTRODUCTION

Surveys were conducted on the coast of British Columbia in 1994 primarily to define broadly the spatial distribution of red sea urchin (*Strongylocentrotus franciscanus*) occurrence, and secondarily, to obtain preliminary estimates of the abundance of red sea urchins in the 0 to10 m below Chart Datum range in areas identified to be of particular interest. These surveys were conducted under informal partnership agreements between Fisheries and Oceans Canada (DFO), the Pacific Underwater Harvesters Association (PUHA), and the Haida, Heiltsuk, Kitasoo and Tsimshian Fisheries Programs.

Earlier analysis of the individual surveys are described in Jamieson *et al.* (unpublished manuscript *a* and *b*), Jamieson and Gijssen (unpublished manuscript), and Jamieson and Sandoval (unpublished manuscript), and a review of the 1993 urchin survey protocol is found in Jamieson (unpublished manuscript).

Briefly, transects were to be located randomly, extending seaward from the kelp line and running perpendicular to depth isopleths. Along each transect, a 1 m x 1 m quadrat was rolled along the ocean floor, with urchins counted in every quadrat. When two consecutive quadrats yielded counts of less than three urchins and no new urchins were visible further along the transect, the quadrat was moved 10 m to the right and the survey was continued in the opposite direction. The zig-zag pattern was continued until the survey was completed, usually at the end of the allowable dive time (about 20 min).

The intended method of sampling was to be a strip-transect sample, where the starting point of each transect is randomly selected along the shore, and the number of urchins was to be measured along the entire length of the transect (from 0 m to 10 m below Chart Datum). If the survey had been completed in this fashion, then the analysis would follow that of a "complete cluster-sample with varying cluster size" as outlined by Cochran (1977). The sampling unit would be the transect and the size of the transect would be the area of the transect (length from 0 to 10 m below Chart Datum x 1 m wide).

As noted in Jamieson (unpublished manuscript), the 1993 surveys have numerous problems which make it difficult to obtain statistically defensible estimates of abundance. Firstly, in some cases (as noted in the individual report analyses), the selection of transects was not "random" but rather, transects were in some cases selected to lie where urchins were suspected to most likely occur. The effect of this non-random selection is that estimates of urchin abundance will be typically too large.

Secondly, survey teams started surveying at the kelp line (where urchin abundances are expected to be large) but turned 180° if, and when, densities were zero in three consecutive quadrates with no urchins in sight. Consequently, the complete portion of the transects will tend to again overestimate the actual density present in the 0 to 10 m below Chart Datum depth range, as quadrats are concentrated in the area of expected higher urchin abundance. There is also no corresponding adjustment for the areal estimate, since only the entire area between 0 to 10 m below Chart Datum was digitiziable.

No analyses to date, including this one, have made any attempt to assess possible observer error.

In this report we will attempt to extract information from the surveys based upon the numbers of urchins counted before a possible switch in transect direction took place. Essentially, we will assume that the transect had zero urchins after the switch until the 10 m below Chart Datum point was reached. This will lead to an underestimate of the true abundance, but the size of the bias can only be estimated. A similar analysis of 1994 data (Jamieson *et al.* 1998a, 1998b) for Pacific Fishery Management Areas (PFMA's) 1-1, 1-2, 1-3, 1-7, 7-18 and 7-25 (combined) gave an average underestimate of 34.83% (SD = 9.17%).

We must also estimate the length of the transect had it been completed to 10 m below Chart Datum. We use a regression approach to extrapolate these lengths. This will also introduce additional error of unknown size into the estimate. Because of both these problems, no attempt will be made to assign a measure of uncertainty (*i.e.,* a standard error) to the final estimate of urchin abundance.

This report starts with an example of the general procedure used in the surveys. Each of the individual surveys is then separately analyzed.

METHODOLOGY

This section gives a detailed example of the method used for the individual surveys, using 1993 data collected by the Haida Fishery Program.

Each of the survey regions covers a number of PFMA's and subareas as delineated by DFO. The general locations of areas of urchin occurrence in each of the subareas were obtained from interviews with urchin fishers. These were drawn on maps of the regions, digitized, and the total area of urchin beds suitable for harvesting within each subarea was calculated (Table 1).

The population of sea urchins for each subarea will be estimated by:

estimated total = area of urchin beds in the subarea x *estimated density*

The density of urchins for each subarea could also be estimated by taking the total number of urchins in the transects that occur in the subarea and dividing this number by the total area of the transects sampled. However, two problems prevent density from being estimated in such a straightforward fashion.

First, as noted in the previous section, when few urchins are found for several consecutive quadrats, a 180^{o} switch in survey direction is made, which might inflate the observed average density above the actual density. Therefore, all counts after the first switch are ignored and it is assumed that there are no urchins from the point of that switch to the maximum depth where harvesting is still feasible (assumed to be 10 m below Chart Datum). For the Haida survey, the actual point of the switch is known for each transect from the dive log books and was used. For the other surveys, actual points are unknown, and the point of switch had to be estimated from the actual data (*i.e.*, three consecutive zero counts).

Because each quadrat is 1 m wide, the area of each transect can be found as its length (from 0 to 10 m below Chart Datum) x 1 m wide. Unfortunately, the length of the transect to 10 m below data is unknown. It was estimated using the following procedure.

The nominal depths recorded on the survey data sheets are converted to absolute depths below Chart Datum using:

$$absolute\ depth = nominal\ depth - tide - modifier,$$

where:

absolute depth is the absolute depth below Chart Datum;
nominal depth is the depth recorded on the dive sheets;
tide is the height of the tide at the closest tidal recording station; and
modifier is an adjustment for each transect to account for the fact it is not at a tidal recording station.

Then, based on the depth by quadrat number recorded for each transect, we can set up a regression model between the absolute depth and the length of each transect (which is the number of quadrats away from the shore):

$$absolute\ depth = intercept + slope \times quadrat\ number.$$

The intercept is required because the first quadrat may not start at Chart Datum. The estimated slope then can be used to estimate the length of each transect from 0 to 10 m below Chart Datum by:

$$estimated\ length = \frac{10\,m\ -\ intercept}{slope}.$$

Because transects generally went from shallow to deep, we expect depth to increase and hence the slope to be positive. Some transects gave slope estimates that were negative or very close to zero. These transects were assigned the mean length of all other transects in that subarea.

Finally, the mean urchin density for each subarea was estimated by dividing the total number of urchins before the switch of all transects in that subarea by the estimated lengths of all transects to 10 m below Chart Datum in that subarea. Then, the total number of urchins for each chart was calculated by multiplying estimated density by the total harvesting area of that subarea. Refer to Appendix 1 for a detailed example of these calculations.

RESULTS FOR THE INDIVIDUAL SURVEYS

HAIDA SURVEY

In this survey, the actual point of switch was available from the actual dive logs and did not have to be estimated.

The estimate for each subarea was produced as outlined in the Methodology and is summarized in Table 2. The survey was divided into an east and west portion. Jamieson *et al.* (unpublished manuscript *b*) indicated that 48.9% of urchins were above legal size (100 mm) on the east side, and 19.0% on the west side. Note that harvestable urchin area was not provided for several subareas; consequently the total number of urchins cannot be estimated for those areas. Also, two subareas had no transects whose length could be estimated.

HEILTSUK SURVEY

In this survey, the switching points are not known. Following the protocol outlined in Jamieson and Sandoval (unpublished manuscript), a switch was assumed to occur when two quadrats in a row were found with less than three urchins. For example, if the counts on a transect were:

Quad	1	2	3	4	5	6	7	8	9 ...
Count	10	5	2	4	2	2	3	10	12 ...

then a switch was assumed to occur after quadrat 6 and the remaining counts were assumed to have been taken on the next leg. All counts after quadrat 6 were ignored.

Table 3 is the summary table from this survey. Jamieson and Sandoval (unpublished manuscript) indicated that 26.3% of urchins were above legal size (100 mm). Note that in two subareas (PFMA's 8-1 and 8-2), the number of transects where the length could be estimated was zero. No estimates were obtained for these subareas.

KITASOO SURVEY

In this survey, the switching point is again not known. Following the protocol outlined in Jamieson *et al.* (unpublished manuscript *a*), a switch was assumed to occur when two quadrats in a row were again found with less than three urchins and so the process is as described here for the Heiltsuk survey.

There were two transects labelled as Transect 1. These were combined together into a single Transect. Seven transects (30, 32, 44, 49, 91, 111, 115) had no, or only one, depth measurements recorded.

Table 4 is the summary table for this survey. Jamieson *et al.* (unpublished manuscript *a*) indicated that 39.9% of urchins were above legal size (100 mm). Note that in PFMA 6-11, three transects were taken, the number of urchins before the switch were all zero, and the estimated slopes were all very close to zero. It was, therefore, impossible to estimate a total transect length, but the zero counts implies that the estimated total was also zero.

TSIMSHIAN SURVEY

In this survey, the switching point is again not known. Following the protocol outlined in Jamieson and Gijssen (unpublished manuscript), a switch was assumed to occur again when two quadrats in a row were found with less than three urchins, as described here in the Heiltsuk survey.

Two transects were found that were both labelled as Transect 69. Because the first occurrence of Transect 69 occurred where Transect 66 would be expected, and because there was no data for Transect 66, we relabelled the first Transect 69 as Transect 66.

One transect (# 74) had no tide measurement; the average length of transects in the same subarea will be assigned as the length of this transect.

Table 5 is the summary table from this survey. Jamieson and Gijssen (unpublished manuscript) indicated that 50.4% of urchins were above legal size (100 mm).

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Table 1. Estimated total area of urchin beds suitable for harvesting within each subarea.

PFMA and Subarea	Area of Urchin beds (km^2)
2-2	.
2-3	2.96
2-6	2.25
2-7	4.60
2-8	3.74
2-10	.
2-11	9.51
2-12	1.01
2-14	2.03
2-15	0.34
2-17	0.36
2-49	.
2-50	.
2-53	.
2-54	.
2-55	.
2-57	.
2-59	.
2-60	.
2-63	.
2-64	0.25
2-66	0.06
2-67	0.70

Table 2. Urchin abundance estimates for the 1993 Haida survey.

A. PFMA 2E

PFMA and Subarea	Number of Transects: Total	Zero Slope	Total Urchins before switch	Estimated Total Transect Length (m)	Estimated Density (urchin/m^2)	Urchin Harvestable Area (km^2)	Estimated Total Urchins (millions)
2-2	3	3	0	.	.	.	.
2-3	5	2	509	556.72	0.91	2.96	2.70
2-6	2	1	0	52.86	0.00	2.25	0.00
2-7	6	1	1609	476.00	3.38	4.60	15.55
2-8	7	2	1836	1070.28	1.72	3.74	6.42
2-10	4	1	446	557.35	0.80	.	.
2-11	8	2	1510	589.01	2.56	9.51	24.38
2-12	6	0	462	3234.00	0.14	1.01	0.14
2-14	9	2	2094	1047.32	2.00	2.03	4.06
2-15	6	3	202	229.56	0.88	0.34	0.30
2-17	11	3	1760	628.47	2.80	0.36	1.01
East Total	67					26.80	54.56
East Legal-Sized							26.68

B. PFMA 2W

PFMA and Subarea	Number of Transects: Total	Zero Slope	Total Urchins before switch	Estimated Total Transect Length (m)	Estimated Density (urchin/m^2)	Urchin Harvestable Area (km^2)	Estimated Total Urchins (millions)
2-49	2	0	255	642.38	0.40	.	.
2-50	2	1	282	70.16	4.02	.	.
2-53	1	0	422	92.95	4.54	.	.
2-54	2	0	105	87.64	1.20	.	.
2-55	1	0	77	25.718	3.00	.	.
2-57	2	0	309	67.59	4.57	.	.
2-59	5	2	284	311.70	0.91	.	.
2-60	3	1	699	385.51	1.81	.	.
2-63	6	0	2080	207.35	10.03	.	.
2-64	2	1	194	52.35	3.71	0.25	0.91
2-66	2	2	346	.	.	0.06	.
2-67	3	3	522	.	.	0.70	.
West Total	31					1.01	0.91
West Legal-Sized							0.17

Table 3. Urchin abundance estimates for the 1993 Heiltsuk survey.

PFMA and Subarea	Number of Transects: Total	Zero Slope	Total Urchins before switch	Estimated Total Transect Length (m)	Estimated Density (urchin/m^2)	Urchin Harvestable Area (km^2)	Estimated Total Urchins (millions)
7-8	5	2	1039	3016.32	0.34	5.11	1.76
7-18	13	9	2277	1054.95	2.16	14.06	30.35
7-20	4	2	1190	471.21	2.53	1.92	4.84
7-25	11	6	4619	26343.0	0.18	13.27	2.33
7-27	8	4	1431	838.39	1.71	8.16	13.93
7-32	4	2	1923	729.59	2.64	4.96	13.06
8-1	2	2	312	.	.	6.77	.
8-2	6	6	2018	.	.	3.12	.
10-1	5	2	2097	2983.99	0.70	5.55	3.90
Total	58						70.17
Legal-Sized							18.45

Table 4. Urchin abundance estimates for the 1993 Kitasoo survey.

PFMA and Subarea	Number of Transects: Total	Zero Slope	Total Urchins before switch	Estimated Total Transect Length (m)	Estimated Density (urchin/m^2)	Urchin Harvestable Area (km^2)	Estimated Total Urchins (millions)
6-11	3	3	0	.	0.00	1.34	0.00
6-13	32	4	7641	2434.24	3.14	14.90	46.77
6-14	11	2	2008	761.64	2.64	2.53	6.67
6-15	8	2	571	425.55	1.34	2.45	3.28
6-16	11	1	2225	881.16	2.53	3.65	9.22
6-17	9	0	3456	520.47	6.64	6.36	42.21
6-18	3	2	161	315.76	0.51	1.03	0.53
6-19	6	3	831	566.31	1.47	0.87	1.27
7-02	4	0	1635	267.96	6.10	0.67	4.09
7-03	14	3	6156	2085.93	2.95	3.39	10.00
7-04	4	1	1420	916.27	1.55	0.93	1.45
7-31	10	4	3200	1025.82	3.12	9.51	29.67
Total	115						155.16
Legal-Sized							61.91

Table 5. Urchin abundance estimates for the 1993 Tsimshian survey.

PFMA and Subarea	Number of Transects: Total	Zero Slope	Total Urchins before switch	Estimated Total Transect Length (m)	Estimated Density (urchin/m^2)	Urchin Harvestable Area (km^2)	Estimated Total Urchins (millions)
3-1	29	9	1627	1011.22	1.61	16.54	26.62
3-2	6	2	119	211.75	0.56	0.98	0.55
4-1	34	11	1414	1264.44	1.12	20.21	22.60
4-2	8	4	685	809.36	0.85	17.57	14.87
4-13	3	1	77	26.52	2.90	2.76	8.00
Total	80						72.64
Legal-Sized							36.61

Appendix 1. An illustration of the method used to estimate the number of urchins in a survey area.

The methodology outlined in the report will be illustrated using data for PFMA 2-3, which has an estimated 2.96 km^2 of harvestable urchin beds.

The transects, number of urchins before the switch, tide, and modifier are:

Transect	Quadrats before switch	Total Urchins before switch	Tide (feet)	Modifier
32	29	189	5.14	6.4573
35	5	0	14.14	-0.5203
79	22	67	1.03	4.7044
80	22	252	4.57	6.2142
82	2	0	13.98	-0.5256
Total		508		

Now consider Transect 32. Depth measurements were taken at four quadrats and the adjusted depth is computed using the tide and modifier values from above:

Transect	Quadrat	Nominal Depth (feet)	Absolute Depth (feet)
32	1	15	3.4027
32	4	18	6.4027
32	12	19	7.4027
32	26	20	8.4027

The fitted regression line is estimated to be:

$$\textit{absolute depth} = 4.6528 \text{ ft} + 0.16278 \text{ ft/m} \times \text{quadrat number}$$

Therefore, the length of Transect 32 up to the maximum depth (10 m or 32.8 ft deep) is estimated as:

$$estimatedlength = \frac{32.8ft - (4.6528ft)}{0.16278ft / mdepth} = 172.92$$

Similarly for the remaining transects in the subarea, we have the following results:

Transect	Estimated Intercept	Estimated Slope	Estimated Length
32	4.6528	0.16278	172.92
35	11.3803	0.00000	111.34
79	8.0156	0.25000	99.15
80	-4.3842	0.60000	61.97
82	13.5456	0.00000	111.34

Notice that for Transects 35 and 82, the estimated slope is 0. The lengths of these transects are assigned the mean length of the three other transects in that subarea, which is 111.34 m.

Now, the density for PFMA 2-3 is estimated by dividing the total urchins before the first switch of all transects in this subarea, which is 508, by the estimated total area of all the transects, which is 556.71 m long times 1 m wide:

$$\textit{estimated density} = 508/556.71 = 0.912 \text{ urchin/m}^2.$$

The total urchins in harvestable areas for PFMA 2-3 is estimated by:

$$\begin{aligned} \textit{estimated number} &= \textit{harvestable area} \times \textit{estimated density} \\ &= 2{,}956{,}000 \text{ m}^2 \times 0.912 \text{ urchin/m}^2 \\ &= 2{,}697{,}000 \text{ urchins} \end{aligned}$$

SURVEY PROTOCOL CONSIDERATIONS FOR 1995 RED SEA URCHIN SURVEYS

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ABSTRACT

Jamieson, G.S., and C.J. Schwarz. 1998. Survey protocol considerations for 1995 red sea urchin surveys. pp. 69-81. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Red sea urchin surveys were first conducted in British Columbia in 1993, and in the first year of survey, little was known about sea urchin spatial distribution and the logistics of how best to sample them. Consequently, a number of problems were encountered in subsequent data analyses, which resulted in changes in survey methodology for 1994. Here, we discuss the implications of these methodological changes, and consider assumptions and potential problems with the current survey design. These include how best to obtain standardized data over a number of surveys, the problem of nil counts in random sampling of a contagious spatial distribution, and problems arising from changing objectives during the course of a multi-year survey approach. We conclude that field and analytical survey procedures are generally robust enough now to allow reasonably cost-effective assessment, placing the onus on managers and industry to define better what their needs are, and what level of precision is required for areas of varying geographical size and location.

INTRODUCTION

Red sea urchin (*Strongylocentrotus franciscanus*) surveys were conducted in British Columbia in both 1993 and 1994. In the first year of surveys, little was known about red sea urchin spatial distribution and the logistics of how best to sample them. Consequently, a number of problems were encountered and changes in survey methodology for 1994 were recommended (G.S. Jamieson, unpublished manuscript). Major changes effected between the 1993 and 1994 surveys were:

1) the inclusion of tide height data at the time of the survey so that the full depth range between 0 and 10 m below Chart Datum could be surveyed;

2) *a priori* assignment of station locations by Fisheries and Oceans Canada (DFO), to reduce opportunity for bias by implementation of a standardized transect assignment protocol;

3) having divers swim the entire transect defined, with no changes in direction along the transect; and

4) instead of taking urchin size frequency measurements every fifth quadrate, five size frequency distributions were randomly collected along each transect, with one size frequency distribution being collected in every 2 m of depth sampled (*i.e.,* between 0-2 m, 2-4, 4-6, 6-8 and 8-10 m depth).

METHODOLOGY

ANALYTICAL PROCEDURES

The characteristics of 1994 surveys that must be accounted for in analyses are:

1) Quadrats within a transect are not independent of each other. For example, if a transect runs through a high density area, then many quadrats on the transect are likely to have high counts.

2) The sampling unit is a transect while the measuring unit is the quadrat.
    - Transect lengths vary among transects.
    - A complete enumeration of urchins within each sampled transect was conducted.
    - Transects were systematically chosen.

It is unlikely that any fluctuations in urchin density will match the spacing of the transects, so the systematic sample may be treated as a random sample of transects.

This, and the other characteristics, suggest that the 1994 protocol is equivalent to a "complete cluster sampling design with unequal sized clusters" (Cochran 1977, Ch. 9A; Krebs 1985, Section 3.3). In these surveys, transects correspond to clusters and the area of the transect corresponds to the size of the cluster.

Analysis of the surveys involves first estimating the mean urchin density (urchins/m^2) for each subarea of the Pacific Fishery Management Areas (PFMA's). This is then multiplied by the area of potential harvest sites to obtain an estimate of the total number of urchins available in the sites. The size frequency distribution is used to estimate the proportion of urchins of harvestable size. This is then multiplied by the number of urchins to give an estimate of the number of urchins available for harvest. Finally, urchin abundance is summed within a PFMA subarea.

Estimates of precision are obtained from the results of complete-cluster sampling with variable sized clusters (Cochran 1977, Ch. 9A; Krebs 1985, Section 3.3). Additional variation caused by imprecision in the proportion of urchins of harvestable size is ignored. In many cases it is based upon a large sample of measurements taken from a subarea, and its variation is small relative to the variation from sampling only a small number of transects in each subarea. The finite population correction is also ignored because the number of transects is very small compared to the total area suitable for harvesting.

ESTIMATING DENSITY OF URCHINS IN A PFMA SUBAREA

Let n = the number of transects sampled in a particular PFMA subarea, U_i = the total number of urchins found in transect i, $i = 1,2,...,n$, and L_i = the total number of quadrats in transect i. Because the quadrats are 1 m^2, L_i is also equivalent to the area of the transect. The estimated density of urchins in the subarea is:

$$\hat{D}_{Subarea} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i} \tag{1}$$

and the estimated standard error is:

$$SE(D_{Subarea}) = \sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\frac{\sum\left(U_i - L_i\left(D_{Subarea}\right)\right)^2}{n-1}} \tag{2}$$

where $\overline{L} = \frac{1}{n}\sum_{i=1}^{n} L_i$ is the average area of the transects in the subarea.

ESTIMATING THE NUMBER OF URCHINS IN A PFMA SUBAREA

Let $A_{Subarea}$ = the area of potentially harvestable sites in the PFMA subarea. This is assumed to be known exactly and is assumed to be the area between Chart Datum and 10 m below Chart Datum depth. Let $P_{Subarea}$ = the proportion of urchins of harvestable size in the subarea. This is determined from the size-frequency relationship gathered from measuring the individual urchins five times on each transect.

The estimated total number of urchins is:

$$\hat{N}_{Subarea} = \hat{D}_{Subarea}\left(A_{Subarea}\right) \tag{3}$$

and the estimated total number of harvestable urchins is:

$$\hat{H}_{Subarea} = \hat{D}_{Subarea}\left(A_{Subarea}\right)\left(P_{Subarea}\right) \tag{4}$$

and the estimated standard errors are:

$$SE\left(\hat{N}_{Subarea}\right) = SE\left(\hat{D}_{Subarea}\right)\left(A_{Subarea}\right) \tag{5}$$

and:

$$SE\left(\hat{H}_{Subarea}\right) = SE\left(\hat{D}_{Subarea}\right)\left(A_{Subarea}\right)\left(P_{Subarea}\right). \tag{6}$$

It should be noted that this estimate will be a slight underestimate of the abundance because of the different ways in which the areas of the transect (along the sea floor) and the area of the 0 to 10 m below Chart Datum (along the surface) are measured. However, unless the gradient is very steep, the bias is considered to be small. For example, suppose that a transect consists of 100 quadrats from 0 to10 m below Chart Datum along the sea floor. Then, assuming a relatively even gradient, the 100 m along the sea floor corresponds to 99.5 m along the surface. ($99.5^2 + 10^2 = 100^2$).

Imprecision in $A_{Subarea}$ or $P_{Subarea}$ are ignored in computing the precision of the abundance estimates, but is expected to be small compared to the imprecision from sampling only a small number of transects.

ESTIMATING THE NUMBER OF URCHINS IN THE PFMA

Estimates for all PFMA's are found by totalling the estimates for all relevant subareas:

$$\hat{N}_{PFMA} = \sum_{All\,subareas} \hat{N}_{subarea} \quad (7)$$

and:

$$\hat{H}_{PFMA} = \sum_{All\,subareas} \hat{H}_{subarea} \quad (8)$$

and the standard errors are estimated by:

$$SE(\hat{N}_{PFMA}) = \sqrt{\sum_{All\,subareas} \left[SE(\hat{N}_{subarea})\right]^2} \quad (9)$$

and:

$$SE(\hat{H}_{PFMA}) = \sqrt{\sum_{All\,subareas} \left[SE(\hat{H}_{subarea})\right]^2}\,. \quad (10)$$

NUMERICAL EXAMPLE

We will illustrate the above procedure with data from a few transects from the 1994 survey in Haida Gwaii (Jamieson *et al.* 1998).

PFMA 1 consists of four subareas where harvesting is thought to likely occur: 1-1, 1-2, 1-3 and 1-7. Four transects were surveyed in PFMA 1-1:

Transect	Total Urchins (U_i)	Total Length (m) (L_i)
23	136	71
24	63	52
25	545	84
27	1,930	461
28	0	101
Total	2,674	769

The estimated density of urchins (urchins per square meter) in PFMA 1-1 is:

$$\hat{D}_{PFMA1-1} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i} = \frac{2{,}674}{769} = 3.48 \tag{11}$$

and the estimated standard error is:

$$SE\left(\hat{D}_{PFMA1-1}\right) = \frac{\sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\sum_{i=1}^{n}\left(U_i - L_i\left(\hat{D}_{PFMA1-1}\right)\right)^2}}{n-1} = \frac{\sqrt{\frac{1}{(153.8)^2}\frac{1}{5}(320{,}405.9)}}{4} = 823 \tag{12}$$

where the average area of transects (square meters) in PFMA 1-1 is:

$$\overline{L} = \frac{1}{n}\sum_{i=1}^{n} L_i = \frac{769}{5} = 153.8\,. \tag{13}$$

From digitized maps of the shoreline, it was calculated that $A_{PFMA\ 1\text{-}1} = 24.84$ km^2. A total of 198 urchins were measured in PFMA 1-1 and the proportion of urchins greater than 100 mm diameter was $P_{PFMA\ 1\text{-}1} = 0.41$. The estimated total number of urchins (millions) is:

$$\hat{N}_{PFMA1-1} = \hat{D}_{PFMA1-1}\left(A_{PFMA1-1}\right) = 3.48\,urchins\,/\,m^2\left(24.84\,km^2\right) = 86.44 \tag{14}$$

and the estimated number of harvestable urchins (millions) is:

$$\hat{H}_{PFMA1-1} = \hat{D}_{PFMA1-1}\left(A_{PFMA1-1}\right)\left(P_{PFMA1-1}\right) = 3.48\,urchins\,/\,m^2\left(24.84\,km^2\right)(0.41) = 35.44 \tag{15}$$

and the estimated standard errors (millions) are:

$$SE\left(\hat{N}_{PFMA1-1}\right) = SE\left(\hat{D}_{PFMA1-1}\right)\left(A_{PFMA1-1}\right) = 0.823\,urchins\,/\,m^2\left(24.84\,km^2\right) = 20.44 \tag{16}$$

and:

$$SE\left(\hat{H}_{PFMA1-1}\right) = SE\left(\hat{D}_{PFMA1-1}\right)\left(A_{PFMA1-1}\right)\left(P_{PFMA1-1}\right) = 0.823\, urchins\, /\, m^2\left(24.84\, km^2\right)(0.41) = 8.38 \quad (17)$$

Results can then be summarized, as in Table 1.

DISCUSSION OF 1994 SURVEY DESIGN

Analysis of survey data relies upon a number of key design features, considered here.

ASSUMPTIONS AND POTENTIAL PROBLEMS WITH THE CURRENT DESIGN

Sampled transects can be considered a random sample from the population of interest. Randomness is what ensures representativeness. If transects were sampled from only high density areas, for example, then it would be quite invalid to multiply an estimated density from these transects by an area that includes low density sections. There is no statistical procedure that can be used to obtain defensible estimates from non-random samples.

This design also assumes that all parts of the urchin beds are sampled with equal intensity. However, shorelines are not linear and some bias can be introduced in sharply convex bays or very concave shores (Fig. 1).

As in Fig. 1 small bays (A_1), ends of transects will tend to oversample deeper areas, while on convex shores (B_1), ends of transects will tend to undersample deeper waters. Unless there are many transects within a small bay or along a very concave shore, though, biases introduced are expected to be small.

We assume that all urchins within a quadrat are counted. This is likely only to be a problem in very convoluted sea bottoms or with very small urchins. There is no evidence to suggest this was a problem in these surveys.

Complete cluster designs work well (*i.e.*, give good precision) when units within a cluster are dissimilar but clusters are similar to other clusters. The biology of the sea urchin suggests that this design is a viable strategy. Densities are higher near shore and decrease with increased depth. Consequently, quadrat counts may be quite variable within a transect (the cluster) but the pattern among clusters will be similar.

Our proposed estimator belongs to a class of procedures called "ratio-estimators". Theoretically, these are known to be biased, but the actual bias in practice is usually small. They perform well when the cluster totals (U_i) have a positive correlation with the cluster size (L_i). Plots (not shown here) showed this to be true in our survey.

Two other estimators are commonly used for complete cluster sampling with varying cluster sizes. The first computes a density for each transect and then averages the densities over the within each subarea to estimate the density for the subarea:

$$\hat{D}_{Alternative1} = \frac{1}{n}\sum_{i=1}^{n}\frac{U_i}{L_i}. \tag{18}$$

This estimator is not unbiased because it fails to weight the transects by their length, *i.e.*, shorter transects have the same weight as longer transects. This bias can be considerable.

The second alternative estimator computes the average of the total urchins per transect and multiplies it by the total number of transects needed to cover the survey area (T):

$$\hat{N}_{Alternative2} = (T)\frac{1}{n}\sum_{i=1}^{n}U_i. \tag{19}$$

This estimator is unbiased, but typically has a large variance because U_i varies considerably from transect to transect. As well, the number of transects needed to cover the study area is not easily determined.

We have also assumed that the area suitable for urchin harvesting and the proportion of urchins of harvestable size are known without error. Any uncertainty in these numbers will cause the estimate standard errors to be underestimates.

OBSERVATIONS AFTER 1994 DATA COLLECTION AND ANALYSIS

FIELD LOGISTIC CONSIDERATIONS

In both the Haida and Hieltsuk surveys, not all transects identified could be sampled, either because of safety considerations or time constraints. This was not unexpected, as it is easy to identify a location on a chart which in the field, proves too dangerous to permit sampling. Problems encountered were extremely rough seas due to exposed location and/or the presence of shallow rocks and kelp beds which prevented the survey vessels from approaching the area. Both factors will also affect the ability of harvesters to exploit urchins which might be present, so it is not unreasonable to exclude such areas from calculations of exploitable biomass.

Although a detailed protocol was given to each First Nation's biologist as to how the surveys were to be implemented, there were still problems from DFO's perspective. These are specifically as follows:

1) The Tsimshian biologist left his employment before the data were transmitted to DFO, leaving untrained native biologists to complete his work. This was not done satisfactorily and consequently, the Tsimshian data has yet to be analyzed and presented to PSARC. It will take some dedicated time to prepare the data for keypunching and to date, sufficient resources have not been available.

2) Because of other on-going surveys on other species, First Nation survey biologists were at times possibly spread too thinly over the surveys being conducted simultaneously. We know of no problems arising from this, but it leaves room for concern that slight changes in sampling protocol might go undetected and not be corrected in a timely manner. This concern will diminish as divers become more experienced, but we are not sure the stage has yet been reached where they can all operate without close supervision.

Recommendation: To ensure that data are processed in a timely manner and that all surveys conducted in a given year are conducted in a similar manner, regardless of First Nation territory, it is recommended that a biologist be hired who will participate in all surveys and ensure that all data collected are standardized to an *a priori* agreed-upon procedure. If any problems such as encountered in 1994 arise, then this person will provide a backup to ensure that data can be submitted for prompt analytical processing.

Transect Methodology

No major problems were encountered in 1994 in data analysis. However, there are some logistic considerations which should be considered. Firstly, the transects end at 10 m below Chart Datum, primarily because of safety considerations regarding decompression tables. Given that tides may be 5 m above this, divers are approaching their limits regarding repetitive diving. Although urchin abundance generally declines with depth below about 10 m depth, urchins may still occur deeper than 10 m below Chart Datum. With existing constraints, these urchins are not considered and so there is some underestimate to our calculated values. A similar concern exists where shallow rocks and kelp beds prevent access to survey sites.

Urchins sampled to date show that their spatial distribution is quite contagious. Survey methodology as proposed does not sample an urchin "bed" but rather a general area occupied by urchins. This can lead to a relatively large number of nil counts. In the 1994 Haida survey, for example, only 33% of the quadrats surveyed had urchins. Improvement on this ratio will require more precise definition of areas of high urchin abundance and more intensive sampling of only these areas. Such "bed definitions" might be extractable from fishery logbook data, but this will require a commitment of significant manpower to capture this information and plot it on maps. To date, this commitment has not been made.

Survey Objectives

Broad-brush surveys have now been conducted in all First Nation's PFMA subareas, with the exception of the Tsimshian, who have both a relatively large area and were unable to complete all they hoped to achieve in 1994 for reasons described above.

It was initially agreed to that broad-brush surveys would primarily allow a feeling to be had for the presence of sea urchins in the overall area. While biomass estimates could be made, there would be a relatively large standard error (SE) around the estimates because areas unsuitable for urchins would be included. Consequently, it was accepted that following broad-brush surveys, more intensive sampling of smaller, selected areas would most likely be recommended so that more precise estimates of urchin biomass in high production areas could be determined.

In this respect, if precise estimates are deemed desirable for areas, such as PFMA subareas, then the overall survey design should be modified to ensure that sufficient transects are taken in each subarea. The current survey can be used to estimate the approximate number of transects necessary to obtain a certain precision:

$$SE(new\,survey) = SE(old\,survey)\sqrt{\frac{transects\,in\,old\,survey}{transects\,in\,new\,survey}} \quad (20)$$

If the number of transects were doubled, the SE (and coefficient of variation, CV) would be reduced by about a factor of $\sqrt{2}$, *i.e.*, the new SE (and CV) would be about 0.71 of the old estimate.

For example, consider the Haida 1994 survey results for PFMA 1-1. Five transects give an estimated SE for urchin density of 0.82/m^2 and a CV of 24% = (0.82)/3.48 x 100%. Suppose that 10 transects are now planned for PFMA 1-1 compared to the 5 taken in 1994. The estimated standard error under the new survey design would be:

$$SE(new\,survey) = \left(0.82\,urchins\,/\,m^2\right)\sqrt{\frac{5}{10}} = 0.58\,urchins\,/\,m^2 \quad (21)$$

On the other hand, if precise estimates are only required over the total of the subareas and not for individual subareas, then transect allocation is a little more complicated. In general, precision depends not only on the number of transects within each subarea but also on the total harvestable areas of the subareas, the proportion of urchins of harvestable size, and the variation among transects within a subarea. In general, more transects should be allocated to larger subareas and those with a high variability (Cochran 1977). A closed form expression can be derived for an optimal allocation, but the computations can be conveniently arranged on a spreadsheet and its optimization function used to solve the problem numerically. For example, Table 2 shows an optimal allocation for future Haida surveys found using SOLVER function of EXCEL.

In Table 2, the overall SE (10.89) was obtained by minimizing its respective cell while modifying the proposed number of transect cells (now containing the optimal allocation of 11.5, 8.5, 17.5 and 7.5) subject to the total number of transects adding to 45.

The optimal allocation (based upon the results of this year's survey) would show that roughly double the number of transects should be allocated to PFMA 1-1 and about half the number of transects should be allocated to PFMA 1-2 compared to 1994. If the total number of transects were to change, the optimal proportions would still be in the ratio of 11.5:8.5:17.5:7.5, respectively.

Of course in practice, this strategy could be modified to take into account that future harvesters will likely be concentrated along the higher density PFMA's (1-1 and 1-2) and that little harvesting will take place in PFMA 1-7 because of low urchin density (even though it contributes almost 25% of the total harvestable urchins). A similar spreadsheet could be designed to allocate future transects among these two areas only.

To incorporate these considerations, direction is required from managers, First Nations and industry as to the geographical areas for which urchin biomass should be calculated. Given these data, and resources estimated to be available for resource surveys, optimal survey designs can be developed *a priori* for implementation. This point should be one of the main areas of discussion in future joint planning and review meetings.

It this context, it should be noted that the Kitasoo decided to forego species sampling in 1994 and instead concentrate on habitat mapping, with the long term intent of focusing sampling only in those areas where substrate is appropriate. A report (Schlagintweit 1994) summarizing technical considerations suggests that while this approach has a great deal of merit, it appears to be quite time-consuming and perhaps only appropriate for relatively small areas where high resolution is required.

A final consideration is the temporal frequency with which an area should be surveyed. Red sea urchins are probably a moderately-lived species, with a maximum life span of probably a few decades at most. It can thus be expected that natural major changes in abundance may occur on at least a decadal basis, with change potentially increased by a significant fishery. Large macrophyte species are the food for urchins, and many species can have significant biomass change on an annual basis. This may also affect urchin population dynamics. In many locations, mortality of large urchins may be storm-related and hence difficult to predict in advance. Lack of data on annual variability suggests that it is worthwhile to initiate some study over a sufficiently large area to remove local site-specific effects to allow documentation of annual change in urchin abundance. Survey of a specified area should perhaps be conducted every 2 to 3 years to assess if annual change is indeed significant.

In summary, field and analytical survey methodologies are now generally robust enough to allow reasonably cost-effective assessment. The survey elements now to be determined relate primarily to better definition of survey objectives and specifically, the degree of precision required for areas of varying geographical size and location. Such considerations are not specifically science-related but require managerial and industry input. Given this input, specific surveys can then be constructed to meet identified objectives.

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Table 1. Example results for PFMA 1.

PFMA and Subarea	No. of Transects	No. of Urchins	No. of Quadrats	Estimated Density	SE	Area of Harvest (km^2)	Total Urchins (10^6)	Prop. >100mm	Total Urchins >100mm (10^6)	SE Urchins >100mm (10^6)
1-1	5	2,674	769	3.48	0.82	24.84	86.44	0.41	35.44	8.35
1-2	15	10,605	1,810	5.86	1.02	7.45	43.66	0.47	20.42	3.57
1-3	16	2,877	1,826	1.58	0.41	25.11	39.67	0.69	27.37	7.10
1-7	9	2,298	2,880	0.80	0.31	18.91	15.13	0.69	10.44	4.04
Total	45	18,454	7,285			76.31	184.90		93.77	

Table 2. Estimated SE of legal urchin abundance with a modified transect arrangement by subarea.

PFMA and Subarea	Current Survey			New Survey			Est. Total Urchins (10^6)	Prop. > 100 mm	Est. no. Urchins > 100 mm (10^6)	Est. SE of Urchins >100mm (10^6)
	# Transects	Est. Density (#/m^2)	SE of Est. Density (#/m^2)	# Transects	Est. SE of Density (#/m^2)	Area of Harvest-ing (km^2)				
1-1	5	3.48	0.82	11.5	0.54	24.84	86.44	0.41	35.44	5.51
1-2	15	5.86	1.02	8.5	1.35	7.45	43.66	0.47	20.42	4.74
1-3	16	1.58	0.41	17.5	0.39	25.11	39.67	0.69	27.37	6.79
1-7	9	0.60	0.31	7.5	0.34	18.91	15.13	0.69	10.44	4.44
Total	45			45.0		76.31	184.90		93.77	10.89
Old est.										12.22

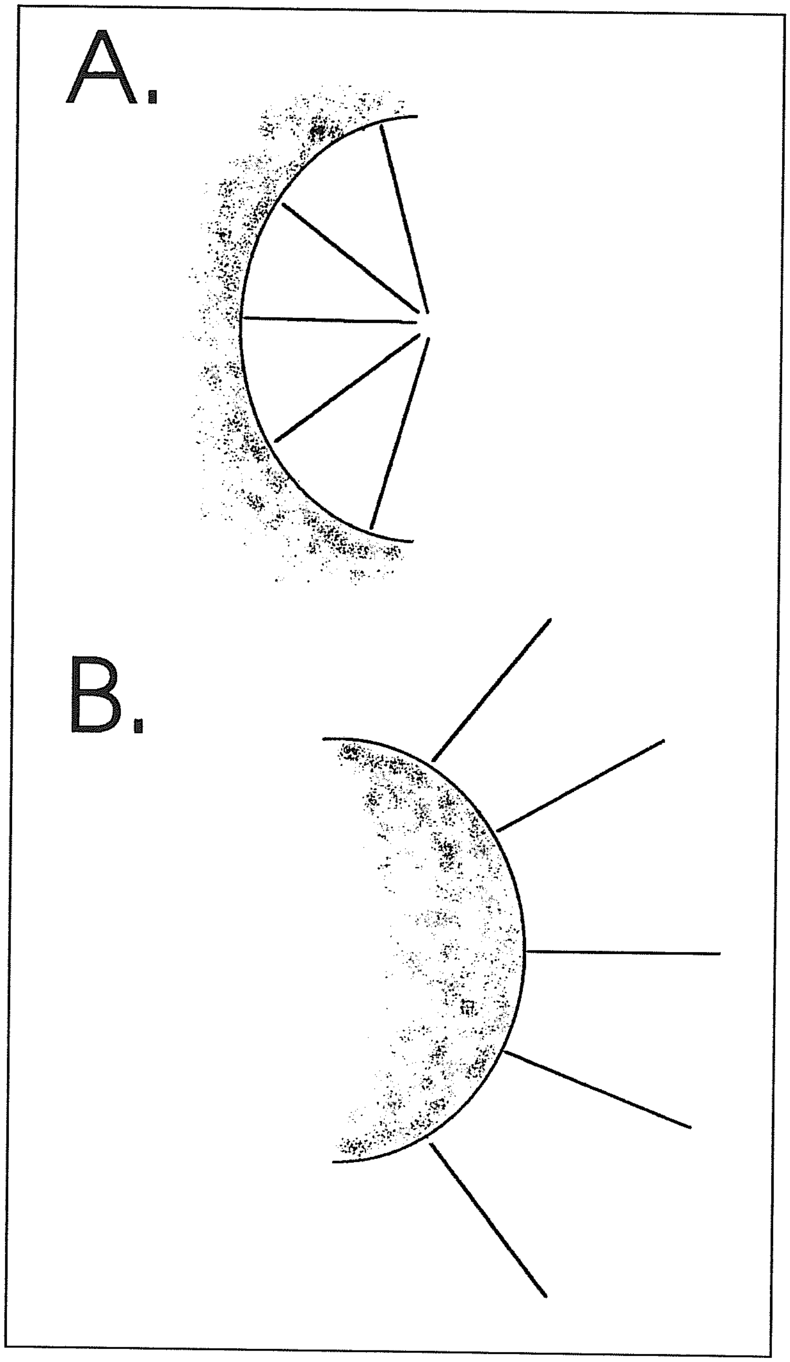

Fig. 1. Schematic examples of over-sampling in bays (A) and under-sampling around points of land (B).

Catch, Effort and Quota Estimates for the Red Sea Urchin Fishery in British Columbia

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ABSTRACT

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Annual landings of red sea urchin (*Strongylocentrotus franciscanus*) started to increase rapidly in the early 1980s for the south coast of British Columbia (B.C.) and the late 1980s for the north coast, but subsequently were reduced and stabilized by arbitrary quotas. Preliminary estimates of coastwide landings were 5,818 t valued at $7.8 M (Cdn.), with 110 licences issued during 1994. Harvest logbook data indicated that there were no clear trends in annual CPUE (kilogram per diver hour) over the 1984-1994 period in each Pacific Fishery Management Area or general region in B.C. Review of published surveys conducted to date provided estimates of density, mean weights and bed areas allowing preliminary estimates of biomass of red sea urchins in B.C. Assuming a natural mortality rate of 0.15 and current biomass estimates, the suggested preliminary quotas options were calculated between 4,990 t and 5,614 t for the north coast of B.C., and between 1,258 t and 1,618 t for the south coast of B.C. A more detailed analysis of CPUE, further surveys for red sea urchin density, and more accurate estimates of bed areas are required.

INTRODUCTION

The red sea urchin (*Strongylocentrotus franciscanus*) has been the subject of a commercial dive fishery in British Columbia (B.C.) since the 1970s. The B.C. coast is divided into two main management areas, the 'North Coast' and the 'South Coast', and the South Coast is further divided into the inside waters of Vancouver Island (Inside Waters) and the west coast of Vancouver Island (WCVI) (Fig. 1). Annual landings started to increase rapidly in the early 1980s for the South Coast of B.C. and the late 1980s for the North Coast, but subsequently were reduced and stabilized by arbitrary quotas (Fig. 2, Table 1). Coastwide landings were 5,818 t valued at $7.8 M (Cdn.) with 110 licences issued during 1994. The history of the management of this fishery is summarized in Campbell and Harbo (1991) and Heizer *et al.* (1997). A number of papers review various aspects of red sea urchin biology (Mottet 1976; Breen 1980; Sloan *et al.* 1987; Tegner 1989; Campbell and Harbo 1991; Botsford *et al.* 1993). Few surveys have been conducted to estimate standing stock of red sea urchins in B.C. (Adkins *et al.* 1981; Jamieson *et al.* 1998a, 1998b, 1998c, 1998d). Consequently there have not been quota estimates based on standing stock of red sea urchins coastwide for B.C.

The purpose of this paper is to (1) review catch and effort trends from the sales slips and harvest logbooks, (2) summarize the surveys conducted to date and calculate preliminary estimates of biomass in B.C., and (3) determine annual quotas for red sea urchins.

METHODS

CATCH AND EFFORT

Catch and effort data were obtained from sales slips and from harvest logbooks that fishers completed each day of fishing. Information from sales slips included total weight (pounds) and value (dollars) landed, CFV number, date and days fished. Information from the harvest logbooks included location of bed (with diagram), date, landed weight and minutes of diving. The harvest logbooks were not completed by each vessel so the data were used as a sample of catch per unit of effort (CPUE, kilograms per minute) only where both total catch and effort were reported per diver for each area per day. An average CPUE per Pacific Fishery Management Area (PFMA) was subsequently calculated as the total catch divided by total effort per PFMA. The PFMA's were grouped for each general region as follows: North Coast (PFMA's 1 to 10, 102, 105, 106); Inside Waters (PFMA's 11 to 19, 28, 29); and WCVI (PFMA's 20 to 27, 123, 125).

Total effort (E), converted from minutes to hours, were estimated using the formula:

$$E = C / R \tag{1}$$

where C = landings (kilograms) from sales slips and R = kilograms per hour from the harvest logbooks per PFMA.

BED AREAS

Commercial beds of red sea urchins were identified two ways, using (1) charts provided by fishers, indicating bed areas in the North Coast region during 1993, and (2) detailed bed areas on charts or diagrams provided by fishers with their harvest logbooks throughout B.C. during 1982-1994. The detailed bed areas were outlined on hydrographic charts from 0 to 10 m below Chart Datum and were digitized and areas estimated. For the first group, chart bed estimates are detailed in Heritage and Campbell (unpublished manuscript). For the second group, the data from the harvest logbooks are detailed in the present paper. The digitized bed areas used in the analyses for this paper are only those indicated as harvested. Estimation of these red urchin bed areas must be treated with caution since the beds were not measured empirically in the field, and the proportion of the substrate types are unknown and may differ from one area to another.

DENSITIES

Densities of red sea urchins were generally estimated within 1 m^2 quadrats along randomly chosen transects. Details of survey methodology varied between surveys (Adkins *et al.* 1981; Jamieson *et al.* 1998b). Density estimates from Adkins *et al.* (1981) could be biased since counts were made only at sites where there were more than 1 red sea urchin/m^2. Test diameters (TD, in millimeters) of urchins were measured in the surveys by Jamieson *et al.* (1998a-1998d) but not by Adkins *et al.* (1981). Size frequencies for each area were used to estimate the proportion of urchins that were of commercial size (≥ 100 mm TD). An overall mean proportion of 0.39 and 0.45 was estimated for the North Coast and the South Coast, respectively, and used in areas where no size frequencies were available.

Where there were no density estimates for a PFMA, an overall mean density of 0.82 and 1.3 urchins/m^2 was calculated for the North Coast and the South Coast, respectively.

MEAN WEIGHTS

The relationship between total wet weight (w_i, in grams) and test diameter (T_i) for size class i (by 1 mm TD) was determined from red sea urchins collected at Campbell River and WCVI (Tofino) (A. Campbell, unpublished data) (Fig. 1). The urchins were left out of water for about 4-6 hr before they were measured so there that would be some loss of water. The data were fitted to a linear regression $\log w_i = \log a + b \log T_i$ where a and b are constants estimated by least squares. A power equation was calculated:

$$w_i = aT_i^b \qquad (2)$$

where $a = 0.0012659$ and $b = 2.7068$ with $r^2 = 0.960$, and sample size was 167 (min. 10 to max. 150 mm TD).

Estimated mean weights (W, in grams) of commercial-sized urchins for each area were estimated from the survey size frequency data as follows:

$$W = \frac{\sum_{i=1}^{n}(w_i N_i)}{N} \qquad (3)$$

where N_i = the number of urchins in size class i, N = total number of urchins of commercial size, n = number of size classes ≥ 100 mm TD, and w_i = the predicted mean total wet weight (grams) in size class i from equation (2).

NATURAL MORTALITY

There are no published estimates of instantaneous natural mortality rate (M) for red sea urchins from northern B.C. Breen (1984) estimated that M ranged from 0.016 to 0.22 for red urchins from three sites in southern B.C. and considered a value between 0.1-0.2 to be acceptable. Woodby (Unpublished manuscript) estimated M = 0.16 for red sea urchins from the Sitka, Alaska area.

Botsford *et al.* (1993) estimated M = 0.14 for a population of red sea urchins in California. For the purpose of the present paper, M was assumed to be 0.15 for red sea urchins in B.C.

RECRUITMENT

Sloan *et al.* (1987) estimated recruitment to be highly variable between areas and to average at about 9.5% of the total number of sea urchins in the size frequencies per area.

BIOMASS ESTIMATION

Total current biomass of red sea urchins for various areas were calculated with:

$$B_c = AWD \tag{4}$$

where B_c = current average biomass (grams), subsequently converted to tonnes (10^6 grams) and summed for each PFMA; A = commercial urchin area (square meters) estimated from digitized charts, subsequently converted to hectares (10,000 m^2 in 1 ha); W = mean weight (grams) of commercial-sized red sea urchins (TD $\geq$ 100 mm) calculated from equation 3; and D = mean density (number per square meter) of commercial-sized red sea urchins. Biomass was calculated using both bed area estimates: Biomass 1 where A = used digitized areas from fishers' charts (North Coast only), and Biomass 2 where A = used digitized areas from harvest logbook entries (all of B.C.).

QUOTA ESTIMATION

A conservative management approach was used to estimate quotas (Q) for the red sea urchin fishery in B.C. A modified surplus production model was used to estimate a maximum sustainable yield (MSY) from a stock in the early stages of exploitation (Schaefer 1954; Gulland 1971). The model assumes that the MSY occurs when the maximum sustainable fishing mortality is equal to M.

$$Q = X\,M\,B_c \tag{5}$$

where B_c is the current biomass, M is the instantaneous natural mortality rate and X = a correction factor to insure that a sustainable fishing mortality rate is well below the calculated MSY. Three values of X (0.175, 0.200, 0.225) were used in this paper to provide a reasonably conservative safeguard to account for errors in estimating the lower current biomass values. These choices were influenced by the recommendations by Caddy (1986) of having a conservative X value of 0.4 and by Garcia *et al.* (1989) of limiting by half (0.5) the harvest predicted by the similar Gulland (1971) model for a virgin population biomass. The correction factor should provide for a range of annual conservative harvest quota options in a developing fishery where little is known about the productivity of the population. Since equation 5 was derived from a Graham-Schaefer production model, recruitment was assumed to be unaltered by these low fishing levels. Although this approximation was developed for an unexploited virgin stock (Bo) B_c was assumed to equal B_o.

Caution is required in the interpretation of these calculations for the quota because there are so many assumptions in the parameters used in the oversimplified model. Also there is considerable error in measuring densities, bed areas and mean weights which would yield large confidence limits (probably at least twice the mean above and below) around the current biomass estimates.

RESULTS AND DISCUSSION

CATCH AND EFFORT

The number of fishing vessels peaked at 116 in 1990 (Table 1, Fig. 3). Coastwide landings peaked at 12,983 t in 1992 (Tables 1 and 2, Fig. 2). Arbitrary quotas have generally restricted landings in the South Coast since 1985 and in North Coast since 1993 (Table 1).

CPUE's (in kilograms per diver minute) from harvest logbooks were variable between years and PFMA's (Table 3). There were no distinct general trends in CPUE at the general region level and PFMA level between 1982-1994 (Fig. 4, Appendix Figs. 1a-1c). The recent coastwide decline in CPUE during 1993-1994 (Fig. 4) may be a source for concern. A possible explanation for the decline is that fishers have increased search time for high quality urchins in response to recent changes in market demands and the implementation of a voluntary individual quota scheme. There was no distinct relationship between CPUE (kilograms per diver minute) and the total estimated fishing hours for each PFMA and year; consequently the data were combined (Fig. 5). The lack in CPUE trends suggests that either the fishery is at an early stage of development or CPUE data for red sea urchins can not be used to indicate fishery trends in B.C.

There was a significantly correlated linear relationship between effort (number of fishing days or total diver hours) and catch (tonnes landed) (Figs. 6 and 7) without any indication of reaching an asymptote at high effort levels. This suggests that the red sea urchin fishery is still in the early stages of development. However, fishers may be maintaining high CPUE values by moving to unexploited sea urchin beds within a PFMA suggesting that CPUE would not decline until most of the sea urchins were removed from most of the areas in the PFMA. There is a need to re-examine the distribution of effort and variability of CPUE data on a smaller spatial scale (*e.g.* PFMA subarea or bed) than the PFMA level to determine whether CPUE is an appropriate index of red sea urchin abundance. How 'diver experience' influences CPUE in the red sea urchin fishery also should be examined from the harvest logbooks.

DENSITY AND MEAN WEIGHTS

Mean densities (number per square meter) and weights of commercial-sized red sea urchins varied considerably from bed to bed and from PFMA to PFMA (Tables 4 to 6). The overall mean density and weight (respectively) of commercial-sized red sea urchins was 0.82 urchins/m^2 and 509.8 g for the North Coast and 1.3 urchins/m^2 and 500.0 g for the South Coast. Adkins *et al.* (1981) estimated a mean drained weight of a legal-sized (at that time, >101.6 mm TD) red sea urchin for the South Coast was 565 g. Without having a standard methodology for all the surveys, estimating upper and lower 95% confidence limits for these means is difficult and suggests that the mean densities and weights should be considered with caution.

BED AREAS

Estimated bed areas, from 1994 harvest logbooks, were variable for each PFMA (Tables 5 and 7). Using charts to estimate bed areas is crude, especially as each location may have different substrate surface areas. The harvest logbooks provide an historical cumulative estimate of fishable sea urchin areas but may include areas that no longer have viable red sea urchin populations. There may be areas still unexplored, especially in the North Coast, that may contain substantial unfished "virgin" populations that have not been included in the biomass estimates. Bed area estimates probably provide the most uncertainty of all the estimates used to calculate biomass. Future surveys might examine a number of randomly chosen sites to estimate the level of precision which could be included in the analysis to establish bounds in bed area estimates.

BIOMASS AND QUOTA

Red sea urchin biomass varied considerably between PFMA's (Tables 5 and 7). Estimated quota options for each region were slightly less than the quotas set for 1994 (Tables 1 and 8). All these biomass and quota estimates must be treated with caution, especially when considering how inaccurate the bed estimates of viable red sea urchin populations may be, *e.g.*, biomass and quota estimates were 28% higher when using fishers' identified areas compared to those from the harvest logbooks for the North Coast (Table 8).

RECOMMENDATIONS

1) Biomass and quota estimates in this paper should be considered only as a preliminary indication of the status of red sea urchin stocks in B.C.

2) Further surveys of red sea urchin density, especially in southern B.C., are required.

3) More accurate estimates of bed areas holding viable populations of red sea urchins are required.

4) Re-examine CPUE data on a small spatial scale (*e.g.* PFMA subarea or bed) to determine whether CPUE is an appropriate index of red sea urchin abundance and can be used in detailed surplus production analyses.

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Table 1. Annual red sea urchin landings (tonnes), value and effort for British Columbia, 1978 to 1994, as reported on sales slips and harvest logbooks.

Year	Type and # of Licences issued	South Coast[1] Quota (t)	North Coast[2] Quota (t)	Number of Vessels with Landings	Total Vessel Fishing Days	Coastwide Landings (t)	Landed Value ($.10^3)	Whole Landed Value ($/t)	X CPUE (t/vessel day)	X CPUE (kg/diver hr)
1978	C			4	54	75	16	213	1.4	-
1979	C			29	298	317	76	240	1.1	-
1980	C			18	331	333	84	252	1.0	-
1981	C	136		18	127	116	34	293	0.9	-
1982	C			21	195	160	56	350	0.8	-
1983	Z 64			36	825	986	358	354	1.2	311
1984	Z 85			47	1150	1764	712	403	1.6	281
1985	Z 86	1803		46	1086	1815	764	419	1.7	360
1986	Z 103	1500		67	1534	2067	1011	455	1.4	363
1987	Z 184	1633		97	1807	2118	1148	541	1.2	325
1988	Z 184	1678		84	1249	2116	1241	587	1.7	296
1989	Z 240	1644		109	1542	2658	1631	614	1.7	360
1990	Z 188	1668		116	2651	3158	1953	618	1.2	298
1991	Z 102	1531		89	3862	6831	4187	613	1.8	363
1992	Z 108	1554		110*	5789	12983	8002	616	2.1	388
1993	Z 107	1401	5400	103	3204	6264	4900	782	1.9	344
1994	Z 110	1543	5897	98	3979	5818	7829	1349	1.5	325

[1] South Coast quota includes exploratory areas, North Coast quota was new in 1993.
[2] From sales slip data.
[3] CPUE from harvest logbook data.
* Larger than the number of licences issued due to licence transfers.

Table 2. Summary of annual red sea urchin landings (tonnes) from sales and validation slips in British Columbia by region and PFMA during 1982-1994.
[1] includes sales slips from PFMA 106, [2] includes sales slips from PFMA 123, [3] includes sales slips from PFMA 125.

REGION	PFMA	YEAR													
		82	83	84	85	86	87	88	89	90	91	92	93	94	TOTAL
North Coast	1			2.2					0.2				96.8	232.3	331.5
	2								223.0	37.3	335.8	1111.0	275.9	548.2	2531.2
	3								1.6	24.5	184.7	1.0	127.2	203.5	542.5
	4						23.0	73.0	116.0	156.8	1085.1		1008.0	720.3	3182.2
	5							11.0	1.3	265.3	2581.3	3294.0	463.0	943.5	7559.4
	6 [1]							7.3	168.4	67.1	97.6	4063.0	2103.0	1134.2	7640.6
	7						179.0	314.0	217.0	1040.1	758.6	2763.0	1012.0	757.6	7041.3
	8						91.0	32.0	65.0		124.1	140.0	35.8	62.0	549.9
	9										30.2	114.0		54.9	199.1
	10					12.0			180.0		296.3	38.0	242.5	182.1	950.9
	Total			2.2		12.0	293.0	437.3	972.5	1591.1	5493.7	11524.0	5364.2	4838.6	30528.6
Inside Waters	11		7.8	0.3		27.0	6.9	2.6		84.8	36.4	8.0	55.6	15.7	245.1
	12	2.5	99.0	437.0	354.0	548.0	420.0	534.0	569.0	437.6	358.7	531.0	329.0	386.2	5006.0
	13		264.0	777.3	492.0	376.0	491.0	480.0	493.0	428.4	370.7	320.0	184.0	203.8	4880.2
	14	46.0	260.0	172.0	167.0	178.0	193.0	78.0	122.0	56.6				0.5	1273.1
	15				106.0	56.0	32.4	21.0	6.7	1.2	8.6			4.7	236.6
	16				5.9	4.4		2.3		0.6					13.2
	17	0.8	59.0	33.0	29.0	57.0	71.0		9.0	43.0	26.6	103.0	21.0	2.6	455.0
	18	11.0	38.0	67.4	48.0	129.0	71.0	22.0	64.0	46.5	94.8	36.0	102.1	41.4	771.2
	19	94.0	112.0	76.3	77.0	105.0	123.0	78.0	57.0	58.6	27.2	86.0	16.3	50.0	960.4
	28						16.8			0.3					17.1
	29			5.7	47.0	2.0	7.8		1.6	1.8	14.1	4.0			84.0
	Total	154.3	839.8	1569.0	1325.9	1482.4	1432.9	1217.9	1322.3	1159.4	937.1	1088.0	708.0	705.0	13942.0

Table 2. (cont.).

REGION	PFMA	YEAR													TOTAL
		82	83	84	85	86	87	88	89	90	91	92	93	94	
WCVI	20		24.0	69.1	29.8	40.0	17.0	74.0	15.0	7.9	31.2	56.0	14.6	15.0	393.6
	21										2.7	9.0			11.7
	23 [2]		22.0	17.3	96.0	154.0	63.0	13.0		59.7	58.4	31.0	43.4	24.8	582.6
	24	5.0	38.0	103.0	158.0	283.8	199.0	250.0	223.0	215.1	185.1	200.0	92.0	112.2	2064.2
	25 [3]				145.0		95.0	66.0	39.0	56.8	115.8	10.0	7.0	52.1	586.7
	26		62.0	3.9	15.0	2.5	8.3						2.0		93.7
	27				45.0	91.0	12.0	58.0	86.0	68.1	121.1	65.0	50.0	75.8	672.0
	Total	5.0	146.0	193.3	488.8	571.3	394.3	461.0	363.0	407.6	514.3	371.0	209.0	279.9	4404.5
South Coast	Total	159.3	985.8	1762.3	1814.7	2053.7	1827.2	1678.9	1685.3	1567.0	1451.4	1459.0	917.0	984.9	18346.5
All PFMA's in B.C.	Total	159.3	985.8	1764.5	1814.7	2065.7	2120.2	2116.2	2657.8	3158.1	6945.1	12983.0	6281.2	5823.6	48875.2

Table 3. Summary of mean catch per unit effort (kilogram per minute) of red sea urchins by PFMA, from harvest log books, 1982-1994. [1] incorporates the data from PFMA 105. [2] incorporates the data from PFMA 106. [3] incorporates the data from PFMA 123. [4] incorporates the data from PFMA 124. [5] incorporates the data from PFMA 125.

REGION	PFMA	YEAR													ALL
		82	83	84	85	86	87	88	89	90	91	92	93	94	YEARS
North Coast	1								3.8				7.6	4.3	5.2
	2								5.9	8.7	7.0	7.5	6.3	5.4	6.8
	3								8.0		6.1		3.3	5.4	5.7
	4							5.4	6.1	4.7	5.4		6.4	5.2	5.5
	5 [1]							4.0	3.5	4.7	6.3	5.7	6.4	5.7	5.2
	6 [2]							5.2	5.2	6.3	5.9	7.0	5.6	6.6	6.0
	7						5.8	4.7	5.3	5.0	5.1	5.1	5.7	5.1	5.2
	8						5.5	5.0	8.4		5.5	6.4		4.7	5.9
	9										5.0	8.9	2.8	4.5	5.3
	10							4.0	7.2		7.1		4.4	4.4	5.4
	Total Mean						5.8	5.1	6.1	5.0	6.2	6.5	5.8	5.1	5.7
Inside Waters	11			2.6		8.0		4.5		4.7	6.5	5.6	6.4	4.0	5.3
	12		5.6	3.4	8.4	7.0	6.6	5.5	5.3	5.4	7.2	7.5	6.0	7.0	6.2
	13		5.2	4.7	5.8	6.6	5.6	3.7	5.5	5.0	6.8	7.7	6.4	5.5	5.7
	14	1.1	3.0	5.2	5.3	7.1	7.9	5.3	5.6	6.0		6.1			5.3
	15				5.6	4.4	5.2	3.8	3.8	2.2	2.9				4.0
	16				7.6	2.6		5.0		1.9					4.3
	17			4.6	3.7	6.4	3.7	5.6		4.5	7.8	5.4	8.2	4.7	5.5
	18		4.2	4.7	3.4	6.3	4.1	3.7	4.7	5.7	6.1	4.0	5.9	4.7	4.8
	19	4.8	3.7	4.1	5.2	7.6	5.0	4.4	4.1	4.3	6.8	4.9	3.3	5.2	4.9
	29			5.8		7.3		4.5			9.4	4.5	7.0	3.8	6.1
	Total Mean	2.9	5.0	5.6	6.1	6.5	5.6	4.8	5.4	5.3	6.6	6.8	5.8	5.6	5.5

Table 3. (cont.).

REGION	PFMA	YEAR													ALL
		82	83	84	85	86	87	88	89	90	91	92	93	94	YEARS
WCVI	20		3.1	4.4	7.3	5.5	1.8	4.9	3.9	4.8	5.6	5.1	5.0	4.5	4.7
	23 [3]		4.7	3.2	5.3	4.2	5.7	6.7		5.2	8.6	6.6	5.2	4.7	5.5
	24 [4]	4.3	3.0	4.8	4.2	5.9	5.3	5.7	4.2	4.8	5.8	8.6	5.0	4.8	5.1
	25 [5]				4.2		4.7	4.0	6.4	5.6	5.9	6.5	5.1	4.4	5.2
	26		4.5	3.2	8.1	5.6	4.2	3.3							4.8
	27				4.8	5.9	6.0	6.0	5.9	5.6	7.3	7.5	4.7	4.7	5.9
	Total Mean	4.3	4.0	4.3	5.1	5.5	5.1	5.1	6.2	5.0	6.2	7.0	5.1	4.8	5.2

Table 4. Estimated mean density (number per square meter) and mean weight (grams) of red sea urchins in B.C., by PFMA, obtained from broad-brush surveys during 1993-94. Data include analyses from Jamieson *et al.* (1998a, 1998b, 1998c) and present study. Legal ≥ 100 mm TD.

PFMA &		Total Transect		Total Urchins		Legal		Mean
Subarea	Year	Number	Length (m)	Number	Density	Percent	Density	weight (g)
1-1	94	5	764.0	2663	3.486	46.62	1.625	502.83
1-2	94	15	1686.0	9371	5.558	48.96	2.721	500.11
1-3	94	16	1795.0	2796	1.558	72.09	1.123	650.99
1-7	94	9	2859.0	2252	0.788	70.86	0.558	618.75
2-3	93	5	556.7	509	0.914	46.25	0.423	523.37
2-7	93	6	476.0	1609	3.380	28.14	0.951	523.75
2-8	93	7	1070.3	1836	1.715	31.04	0.532	513.03
2-10	93	4	557.4	446	0.800	52.36	0.419	626.48
2-11	93	8	589.0	1510	2.564	33.16	0.850	544.72
2-12	93	6	3234.0	462	0.143	52.00	0.074	485.67
2-14	93	9	1047.3	2094	1.999	23.44	0.469	478.61
2-15	93	6	229.6	202	0.880	34.92	0.307	602.94
2-17	93	11	628.5	1760	2.800	40.50	1.134	517.19
2-49	93	2	642.4	255	0.397	15.25	0.061	489.80
2-50	93	2	70.2	282	4.019	30.21	1.214	438.75
2-53	93	1	93.0	422	4.540	29.70	1.348	421.71
2-54	93	2	87.6	105	1.198			
2-55	93	1	25.7	77	2.994	13.37	0.400	559.79
2-57	93	2	67.6	309	4.572			
2-59	93	5	311.7	284	0.911	9.84	0.090	425.19
2-60	93	3	385.5	699	1.813	4.82	0.087	416.91
2-63	93	6	207.4	2080	10.031	11.27	1.130	373.10
2-64	93	2	52.4	194	3.706	7.40	0.274	404.07
3-1	93	29	1011.2	1627	1.609	46.81	0.753	541.78
3-2	93	6	211.8	119	0.562	55.02	0.309	578.18
4-1	93	34	1264.4	1414	1.118	52.48	0.587	575.04
4-2	93	8	809.4	685	0.846	52.50	0.444	569.93
4-13	93	3	26.5	77	2.903	43.84	1.273	537.32
6-10	94	27	4753.0	9895	2.082	44.85	0.934	536.60
6-12	94	7	524.0	676	1.290	32.41	0.418	561.16
6-13	93	32	2434.2	7641	3.139	38.46	1.207	507.55
6-14	93	11	761.6	2008	2.636	43.32	1.142	560.42
6-15	93	8	425.6	571	1.342	47.75	0.641	510.55
6-16	93	11	881.2	2225	2.525	27.68	0.699	442.73
6-17	93	9	520.5	3456	6.640	44.24	2.938	484.75
6-18	93	3	315.8	161	0.510	45.28	0.231	444.52
6-19	93	6	566.3	831	1.467	30.77	0.452	419.51
7-2	93	4	268.0	1635	6.102	30.35	1.852	479.40
7-3	93	14	2085.9	6156	2.951	37.21	1.098	469.43
7-4	93	4	916.3	1420	1.550	39.66	0.615	480.48
7-8	93	5	3016.3	1038	0.344	30.82	0.106	452.06
7-18	94	26	1458.0	4988	3.421	30.59	1.046	459.64
7-20	93	4	471.2	1190	2.525	20.50	0.518	418.27
7-25	94	26	1286.0	3726	2.897	41.05	1.189	489.37
7-27	93	8	838.4	1431	1.707	25.73	0.439	440.22
7-31	93	10	1025.8	3200	3.119	42.26	1.318	473.64
7-32	93	4	729.6	1923	2.636	21.95	0.578	436.54
10-1	93	5	2984.0	2097	0.703	12.35	0.087	438.03
106-2	94	28	2633.0	11970	4.546	38.79	1.763	475.76

Table 5. Summary of estimated red sea urchin biomass from commercial-sized urchin density and mean weight, and digitized bed areas identified from (1) fishers' charts and (2) harvest logbooks in the PFMA's of the North Coast. Sea urchin biomass = bed area x density x mean weight. Density estimates and mean weights calculated from Jamieson *et al.* (1998a, 1998b, 1998c) and re-analyses of data. *Estimated as overall weighted mean density and weight from all survey data.

PFMA	URCHIN DENSITY (no./m^2)	URCHIN WEIGHT (grams)	BED AREA (FISHERS) (hectares)	URCHIN BIOMASS 1 (tonnes)	BED AREA (LOGBOOKS) (hectares)	URCHIN BIOMASS 2 (tonnes)
1	1.33	552.7	7643.9	56189.4	7006.1	51501.1
2 East	0.42	523.2	2768.6	6083.9	3270.7	7187.1
2 West	0.29	410.9	232.0	276.5	1062.5	1266.1
3	0.68	544.7	1799.0	6663.5	837.6	3102.3
4	0.54	572.3	5654.8	17475.8	3665.7	11328.6
5			9550.9	.	8224.9	.
6	1.00	515.2	7634.5	39333.1	8298.7	42754.8
7	0.75	468.3	7515.8	26397.5	4349.6	15276.9
8			1279.4	.	202.6	.
9			728.4	.	474.1	.
10	0.09	438.0	1730.9	682.4	839.6	331.0
102			35.2	.	.	.
105			176.0	.	.	.
106	1.76	475.8	4120.9	34506.2	1554.8	13018.9
108			107.4	.	.	.
TOTAL	0.82 *	509.8 *	50977.8	213122.4	39786.8	166336.4

Table 6. Published total density estimates of red sea urchins for South Coast.

Location	PFMA	Date	Urchin Density $\#/m^2$
Breen *et al.* (1978)			
Site #2, S. Vargas I.	24	Nov. 1977	5.7
Site #3, Thorn Reef	24	Nov. 1977	9.6
Site #3, Thorn Reef	24	Aug. 1974	4.8
Site #3, Thorn Reef	24	Jun. 1976	5.6
Breen *et al.* (1976)			
S. Vargas I.	24	Jun. 1976	12.6
Adkins *et al.* (1981)			
80-93, Nose Point	18	Nov. 1980	4.32
80-95, Ballingall Islets	18	Nov. 1980	1.68
80-96, Wilmont Head	18	Nov. 1980	1.59
80-97, S. Parker I.	18	Nov. 1980	1.5
80-98, Phillmont Pt.	18	Nov. 1980	4.41
80-100, Beaver Pt.	18	Nov. 1980	3.24
80-101, Yeo Pt.	18	Nov. 1980	1.5
80-102, Channel I.	18	Nov. 1980	5.84
80-104, Active Pass	18	Nov. 1980	1.86
80-105, Active Pass	18	Nov. 1980	5.8
80-108, Rock N. Secret I.	18	Nov. 1980	9.76
80-114, Conconi Reef	18	Nov. 1980	1.77
80-118, Kendrick Rock	17	Nov. 1980	2.83
80-120, Gabriola Pass	17	Nov. 1980	3.59
80-121, Gabriola Pass	17	Nov. 1980	4.04
80-122, Portland Island	19	Nov. 1980	2.88
80-123, Portland Island	19	Nov. 1980	1.20
80-127, Dock I.	19	Nov. 1980	2.43
80-128, Pelorus Pt.	19	Nov. 1980	3.48
80-129, Pt. Fairfax	19	Nov. 1980	1.43
80-130, Brethour I.	19	Nov. 1980	1.0
80-132, Gooch I.	19	Nov. 1980	2.63
80-133, N. Cod Rock	19	Nov. 1980	7.76
80-134, Forrest I.	19	Nov. 1980	3.85
80-135, Halibut I.	19	Nov. 1980	1.59
80-137, Little D'arcy I.	19	Nov. 1980	4.27
80-138, Little D'arcy I.	19	Nov. 1980	0.1

Table 6. (cont.)

Location	PFMA	Date	Urchin Density #/m^2
Sloan *et al.* (1987)			
Gabriola Pass-Site 101	17	Oct 84-Feb 85	7.0
Gabriola Pass- Site 102	17	Oct 84-Feb 85	1.6
Gabriola Pass- Site 103	17	Oct 84-Feb 85	2.1
Gabriola Pass- Site 104	17	Oct 84-Feb 85	8.3
Hornby I.- Site 201	14	Oct 84-Feb 85	3.1
Hornby I.- Site 202	14	Oct 84-Feb 85	0.9
Hornby I.- Site 203	14	Oct 84-Feb 85	3.2
Hornby I.- Site 204	14	Oct 84-Feb 85	4.6
Hornby I.- Site 205	14	Oct 84-Feb 85	9.6
Tofino- Site 302	24	Oct 84-Feb 85	4.4
		Mean	4.0
Jamieson *et al.* (1998d)			
Subarea 3	12	Jan - Feb 94	2.02
Subarea 5	12	Jan - Feb 94	1.36
Subarea 6	12	Jan - Feb 94	0.35
Subarea 8	12	Jan - Feb 94	0.73
Subarea 11	12	Jan - Feb 94	3.05
Subarea 12	12	Jan - Feb 94	6.48
Subarea 16	12	Jan - Feb 94	0.46
Subarea 18	12	Jan - Feb 94	1.46
Subarea 39	12	Jan - Feb 94	0.08
		Mean	1.77

Table 7. Estimated red sea urchin biomass from commercial-sized urchin density and mean weight and digitized bed areas identified from harvest logbooks of PFMA's in South Coast. Sea urchin biomass = bed area x density x mean weight. *Average of mean density calculated from means 4.0 and 1.77 from Table 6 and reduced by 0.45 for urchins ≥ 100 mm test diameter. +Overall mean weight approximated from size frequencies of South and North Coast.

PFMA	URCHIN DENSITY (no. / m^2)*	URCHIN MEAN WEIGHT (grams)+	BED AREA (hectares)	URCHIN BIOMASS 2 (tonnes)
Inside Waters				
11	1.3	500	218.6	1420.9
12	1.3	500	2022.2	13144.3
13	1.3	500	1201.2	7807.8
14	1.3	500	820.3	5331.9
15	1.3	500	36.9	239.9
17	1.3	500	169.4	1101.1
18	1.3	500	439.5	2856.8
19	1.3	500	230.0	1495.0
28	1.3	500	6.5	42.2
29	1.3	500	61.8	401.7
Total	1.3	500	5206.4	33841.6
WCVI				
20	1.3	500	534.0	3471.0
23	1.3	500	169.4	1101.1
24	1.3	500	555.0	3667.5
25	1.3	500	455.2	2958.8
26	1.3	500	37.8	245.7
27	1.3	500	371.4	2414.1
125	1.3	500	48.0	312.0
Total	1.3	500	2170.9	14110.8

Table 8. Quota (tonnes) estimated for red sea urchins from the current biomass (tonnes) estimates (Tables 5 and 7) and assuming digitized bed areas (hectares) from harvest logbooks except where shown. [a] = values in brackets based on bed areas digitized from fishers' identified areas. X = correction factor in quota calculation equation (5); see text for details.

REGION	BED AREA	CURRENT BIOMASS B_c	QUOTA		
			X = 0.175	X = 0.200	X = 0.225
North Coast					
	39,786.8 (50,977.8[a])	166,336.4 (213,122.4)	4,366.3 (5,594.5)	4,990.1 (6,393.7)	5,613.9 (7,192.9)
Inside Waters					
	5,206.4	33,841.6	888.3	1,015.3	1,142.2
West Coast Vancouver Island					
	2,170.9	14,110.8	370.4	423.3	476.2
South Coast Total					
	7,377.3	47,952.5	1,258.8	1,438.6	1,618.4
Total B. C.	47,164.1	214,288.9	5,625.1	6,428.7	7,232.3

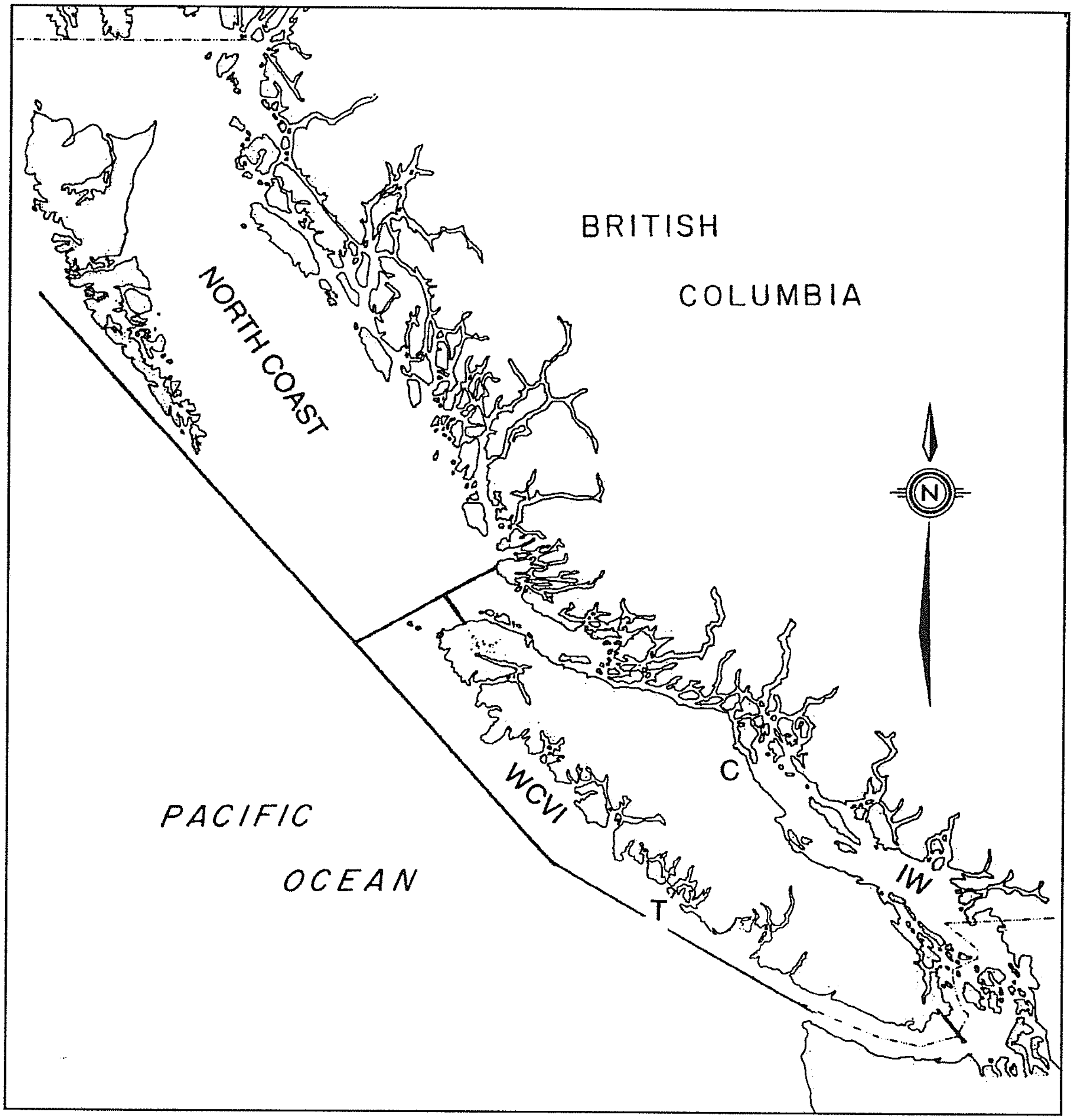


Fig. 1. Location of general coastal regions where red sea urchins are harvested and study areas in British Columbia. South Coast regions: WCVI = west coast of Vancouver Island; I.W. = Inside Waters. Study areas: C = Campbell River; T = Tofino.

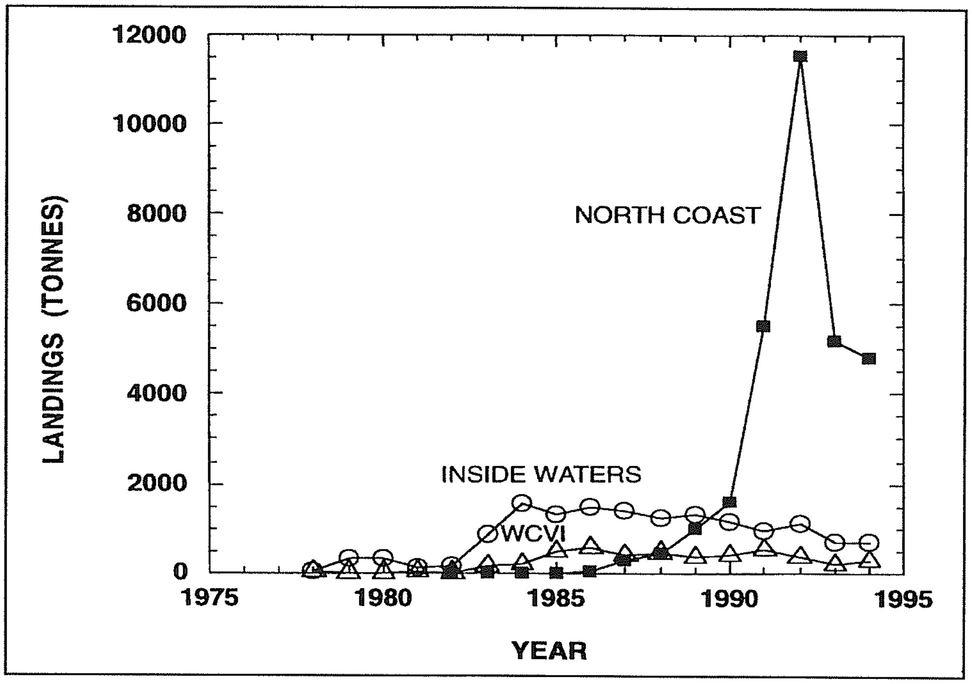


Fig. 2. Annual landings in tonnes for the North Coast (filled squares), South Coast - Inside Waters (open circles) and WCVI (open triangles) from sales slips.

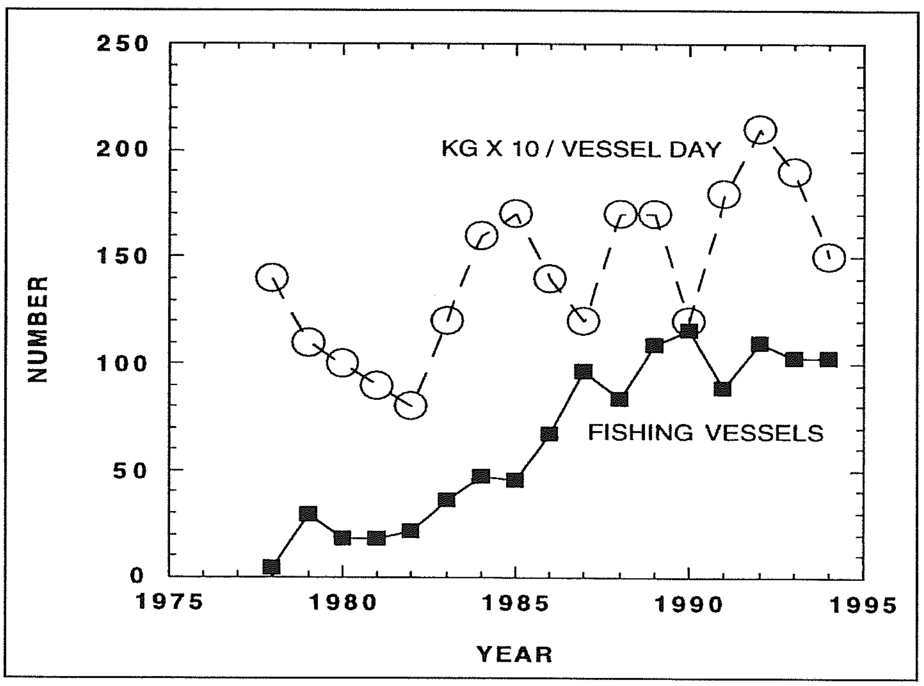


Fig. 3. Annual number of fishing vessels (filled squares) and mean weight (kilograms x 10) per vessel per day (open circles) from sales slips for the red sea urchin fishery in B.C.

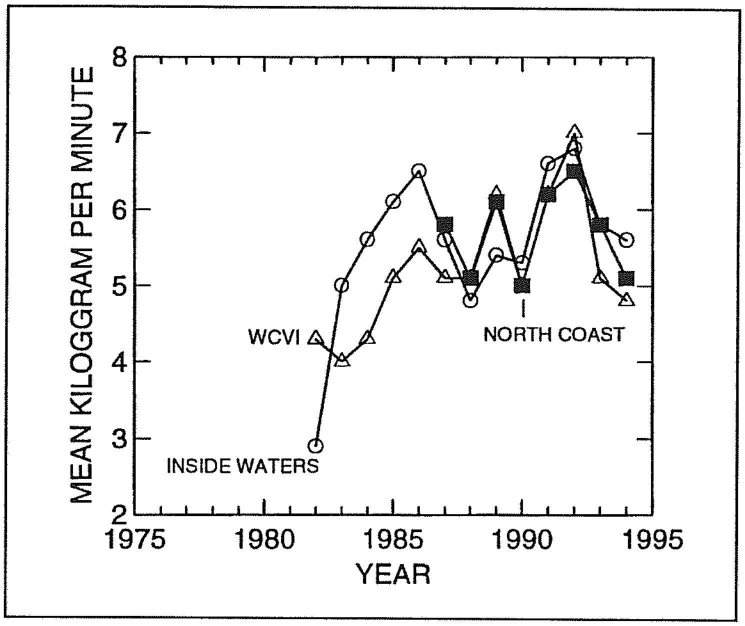


Fig. 4. Annual mean CPUE's (kilograms per diver minute) from harvest logbooks for the North Coast (filled squares), South Coast - Inside Waters (open circles) and WCVI (open triangles).

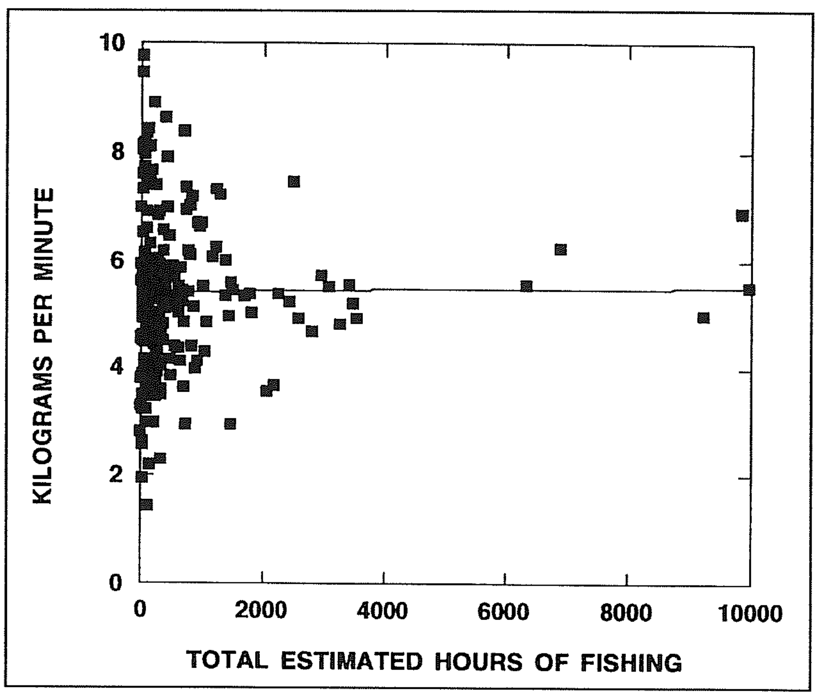


Fig. 5. The relationship between CPUE (kilograms per diver minute) and total estimated hours of fishing for all PFMA's and years, from combined sales slips and harvest logbooks. Values for total fishing hours > 3000 are from North Coast; the remainder are from both North and South Coast.

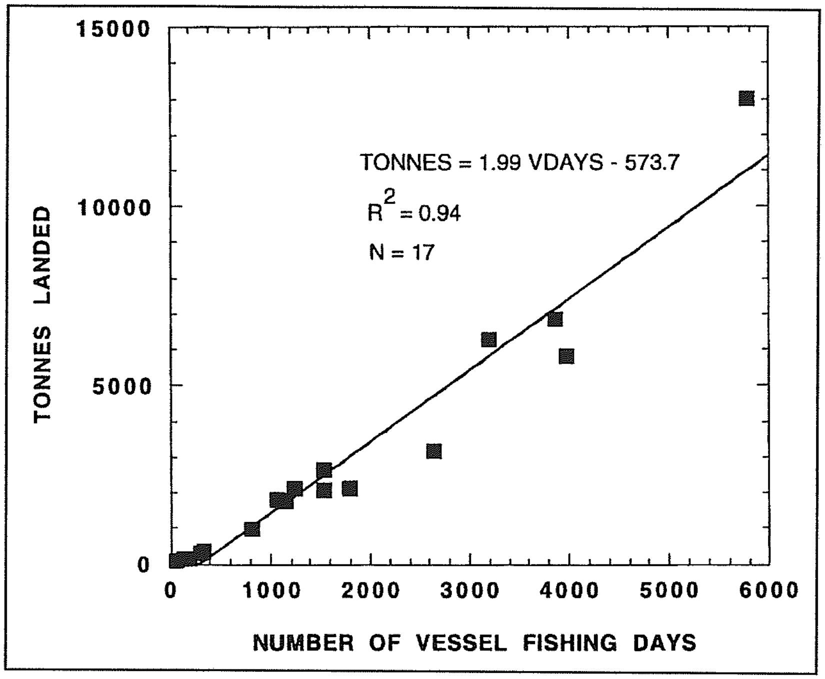


Fig. 6. Relationship between the total number of fishing days and red sea urchin landings (tonnes) in B.C. annually during 1978-1994. Data from sales slips.

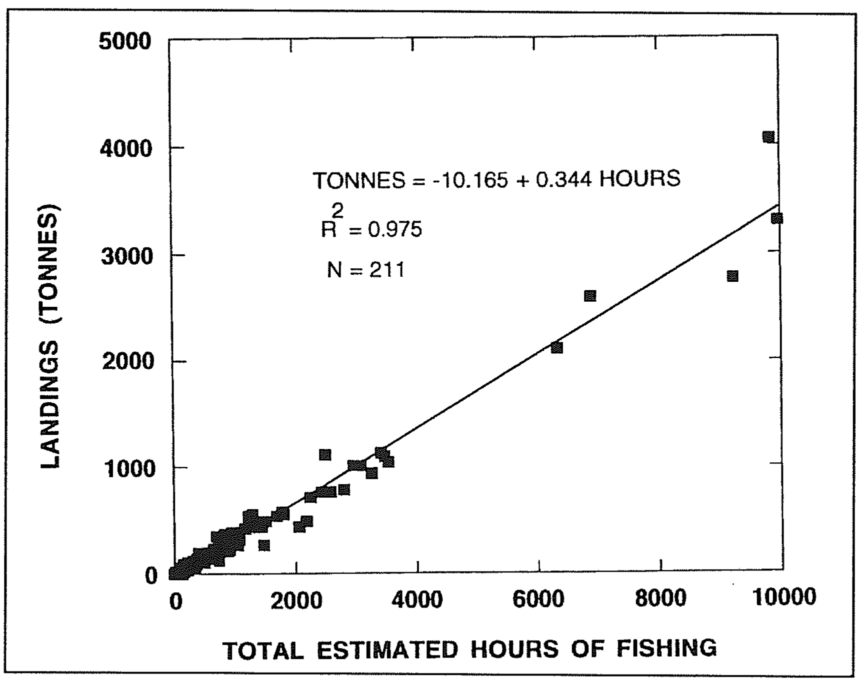
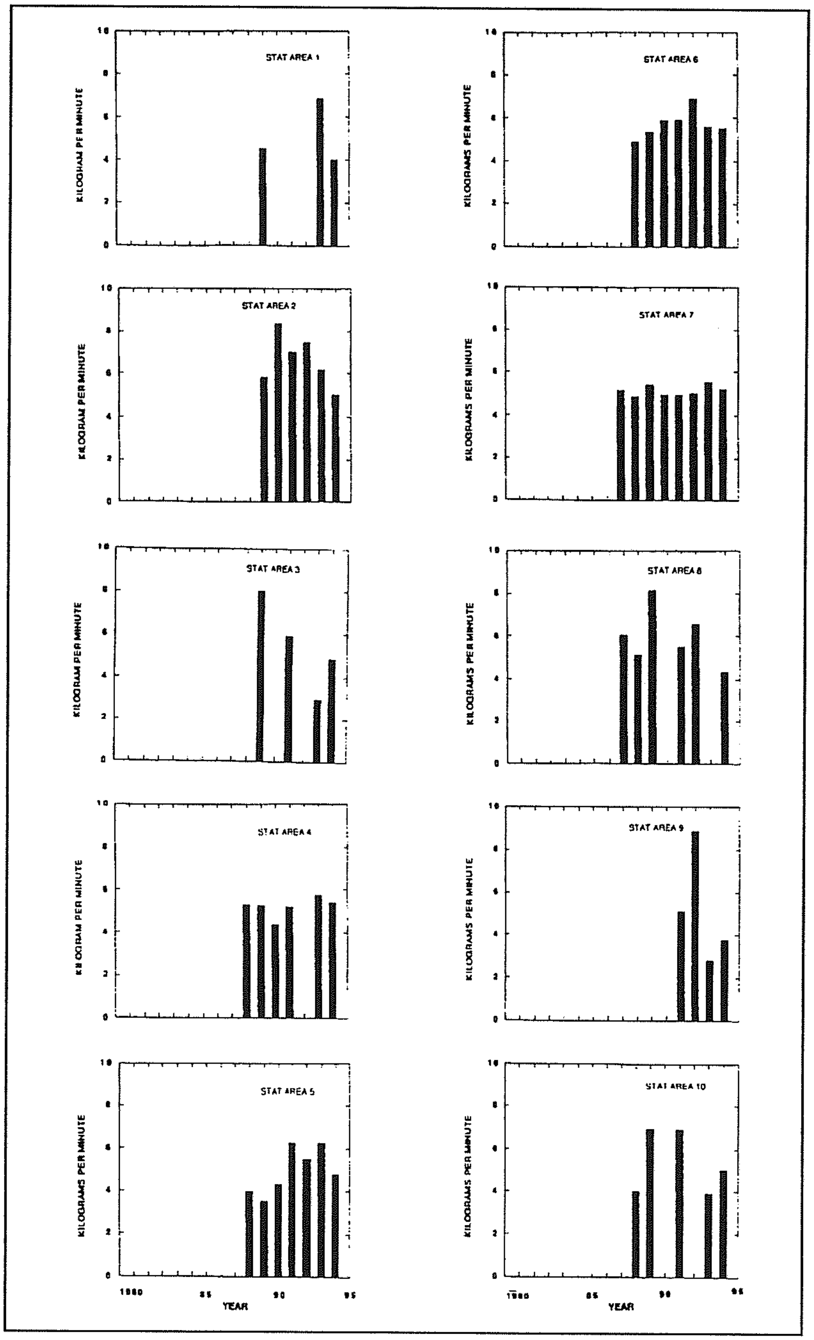
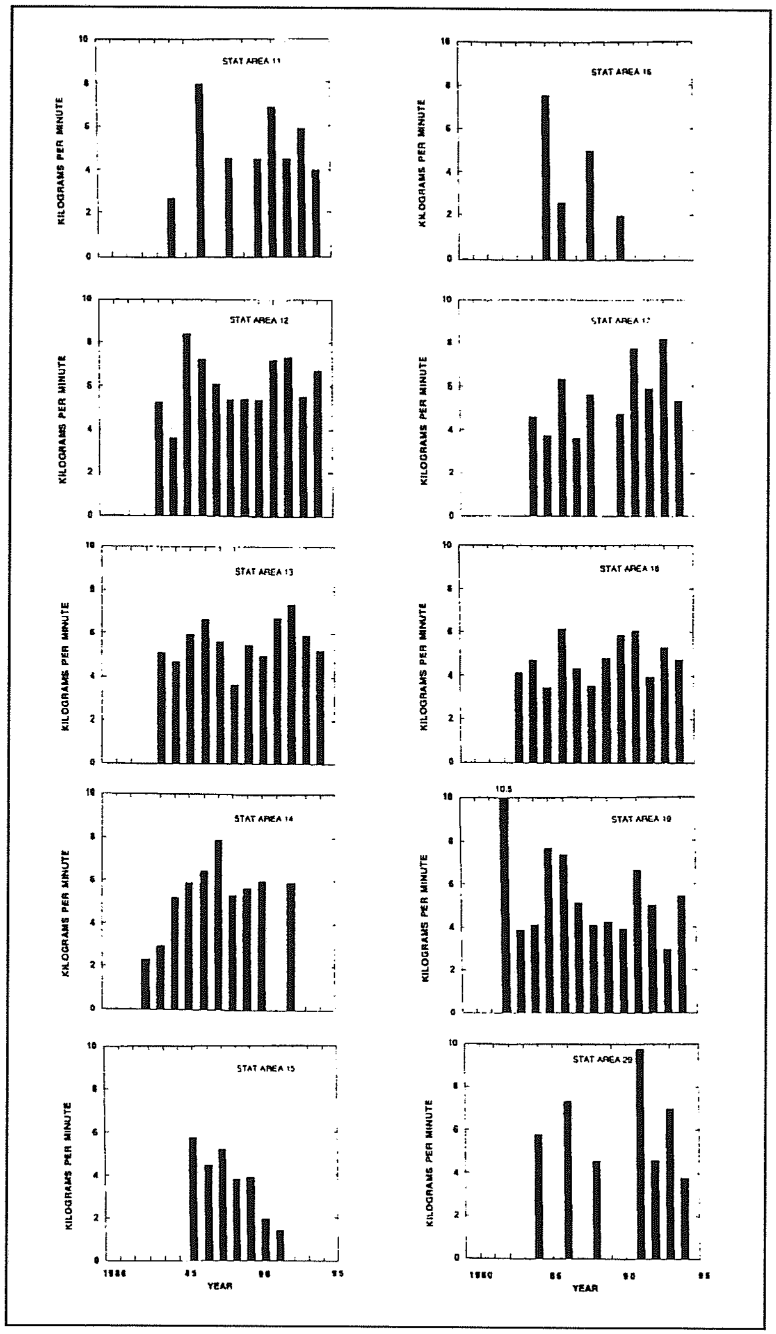


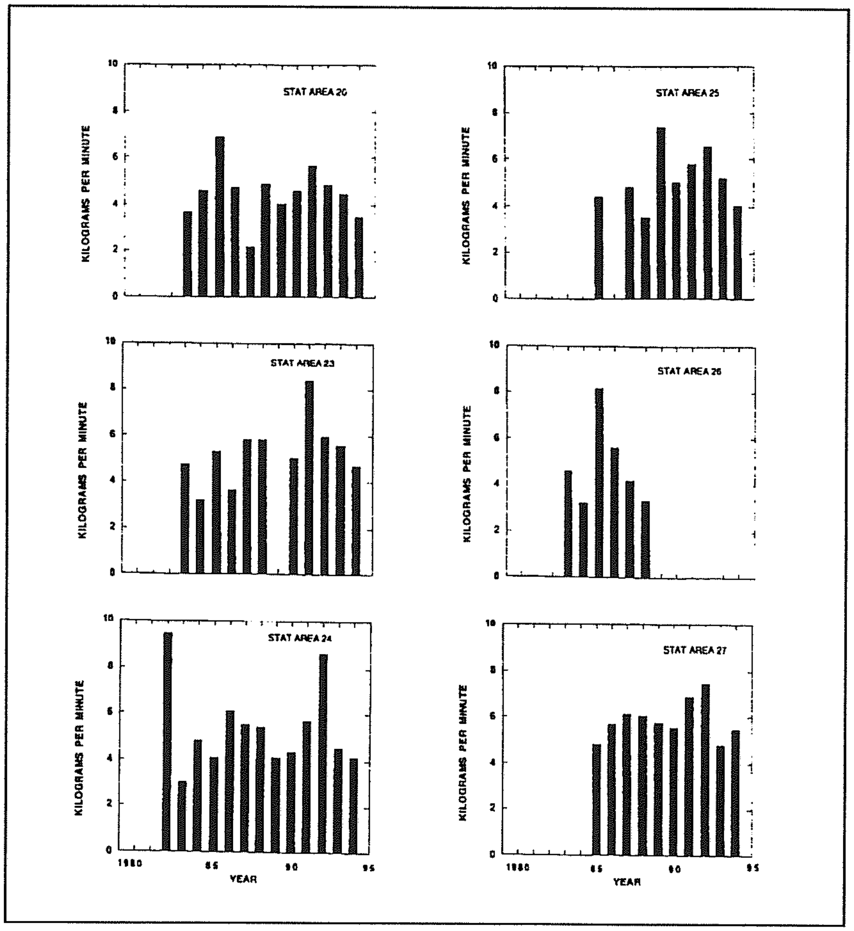
Fig. 7. Relationship between the total estimated hours of diving and red sea urchin landings (tonnes) in B.C. (all PFMA's and years combined). Data from harvest logbooks and sales slips.



Appendix Fig. 1a. Histograms of mean CPUE's (kilograms per diver minute) of red sea urchins for each PFMA (Stat. Area) in the North Coast. Data from harvest logbooks.



Appendix Fig. 1b. Histograms of mean CPUE's (kilograms per diver minute) of red sea urchins for each PFMA (Stat. Area) in the Inside Waters. Data from harvest logbooks.



Appendix Fig. 1c. Histograms of mean CPUE's (kilograms per diver minute) of red sea urchins for each PFMA (Stat. Area) in the WCVI. Data from harvest logbooks.

Review of Fishery-Dependent Data and Quota Recommendations for 1995/96 for the Green Sea Urchin Fishery in British Columbia

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ABSTRACT

Perry, R.I., B.J. Waddell, A. Campbell, and K. Hobbs. 1998. Review of fishery-dependent data and quota recommendations for 1995/96 for the green sea urchin fishery in British Columbia. pp. 111-145. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

The fishery for green sea urchins (*Strongylocentrotus droebachiensis*) on the British Columbia coast developed rapidly from 1987 to 1991, peaked in 1992 with landings of 1,042 t, followed by declining landings and catch per unit of effort (CPUE) and the imposition of management restrictions since 1992. In 1994, coastwide landings were 324 t, with South Coast landings of 276 t, below the quota of 449 t. The principal Pacific Fishery Management Areas (PFMA's) for green sea urchins are 12, 13 (Queen Charlotte and Johnstone Straits) and 18, 19, 20 (Gulf Islands-Juan de Fuca Strait). Harvest logbook information was examined, and required extensive editing. Information on CPUE was derived from the harvest logbook data, and separated into northern and southern regions of the South Coast 'Inside Waters' (inside waters of Vancouver Island) to distinguish the major fishing areas. A biomass dynamic model was developed for the northern region (PFMA's 11 to 16) with an estimated maximum sustainable yield (MSY) of 257 t. A scaling factor was developed to estimate the MSY for each PFMA. Considering the uncertainties in the input CPUE data and its persistent downward trend, and the weaknesses of the dynamic production model, caution is advised in the management of this stock. Yield options range from 0 (no fishing) to 0.5-0.6 of MSY for each PFMA. This provides estimates of 185-222 t for the South Coast and 24.4-29.3 t for the North Coast, although few data are available for this latter region. Recommendations are provided on improvements to the harvest logbook process and database, quotas, and provision of fishery-independent and biological information.

INTRODUCTION

The fishery for green sea urchins, *Strongylocentrotus droebachiensis*, is relatively new, with commercial harvesting beginning in 1987. It developed rapidly, with landings reaching a peak of 1,042 t and a landed value of 4.4 million dollars in 1992, followed by a sharp decline. It is conducted by divers, and is principally a roe fishery whose product is landed and shipped live to the Japanese market. Highest market prices occur around Christmas. As a result, the fishery for green urchins is conducted during winter.

In this current assessment, data are derived from the fishery itself; there are no fishery-independent data sources available for analyses. This paper has two principal objectives:

1) to examine and compare the available landings information for green sea urchins in B.C. with information submitted by fishers in their harvest logbooks (submission of which is a condition of licence); and

2) to develop a biomass dynamic production model to provide guidelines for the status of green urchin stocks in B.C. and their management.

BIOLOGY AND FISHERY BACKGROUND

The distribution and biology of green urchins in B.C. was summarized by Harbo and Hobbs (1996), but is generally poorly known. Green urchins on the Pacific coast of North America range from Alaska to northern Washington State. They occur intertidally to depths of >140 m. They can reach a maximum test diameter of >100 mm, and are first mature at about 46-50 mm in Alaska. Urchin growth rates vary considerably depending on food availability. Green urchins appear to be more mobile than red urchins, and unpredictable (in space and time) aggregations are common. They may undertake deep-shallow migrations.

There are major fisheries for green urchins on the Atlantic coasts of Canada and the United States. In 1994, landings were 20,861 t in Maine and 2,323 t in Maritime Canada (S. Robinson, St. Andrews Biological Station, DFO, pers. comm.). A fishery also takes place in the inside waters of Washington State, managed by licence limitation, a limit of one diver in the water, 2 d/wk openings and an annual quota of 272 t (Harbo and Hobbs 1996).

The fishery in B.C. is managed with a 55 mm test diameter size limit, licence limitations, and seasonal and daily restrictions. Management actions since the inception of the fishery are summarized in Table 1. Submission of sales slips and harvest logbooks are conditions of licence. In 1994, a ceiling catch of 449 t and area quotas were established. The fishery is conducted by SCUBA divers using small vessels due to the patchy distribution of the resource. Recently, the fishery has expanded to more remote locations with the addition of packer vessels (Harbo and Hobbs 1996). Fishers report that their fishing practices have changed as a result of quota restrictions and market demands for high quality roe, *i.e.*, they now spend more time searching for high quality roe. The North Coast fishery in particular appears to suffer from poor roe yields and quality (Harbo and Hobbs 1996). However, some fishers on the South Coast indicate that despite the increased search time they continue to fish the same grounds with similar catches to previous years.

METHODS

We first present data and analyses of the green urchin fishery on a coastwide basis (for consistency with previous assessments (Harbo and Hobbs 1996)), then separately for the South Coast Inside Waters. This region is defined here to include Queen Charlotte Strait to the Strait of Juan de Fuca.

Since annual landings may reflect management actions rather than abundance of urchins, when possible we have used catch per unit of effort (CPUE) as our abundance index to assess stock status. The use of CPUE data as an index of abundance has several difficulties, mostly associated with assumptions of random fishing over too broad an area (Hilborn and Walters 1992). To reduce these problems and to focus on those areas contributing most to the fishery, we further separated these Inside Waters into northern Pacific Fishery Management Areas (PFMA's) 11 to 16 and southern (PFMA's 17 to 20, 28, 29) components. While no empirical data are available to support this separation, it was felt to be reasonable for data exploratory purposes considering the distances between the major fishing grounds of each region and the general physical circulation patterns in the Strait of Georgia.

Basic information on landings (*L*) and landed values are derived from sales slip information as collected by the Catch and Effort Unit of the Biological Data and Analysis Division. These data have been accepted as received, with no further editing by us. Since catches in the harvest logbooks do not represent 100% of the landings (see below), total effort (*TE*, in diver hours) was estimated as landings divided by the CPUE (*U*) from the harvest logbook database, *i.e.*:

$$TE = \frac{L}{U} \quad . \qquad 1$$

Calculation of U is described below.

Detailed information on catch, effort, depth and locations fished for all years (1987-1994) are provided in the fishers' harvest logbooks, completion of which is a condition of licence. This is the first year that the harvest logbook data have been closely scrutinized, and we discovered many errors. Problems with interpreting poor handwriting, and the occasional inclusion of red urchin data were encountered. The most serious problem was poor effort data; additional problems were recording of minimum and maximum depths fished, catch weights, and fishing locations. These are discussed, and recommendations provided, in the Discussion section. To identify and resolve these problems, the harvest logbook data required extensive error checking and editing. We have edited the data from all years to some extent, and concentrated on the data from 1992 to 1994. There are likely to be additional errors in the earlier data that require editing. Therefore, the results published for the harvest logbook data should be considered preliminary.

Catch (*C*) is obtained as the sum of all catches in the harvest logbook database. Effort (*E*; diver hours) is also obtained from the harvest logbook database. CPUE (*U*) is calculated as:

$$U = \frac{\sum c_j}{\sum e_j}$$

where c_j and e_j represent those harvest logbook records (*j*) with non-zero entries for both catch and effort.

Changes in the range of depths fished may be useful as additional information on the status of the stocks (for example if fishers must consistently go deeper to find harvestable concentrations of urchins). We calculated mean minimum and maximum depths fished from the harvest logbook data, excluding zero values for either depths (and excluding the average depth values occasionally provided by fishers).

Information from fishers' harvest logbooks on fishing beds and their locations have been coded and transferred to hydrographic charts throughout the fishery. In 1995, these fishing beds were digitized using the COMPUGRID Geographic Information System. These estimates of fishing bed areas have not been critically examined and edited, and are provided here as preliminary figures. These estimates were calculated for each year and PFMA by identifying the PFMA subareas fished as recorded in the harvest logbook database, then summing the fishing bed areas in those subareas. This procedure incorporates the expansion in numbers of fishing beds as the fishery developed and new locations began to be exploited. It is presented as a preliminary indication of interannual and inter-regional changes in fishing ground areas.

BIOMASS DYNAMIC MODEL

Development of a biomass dynamic production model followed the approaches outlined in Schnute (1977), Polovina (1989), and Hilborn and Walters (1992). The following is adopted from Polovina (1989). Schnute (1977) developed a linear approximation to the dynamic Schaefer production model as:

$$\ln\left(\frac{U_n}{U_{n-1}}\right) = r - q\frac{(E_{n-1}+E_n)}{2} - \frac{(r/qk)(U_{n-1}+U_n)}{2} \qquad (1)$$

with U_n the CPUE for year n, E the effort for year n, r the intrinsic rate of population increase of biomass, q the catchability coefficient, and k the unexploited biomass. This equation can be represented as a regression of the form

$$Y_n = \alpha + \beta X_n + \gamma Z_n + \varepsilon_n \qquad (2)$$

with

$$Y_n = \ln(U_n/U_{n-1}),$$
$$X_n = (E_{n-1} + E_n)/2,$$
$$Z_n = (U_{n-1} + U_n)/2$$

and ε_n a lognormal error term. The parameters α, β, γ are then equal to r, $-q$, and $-r/(qk)$, respectively. Solutions to this regression equation were calculated using SYSTAT (Wilkinson 1990).

Once r, q, and k are known, the catch in year n+1 can be estimated as:

$$C_{n+1} = ((qk/r)E_{n+1}) \ln[1 + \frac{(r - qE_n)}{(r - qE_{n+1})}$$

$$x\ (\frac{\exp(r - qE_{n+1}) - 1}{1 - \exp(-(r - qE_n))})\ (1 - \exp(\frac{-rC_n}{qkE_n})))] \tag{3}$$

and the traditional Schaefer model under equilibrium conditions is represented as:

$$C = qkE\,(1 - (q/r)E)\,. \tag{4}$$

Hilborn and Walters (1992) provide the following summary of management parameters once the parameters of the Schaefer model have been determined:

maximum surplus yield (MSY)	$rk/4$
stock size for MSY	$k/2$
rate of exploitation at MSY	$r/2$
effort required to achieve MSY	$r/2q$

RESULTS

The history of this fishery has been one of a boom developmental period from 1988 to 1991, peak landings in 1992, followed by declining landings and CPUE, and the imposition of management restrictions, since 1992 (Table 2, Fig. 1). Management actions are summarized in Table 1, with quota limitations imposed for 1994. These quotas were set as 5 year average landings for the fishery over the period 1987 to 1991 (Harbo and Hobbs 1996). Preliminary landings for 1994 for the South Coast (the dominant fishing region) of 276 t were 61% of the quota of 449 t. Reasons for the failure to achieve this quota include the imposition by the fishers of a voluntary Individual Vessel Quota (IVQ) system, the desire by fishers to take their catch at times of peak market value (Christmas), and the bad weather conditions in late 1994 that prevented fishers from fishing at this time. PFMA boundaries for the South Coast are shown in Fig. 2. Coastwide statistics of landings, catches, landed values, CPUE, and a general comparison of sales slip and harvest logbook information is provided in Table 2 and Fig. 1. There is general agreement between sales slip and harvest logbooks in the trends of the catch and effort data, with the logbooks providing more detail on effort (*i.e.*, on a diver hour basis) and the catch achieved from that effort. In particular, the trend in mean CPUE is downward in recent years for both sales slip information (as tonnes/vessel day) and harvest logbooks (kilogram/diver hour). The local maximum in 1992 in CPUE (as tonnes/vessel day), in contrast to the harvest logbook CPUE series (kilogram/diver hour) is due to licence holders adding more divers per vessel. Catches as reported in the harvest logbooks had better than 88% agreement with landings recorded on sales slips for the peak fishery years of 1991-1993, but declined to a record low of 61% for 1994 (Table 3). The poor comparison in 1994 may be a result of these being preliminary data, but anecdotal information from fishers also suggests that this may be due to fishers who did not intend to continue fishing green urchins and therefore had no incentive to return logbooks to renew licences.

The principal fishing areas have consistently been in Queen Charlotte Strait and Johnstone Strait (PFMA's 12 and 13; 70% of 1987-1994 total coastwide landings) and in the Gulf Islands-Victoria region (PFMA's 18 and 19; 18% of 1987-1994 coastwide landings), as indicated by summaries of landings (from sales slips) separated by PFMA's for the northern B.C. coast (Table 4) and the southern B.C. coast (Table 5). Results from analyses of harvest logbook data are consistent with identifying these as the most productive PFMA's. Catch, effort, and CPUE by year and PFMA from the harvest logbook data for those PFMA's with total landings for the years 1987 to 1994 of >50 t are shown in Appendix Figs. 1 to 3. These suggest that in some PFMA's (*i.e.*, 18 and 19) the CPUE has remained relatively stable since 1992.

Distributions of landings by month for 1994 (preliminary) show the fishing season from October to February on the North Coast, and from November to January on the South Coast (Table 6). The fishing season in previous years ran from October to February in both regions; the 1994 data for the South Coast reflect the limitations of fishing due to management actions (Table 1).

Since the South Coast Inside Waters (defined here as PFMA's 11 to 20, 28, 29; i.e., including Queen Charlotte to Juan de Fuca Straits) are the dominant producers (97% of the 1987-1994 total coastwide landings), the time series of landings from this region (Fig. 3a) are similar to the coastwide landings series (Fig. 1). Total effort, as estimated from total landings and the harvest logbook CPUE data, for the Inside Waters indicate the very large effort exerted in 1992-1993 (Fig. 3b). The increase in effort in 1992-1993 despite licences being limited to 47 in 1991 was due to increases in the number of divers per vessel.

Fig. 3 also demonstrates the differences in landings and effort between the northern and southern regions of these Inside Waters. The northern region dominates landings (75% of 1987-1994 total Inside Waters landings), and so its interannual pattern reflects the total Inside Waters and coastwide patterns (Fig. 3a). Total effort in the southern region has remained reasonably steady since 1991 at about 2000 diver hours (Fig. 3b). The time series of CPUE in each region are relatively similar, particularly after 1991 (Fig. 4), with the southern region having slightly lower catch rates.

The fishing ground areas in the northern region of the Inside Waters were consistently greater than those in the southern region (Fig. 5). There appeared to be a marked reduction in the area fished in the southern region in 1992, perhaps reflecting a shift of effort to the northern region, although possible errors in the estimates of fishing ground areas cannot be eliminated. Expressing landings and effort for both northern and southern regions of the Inside Waters standardized by the areas of the fishing grounds suggests that the fishing intensity (effort/unit area of fishing ground) was greater in the southern region, with correspondingly higher landings/unit area (Fig. 6). Within the same range of fishing intensity (<1 (diver hr)/ha) the landings/unit area were similar between regions.

There has been a tendency in recent years towards an increasing range of depths fished, with an increase in the mean maximum depths fished for coastwide, northern and southern Inside Waters (Fig. 7). This is consistent with anecdotal reports from fishers about having to fish deeper for green urchins in recent years (since 1992).

Biomass Dynamic Model

Landings versus total effort in the South Coast Inside Waters show an increasing yield with increasing effort from 1987-1992, but when effort was reduced in 1993 and 1994, landings were lower than during the previous period of the developing fishery (Fig. 8a). Landings versus total effort for the northern (Fig. 8b) Inside Waters show a similar pattern. For the southern Inside Waters, landings appeared to be relatively insensitive to changes in effort from 1988-1990 (Fig. 8c). Calculation of the regression (equation 2) to determine the parameters of the dynamic production model was done for the Inside Waters overall, and separately for the northern and southern Inside Waters (Table 7). Only the model for the northern region produced meaningful parameter estimates and a reasonable probability level ($p=0.151$, $r^2=0.61$). Although the overall p-level indicates a higher acceptance of Type I errors (*i.e.*, the risk of accepting the regression model as true when it is not), this model does provide at least an initial estimate that can be used to identify potential management options for this stock. Reasons why the model failed to give meaningful parameter estimates for the southern region of the Inside Waters are unclear, and may involve failure of the linear approximation to the Schaefer model when the fishery conditions are changing rapidly (Schnute 1977). Note that the pattern of landings versus effort for this southern region (Fig. 8c) differs from the northern region, with the highest landings achieved at intermediate levels of effort during the early years of the fishery. Comparison of the observed and predicted landings for the northern region over the time series using these model parameters is quite good (Fig. 9), although the observed data were used to derive these parameters. Using these parameter estimates, the predicted landings for the northern Inside Waters region in 1995 can be estimated (equation 3) given various levels of effort, based on the 1994 landings data (Fig. 10). The equilibrium Schaefer model (equation 4) for landings versus total effort in the northern region is also shown in Fig. 10, and the management parameters derived from this model are presented in Table 7. These indicate an unexploited biomass of 2,340 t and an MSY of about 250 t for the northern region of the Inside Waters, achievable with an exploitation rate of 5,500 diver hr.

Assuming that landings (L) are equivalent to total effort (TE) times biomass (B) scaled by the catchability coefficient (q) (Hilborn and Walters 1992):

$$L = qB(TE)$$

then

$$B = \frac{1}{q}\,\frac{L}{(TE)}$$

can be used to estimate the fishable biomass for any year. Using the parameters for the northern region of the Inside Waters model, *i.e.*, q=0.00004, and an average CPUE for this region over the early fishery period (1988-1992) of about 100 kg/diver hr (Fig. 4), gives an estimate of about 2500 t for the fishable biomass (in the period 1988-1992). This is close to the biomass dynamic model estimate of 2,340 t for the unexploited biomass (although note the circular argument). However, for this same period, the average landings for this northern region were about 466 t (Fig. 3a), compared with an estimated MSY of about 250 t, *i.e.*, 1.9 times larger than is calculated to be sustainable, with some years much greater still (*e.g.*, 1992). We therefore conclude that the stock, at least in the northern region of the Inside Waters, has been overfished.

PFMA YIELD OPTIONS

The biomass dynamic model calculated for the northern region of the Inside Waters was the only model to produce meaningful parameter estimates with a low p-value. Therefore, in order to estimate yield options for 1995 and 1996 by PFMA for management purposes, we have assumed that this model can be applied to all PFMA's of the coast. We use the ratio of the estimated MSY from the production model (Table 7), divided by the average annual landings from 1988-1991 (*i.e.*, the developing fishery years excluding 1987, which had low landings and is considered here as a start-up fishing year) for the northern region to establish a scaling factor to estimate yield options by PFMA. For the northern region of the Inside Waters, this factor is 250/350 = 0.7. Application of this factor to the 1988-1991 average annual landings of each PFMA is shown in Table 8. The total yield derived this way, *i.e.*, the sum of each PFMA (371 t), is higher than proposed for 1995 by Harbo and Hobbs (1996), who used a factor of 60% of the 5 year average (1987-1991). Considering that these stocks of green urchins in the Inside Waters have been overfished, the downward trend in the CPUE series, and that fishers appear to be fishing deeper to obtain their catch, we suggest that a more cautious approach to setting quotas for 1995 and 1996 should be followed rather than the MSY. Mace (1988) recommends a range of 0.6-0.9 of MSY as a cautionary reduction for deterministic production models (such as developed here), since the deterministic MSY is not usually sustainable in a stochastic environment (Mace 1988). Garcia *et al.* (1989) recommend a maximum target of 1/2 to 2/3 of the estimated MSY. This range (0.5-0.9 of MSY) can be used to provide a first estimate of the variability or uncertainty about the calculated yield options. Using a factor of 0.75 of MSY makes the quotas similar to those proposed for 1995 by Harbo and Hobbs (1996), and has the advantage of attempting to provide some stability to predicted fishing levels for planning by industry. Considering the uncertainties in the input data and the model parameter estimates, we recommend using the lower part of the precautionary reduction from MSY (*i.e.*, 0.5-0.6 of MSY), and present these yield options for the South Coast PFMA's in Table 8.

Very few data are available for the North Coast (Table 4) and the west coast of Vancouver Island (PFMA's 21 to 27, Table 5). It is unknown whether this reflects an absence of green urchins in these PFMA's, or the distances to landing sites (considering that the product is shipped live) and difficulties of fishing in exposed areas. One strategy to attempt to avoid overfishing the stocks that occur in these regions is to apply the same procedure used to determine yield options in the South Coast. The yields estimated for the west coast of Vancouver Island are presented in Table 8. For the North Coast, only 3 PFMA's produced substantial landings (>3 t/yr of fishing, on average): PFMA's 1, 4, and 9 (Table 4). Application of the factor 0.7 to these annual averages to determine the MSY landings, then a further 0.4 (0.5) reduction [*i.e.*, 0.6*MSY (0.5*MSY)] produces quotas of 2.7 (2.3) t, 25.0 (20.8) t, and 1.6 (1.3) t for PFMA's 1, 4, and 9, respectively. Some form of exploratory fishing for these PFMA's would be useful.

DISCUSSION

HARVEST LOGBOOKS

There are several issues and concerns that deserve comment. The data for the assessment (CPUE from the harvest logbooks) had numerous errors. Diver minutes were often either not entered or were only roughly estimated (*e.g.*, whole pages of harvest logs, representing many days of diving, would have the same value entered for effort). Some effort values appeared to be too small or too large. It is also not known how effort was measured, *e.g.*, only the time the divers were actually collecting sea urchins, or the full time they were in the water (including decompression time when applicable)? Effort was likely being recorded in different ways and we therefore recommend that the fishers (not just the licence holders) be fully informed that diver minutes are to be recorded as the time from when the divers reach bottom to when they leave bottom for the surface. In addition, fishers indicated that with the imposition of quotas in 1994 they have changed their fishing strategy to be more selective of urchins with high quality roe. Some fishers suggest that this has increased their search time as a component of effort, rather than an actual increase in harvesting time.

Another common error involved the recording of minimum and maximum depth. Minimum depth or maximum depth (and sometimes both) were occasionally not recorded. Sometimes a minimum depth of zero was valid, but other times it indicated that the value recorded for the maximum depth was actually the average depth. There were several occasions in which the minimum and maximum depths were reversed, and there were a few instances in which the minimum depth, maximum depth, and the diver minutes were recorded in the wrong columns. Depth data, like the effort data, were often roughly estimated (*e.g.* minimum and maximum depths would be repeated for several pages).

There were also problems with the catch (weight) data. Occasionally weight was not entered, but more often weight was entered as a sum for one or two days' catch instead of for each diver for each day. This was not a big problem unless it was not made clear on the harvest logbook what the weight represented. However, it appears to have created problems during the coding of the logbooks. In order for weight data to be recorded for every diver (*i.e.*, for every line of data), the coder would divide the catch amongst the divers. Unfortunately, the coders seemed to change every year and the methods for dividing catch among the divers changed with them. The coders would "white out" or cover up the original weight data on the harvest logbooks and replace them with the revised weight data. We recommend that the original data not be "whited out" so that it may be saved for checking.

The location data also had problems, mostly involving missing information. Data were missing for 0.3% of the PFMA's, 5% of the subareas, and 38% of the beds. This was mainly because fishers did not provide sufficient maps or information as to where they fished, despite this being a requirement. Occasionally the subareas and beds were recorded or coded incorrectly.

There were very few entries (3%) of the number of pieces caught. Although this could be useful information (*i.e.*, average weights per individual could be obtained) we feel this is too much to ask of fishers and that this column should be eliminated from the harvest logbooks. Fishers occasionally incorrectly entered weight in this column, which then needed correction.

BIOMASS DYNAMIC MODEL

Development of the dynamic production model is only the first step towards a scientific basis for management of this species in B.C. The expansion of fishing bed areas and increasing depths fished in recent years suggests that the distribution of fishing has changed during the time series; dynamic production models may not be the best tool for such circumstances. Further analyses of the fishing bed area data presented in this report are planned, and the results incorporated into the dynamic production model.

In addition, the value of r, the intrinsic rate of increase of the population biomass, calculated from the biomass dynamic model (0.44) seems rather high, representing about a 50% increase in biomass per year. However, green urchins in Alaska appear to be capable of relatively rapid growth, with test diameters increasing between 25%-200% per year over the first 4 years of life (Munk 1992). Actual population growth rates will depend on food availability, temperature, predators, recruitment, etc. However, considering the warmer temperatures of southern B.C. waters, green urchins in this area could have similar rapid rates to those in Alaska, if other conditions were equal. This needs further investigation (including recruitment) to confirm the ability of this stock to sustain itself under fishing pressure.

Considering the heavy exploitation of the green urchin population in southern B.C. and the weakness of the input data and production model, the option of no fishery for 1995 and possibly 1996 could be considered, instead of the yield options identified in Table 8. This has the disadvantage of not providing any information with which to monitor the population. In the absence of a fishery, fishery-independent surveys are the only means to acquire information on the status of the population. However, the ability of green urchins to undertake deep-shallow migrations and to undergo sporadic aggregations makes designing and implementing such surveys difficult and expensive. Therefore, we recommend the yield options calculated in Table 8 for 1995, with the same yields for 1996, although this should be re-evaluated based on results from the 1995 fishery. Closures of PFMA's with small landings is an option, although it would likely do little to limit exploitation on the majority of the green urchin population. PFMA'as such as 14 to 17 in the central Strait of Georgia contributed only 2.5% to the total South Coast landings for the period 1987-1994. Closure of these PFMA's in 1994 would have resulted in a loss of only 1.3 t. Yield options for the west coast of Vancouver Island and the North Coast are purely precautionary, as few data are available to determine stock status. Exploratory fishing in these PFMA's with close observation would be a useful option.

FISHERY-INDEPENDENT STUDIES

Fishery-independent studies of green urchins to estimate areas of fishing grounds and densities of animals, and local studies to investigate seasonal depth migrations, are valuable to assist confirmation of the biomass dynamic model and to provide alternate methods of estimating stock status. Information on green urchins is presently being collected during dive surveys for red urchins in the Queen Charlotte and Johnstone Strait areas. These data need to be processed and analysed for additional information on green urchin densities and bed areas, as well as biological characteristics such as size structure, movement, etc. Information on green urchin larval biology and recruitment patterns in time and space would also help assess stock status and responses to fishing, for example by identifying the importance of recruitment pulses into the population, and to establish a time-scale should rotating area closures be employed to manage the fishery. Few biological data are available from the fishery itself, *e.g.*, size composition of the catch, and such information would be useful to assess stock status.

The poor harvest logbook return in 1994 has been noted in this analysis, and needs to be addressed in future years (as is being done through the licence renewal process).

Finally, we suggest that the analysis of the fishing data be changed from the calendar year basis that is currently used to a fishing season basis, *i.e.*, from October of year n to February of year $n+1$. This seems a more reasonable method of reporting the results of fishing activities, and would allow for analyses of information from contiguous months of fishing. Time series of coastwide catch, effort, and CPUE on a fishing season basis (Fig. 11) produce a slightly different picture of recent trends in the fishery than using a calendar year basis (Fig. 1).

SUMMARY OF RECOMMENDATIONS

1) Improvements to the harvest logbook database

Fishers:

a) standardization of recording effort, *i.e.*, as the time from when the divers reach bottom to when they leave bottom for the surface;

b) clarification to fishers as to recording minimum and maximum depths fished;

c) improvements in recording fishing location;

DFO coding:

d) maintaining original data (particularly on catch) on the harvest logbook coding forms;

e) eliminate the entry field for "number of pieces caught".

2) Yield Options:

Considering the recent downward trend in CPUE, and uncertainties in the input data and the production model, caution is urged in the management of this species. Yield options for 1995 and 1996 by PFMA should be conservative. These options range from 0.5 to 0.6 of the estimated maximum sustainable yield (MSY), but also include the option of no fishery. The South Coast total would then range from 185 to 222 t. Yield options for the North Coast are provided in the range of 25-29 t, although few data are available on the status of stocks in the North Coast or on the west coast of Vancouver Island.

3) Detailed analyses need to be conducted of the fishing bed areas of green urchins and their variability in time and space, to clarify changes in fishing patterns over time and for inputs to the dynamic production model.

4) Fishery-independent and biological information:
   Analyses of green urchin data collected during surveys for red urchins should proceed, to evaluate their effectiveness as a fishery-independent source of stock information. Biological data on the catch by the fishery would also be useful, especially in collaboration with industry. Information on green urchin larval biology and recruitment is needed to identify recruitment pulses and to determine time-scales for rotational fishery closures (should they be proposed).

ACKNOWLEDGEMENTS

We thank Rick Harbo for discussions on green sea urchin biology and status is B.C. waters.

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Table 1. Summary of management actions in the green sea urchin fishery, 1987 to 1994 (from Harbo and Hobbs 1996).

Year	Management Actions
1987	Scientific permits were issued, July 22 to December 31, to fishing vessels for harvest by diving. Logbooks were issued with permits to collect data on stock abundance and distribution. Permits were limited to the inside waters of Vancouver Island, PFMA's 12 to 19, 28 and 29. Some minor area closures for parks or study areas were in effect as for most dive fisheries. A precautionary minimum size limit of 40 mm was set as a condition of the permit. Sales slip data did not have a separate species code, so green and red sea urchin landings are mixed. As a result, landings have been estimated from logbook returns and hails from processors. Effort was restricted by limiting the season to the months of traditional peak market demand for sea urchins, Oct.-Dec. and Jan.-Feb. Nineteen vessels reported landings.
1988	Permits were issued for the period Jan. 16 to Feb. 28. Sales data for green sea urchins was recorded with a separate species code. A conservative closure was set, Jan. 16 to Feb. 28 in PFMA 13, subareas 1 to 3 due to the intensive fishery in a small area. A Z category (Z-A) licence for green sea urchins was introduced for the fall fishery which opened Oct. 1. The minimum size limit was increased to 55 mm test diameter and set as a condition of licence. The season was limited again, Jan. 1-Feb. 28 and Oct. 1-Dec. 31. Sixty-eight vessels reported landings.
1989	The Z-licence, minimum size limit and seasonal restrictions continued. A conservation closure was set for PFMA subareas 12-1 and 13-29 to 13-40, north of Campbell River, Jan. 31-Feb. 28/89 due to heavy fishing pressure and a high incidence of undersized urchins landed. One hundred thirteen vessels reported landings.
1990	The Z-licence, minimum size limit and seasonal restrictions continued. There were 91 vessels reporting landings. Licence limitation for 1991 was announced with the eligibility criteria of landings of 9,072 kg (20,000 lb) over the two yr period 1988 and 1989. At least 33 vessels were expected to qualify before appeals were held.
1991	Licence limitation - 47 vessels qualified and 47 vessels reported landings.
1992	A conservation closure was set in the Kelsey Bay area, PFMA subareas 12-1, 13-32, 13-33 and 13-35, Feb. 25-Feb. 28. These subareas did not reopen for fall fishing until Dec. 7.
1993	Licences increased to 49. Notification of fishing required. No suction devices. Additional permanently closed areas for parks and reserves, IFF. <u>South Coast</u>: Reduced fishing times; Inside waters: season Jan. 4 to Jan. 28, 7 d/wk; Feb. 1 to Feb. 25, 4 d/wk, Mon.-Thurs. Fall fishery Nov. 1 to Dec. 16, 4 d/wk, Mon.-Thurs.; Dec. 6 to Dec. 30, 7 d/wk. Kelsey Bay limited to 7 d, Jan. 4 to 10. W.C.V.I.: season reduced to Oct. 4 to 28, 1992, 7 d/wk. <u>North Coast</u>: 7 d/wk, season reduced to Jan. 1 to Feb. 28 and Oct. 1 to Dec. 31.
1994	<u>South Coast</u>: a ceiling catch of 990,000 lb (449 t) was set along with area quotas. Fishers requested to harvest 25% in Jan.-Feb. and the balance in Nov.-Dec. The days fishing were limited to 4 d/wk (M-R) for some periods and others at 7 d/wk. <u>North Coast</u>: no quota set; season reduced to periods Jan. 1 to Feb. 28 and Nov. 1 to Dec. 31. Consideration will be given for spring/summer fisheries depending on roe quality and landings.

Table 2. Green sea urchin landings (tonnes) and effort for British Columbia, 1987 to 1994, as reported on sales slips and harvest logbooks. All harvest logbook data should be considered preliminary.

Year	Licence Type	# of Licences Issued	Vessels with Landings	Fishing Days	Average Fishing Days/ Vessel	Landings (t)	Landed Value ($)·$10^3$	Whole Landed Value ($/t)	Mean CPUE (kg/diver hr)	Mean CPUE (t/vessel day)	Total Diver Hours	Average Hr/Diver Day	Total # Divers	Average Hr/Vessel Day
1987[1]	Permit[3]	38	20	248	12.4	120	127	1058	0.48					
1987[2]			21	173	8.2	133			0.77	168	729	3.09	29[++]	1.42
1988[1]	Z	89	68	690	10.1	444	584	1315	0.64					
1988[2]			63	637	10.1	379			0.64	120	2,544	2.71	123[++]	3.99
1989[1]	Z	191	110[+]	1394	12.7	611	1020	1669	0.44					
1989[2]			95	932	9.8	430			0.46	137	2,997	2.43	153[++]	3.22
1990[1*]	Z	155	90[+]	1352	15.0	475	939	1977	0.35					
1990[2*]			66	1028	15.6	385			0.37	98	3,568	2.30	158[+]	3.47
1991[1*]	Z	47	47[*]	1348	28.7	607	1795	2957	0.45					
1991[2*]			43[*]	1210	28.1	574			0.47	93	5,972	2.59	133[+]	4.94
1992[1*]	Z	49	49[+]	2096	42.8	1042	4424	4246	0.50					
1992[2*]			49	1963	40.1	995			0.51	84	11,412	2.80	200	5.82
1993[1*]	Z	49	53[+]	1631	30.8	721	3777	5239	0.44					
1993[2*]			49	1418	28.9	630			0.44	64	8,623	2.72	190[++]	6.12
1994[1*]	Z	49	46[+]	943	20.5	324	2090	6451	0.34					
1994[2*]			34	657	19.3	198			0.30	54	3,329	2.48	116[++]	5.07

[1] from sales slip data
[2] from harvest logbooks
[3] scientific permits were issued to 38 vessels for fall 1987 to spring 1988 fishery. 1987 landings and fishing days are from harvest logbooks as green sea urchins were not separated from reds on sales slips until mid-1998.
[*] preliminary data for 1994.
[+] possibly one or two more (due to sales slips with no CFV #, or missing diver codes)
[++] probably several more (due to missing diver codes)

Table 3. Green sea urchin landings reported on sales slips compared to harvest logbook records, 1987 to 1994.

Year	Sales Slips (t)	Sales Slips (lb)	Harvest Logbooks (lb)	% Logbook Returns
1987	120	264,552	292,383	110.5%
1988	444	978,842	835,045	85.3%
1989	611	134,6505	947,623	70.4%
1990	475	1,046,562	848,060	81.0%
1991	607	1,337,357	1,264,778	94.6%
1992	1042	2,298,005	2,194,243	95.5%
1993	721	1,569,823	1,389,452	88.5%
1994	324	715,019	435,481	60.9%

Note: The above data assumes that all sales slips have been submitted annually, which may not always be the case. Sales slips landings for 1987 and 1988 are actually harvest logs combined with a best guess from sales slips, as there was not a separate species code assigned to green sea urchins until the fall fishery in 1988.

Licence limitation was announced in 1989 for the 1991 fishery. Licence eligibility was based on landings from 2 of the 3 years 1987, 1998, and 1989. Fishers who knew they would not meet the landing criteria to get a limited licence were not inclined to submit harvest logbooks at the end of 1989 or in 1990, as they knew they could not renew their licence.

Table 4. Summary of green sea urchin landings (tonnes) by PFMA for the North Coast, 1987 to 1994, as reported on sales slips. (* preliminary data for 1994).

	PACIFIC FISHERY MANAGEMENT AREAS										
Year	1	2E	3	4	5	6	7	8	9	10	Annual Landings
1987											0
1988		0.4								0.4	1
1989	12.3					0.7					13
1990											0
1991	0.4					3					3
1992									1.7		2
1993				71	1	4			9	0.1	85
1994*				48					0.9		49
1987 to 1994	13	0	0	119	1	7	0	0	12	1	154

Table 5. Summary of green sea urchin landings (tonnes) by PFMA for the South Coast, 1987 to 1994, as reported on sales slips. (*preliminary data for 1994).

	PACIFIC FISHERY MANAGEMENT AREAS																		
	East Coast Vancouver Island											West Coast Vancouver Island							Annual
Year	11	12	13	14	15	16	17	18	19	28	29	20	21	23	24	25	26	27	Landings
1987		1.8	58			2.5		4.2	37	17									121
1988	2.8	50.5	168.7	18.3	8.5	1.2	12.3	59.8	78.5	19.5	10	1.4		2.6	4.7	0.2	4.3		443
1989		272	145	1			37	75	37	7	2	1		1	6			12	596
1990	1	160	151	5			2	99	38	4		14		0.5					475
1991	1	241	165	2.8	1.3	0.9	0.6	68	58	5.4	7	51			0.1			2	604
1992	37	639	253	0.3	0.4	5	0.4	28	34		14	30			0.3				1041
1993	8.2	415	81	0.9	1	0.1	0.8	23	60	2.1	1.3	31.6	3.8		0.4	7			636
1994*	2	123	77	1		0.3		23	35		0.3	14							276
Total 1987 to 1994	52	1902.3	1098.7	29.3	11.2	10	53.1	380	377.5	55	34.6	143	3.8	4.1	11.5	7.2	4.3	14	4192
% of Total	1.2	45.4	26.2	0.7	0.3	0.2	1.3	9.1	9	1.3	0.8	3.4	0.1	0.1	0.3	0.2	0.1	0.1	100

Table 6a. Summary of green sea urchin landings (tonnes) by North Coast PFMA and month in 1994 (preliminary), as reported on sales slips.

	PACIFIC FISHERY MANAGEMENT AREAS											North Coast
Month	1	2E	2W	3	4	5	6	7	8	9	10	(t)
Jan												
Feb					22.6							23
Mar												
Apr												
May												
June												
July												
Aug.												
Sept.												
Oct.					21.1					0.9		22
Nov.					2.6							3
Dec.					1.2							1
Area Totals					48					1		49

Table 6b. Summary of green sea urchin landings (tonnes) by South Coast PFMA and month in 1994 (preliminary), as reported on sales slips.

	PACIFIC FISHERY MANAGEMENT AREAS																		SOUTH
	East Coast Vancouver Island											West Coast Vancouver Island							COAST
Month	11	12	13	14	15	16	17	18	19	28	29	20	21	23	24	25	26	27	(t)
Jan		34.2	22.3					7.1	18.2		0.2	4.5							87
Feb.																			
Mar																			
Apr.																			
May																			
June																			
July																			
Aug.																			
Sept.																			
Oct.																			
Nov.	1.7	22.2	14.8					9.8	6.9		0.1	3.3							59
Dec.	0.6	66.9	40.1	1.2		0.3		5.7	9.6			6							130
Area Totals	2	123	77	1		0		23	35		0	14							276

Table 7. South Coast Inside Waters. Estimates for the parameters α, β, γ for the regression of equation (2), probability levels (p-levels), and calculation from these parameters of the values of *r*, *q*, and *k* for the dynamic production model (equation 2). Management parameters MSY (maximum sustainable production) and effort at MSY are calculated as described in Methods.

	Regression Parameters							Management parameters	
	I	J	K	Model	r	q	k (t)	MSY (t)	effort at MSY (diver hr)
Overall	0.00295	-0.00001	-0.00137		0.00295	0.00001	215	0.159	148
p-level	0.996	0.810	0.715	0.918					
Northern region	0.442	-0.00004	-0.0047		0.44	0.00004	2340	257	5500
p-level	0.256	0.284	0.080	0.151					
Southern region	-1.34	0.00038	0.0064		-1.34	-0.00038	-551		
p-level	0.508	0.603	0.499	0.737					

Table 8. Calculations of quota recommendations for green sea urchins in South Coast PFMA's. Quotas recommended for 1995 and 1996 are in Row C and their possible ranges in Row D (recommended quota ranges are Row D_2 to Row C); values are landings in tonnes. In addition, yield options of 0 t (*i.e.*, no fishery) could be considered due to the uncertainties in the fishery input data and the production model.

	PACIFIC FISHERY MANAGEMENT AREAS																	
	East Coast Vancouver Island												West Coast Vancouver Island					
	11	12	13	14	15	16	17	18	19	20	28	29	23	24	25	26	27	**Total**
A: average landings 1988-91	1.2	180.9	157.4	6.8	2.5	0.5	13.0	75.5	52.9	16.9	9.0	4.8	1.0	2.7	0.1	1.1	3.5	
B: MSY factor (Row A*0.7)	0.8	126.6	110.2	4.7	1.7	0.4	9.1	52.8	37.0	11.8	6.3	3.3	0.7	1.9	.04	0.8	2.5	370.6
C: Precautionary reduction (Row B*0.6)	**0.5**	**76.0**	**66.1**	**2.8**	**1.0**	**0.2**	**5.5**	**31.7**	**22.2**	**7.1**	**3.8**	**2.0**	**0.4**	**1.1**	-	**0.5**	**1.5**	**222.4**
D: Range of Precautionary reduction:																		
D_1: (Row B*0.9)	0.7	113.9	99.2	4.2	1.5	0.4	8.2	47.5	33.3	10.6	5.7	3.0	0.6	1.7	-	0.7	2.2	333.4
D_2: (Row B*0.5)	**0.4**	**63.3**	**55.1**	**2.4**	**0.9**	**0.2**	**4.6**	**26.4**	**18.5**	**5.9**	**3.2**	**1.7**	**0.4**	**1.0**	-	**0.4**	**1.3**	**185.7**

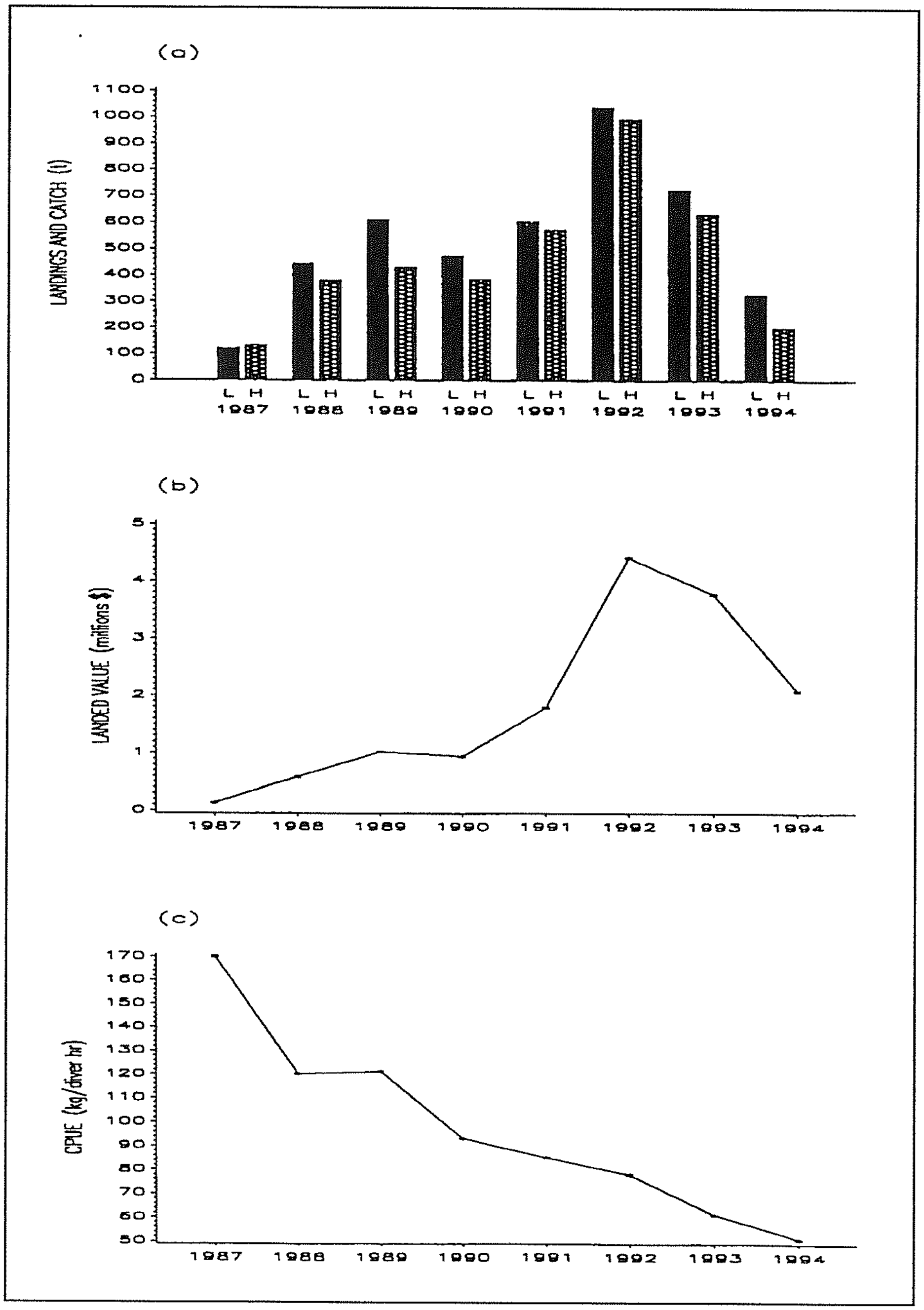


Fig. 1. Time series of: (a) landings (L, from sales slips: solid bars) and catch (H, from harvest logbooks: hatched bars) by year; (b) landed value from sales slip information; (c) CPUE, calculated from harvest logbook information.

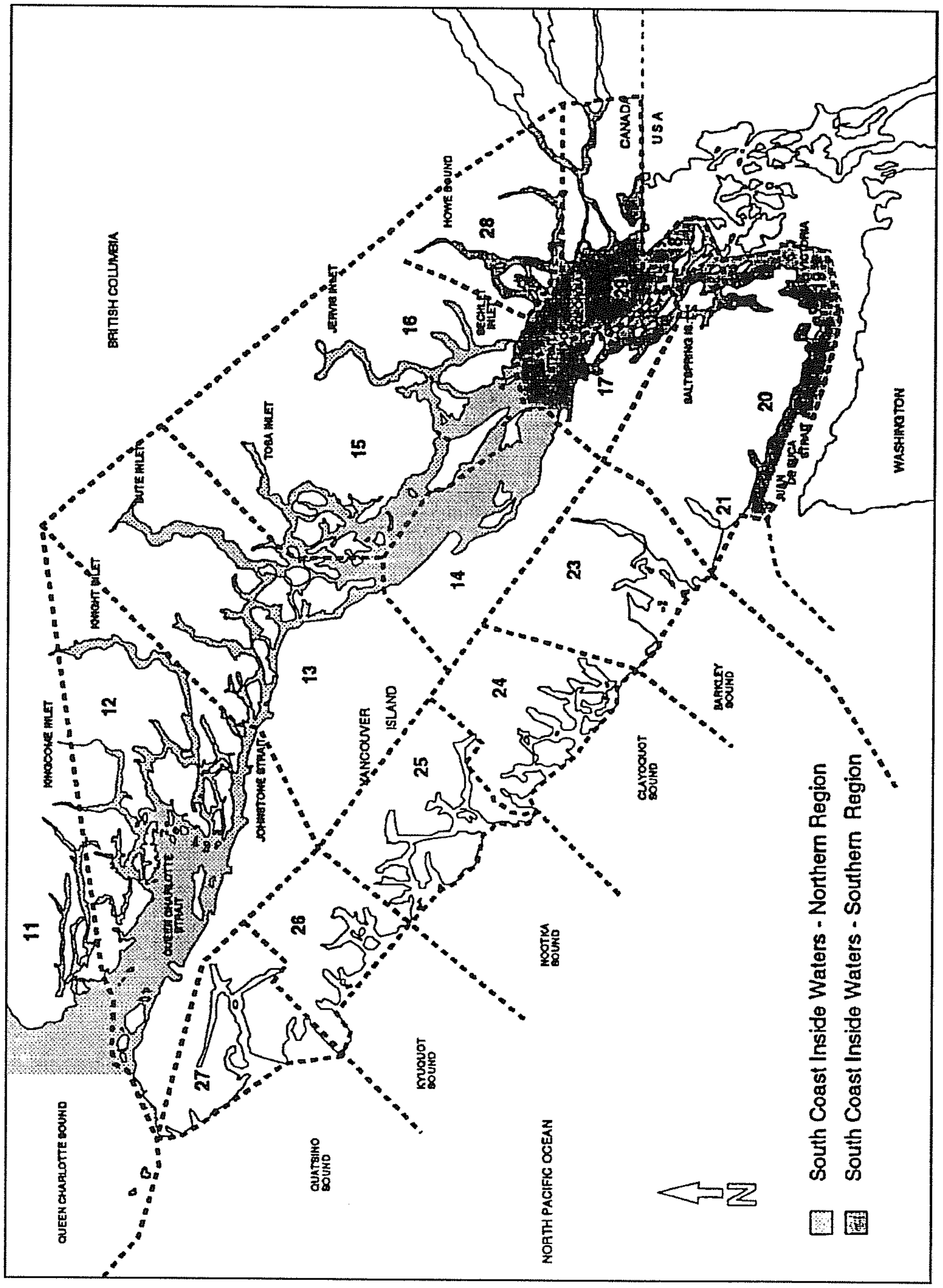


Fig. 2. Pacific Fishery Management Areas (PFMA's) for the South Coast of British Columbia, with green sea urchin regions.

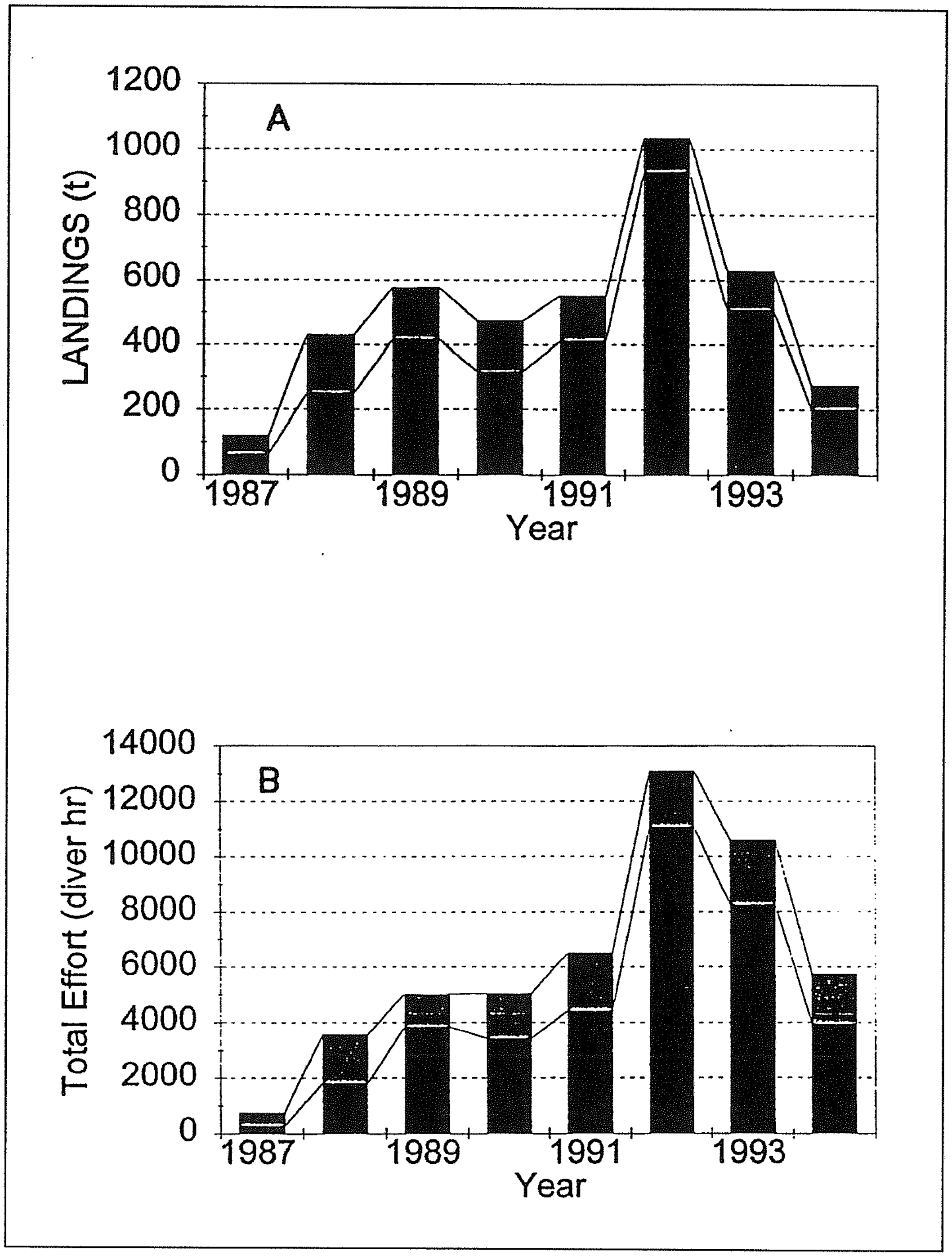


Fig. 3. South Coast Inside Waters: (a) landings (from sales slip information) for the northern region (PFMA's 11 to 16) (solid) and the southern region (PFMA's 17 to 20, 28, 29) (grey); (b) total effort (calculated from sales slip landing and harvest logbook CPUE data) for the northern (solid) and southern (grey) regions.

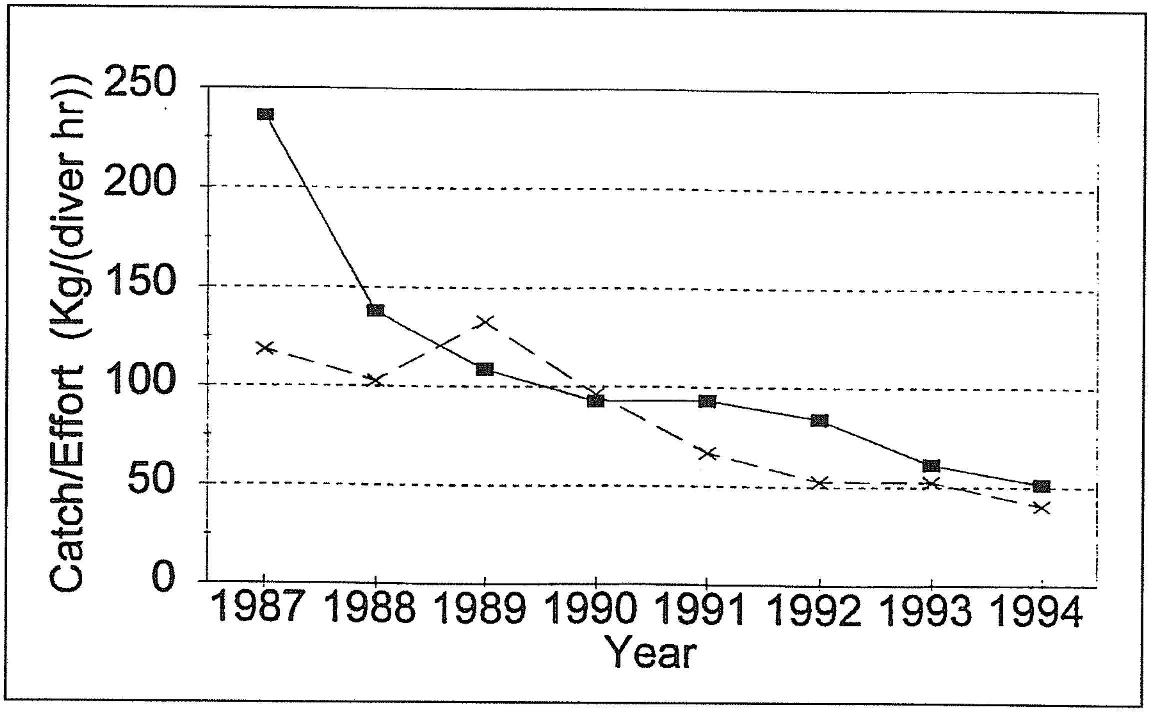


Fig. 4. Catch per unit of effort from harvest logbook data for the South Coast Inside Waters. Solid line-northern region; dashed line-southern region.

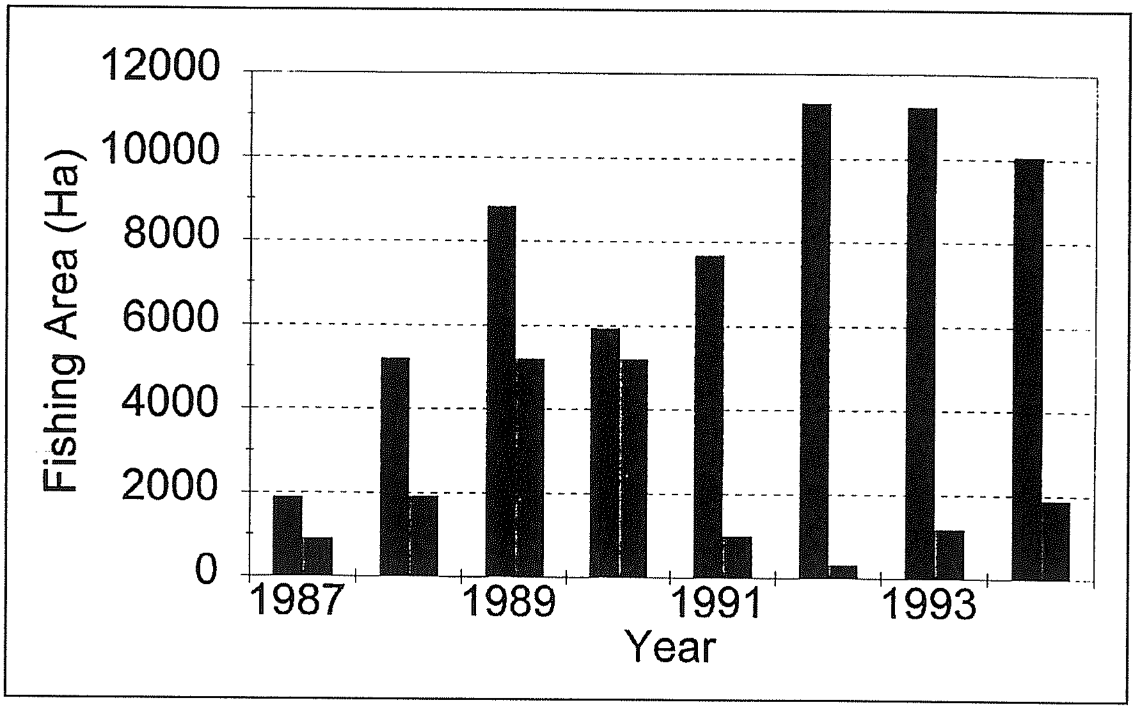


Fig. 5. Areas of green sea urchin fishing grounds in the northern (solid) and southern (grey) Inside Waters.

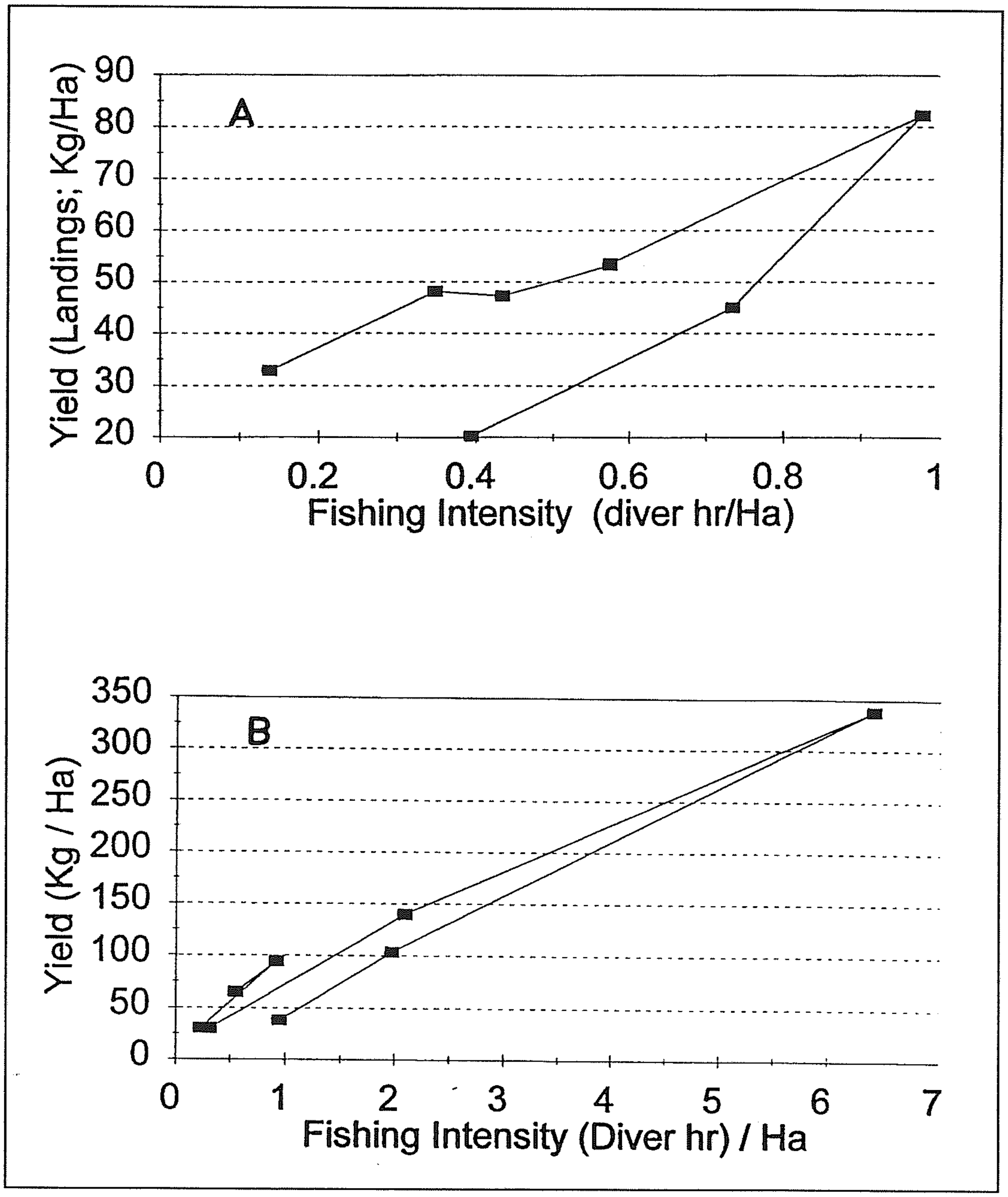


Fig. 6. Yield (sales slip landings/unit area of fishing grounds) versus fishing intensity (effort/unit area of fishing ground) for the northern (a) and southern (b) Inside Waters. Lines connect annual data from 1987 to 1994. Note different scales.

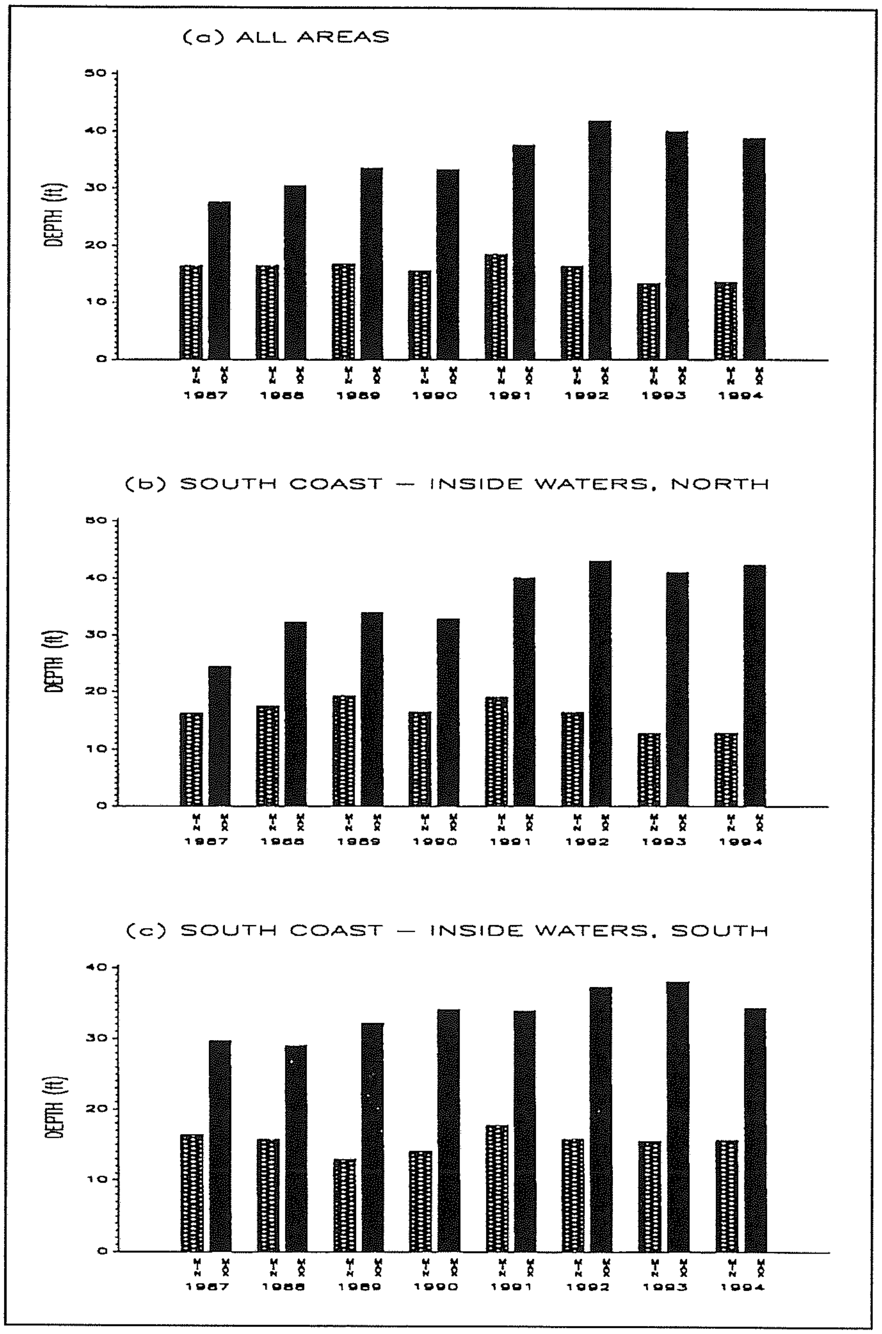


Fig. 7. Mean minimum (hatched) and mean maximum (solid) depths fished for: (a) the whole coast; (b) northern region of Inside Waters, and (c) southern Inside Waters. Data are from harvest logbooks.

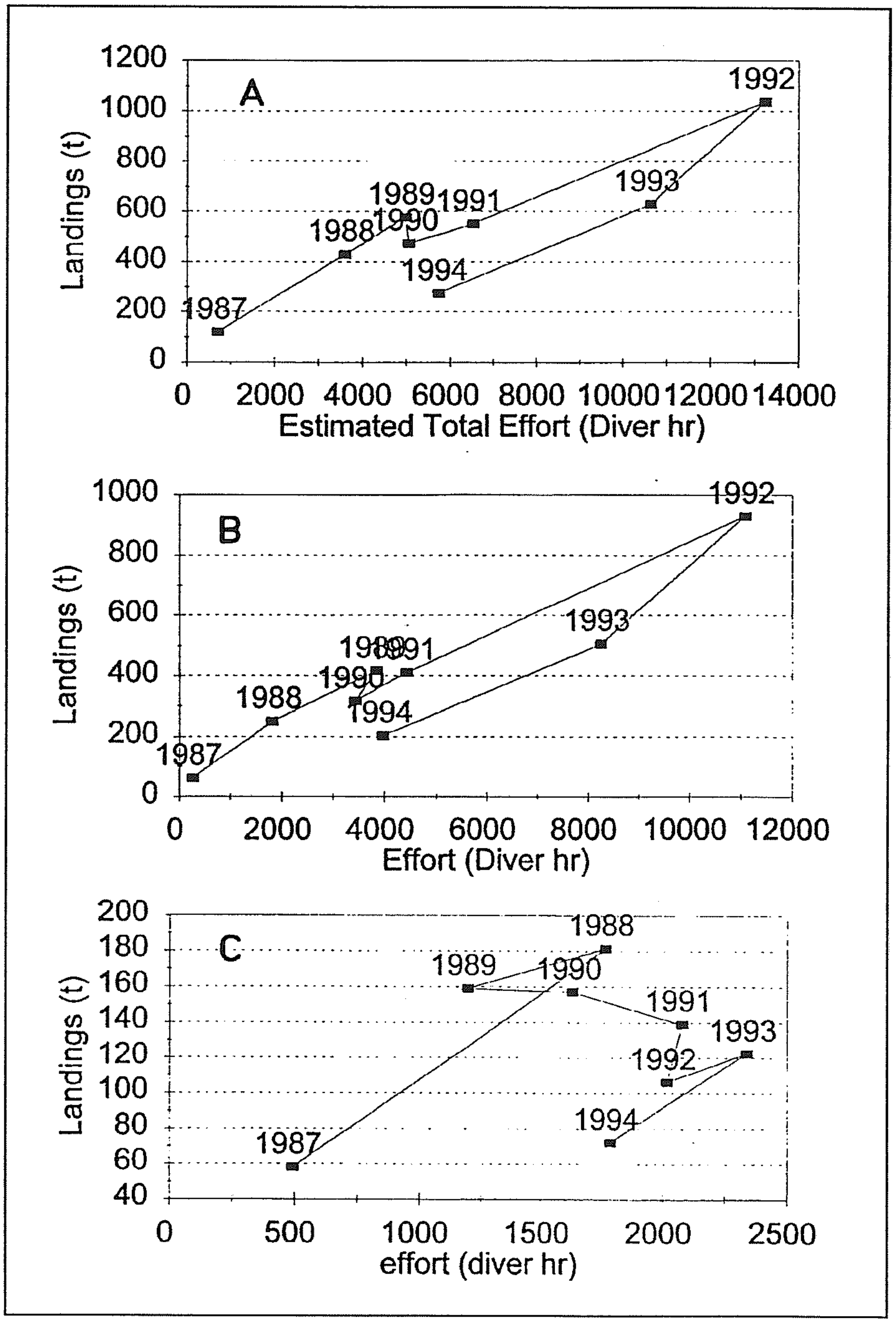


Fig. 8. Landings versus total effort for: (A) overall South Coast Inside Waters; (B) southern region (PFMA's 11 to 16) of the Inside Waters; (C) southern region (PFMA's 17 to 20, 28, 29) of the Inside Waters. Numbers identify individual years; note different scales.

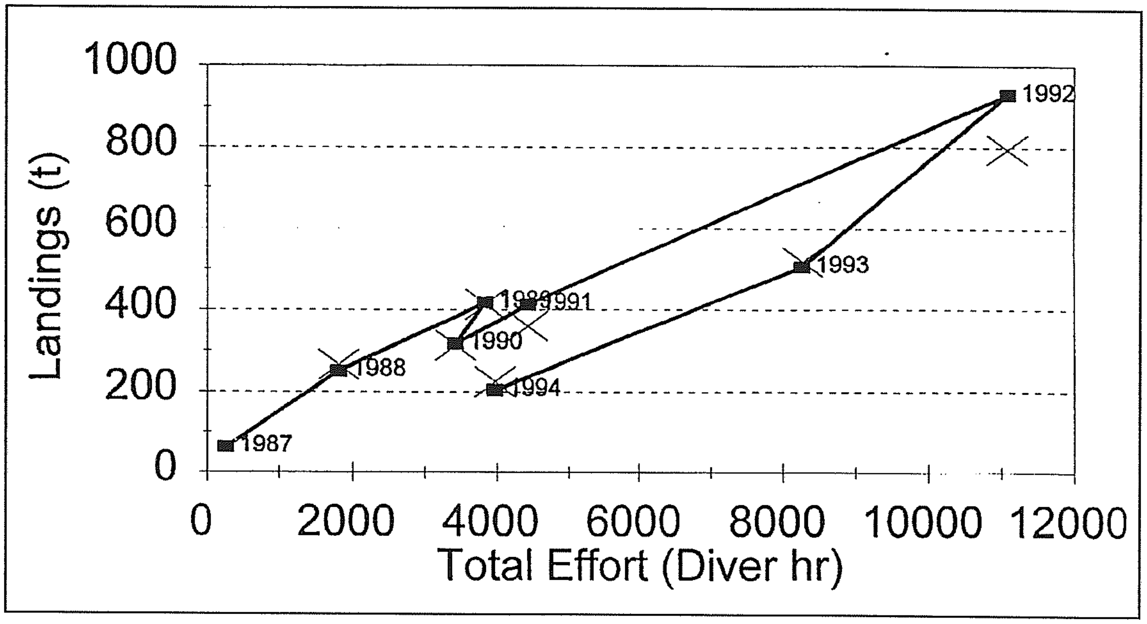


Fig. 9. Comparison of observed (line) and predicted (x) landings for observed levels of effort in the northern Inside Waters. Data years are indicated.

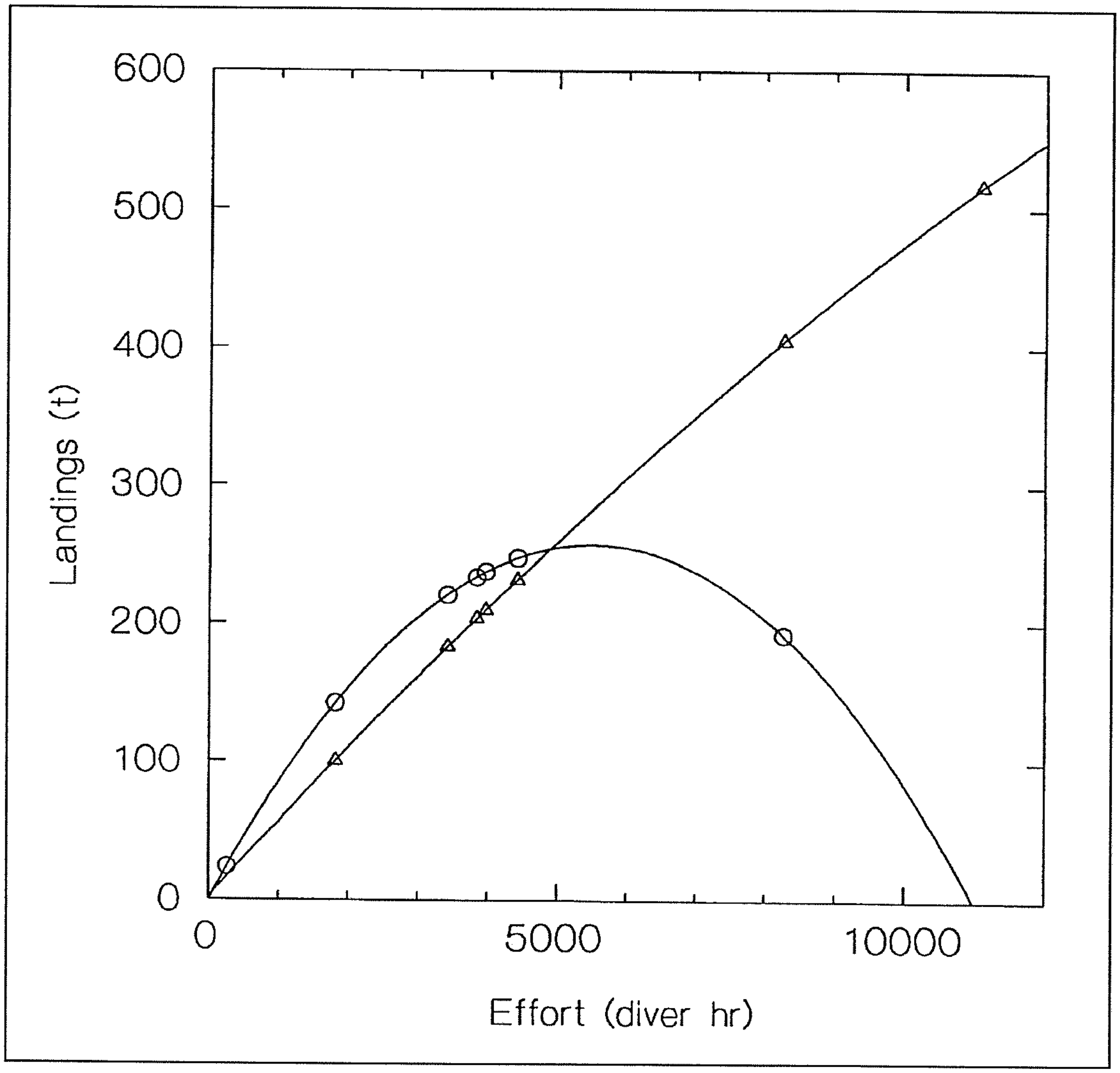


Fig. 10. Predicted landings for 1995 (triangles) and equilibrium Schaefer model (circles) for the northern (PFMA's 11 to 16) region of the Inside Waters.

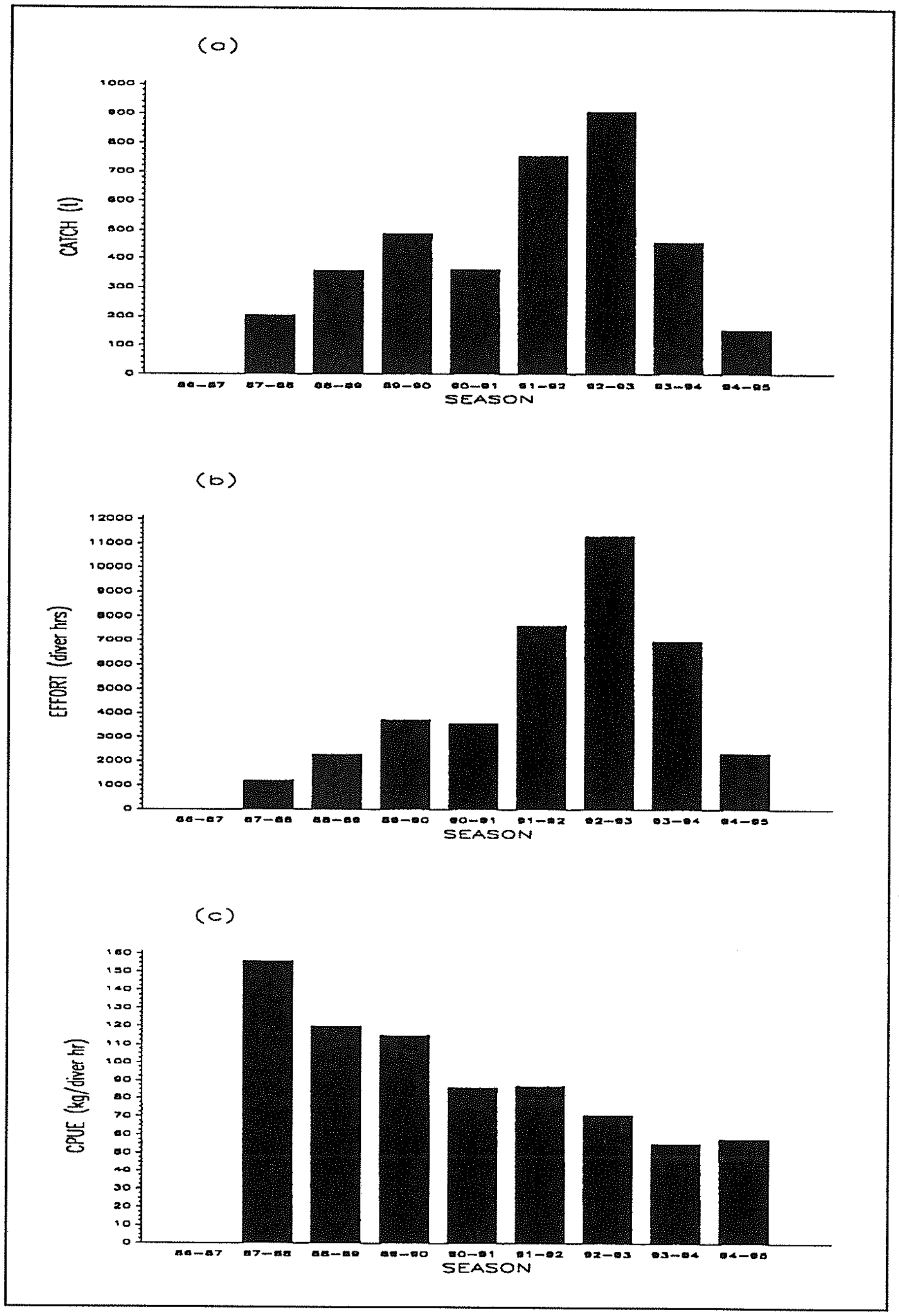
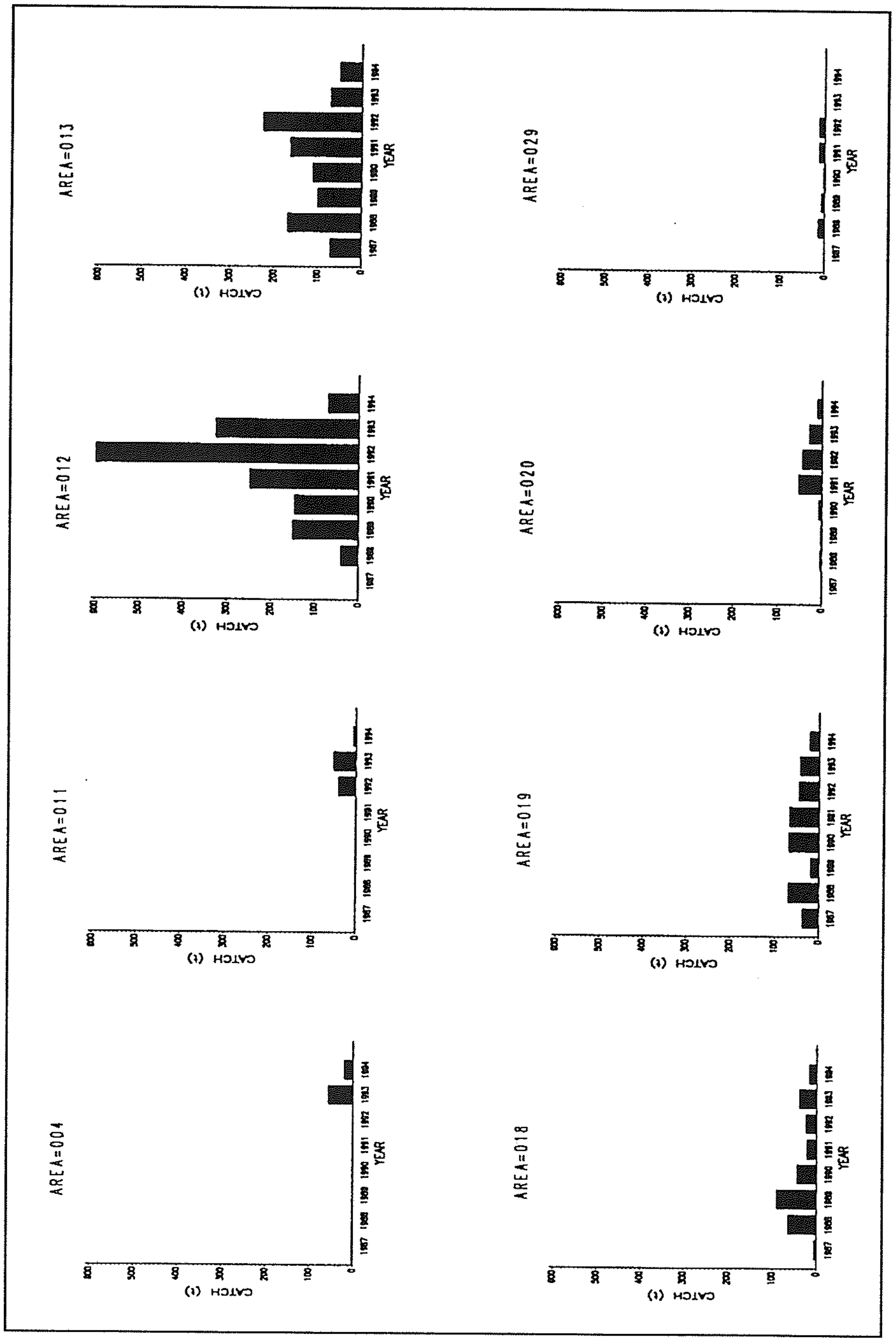
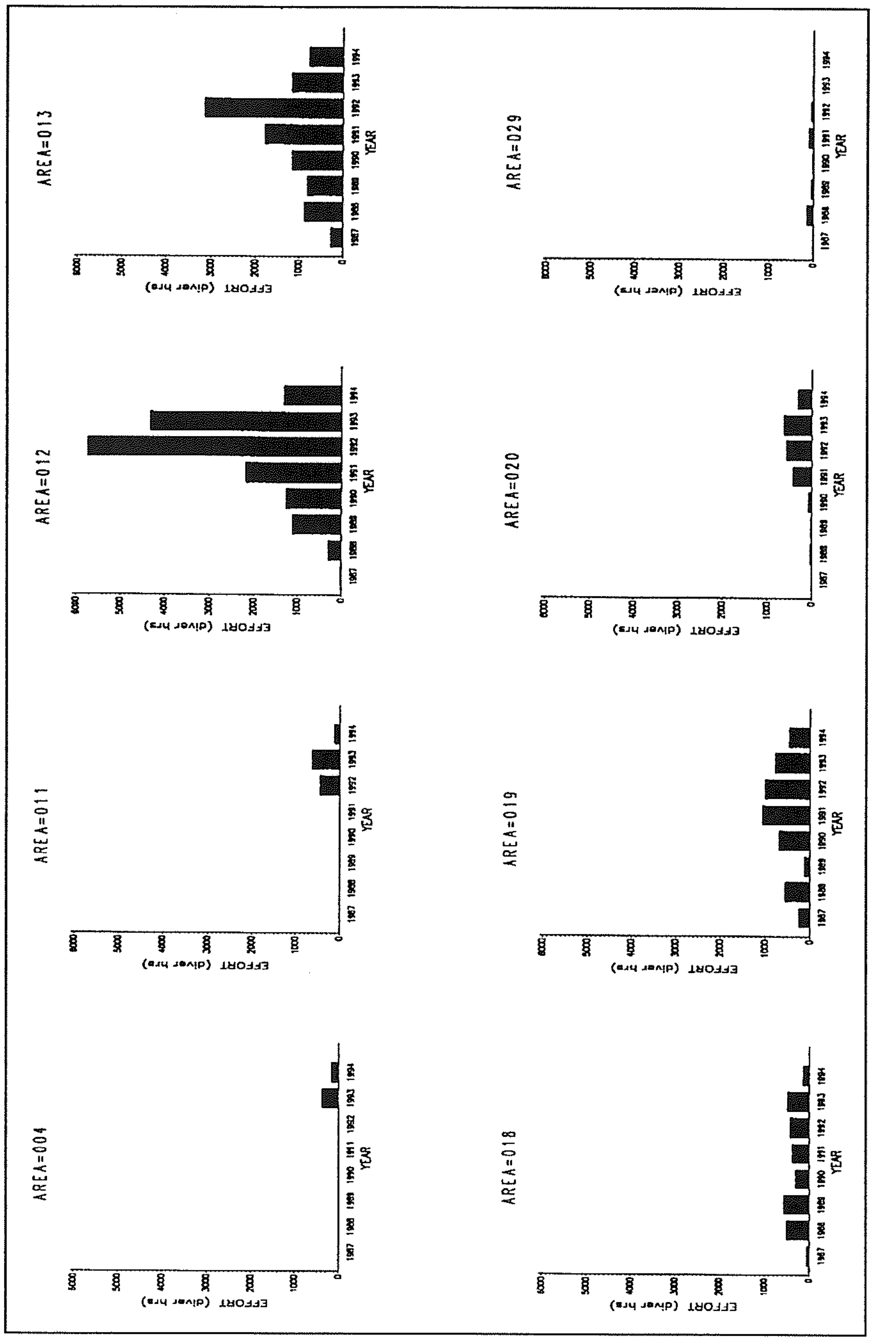


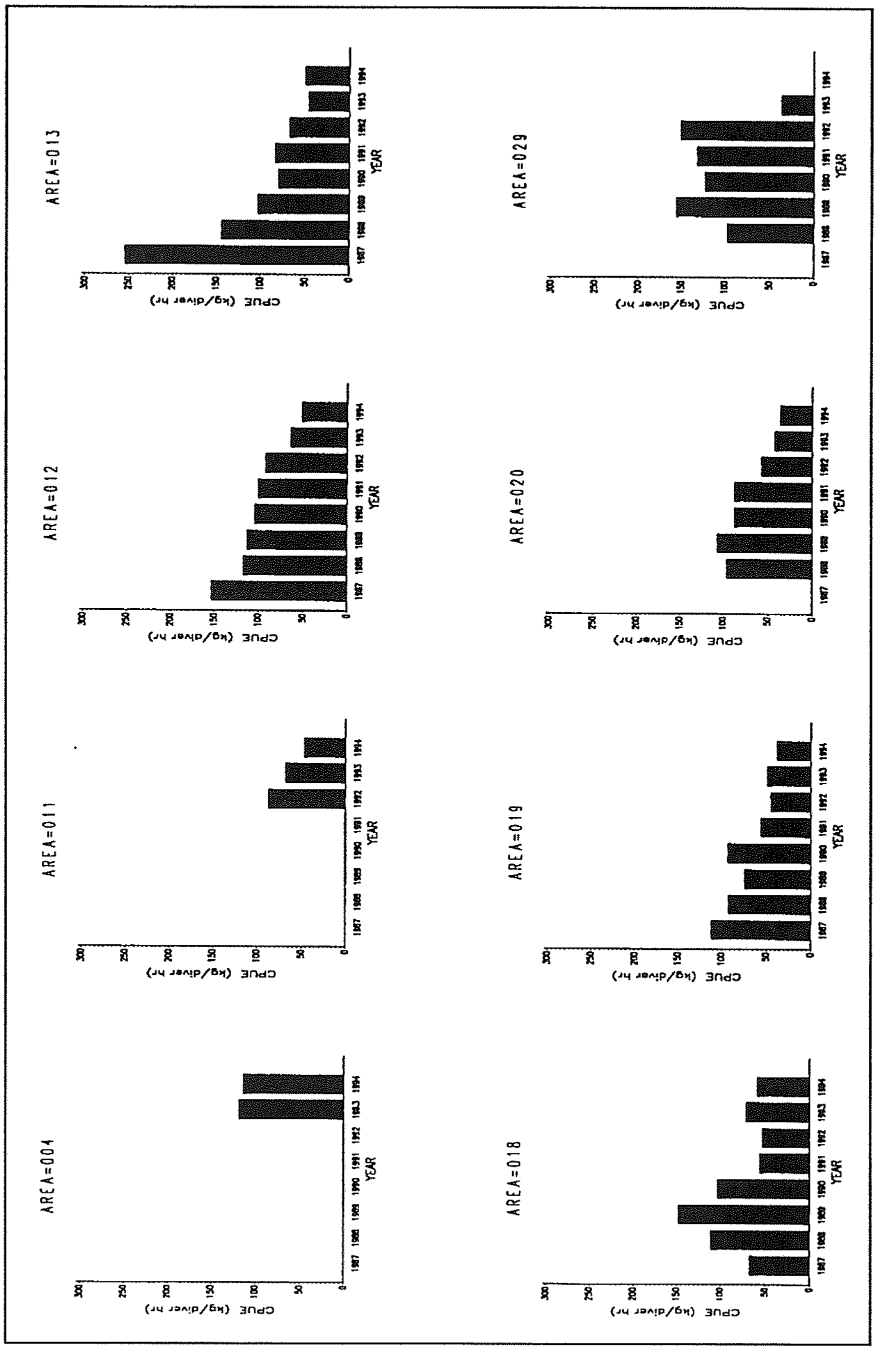
Fig. 11. Coastwide time-series of catch, effort, and catch/effort for harvest logbook information on a fishing season basis, *i.e.*, October of year *n* to February of year *n+1*.



Appendix Fig. 1. Catch (tonnes) by PFMA (Area) and year for those areas with total landings of >50 t for the years 1987-1994, from harvest logbook data.



Appendix Fig. 2. Effort (diver hour) by PFMA (Area) and year for the areas shown in Appendix Fig. 1, from harvest logbook data.



Appendix Fig. 3. Catch per unit of effort (kilogram/(diver hour)) by PFMA (Area) and year for the areas shown in Appendix Fig. 1, from harvest logbook data.

Stock Assessment and Quota Options for the Sea Cucumber Fishery

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ABSTRACT

Phillips, A.C., and J.A. Boutillier. 1998. Stock assessment and quota options for the sea cucumber fishery. pp. 147-167. *In*: B.J. Waddell, G.E. Gillespie, and L.C. Walthers [eds.]. Invertebrate Working Papers reviewed by the Pacific Stock Assessment Review Committee (PSARC) in 1995. Part 2. Echinoderms. Can. Tech. Rep. Fish. Aquat. Sci. 2215.

Giant red sea cucumber (*Parastichopus californicus)* stocks in British Columbia have in past been managed by arbitrary Pacific Fishery Management Area (PFMA) quota using reduction in CPUE from observation of the fishery and declining landings from sales slip data as indicators of overharvest. Little is known of growth rates, recruitment, age or natural mortality for this species. In the absence of sound biological data, a surplus production model using biological parameters derived from harvest logbooks and from published sources was used to indicate low, medium and high risk harvest quotas by PFMA for 1995.

Analysis of catch logbooks and sales slip data has revealed several shortcomings in our database related both to the difficulty in defining biomass in such a plastic and seasonally variable animal, and to errors or omissions in reporting. Owing to the management strategy of rotational closure now in place, there are few PFMA's which have been fished in consecutive years from which production and recruitment information can be derived. Finally, divers move between isolated concentrations of cucumbers before any reduction in CPUE is apparent. Pre-season scouting and stockpiling may artificially increase production. The cumulative effect is to make any estimate of biomass subject to a great deal of uncertainty. Notwithstanding, the density estimates made from our calculations agree favourably with other independent estimates. Harvest quotas proposed for the low risk option are in many instances near those set for the 1994 fishery. Present analysis indicates that the North Coast is generally harvesting below MSY while the South Coast is harvesting at or slightly above the MSY.

Recommendations to address these problems include: changing logbook data collection and redesigning the database; managing on a finer scale than the five quota areas now in place; managing in a manner to provide consistent stock information; seeking biological information through other fisheries or aquaculture ventures; and sanctioning fishers who fail to report or report incorrectly.

INTRODUCTION

In absence of biological data, the fishery for giant red sea cucumber, *Parastichopus californicus*, in British Columbia historically has been managed using arbitrary quotas and restricted openings and entry as a means of controlling the effort. Adjustments in the allowable catch of the resource have been based on previous effort calculations and perceived decline in CPUE from sales slip data. Any improvement in this method of managing this resource for sustainable utilization requires improved biomass estimates and quotas developed from information based on biological parameters for the animals. This PSARC paper was prepared at the request of managers to review the available data from the sea cucumber fishery and where possible conduct an assessment of the stocks and determine biologically based quotas for the fishery on these stocks.

BIOLOGY

The giant red sea cucumber (hereafter simply referred to as 'sea cucumber') is an holothuid echinoderm found subtidally to at least 90 m from California to Alaska (Sloan 1986). They are benthic detritus feeders tending to favor cobble, sand or mud bottoms with relatively low current velocities. Spawning occurs from late spring through the summer. Gametes are released into the water where fertilization occurs. The resulting gastrula develop within several days into a feeding auricularia larva which remains planktonic for between 65 and 125 days (McEuen 1987). This protracted larval stage, which presumably optimizes dispersion to favorable habitats, is followed by a brief transitional stage, the doliolaria, before benthic settlement finally occurs.

The benthic pentactual larva, although morphologically similar to the adult is approximately 0.25 mm long. It consists of a body with one tube foot (pedicle) and five buccal tentacles (Cameron and Fankboner 1986). After one year of growth, juveniles attain a size between 5 and 15 mm. At the end of two years they are between 4 and 10 cm in length. Juveniles are rarely observed in adult habitats and juveniles less than one year old or 1 cm in length are seldom encountered by divers (Cameron and Fankboner 1986).

Because sea cucumbers have not successfully been aged to date, size at sexual maturity is circumstantial. Likewise, the age structure of an adult population cannot be determined with accuracy although all individuals tend to be the same size at a given location. Growth rates, derived from settlement of larvae on mussel culture strings near Tofino, have enabled assignment of age, through modal analysis of length frequency data, to juvenile sea cucumbers for up to three years (P. Fankboner, Simon Fraser University, pers. comm.). However, age determinations of individuals after three years have not been successful due to lack of structure in the length frequency data and the inability to tag and follow individuals for long periods of time (A. Bradbury, Washington Department of Fish and Wildlife; A. Campbell, Fisheries and Oceans Canada; P. Fankboner; pers. comm.). Age at recruitment to the fishery is not known with any certainty, but estimates between 4 and 8 years are speculated. These likely vary considerably throughout their range. Mortality rate and maximum age are also unknown. The only published estimate of maximum age for cucumbers in B.C. water is 12 years (Imamura and Kruse 1990).

The Alaskan surplus production model assumes a maximum age of 14 years (Woodby *et al.* 1993).

Sea cucumbers undergo annual fluctuations in body mass due to their tendency to resorb visceral organs during the winter and regenerate them throughout the spring and summer. They are also known to eviscerate as a defensive tactic. The skin thickness varies annually, becoming thicker during the winter months.

Locomotion along the bottom is achieved by body contractions with the aid of tube feet. Swimming behavior has been observed (Cameron and Fankboner 1989) where non-directional undulatory movement produced by rapid contractions of longitudinal muscles causes the animal to rise into the water column. This is probably a predator avoidance response. There are no confirmed reports of this method being used to travel, although sustained swimming assisted by tide could result in fairly rapid transportation. Little is known of about migratory patterns for these animals although Bradbury (pers. comm.) noted seasonal differences in the abundance indices in some fishery-independent surveys. Whether this could be due to migration between areas or between depths is unknown. Fankboner (pers. comm.) has conducted a number of similar studies on sea cucumbers but has not observed or recorded this phenomenon.

HISTORY OF THE FISHERY

The dive fishery for sea cucumbers in British Columbia began in 1980 fueled by a demand for `trepan' (dried cucumber skins) in Asia. Trepan has been an Asian commodity for at least 1,000 years. Most exports are of this dried product or the dried muscle bands, and are sent to the main distribution ports of Hong Kong and Singapore.

British Columbia cucumber landings increased sharply from 1984 reaching a peak of 1,922 t in 1988. Thereafter, quotas, licence restrictions and restricted (shotgun) openings were introduced. Coastwide quotas were set at 800 t for the years 1989-92 with further reductions to 650 t in 1993 and 574 t in 1994 due to apparent declines in abundance associated with overages in the 1987-93 quotas (Fig. 1). The pattern of exceeding quotas has been repeated annually due to poaching, prefishing, unreported catches and the inability to determine landings in time to limit the fishery. The value of the fishery is around $1.0 M annually and presently ranks 7th in value amongst the B.C. invertebrate fisheries.

MANAGEMENT STRATEGIES

BRITISH COLUMBIA

Management of the sea cucumber fishery in British Columbia is by arbitrary annual quota initiated because of a perceived reduction in CPUE. There are three Sea Cucumber Quota Areas (SCQA's) on the North Coast and two on the South Coast. In 1993, a 2 and 3 year rotation period was initiated in northern and southern coastal SCQA's, respectively. Licences were limited to 84 in 1994. Logbooks with weekly hailing of landings are required as a Condition of Licence. Harvest depth is limited to depths where harvest is practical, generally less than 20 m, and there are depth restrictions in the Conditions of Licence which require adherence to Worker's Compensation Board diving regulations. In addition, a number of ecological reserve areas, provincial and federal parks, native food fishery areas and research areas are closed to harvest and serve as sanctuaries for the stocks. To date, little is known of the recruitment processes or growth rates of these animals. Management has therefore tried to be conservative and any indications of reduced abundance have resulted in lowered quotas.

WASHINGTON STATE

Washington State has developed a management strategy similar in many respects to that employed in British Columbia. Until 1994, quotas and closures were made on the basis of empirical analysis of catch and effort data (A. Bradbury, pers. comm.). Four harvest SCQA's were established in 1987 with a rotational closure of all but one SCQA annually. Fishing licences are limited and logbooks and hail of catch are mandatory. Logbook data were augmented by dive survey work and population trends were followed using a Leslie analysis.

During 1994, all four SCQA's were opened at the beginning of May for three days per week and remained open until the established SCQA quota was taken. This new strategy was adopted due to an apparent inequity between SCQA's in cucumber abundance and with problems associated with concentrating the fleet (A. Bradbury, pers. comm.). Estimates of harvestable biomass were made possible by the development of a modified Schaefer model applied to data accumulated during five years of dive surveys done at Puali Pt. Washington (A. Bradbury, pers. comm.). Surplus production was calculated for each of the SCQA's and adjusted by a productivity index established from previous fishing in the SCQA. This had the effect of generally lowering the overall quota of cucumbers for that year.

1995 harvestable biomass estimates will be further enhanced by new information available from four sources (A. Bradbury, pers. comm.):

1) underwater video estimates of biomass conducted for two years in one district;

2) declining CPUE (Leslie) for at least one year's data within SCQA's;

3) dive survey estimates before and after the fishery; and

4) a new production model (Woodby *et al.* 1993) which calculates harvestable biomass on the lower 95% confidence limit of the estimated biomass.

ALASKA

Alaska's cucumber fishery began in 1987 and by 1990, had grown beyond the ability of the Alaska Department of Fish and Game to regulate using the permit system in place at that time. The present management plan (Woodby *et al.* 1993), is based on a surplus production model which uses transect survey data to estimate a virgin biomass. Annual harvest is calculated on the lower 90% confidence limit of this estimate and is made more conservative by setting the maximum sustained yield (MSY) at 0.2 x mortality rate x virgin biomass. Harvest is then further restricted by prohibiting harvest below 18 m depth. This assumes that recruitment to the harvestable stock can then take place from depth as well as from adjacent geographical areas and through settlement of larvae.

Annual surveys conducted in Alaska to estimate biomass consist of transects run perpendicular to shore to a depth of 18 m, at roughly 4 km intervals. The sum of all transect counts divided by the transect width (2 m) is then multiplied by the entire length of coastline associated with the harvest to yield a biomass estimate. These surveys, while costly, provide detailed abundance and distribution data over a large geographic range (Woodby *et al.* 1993). Catch and effort statistics are also collected. The fishing season opens in October and is limited by quota.

METHODS AND MATERIALS

DATA

The data used in this assessment comes from fishery dive logbooks, which have been collected since 1985, as they are the only data available which have catch, effort and PFMA data in the detail required for the analysis. This is the first attempt to analyze these data for assessment purposes. Logbook design has changed since they were initially collected and, over time, there have been improvements in reporting of diver and location data. The use of these data was not without its own set of unique challenges. Some have been overcome, and some will require further work, as all problems could not be addressed in this assessment.

Landing Weights

Probably the most unique challenge with this data set was to determine what the reported weight represents. Heizer and Hobbs (1996) reported, to PSARC, the problem in trying to standardize the unit of measurement for the landed product (*i.e.*, whole weights, split weights etc.). The logbooks have three columns for catch in which to report number of animals landed, weight landed (in pounds) and landed form (*i.e.*, round or split). For ease of comparison, landings reported in the logbooks were initially analyzed in kilograms of round weight (standard round weight) by converting the pounds landed and adjusting if necessary the weight for the form of the landing. Since 1992, DFO has been setting and monitoring quotas based on split (eviscerated and drained) weight using a multiplier of 2.73 to convert to round weight. It was found that the logbook data prior to 1991 were generally reported as round weights and from 1991 to present the logbooks generally report the product as split weights. To further confound estimation of biomass and the meaning of that estimate is the seasonal variability associated with loss of the digestive tract and body mass during the winter. Some confusion exists as to whether this loss of tissue is confined to the digestive organs. This loss of body mass may be independent of skin thickness which is of prime importance to producers as it affects meat recovery during preparation and drying. Producers claim the best product is landed during cold weather as the skin is thicker giving better recovery (Morris 1995).

Average Weight of a Cucumber

As mentioned above, the logbooks have space for reporting both number of animals and weights. Where both numbers and weights were recorded, the average weight of the cucumbers was calculated by dividing total standard round weight by total number.

Number of Animals Landed

Number of animals landed was either reported directly in the logbooks or calculated taking the standard round weight for each PFMA/year combination and dividing by the average weight of cucumbers for that PFMA/year. Estimates of total animals landed by PFMA for all years combined are shown in Fig. 2. The logbook records that have numbers of animals caught is assumed to be a random sample of the errors associated with product form and therefore the calculated numbers of animals caught should be a better reflection of actual catch.

CPUE

For the purposes of this analysis, CPUE was calculated as either kilogram per dive hour or cucumbers per dive hour. There was no correction made for any seasonal differences in availability. Both Washington State and Alaska are pursuing investigations into the impact of seasonal availability differences.

Effort

Effort in the logbooks is record as dive minutes. This was converted to dive hours for the purposes of this analysis. Where effort figures were missing from the logbook data, effort was calculated from the total standard weight or total animals divided by the average CPUE for the PFMA and year. There was no attempt at this time to standardize effort by diver. Only data that included dive times were used in the calculation of the average CPUE by PFMA.

Area

Area was calculated with information provided by fishers that was copied onto Canadian Hydrographic Services charts and digitized into the Shellfish Database GIS system, Compugrid. The bed sizes are calculated by the Compugrid system. Unfortunately, location of harvest is not available for all the landings. Estimates of bed size by PFMA for all years combined are shown in Fig. 2.

PARAMETER ESTIMATION

Population Size

The data were fit to a modified Schaefer biomass dynamic model (production model) using the Walters and Hilborn (1976) difference model regression estimation procedure:

$$\frac{U_{t+1}}{U_t} = r - \left(\frac{r}{kq}\right)U_t - qE_t \qquad (1)$$

Where U_t and U_{t+1} are the CPUE in the respective years; r is the intrinsic growth rate; $-r/kq$ is the density dependent reduction in growth rate; $-q$ is the catchability coefficient; and E_t is the effort in year t. Using U_t , U_{t+1} and E_t as independent variables, the calculated parameters of the regression are r, $-r/kq$ and $-q$.

Data were reviewed at the bed, PFMA subarea, PFMA, SCQA, North/South Coast and coastwide levels. Initially the data used were the standard round weight of the catch, the average kilogram per dive-hour and the total number of dive-hours. An analysis of the average size of animals by PFMA by year indicated that there might be a bias in weight data for the years where a conversion factor from split to round weight was used. Because of this apparent problem with the weight of the animals, the analysis was repeated using the values representing numbers of animals. For the purposes of the remainder of this document, the model results will be based on number of animals caught, average number per dive-hour and total number of dive-hours.

Since the data reflect the total history of the fishery, the estimated virgin biomass is the calculated value of k (the unfished equilibrium stock size) from the model.

Natural mortality rate

Ageing and tagging of sea cucumbers has proven to be very difficult, therefore the estimate of natural mortality rate (M) used in this analysis comes from Hoenig's (1983) relationship between the logarithms of maximum age and instantaneous mortality rates:

$$\ln(M) = 1.44 - 0.982\ln(t_{\max}) \qquad (2)$$

where t_{max} is the maximum age in years. As was pointed out earlier, t_{max} is assumed to be 12 years for British Columbia.

MSY MODEL

The surplus production model assumes that a population grows according to a logistic formula or a sigmoidal shaped curve, with slowest growth rates at low and high population levels and the fastest at moderate population levels.

MSY can be calculated either from the model estimates:

$$MSY = \frac{rk}{4} \tag{3}$$

or by assuming that at the population size at MSY, the fishing mortality rate is equal to the natural mortality rate, M, and the calculated MSY is:

$$MSY = XMB_0 \tag{4}$$

where B_0 is the virgin biomass and X is a scaling factor which has been estimated to be 0.5 (Gulland 1971), or 0.4 (Caddy 1986). In general, it is felt that 0.5 will overestimate MSY in most cases and Garcia *et al.* (1989) suggested that in data-limited situations that the target catch should be 1/2 to 2/3 of the estimated MSY. This would depend on whether the stock is considered lightly or heavily exploited. Woodby *et al.* (1993) use this suggestion and have used X = 0.2 (1/2 of .4) for newly developing fisheries on cucumber stocks in Alaska. In this case the target catch is then calculated to be:

$$MSY = 0.2MB_0 . \tag{5}$$

RESULTS

A review of the data for conducting this analysis showed that there are insufficient data at this time to analyze the logbooks at the bed level for trends in abundance. Many of the logbooks did not specify bed information. For those logbooks in which bed information was reported, it was evident that fishers tended to move from bed to bed within the fishing season and between years. Only in seven instances were there records of the same diver fishing the same bed on more than one occasion. In these seven instances, two divers were involved, one which repeatedly fished four beds and the other which repeatedly fished three beds. In all cases, these repeat fishing events took place two years apart and there was fishing on the bed in the intervening year. In all seven cases the CPUE declined on those beds. These declines ranged from 6% to 69%.

AVERAGE WEIGHT OF A CUCUMBER

Average weight estimates based on logbook data (Fig. 3) indicate that average weight of cucumbers increased dramatically between 1991-94. Possible explanations of the increase in average size include: 1) a miraculous substantial increase in growth rates of cucumbers all over the coast; or 2) there are some problems with the data. We believe the latter to be true. The years showing an increase are the same years when most of the catch in the logbooks was reported as split weight. Standard round weight was estimated from split weight using the 2.73 conversion factor. Two factors may contribute to this conversion problem: 1) the landing form on the logbooks is incorrect; or 2) the conversion factor is too large. Some cucumber surveys indicated a conversion factor from round to split weights ranged from 2.37 to 2.51 for cucumbers that were out of water for 5 hr (K. Cripps, Kitasoo First Nation, pers. comm.). This work may indicate that there is a small problem with the conversion rate, however it does not account for the very large differences seen in the average size. Heizer and Thomas (1997) pointed out that there was a continuing problem with weights and landing forms on sales slips. This problem seemed to be most prevalent in 1991, and seems to be improving over time (Fig. 4).

As the weight conversion problem could not be resolved at this time, the data used were the number of animals caught. The calculations were conducted using 'total animals landed', 'animals per dive hour', and 'total dive hours'. Fig. 4 shows the differences in the landings as reported by numbers and round weight.

PARAMETER MODELS

Population Size

The biomass dynamic model was run using various subsets of the data. This model works on the principle:

$$B_{t+1} = B_t + R + G - C - A \tag{6}$$

where B_t = initial biomass; B_{t+1} = biomass the following year; R = recruitment; G = growth; C = catch; and A = annual mortality. In the absence of catch, production, P, is defined as:

$$P = R + G \tag{7}$$

and surplus production, P_S, is defined as:

$$P_S = P - A \tag{8}$$

Data subsets were selected for modeling by using different sized areas (*i.e.*, PFMA's, subareas, and several PFMA's combined). The subsets at the most gross level was a coast-wide calculation and at the finest level of resolution at the bed level. There were numerous analyses that did not fit the model and gave unrealistic (*i.e.*, negative) values of q and r. The results for the model that gave realistic values are given in Table 1 along with calculations of the virgin biomass, k.

Natural mortality rate

Using $t_{max}=12$ the calculated M for sea cucumbers in British Columbia was 0.37.

MSY CALCULATIONS

Estimates of MSY will be presented by PFMA (Table 2) using three methods of calculations:

1) Low Yield: $0.2MB_0\,(lcb)$ where $B_0\ (lcb)$ is the lower one tailed 90% confidence level of the estimated density (cucumbers per hectare) times the reported bed size in the various PFMA's. The estimate used in these calculations is 992 cucumbers/ha or 0.0992 cucumbers/m^2. This estimate falls within the range of estimates that Bradbury (pers. comm.) reports from his video surveys (0.0771 to 0.1585 cucumbers/m^2).

2) Medium Yield: $0.2MB_0$ where B_0 is calculated from the mean density (cucumbers per hectare) times the reported bed size in the various PFMA's. The estimate used in these

calculations is 1,988 cucumbers/ha or 0.1998 cucumbers/m^2. This estimate falls within the range of estimates that Cripps (pers. comm.) reported for dive surveys from four locations in PFMA 6 (0.5397, 0.1490, 0.1069, 0.1376 cucumbers/m^2).

3) High Yield: *rk/4* where the values for *r* and *k* are the model estimates for the coastwide calculation. This MSY is then allocated to each PFMA by proportioning the PFMA's reported bed sizes to that of the whole coast.

DISCUSSION

The results of this assessment should be viewed in light of the data quality and the uncertainty of the model results, as such the following points should be kept in mind.

As noted above, the data is fraught with problems including missing or misreported data. These types of data problems can bias the results. In most cases, they lead to exploitation rates higher than biological objectives would dictate. The types of errors that occur are:

1) There are some very obvious problems like PFMA 17, which has reported landings of cucumbers but has a bed size of 0.0 ha. This lack of information will result in quotas exceeding MSY in all PFMA's except for PFMA 17 in each of the three yield options.

2) Heizer and Thomas (1997) point out the problem of fishers stock piling sea cucumbers prior to the fishery. This activity would bias the CPUE and population estimates upward.

3) Sea cucumbers, at times, form dense aggregations that are readily available to the dive fishery. Interviews with fishers indicate that fishers will scout out areas of high sea cucumber abundance during other fisheries and will target these areas during the sea cucumber fishery. Not unaccounting for search time for dense aggregations, and the fact that fishers seldom go back to the same areas, will keep the CPUE high for a long period of time and tend to lead to an overestimation of MSY and biomass.

4) Virtually all cucumbers are removed from a given location in one pass. Most individuals in a population are about the same size so there is little or no size selection. This will increase the occurrence of localized overfishing. Unfortunately we do not have information as to the extent and boundaries of a stock and what might be perceived as localized overfishing may in fact be recruitment overfishing of a discrete stock.

Biomass dynamic models have a long history of use in fisheries, especially in data-limited situations where biological information on the age structure, growth and recruitment mechanisms are unknown. Hilborn and Walters (1992) felt that these models could perform quite adequately if the data had good range and contrast between levels of fishing effort at various stock abundance indices. However, Hilborn (1979) pointed out that these models also have a checkered history of poor performance when data are limited and provided poor contrast. This model is the only one available for our analysis, and the results may have to be treated with caution for the following reasons:

1) Both Washington State and British Columbia have had anecdotal reports of widespread reduction of stocks since the fishery for cucumbers began. These reports may reflect localized overfishing and may not affect the overall abundance of the stock and subsequent recruitment. However, field studies indicate that the successful recruitment of juveniles might be related to the presence of adults in the area (Fankboner, pers. comm.). The other problem with localized overfishing is that there is no biological basis for the definition of a stock and, as such, localized overfishing may in fact translate into systematic depletion of discrete stocks.

2) Biomass dynamic models usually require a time series of data spanning a decade or more. Even though the fishery has been promulgated for this length of time in B.C., there are holes in the data because the fishery has been moved around from year to year between PFMA's. There is no consistent pattern of data from a PFMA. There will be 4 or 5 years of consistent data then the fishery is stopped for a year or two. Missing data can not be estimated without biasing the results of the model.

3) The model r^2 values from the various runs are generally very poor and the variance in the rate of change in the biomass indices can only be partially explained by the variances in the CPUE and effort data (see Table 1).

4) This type of model assumes a logistic growth rate. We have no data to either support or reject this assumption. If it is not true and the population did not respond with some compensatory density dependent mechanisms, then there would be serious consequences in terms of recruitment and replacement to the fished populations.

5) The calculated PFMA quotas, when compared to average annual catch by PFMA for the low, medium and high yield scenarios (Figs. 5, 6 and 7 respectively), indicate that the North Coast is underutilizing their cucumber resources while the South Coast is overfishing or fishing at MSY. These quotas are very sensitive to the reported size of beds for the PFMA and under-reporting of bed size (as in PFMA 17) will result in higher quotas in PFMA's which report the fishing areas properly.

There are some other factors that will make the resulting estimate biased on the low side of MSY:

1) The whole population is not accounted for in the index of abundance estimates. The animals range to a depth of 90 m and the present analysis only accounts for trends in population indices for a fishery promulgated to a depth of 20 m. The proportion of the population available to the fishery may vary seasonally (as suggested by Bradbury) but the extent of the variance is unknown at this time. Little is known of the cucumbers ability to recolonize from adjacent areas or depths. Evidence to date suggests little movement between areas, but failure to devise a method of tagging adults for periods exceeding about three months has prevented collection of dispersal data.

2) A major problem in setting and adhering to quotas is the difficulty in quantifying landings and relating these to live biomass. Originally all landings were reported in round weight (body intact, viscera remaining). Depending on the method of treatment and the time of year, the weights could vary by as much as a factor of two. Often, cucumbers packed in containers eviscerate and lose much of their water. In 1992, official quotas and landings were given in split weights. The average weight of a whole cucumber is about 0.635 kg. A conversion factor of 2.73 was established to convert split to round weights. As suggested by the information on the changes in the average size of the cucumbers, this conversion rate may be too high and the quotas are actually not being achieved.

RECOMMENDATIONS

1) The database needs to be redesigned and corrections made. The collection of data should concentrate on getting good information on effort (diver and dive time), location (bed code information from maps) and counts of catch. Weight data should be discarded and information on changing patterns of growth over time should be collected through a biological port sampling program.

2) Quota management should be on a much finer scale than the large SCQA's presently used. Evidence of localized overfishing is present in this fishery and until we know what constitute a stock (in terms of recruitment overfishing) it is safer to manage smaller units. PFMA should be the largest quota area.

3) One of the management objectives should be to manage the fishery in a manner which will provide data that can be used to evaluate the impacts of the fishery. With the lack of biological information about sea cucumbers and the likelihood that this will not improve in the near future, the use of biomass dynamic models will be the only tool available to evaluate the state of the various stocks being fished. For this kind of model to work properly there must be a consistent set of fisheries data without the gaps created by the 2 or 3 year rotational fishery management strategies.

4) Biological data on this species will be hard to collect. In addition to the wild fishery, it is appropriate to review data from new ventures such as aquaculture outgrowing experiments. Data reporting should be a condition of aquaculture venture permits, in the same way as the logbook requirement is applied to the commercial fishery.

5) DFO and Industry must work together to collect the most useful data possible for the management of this fishery. If fishers continue to supply incorrect or incomplete data then it will be necessary to withhold licencing approval until the data are provided in an accurate and timely fashion.

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Table 1. Results of the Biomass Dynamic Model for various subsets of data.

Location	r	-r/kq	-q	K	Model r^2	Area (ha)	Density (no./ha)
Coastwide	1.277	-0.0025	-1.4E-05	37616354	0.71	28222	1333
North Coast	1.653	-0.0024	-0.00026	2640988	0.73	17907	147
South Coast	0.827	-0.0016	-6.1E-06	81870720	0.45	10314	7938
WCVI	1.589	-0.0028	-0.00025	2303377	0.72	3471	664
PFMA 2 89-93	4.511	-0.0066	-0.00373	183460	0.97	3464.2	53
PFMA 6	0.835	-0.0014	-0.00143	411845	0.85	6571	63
PFMA 12 87-90	4.026	-0.0054	-0.00517	145266	0.48	1136.1	128
PFMA 18	0.751	-0.0016	-9.2E-05	5120556	0.33	951	5384
PFMA 18-06	2.485	-0.0039	-0.00342	188394	0.84	337.7	558
PFMA 19-05	1.311	-0.0035	-0.00078	474816.8	0.46	220.5	2153
PFMA 24	0.934	-0.0015	-0.00029	2111049	0.43	1613.6	1308
PFMA 24-07	0.636	-0.0013	-0.00038	1269612	0.58	306.8	4138

Notes: r = intrinsic growth rate; -r/kq = density dependent reduction of growth rate; -q = catchability coefficient; k = calculated unfished equilibrium stock size.

Table 2. Calculated MSY (number of cucumbers) by PFMA for various levels of yield.

PFMA	Area (ha)	Low Yield MSY	Medium Yield MSY	High Yield MSY
2	3,464	254,297	509,876	1,474,000
3	219	16,065	32,210	93,116
4	1,136	83,397	167,215	483,402
5	4,408	323,553	648,737	1,875,434
6	6,571	482,370	967,171	2,795,995
7	2,032	149,165	299,082	864,616
8	78	5,714	11,457	33,121
12	3,384	248,413	498,077	1,439,892
13	1,387	101,823	204,159	590,203
14	28	2,088	4,186	12,101
15	11	831	1,666	4,817
16	281	20,642	41,389	119,651
17	0	0	0	0
18	951	69,808	139,968	404,633
19	549	40,278	80,758	233,463
20	181	13,293	26,652	77,050
23	398	29,222	58,592	169,383
24	1,614	118,454	237,505	686,604
25	294	21,582	43,273	125,097
26	143	10,486	21,024	60,778
27	841	61,771	123,854	358,050
28	252	18,502	37,097	107,243
Total	28,222	2,071,753	4,153,948	12,008,648

Notes: MSY at 0.2 MB_0 based on lower bound of 90% confidence interval around the mean density (Low Yield); 0.2 MB_0 of the mean density (Med. Yield) and rk/4 from Schaefer model (Hilborn and Walters 1992) based on coastwide averages of r and k (High Yield).

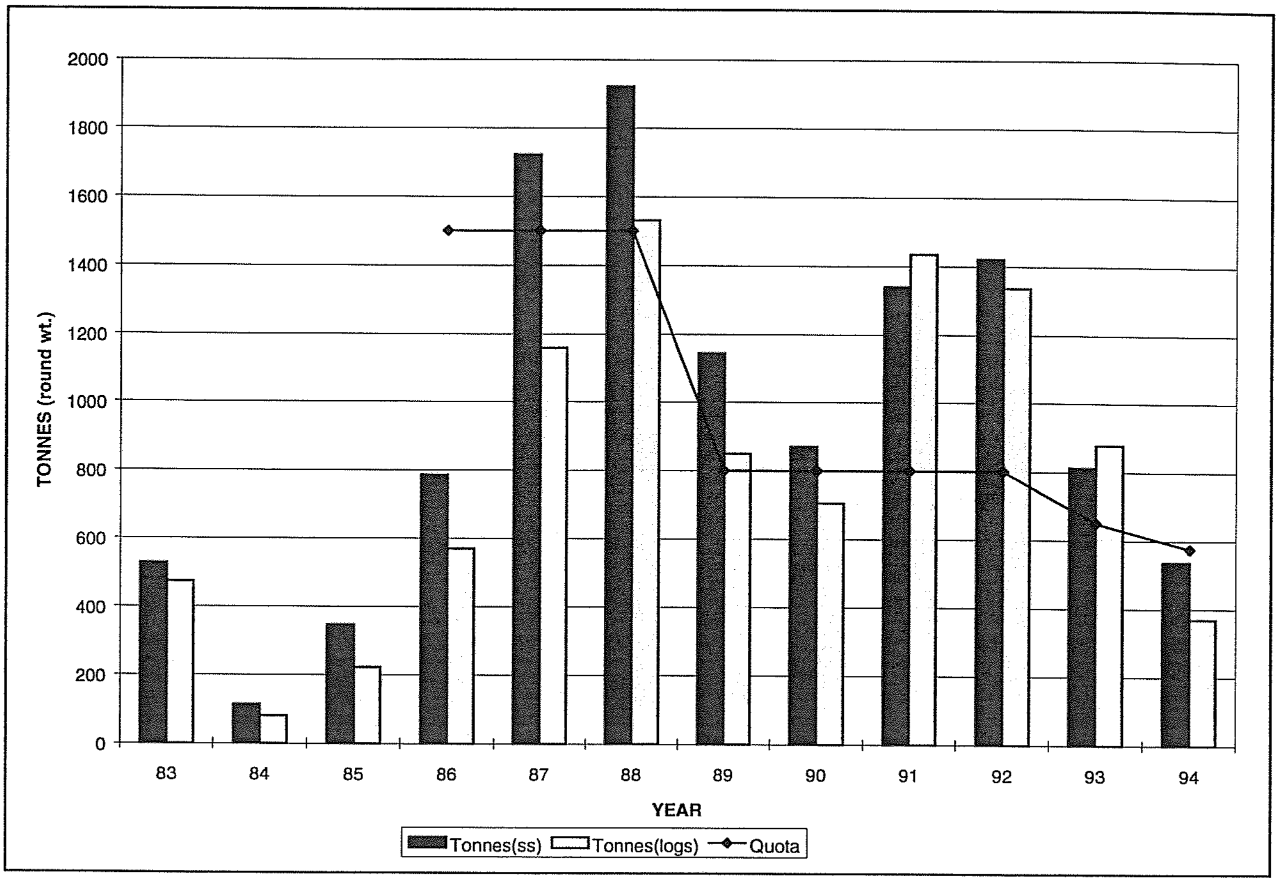

Fig. 1. Annual catch of sea cucumbers (t) from sales slips and logbooks, and annual quota, 1983-1994.

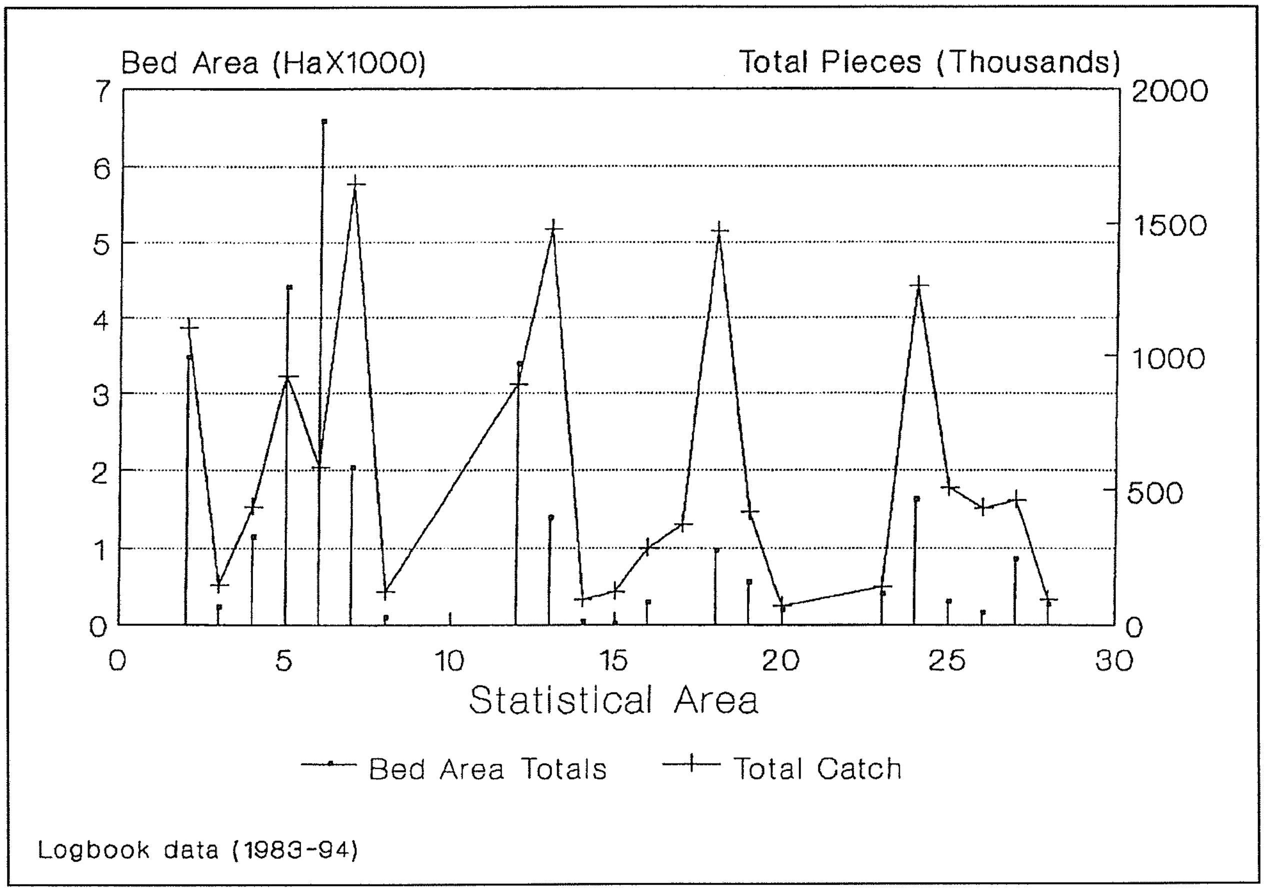

Fig. 2. Total catch (pieces) of sea cucumbers in relation to bed size (ha) by PFMA. Data are from 1983-94 harvest logbooks.

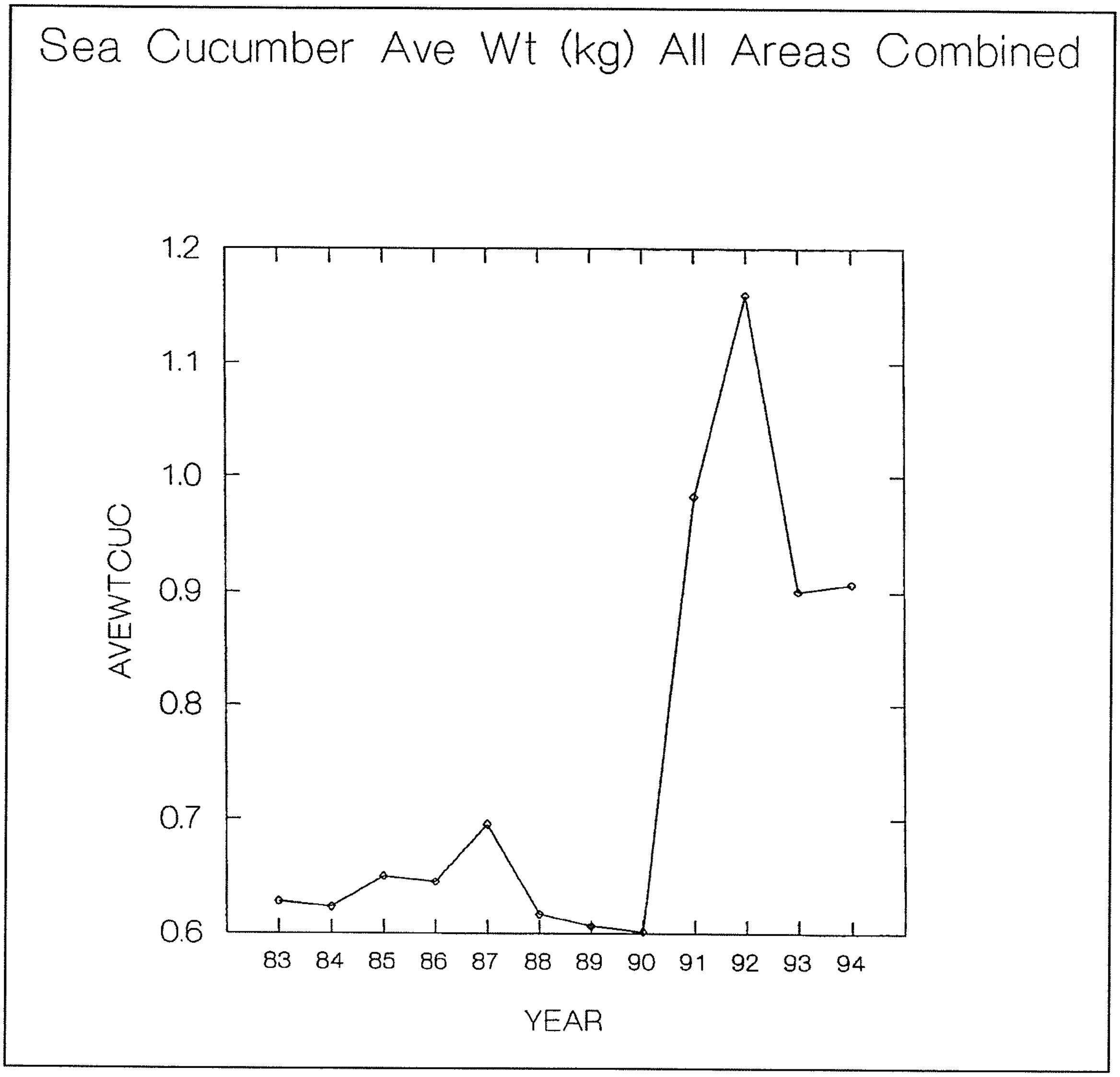

Fig. 3. Estimated average weight (kg) of sea cucumbers, all PFMA's combined, 1983-94.

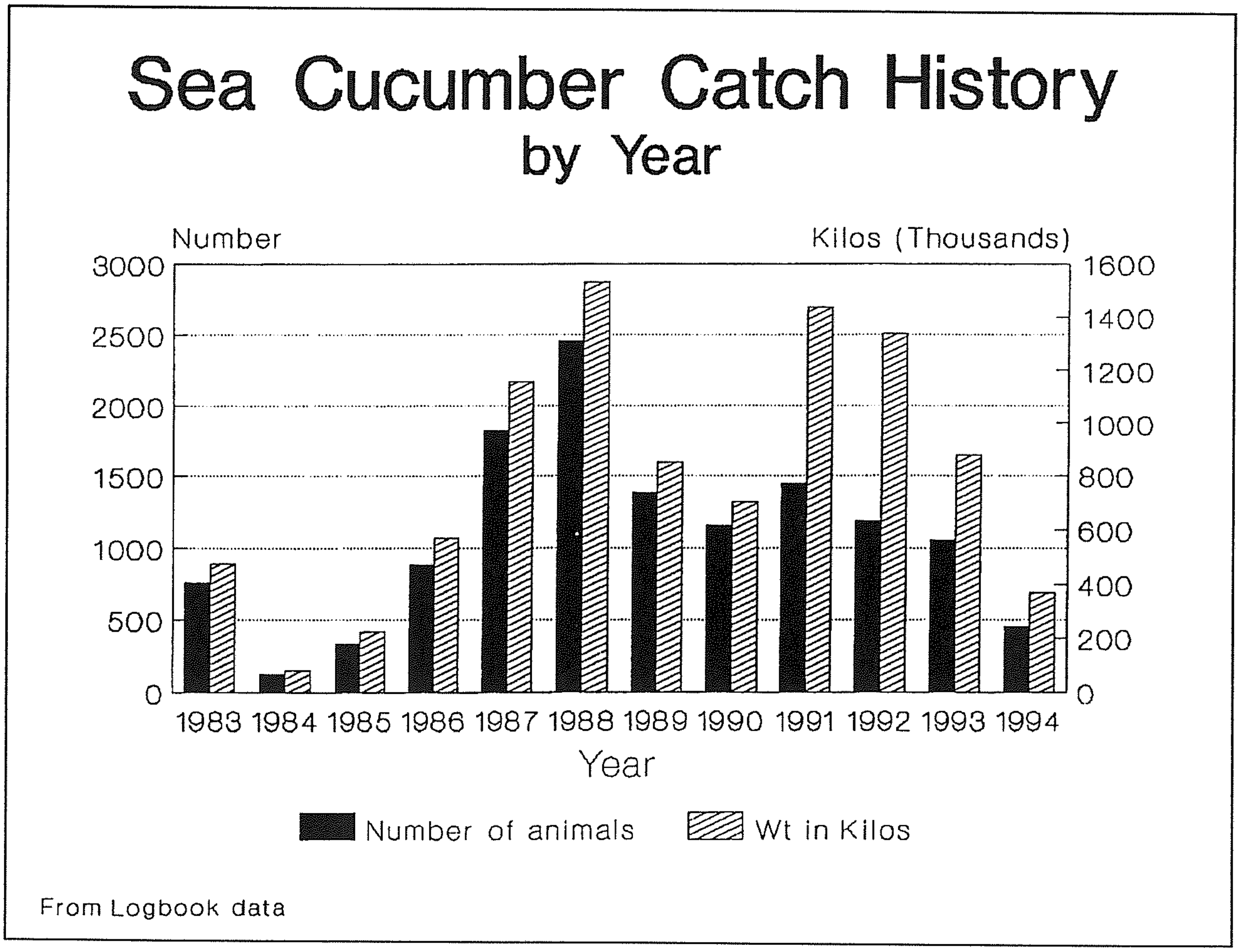

Fig. 4. Annual catch (kilograms and pieces) of sea cucumbers from logbook data, 1983-94.

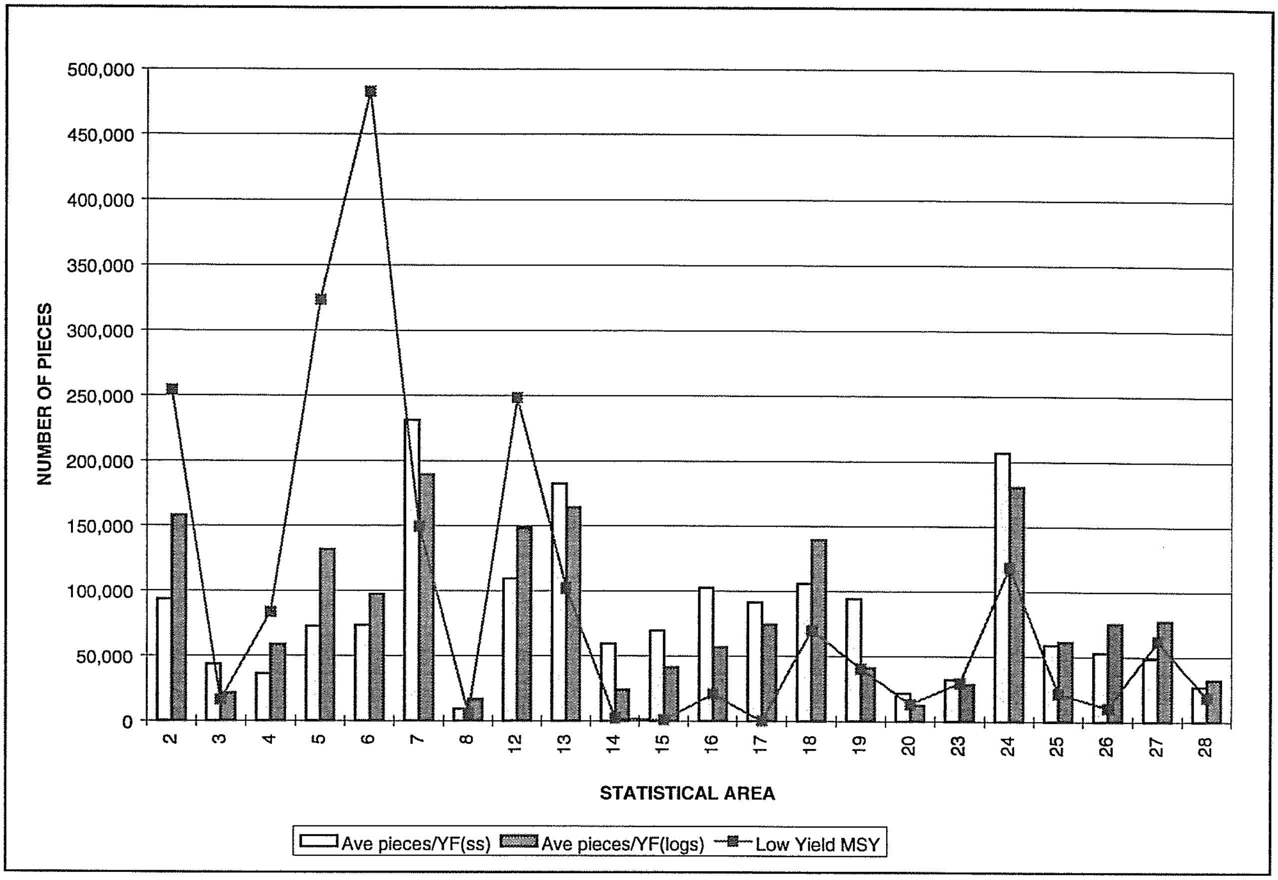

Fig. 5. Estimated low yield MSY and average annual catch (pieces) from sales slips and logbook data by PFMA. (Statistical Area = PFMA).

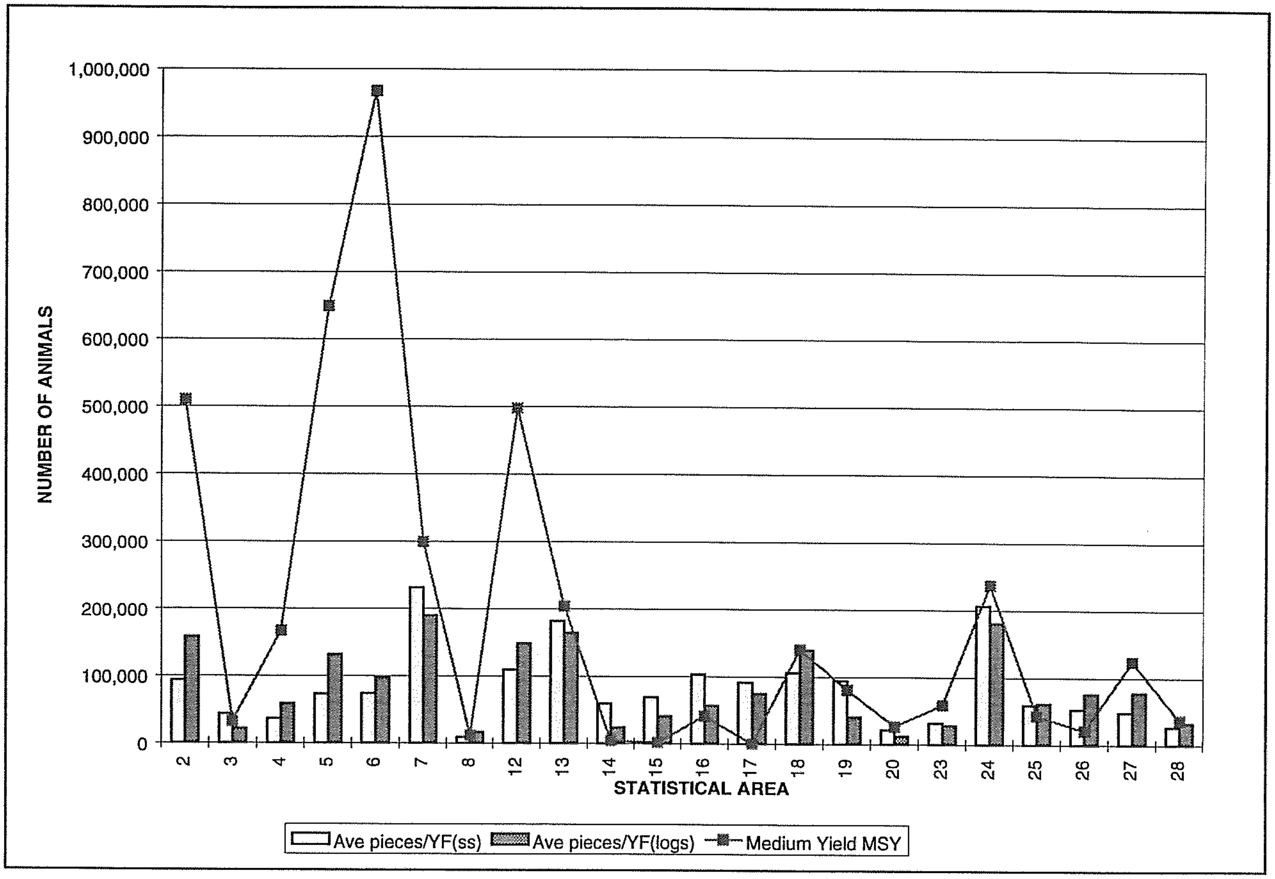

Fig. 6. Estimated medium yield MSY and average annual catch (pieces) from sales slips and logbook data by PFMA. (Statistical Area = PFMA).

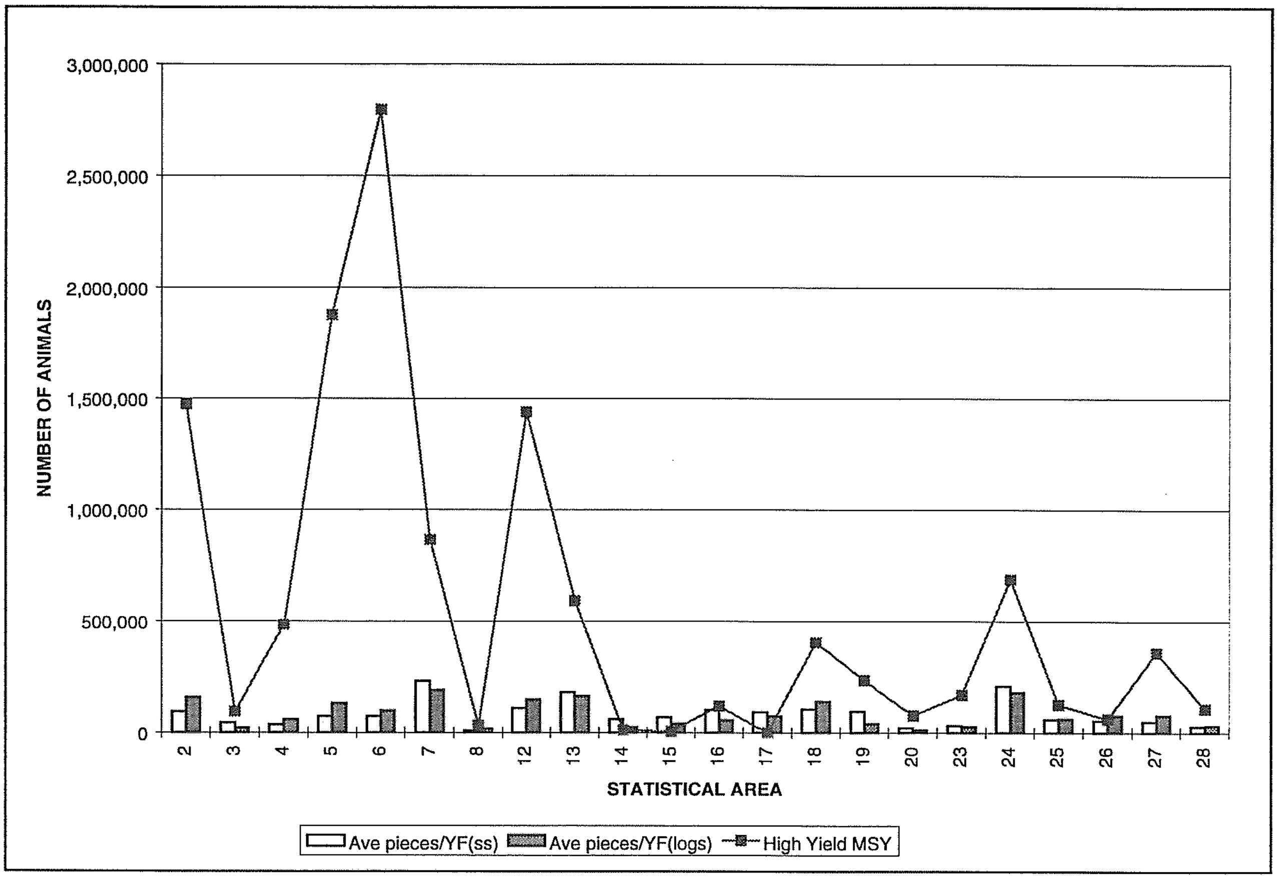

Fig. 7. Estimated high yield MSY and average annual catch (pieces) from sales slips and logbook data by PFMA. (Statistical Area = PFMA).