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# USE OF THE LESLIE STOCK DEPLETION MODEL FOR THE ASSESSMENT OF LOCAL ABUNDANCE OF PATAGONIAN TOOTHFISH (*DISSOSTICHUS ELEGINOIDES*)

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Abstract

The Leslie depletion model has been used to examine local patterns in catch per unit effort (CPUE) in the longline fisheries for Patagonian toothfish (*Dissostichus eleginoides*) around South Georgia and the Pacific coast of Chile. This paper presents a re-working and synthesis of previous analyses to examine whether declines in CPUE can be modelled using a linear regression of catch per hook against cumulative catch, when single vessels operate in localised areas for periods of at least three days. The results suggest that there is greater potential for application of the model in some areas than in others, but in general there is no sufficiently consistent signal in the data for the depletion model to be used to estimate local abundance. A number of possible explanations are considered, including movements of fish, the behaviour of fishermen, variable catchability and insufficiently high catch to cause local depletion. Suggestions are made for further work.

Résumé

Le modèle d'épuisement de Leslie a été utilisé pour examiner les tendances locales de la capture par unité d'effort de pêche (CPUE) des pêcheries à la palangre de légine australe (*Dissostichus eleginoides*) autour de la Géorgie du Sud et le long de la côte Pacifique du Chili. L'auteur de cette communication a repris les calculs et fait une synthèse des analyses précédentes dans le but d'examiner la possibilité de modéliser des baisses de CPUE par une régression linéaire de la capture par hameçon en fonction des captures cumulées, lorsqu'un navire mène seul des opérations dans une localité limitée pendant une période d'au moins trois jours. Les résultats suggèrent que l'application du modèle conviendrait mieux à certains secteurs qu'à d'autres, mais en général les données ne fournissent aucun signal assez marqué pour que le modèle d'épuisement permette d'estimer l'abondance locale. L'auteur examine plusieurs explications possibles : le déplacement des poissons, le comportement des pêcheurs, la capturabilité variable et une capture insuffisamment élevée pour causer un déclin de l'abondance locale, entre autres. De nouveaux travaux sont proposés.

Резюме

Для изучения локальных закономерностей в значениях улова за единицу усилия (CPUE) при ярусном промысле патагонского клыкача (*Dissostichus eleginoides*) в районе Южной Георгии и побережья Чили использовался метод истощения запаса по Лезли. В данной работе приводятся результаты вторичного проведения и синтеза выполненных ранее анализов с целью изучения возможности моделирования снизившихся величин CPUE с помощью линейной регрессии 'улов на крючок' по сравнению с кумулятивным выловом при условии того, что одиночные суда работали в локализованных районах в течение периодов, как минимум, трех дней. Результаты указали на то, что возможность применения модели выше по отношению к некоторым районам, хотя в общем в данных отсутствует какой-либо последовательный признак, который позволил бы использовать модель истощения для оценки локальной численности. Здесь рассматривается ряд возможных причин этого, включая миграцию рыб, поведение рыбаков, изменчивую уловистость и слишком низкий вылов, который не мог бы вызвать истощение. Даются различные предложения по дальнейшей работе.

Resumen

El modelo de reducción de Leslie ha sido utilizado para estudiar las características de la captura por unidad de esfuerzo (CPUE) de las pesquerías de palangre del bacalao de profundidad (*Dissostichus eleginoides*) a nivel local, alrededor de Georgia del Sur y la costa chilena del Pacífico. Este trabajo presenta una revisión y un resumen de análisis previos a fin de examinar si las disminuciones en el CPUE pueden ser modeladas mediante una regresión lineal de la captura por anzuelo en función de la captura acumulativa cuando los barcos operan aisladamente en una zona localizada durante tres o más días. Los resultados demuestran que existen algunas zonas donde el potencial de aplicación del modelo es mayor, pero en general, no se distingue una señal lo suficientemente persistente para utilizar el modelo de reducción en la estimación de la abundancia local. Varias posibles explicaciones han sido consideradas, entre las cuales se cuenta el desplazamiento de los peces, el comportamiento de los pescadores, la variabilidad en la captura y un nivel de captura insuficiente para producir una reducción a nivel local. Se han propuesto algunas sugerencias para estudios en el futuro.

Keywords: CCAMLR, Leslie, longline, *Dissostichus eleginoides*, South Georgia, stock assessment

## INTRODUCTION

A deep-water demersal longline fishery for Patagonian toothfish (*Dissostichus eleginoides*) has been established in CCAMLR Subarea 48.3 (South Georgia) since 1989. Vessels from the former Soviet Union dominated the fishery for the first three years. Since the start of the 1991/92 season vessels from Chile, Bulgaria, the Republic of Korea and Argentina have entered the fishery. The total reported annual catch peaked at just over 8 000 tonnes in 1989/90. Since then the reported catch has been in the region of 3 000 to 4 000 tonnes, with the exception of 1993/94 when it fell to only 473 tonnes, due to a reduction in both the total allowable catch (TAC) and the fishing effort. In addition to these catches recorded in the CCAMLR database, there are indications of significant levels of unreported catch from Subarea 48.3. At its 1995 meeting the CCAMLR Working Group on Fish Stock Assessment (WG-FSA) made an estimate of the total removals of fish from Subarea 48.3 and adjacent waters. These estimates were, in some years, substantially different from the reported catch. The best estimates of the real catches are in the region of 5 500 to 6 000 tonnes per annum since 1992 (SC-CAMLR, 1995).

CCAMLR has given a high priority to the scientific assessment and sustainable development of the longline fishery. However, the effect of longline fishing on the target species is difficult to assess, particularly in the early years of the fishery when information is sparse. Particular problems encountered in attempts to assess the status of the longline fishery in Subarea 48.3 include a lack of detailed data from the early years of the fishery, differences in catchability between vessels due to differences in fishing method, and changes in catchability over time due to changes in hook type. There is also considerable uncertainty regarding the stock structure of *D. eleginoides* in the CCAMLR Convention Area and adjacent waters.

WG-FSA has attempted to assess the status of the toothfish fishery in Subarea 48.3 at its annual meetings since the start of the fishery. Since 1991 these assessments have been based on attempts to estimate local abundance using a Leslie depletion model (Leslie and Davis, 1939). The application of the model assumed that a single vessel fishing in a small area over a number of days would reduce the local population size, and that this reduction would be indicated by a significant decline in an abundance index with accumulated catch. The abundance index used was catch per unit effort (CPUE), expressed in terms of either catch per hook or catch per hook hour. Application of the model relies on a number of assumptions, including constant catchability and no significant movement of fish in or out of the local area. $M$ was assumed to be not significantly different from zero over the time period for which the model was fitted, which was generally of the order of about 10 days.

The depletion model approach to estimating local abundance has also been applied to fisheries for *D. eleginoides* off the Pacific coast of Chile. An experimental approach similar to the CCAMLR experimental protocol (CCAMLR, 1993) was used in the industrial fishery in southern Chile. It has also been applied to the artisanal longline fishery for *D. eleginoides* off Valdivia (Lemaitre et al., 1991).

This paper draws on information from both the work on CCAMLR data and the Chilean studies to provide a review of the methodology and its applicability to the stock assessment of longline fisheries for *D. eleginoides*. It includes results from the re-analysis of data from Chilean vessels operating in Subarea 48.3 and adjacent waters during 1992/93, previously presented in Parkes and Pilling (1994) (with slight modifications). It also includes a re-analysis of data reported to CCAMLR from Chilean vessels operating in Subarea 48.3 during the 1991/92 season, using the same method.

## METHOD

### The Database

Not all of the catch/effort data from commercial longline fisheries are suitable for use with the local depletion model, because fishing vessels do not always fish consecutive lines within a localised area. Two approaches have been used to solve this problem.

The first approach is to select series of data from the commercial dataset which fulfil the criterion that they result from a single vessel fishing three or more consecutive lines within a localised area. The size of the localised area is usually restricted to a circle of about 10 n miles diameter (the approximate length of a longline), or a polygon of a similar scale. This method was used in the re-analysis of data from Chilean vessels operating in Subarea 48.3 and adjacent waters during 1992/93, previously presented in Parkes and Pilling (1994).

The second approach is to require commercial vessels to fish within a restricted area for a fixed number of longline sets, or for a fixed period over which depletion might be expected to be detected. This approach was used for the CCAMLR experimental protocol for longline fishing for *D. eleginoides* (CCAMLR, 1993) which was applied in Subarea 48.3 during the 1993/94 season. This was an attempt to provide suitable data for a series of local estimates of population size to be made using the depletion model. Several papers were submitted to WG-FSA in 1994 presenting results of the depletion experiments and estimates of local abundance using the Leslie depletion model (Jones and Parkes, 1994; Rubilar et al., 1994; Anon., 1994). This 'experimental fishing' approach was also used in an attempt to assess the industrial longline fishery on the Pacific coast of Chile.

The datasets examined during this study presented in this paper are described in Table 1.

Table 1: Description of the datasets.

| Dataset | Description |
|---|---|
| A | Commercial data in the CCAMLR database from Chilean longline vessels operating in Subarea 48.3 and adjacent areas during the 1991/92 and 1992/93 seasons. |
| B | Commercial data from the artisanal fishery for *D. eleginoides* off Valdivia, in the Chaihuin submarine canyon, between 28 June and 8 August 1992. |
| C | Data from experimental fishing in the industrial fishery in the south Pacific zone of Chile, between 47°S and 57°S during the period September 1991 to June 1992. These were subdivided into two zones:<br>Zone 1: latitude 53°45'- 54°45'S; longitude 73°40'- 74°10'W<br>Zone 2: latitude 55°50'- 56°12'S; longitude 66°- 66°15'W. |
| D | Six depletion experiments undertaken in Subarea 48.3 during the 1993/94 season. The data were analysed at the 1994 meeting of WG-FSA (SC-CAMLR, 1994). A discussion of the results is included in this paper, but no re-analysis was undertaken. |

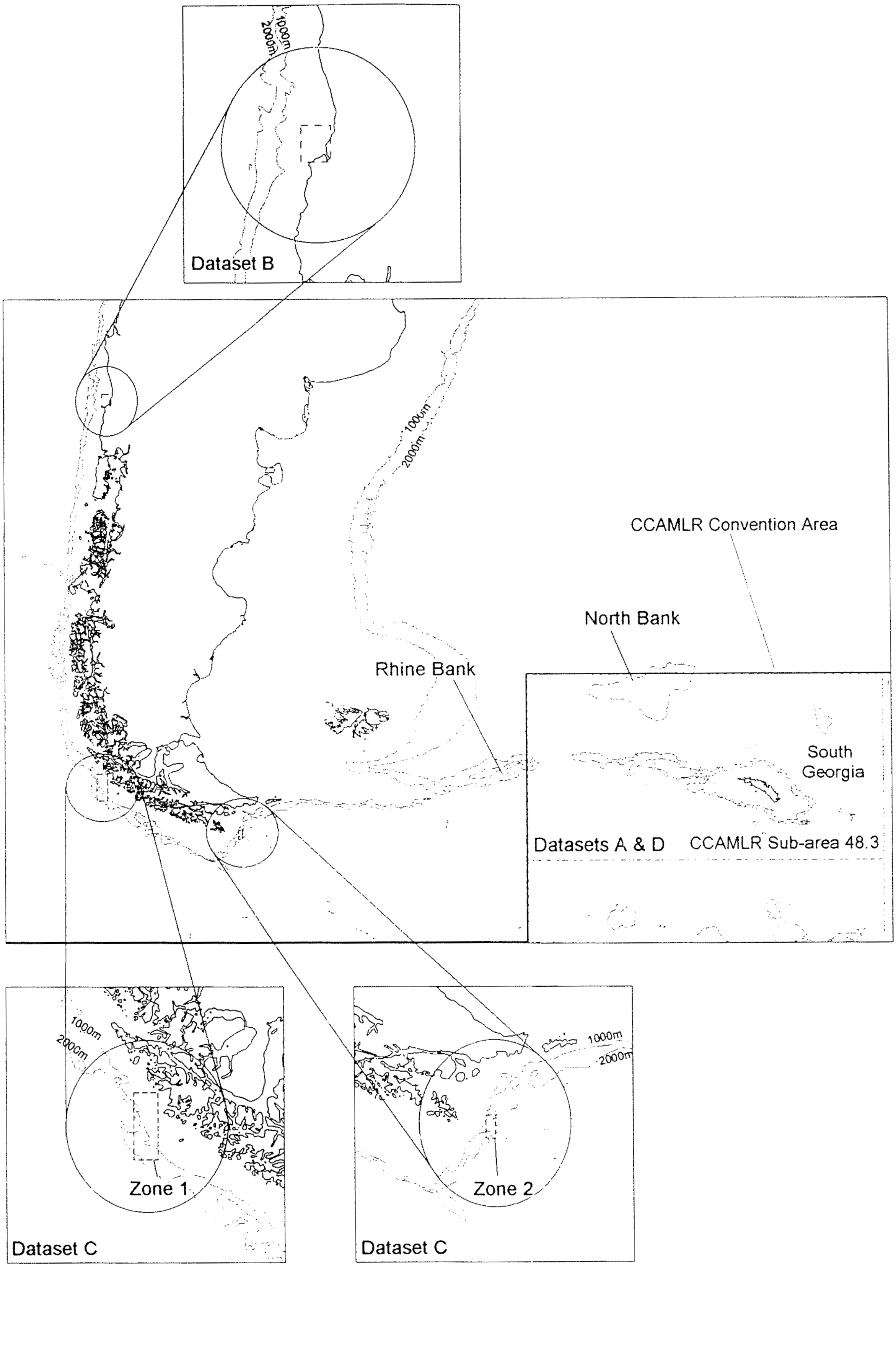


Figure 1: Map showing locations of fishing grounds at which the data for this study were collected.

The locations of the fisheries from which these datasets were taken are shown in Figure 1. Three of the datasets are from deep-water (about 1 000 m) industrial longline fisheries for *D. eleginoides* and one (dataset B) is from a shallow-water artisanal longline fishery for the same species.

The analysis of CCAMLR data from 1991/92 and 1992/93 was restricted to the Chilean fleet because at that time this was the largest fleet operating in the region, and catchability for individual vessels was believed to be more or less constant over time.

### Methodology for Selection of Series of Data from the Commercial Catch Data (Datasets A and B)

The selection of series of data from the commercial catch data suitable for modelling using the Leslie depletion model was performed in two steps.

Firstly, reported positions of vessels were plotted on axes of latitude and longitude, each point being labelled with the date on which the catch was taken. Series of catch/effort data were selected only on the basis of single vessels fishing three or more consecutive lines in localised areas for periods of three days or more. The size of the localised area was restricted to a circle of about 10 n miles diameter, as specified in the 1993/94 CCAMLR experimental protocol, or a polygon of a similar scale.

Secondly, all of the selected series of vessel positions and dates were plotted on the same axes to show where the series overlapped in time and space. The cumulative catch was then calculated separately for each series, including any catches taken by other vessels which overlapped with the series being analysed. Note that no detailed position information was available for catches not reported to CCAMLR. These 'illegal' catches could therefore not be included in the analysis, even though it is possible that some of these may have overlapped with the selected data series.

Twenty-two data series were selected from Subarea 48.3 in the 1991/92 season. Twenty-six data series were selected from Subarea 48.3 in the 1992/93 season and a further 19 and 15 were selected from the North and Rhine Banks respectively in that year (see SC-CAMLR, 1993 - Figure 4). The numbers of data series for 1992/93 are slightly higher than in the previous paper presented to CCAMLR (Pilling and Parkes, 1994), because a few of the data series originally selected included gaps in the fishing effort time series, which were considered to be too long. These long time series were therefore subdivided into separate, shorter series.

Four data series were selected from the artisanal fishery off Valdivia in 1992 (dataset B).

### The Experimental Fishing Approach

In the experimental approach, commercial vessels are required to interrupt their normal fishing plan to fish a fixed number of lines within a restricted area. This is done in the expectation that the resulting catch and effort data will indicate that significant local depletion has occurred.

In the case of the CCAMLR experimental protocol applied in the 1993/94 season, five separate fishing sites were chosen within the existing fishing grounds. Each site consisted of a circle of 10 n miles diameter, within which some part of 10 consecutive lines had to be set. In the event, a total of six local depletion experiments were undertaken.

The experimental data from the industrial fishery off southern Chile in 1991/92 (dataset C) included 15 data series: 8 from Zone 1 and 7 from Zone 2. The CCAMLR experimental protocol in 1993/94 (dataset D) generated six data series.

## The Depletion Model

The depletion model is as follows:

$$N_{t+1} = N_t e^{-M} - C_t e^{-\frac{1}{2}M} \qquad (1)$$

where $N_t$ is the abundance in terms of numbers of fish at start of time $t$, $C_t$ is total catch taken over time $t$ and $M$ is natural mortality. This assumes that there is no recruitment to the population.

### Parameter Estimation

Over the time period of the selected data series (a few days), $M$ was assumed to be zero. This reduces equation (1) to:

$$N_{t+1} = N_t - C_t \qquad (2)$$

or, in terms of the population numbers at the start of the period $N_1$:

$$N_t = N_1 - C_{cum} \quad (3)$$

where $C_{cum}$ is the cumulative catch between time 1 and time $t$. $N$ cannot be measured directly, but it can be expressed in terms of an index which can be measured:

$$y = qN \quad (4)$$

where $y$ is an index of abundance and $q$ is catchability. Substituting equation (3) into equation (4) gives:

$$y_t = qN_1 - qC_{cum} \quad (5)$$

which is in the form of a linear regression $y = a + bX$, where the intercept (constant) $a$ is $qN_1$, the slope $b$ is $-q$ (the slope is negative) and the independent variable (X) is $C_{cum}$. Thus a regression of the abundance index $y_t$ (dependent) against the cumulative $C_{cum}$ can be used to estimate $q$ and the initial population size $N_1$ (the latter being the ratio of $a/b$, or the intercept of the regression line on the X axis).

### Abundance Index

The abundance index available for the longline fishery for *D. eleginoides* is CPUE, measured either as catch per hook or catch per hook-hour (i.e. including the soak time).

The relationship between soak time and the catching power of longlines in the *D. eleginoides* fishery in Subarea 48.3 is not well understood. A limited analysis was undertaken by WG-FSA at its meeting in 1992, which showed no relationship (SC-CAMLR, 1992). However, it was considered premature to reach any specific conclusion and further analyses were recommended. Generalised linear models (GLM) were used to standardise CPUE indices at the 1995 meeting of WG-FSA (SC-CAMLR, 1995). A specific GLM analysis was performed, using soak time as a continuous covariate in an analysis of catch per hook. The results of that analysis suggested that soak time was an important component of the variability in catch rates, but that soak time and depth were highly correlated. In that analysis, soak time was calculated as the difference between the time at the start of setting and the time at the start of hauling. It was generally felt by WG-FSA that this was possibly not an appropriate method.

Concerns over the measurement of soak time on the scale of individual longlines centre on variation at the level of individual hooks, which may arise due to a number of factors. These include technical aspects of longline fishing, such as differences in the speed at which the line is set and hauled (the former is considerably faster), differences in the length of time taken for the hooks to reach the fishing depth and the fact that hauling may not always start from the same end of the line at which setting started. All of these factors are potentially quantifiable; however many of the older data are not available in sufficient detail. This is one area in which this type of analysis could be explored further in the future as more detailed data become available.

All the analyses undertaken by WG-FSA on local depletion between 1992 and 1994 used catch rates measured as catch per hook. The analysis presented in this paper was principally intended as a re-working of WG-FSA's analyses, with the addition of the data from the Chilean domestic fishery. It was therefore decided to use catch per hook (CPH) throughout.

According to the model, CPH should decline with cumulative catch over the data series selected for analysis. In order to obtain a valid estimate of $N1$ from a data series, the linear regression of CPH against cumulative catch should show a significant negative slope.

### Cumulative Catch

The model described by equations (1) to (5) uses cumulative catch measured in terms of numbers of fish. However, most of the catch data available for this study were in terms of total weight.

A number of assumptions must be satisfied for weight to be used in the model as a proxy for numbers of fish. For instance, it must be assumed that there was no change in the mean weight of individuals over the period of each of the data series. It must also be assumed that the gear type did not alter during the time series and that fish are caught randomly, irrespective of weight. Given the short duration of each of the data series and in the absence of information to the contrary, or any means of further testing at this stage, these assumptions were all considered to be reasonable.

However, there is the added problem of catches taken by vessels which overlapped in time and space with the data series selected from the commercial datasets (A and B) (see 'Methodology' for selection of series of data from the commercial catch data (datasets A and B)). These catches were taken by other vessels with different gear, possibly with different selectivities. It is possible, therefore, that the mean weight of the fish was different from those taken by the vessel from which the CPUE data were taken. Table 2 provides a summary of the data series for which the correction of the cumulative catch was applied.

For this reason, it could be argued that the data series indicated in the last column of Table 2 should have been excluded from the analysis, because catch weights were used rather than numbers. This would eliminate virtually all of the 1991/92 data series from Subarea 48.3, but only relatively few of the other series. It will be shown later in the paper that the data series to which this applies include both those that showed significant declines in CPH and those that did not. For the purposes of this paper, the authors considered that the analytical approach used provided a reasonable approximation for the application of the depletion model, and that the basic conclusions drawn from the analysis would not be changed.

Datasets C and D were from specifically-designed fishing experiments in which there were no overlapping fishing events and therefore no corrections required for the cumulative catch.

### Data Analysis

Cumulative catches were calculated and linear regressions performed on each data series. At its 1994 meeting, WG-FSA used a one-tailed Student's *t* Distribution test to determine whether the gradients of the regressions on data series in dataset D were significantly different from the horizontal in the negative direction ($p = 0.05$) (SC-CAMLR, 1994). Only those series for which the gradient was negative and significantly different from 0 were considered to conform to the Leslie model. The same approach was applied in this study.

## RESULTS

A summary of the regression analyses is provided in Table 3. The gradients and *P* values

Table 2: Summary of the data series for which the correction of cumulative catch in the commercial data was applied.

| Data Series | Total Number of Data Series | Total Number of Series with Correction Applied | Identification Numbers for Corrected Series |
|---|---|---|---|
| Dataset A - 1991/92 Subarea 48.3 | 22 | 17 | 1, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 22 |
| Dataset A - 1992/93 Subarea 48.3 | 26 | 5 | 3, 9, 15, 19, 22 |
| Dataset A - 1992/93 North Bank | 15 | 3 | 6, 10, 14 |
| Dataset A - 1992/93 Rhine Bank | 19 | 4 | 2, 8, 9, 12 |
| Dataset B - Chile artisanal fishery | 4 | 0 | - |

Table 3: Summary results of the regression analyses.

| Dataset | Total Number of Data Series | Number of Data Series with a Negative Slope | Number of Data Series with a Significant Negative Slope ($P < 0.05$) |
|---|---|---|---|
| A - 1991/92 Subarea 48.3, Table 4 | 22 | 12 | 3 |
| A - 1992/93 Subarea 48.3, Table 5 | 26 | 15 | 5 |
| A - 1992/93 North Bank, Table 6 | 19 | 6 | 1 |
| A - 1992/93 Rhine Bank, Table 7 | 15 | 8 | 2 |
| B - 1992 Chile artisanal fishery, Table 8 | 4 | 2 | 0 |
| C - 1991/92 Chile industrial, Zone 1, Table 9 | 8 | 6 | 4 |
| C - 1991/92 Chile industrial, Zone 2, Table 10 | 7 | 2 | 1 |
| D - 1993/94 Subarea 48.3 (SC-CAMLR, 1994) | 6 | 3 | 2 |

for all of the regressions on datasets A, B and C are provided in Tables 4 to 10 which are given at the end of the paper.

Plots of CPUE (CPH) against cumulative catch for all of the data series (with the exception of those for the CCAMLR experimental protocol in 1993/94 - dataset D) are presented in Figures 2 to 7 which are given at the end of the paper. Regression lines are shown only for those series with negative slopes significant at the 5% level. No other formal statistical tests on the data, besides the *t*-test, are presented here. However, a large proportion of the data series showed marked patterns in residuals, which suggested that the data were not well described by the simple regression model. This was true for plots both with and without slopes significant at the 5% level. For example, particularly clear patterns were evident from the data series with significant slopes shown in Figure 2, plot 14 and Figure 5, plot 11.

## DISCUSSION

Fifty-four data series of CPH showed a negative trend with cumulative catch, which is just over half of the total number examined. According to binomial theory, this is not more than would be expected by chance. However, the results vary between datasets. In dataset C, Zone 1 (Table 8), six of the eight data series showed negative slopes, which is on the borderline of what would be expected by chance. In fact, the CPH plots in Figure 7 show good potential for analysis of local abundance using the Leslie depletion model. However, this is by far the most promising of the datasets examined. The next highest proportion of the data series with negative slopes is 15 out of 26 (dataset A, Table 4) and the lowest is only 6 out of 19 (dataset A, Table 5).

Eighteen of the 107 data series showed a significant negative trend at the 5% level. Again, however, there was variation between datasets. The best was 4 out of 8 with significant negative slopes (Table 8) and the worst was 1 out of 19 (Table 5). An anonymous reviewer pointed out that the predictive least squares regression used during this analysis, and used previously by WG-FSA, assumes independence in the errors used for each axis. This is not the case for this study, in which catches appear in the data for each axis. This may call into question the validity of conclusions drawn from the *t*-test of the significance of slopes. The authors acknowledge that this is strictly correct, but we feel that in this case there is little danger of a misinterpretation of the data resulting from the practical application of the test. In most cases there are significant problems in applying the regression model to the data, which are unlikely to be explained by this effect. For example, there are patterns in residuals in many of the plots which indicate that there are effects on CPUE, besides the cumulative catch, which would require a more complex model. However, the form that such a model might take is not straightforward. There is little apparent consistency in the patterns between data series. For example, plots 11 and 14 in Figure 2, which both have significant negative slopes, show contrasting patterns, which suggest rather different processes affecting CPH as catch accumulates.

Although one of the datasets shows apparently good potential for analysis using the Leslie depletion model, the overwhelming indication from this analysis is that the model is too simple and there is too much residual variance for it to be applied effectively to the local-scale longline catch and effort data in this study.

Perhaps the worst of the datasets is that from Subarea 48.3 and adjacent areas (dataset A, Tables 4 to 7 and Figures 2 to 5). A number of data series in this dataset actually showed a significant increase in CPH with cumulative catch (e.g., Figure 2, plots 9 and 15). WG-FSA has received information which suggests that there has been a substantial amount of unreported fishing activity and catches in Subarea 48.3 (SC-CAMLR, 1995). None of this information is included in the datasets examined. It is possible that a substantial amount of additional correction of the cumulative catch would be required before the data could be analysed realistically.

The expectation that the data would be satisfactorily modelled by a linear regression is apparently too simplistic. There are a number of effects, relating to both the behaviour of the fish and the behaviour of the fishermen, which have the potential to complicate the picture and make the application of the regression model inappropriate.

One of the principal assumptions of the depletion model is that the rate of removal of fish is substantially greater than the rate of movement of fish in or out of the area of fishing. This raises questions about the rate of movement, the distances over which movements take place and the area of influence of a longline. WG-FSA discussed these issues at a specially convened workshop, with invited experts, in October 1995 (SC-CAMLR, 1995). There was some evidence from a trawl fishery for *D. eleginoides* at Macquarie Island of movements on the time scale of a few days, which could influence the results of this study. The question of the distances over which fish are attracted to longlines remains largely unanswered. It is complicated by the fact that there are both vertical and horizontal components, but little is known at present about the distribution of the fish in the water column.

Variable catchability, $q$, has been cited as the greatest potential source of error in the application of methods using CPUE to indicate changes in abundance (Ricker, 1975). $q$ in longline fisheries for *D. eleginoides* has been shown to vary substantially with changes in fishing gear, such as hook type (Moreno, 1991). However, it is unlikely that $q$ changed significantly as a result of changes in fishing gear or fishing method over the short periods of the data series examined in this study. The regressions estimate $q$ separately for each data series; hence changes over a longer time scale are not important. Changes in $q$ may also arise due to changes in fish behaviour. There are indications, for instance, that at certain times and depths there may be differences in $q$ between male and female fish and fish of different sizes. Hilborn and Walters (1992) suggested that after an initial period in which the most vulnerable fish are caught, $q$ may fall because the remaining fish are for some reason less vulnerable. There may even be some fish for which $q = 0$. For example, the longline hooks are known to be highly size selective, and the fishermen target a very specific depth range. Under such circumstances the overall estimate of $q$ would be biased upwards and abundance biased downwards.

Many of the data plots in Figures 2 to 7, both with and without regression lines plotted, indicate autocorrelation in residuals. This can be associated with the behaviour of fishermen, particularly where there are trends in increasing catch rate with cumulative catch. This may be a result of fishermen moving into a new local area, where they spend some time learning, or prospecting. As they learn from their experiences and target the fish better, so the CPUE will increase. This may be followed by a period of stabilising catch rates, or a subsequent fall. A few plots show this pattern, for example Figure 2, plot 21 and Figure 5, plots 1 and 11, but there is little consistency between data series. This perhaps requires a substantially more detailed study of the ways in which the fishermen select a pitch on which to lay the longline, and the local-scale effects on catch rates of changes in location, orientation and topography.

Most of the data series are quite short. The largest contains 29 data points, but most are in the region of 10 to 15. It may be that there are patterns in the data, but that at this spatial and temporal scale there is simply too much noise for them to be modelled using the linear regression.

An alternative explanation which should be mentioned is that the levels of catches taken are, in fact, insufficient to deplete the stocks and the levels of fishing effort applied are sustainable. However, this would be a dangerous conclusion to reach in the absence of additional information about stock status and given the uncertainties about the true levels of catches taken. The relationship between catch per hook and abundance may not be linear. The local abundance may be declining, but this may not be mirrored by a drop in the catch per hook of a single vessel over a short time period (e.g., hyperstability - Hilborn and Walters, 1992). Factors which can influence this process include the range over which the longline attracts fish into the area being fished and saturation of the fishing gear.

## CONCLUSION

In conclusion, the results indicate that the method of application of the Leslie depletion model adopted by WG-FSA over the period 1992 to 1994, and reviewed in this paper, is not suitable for estimating local abundance from the longline catch and effort data studied here. There is also some doubt as to the general applicability of the depletion model to longline fisheries for *D. eleginoides* on the scale of single vessels operating in localised areas. Despite this overall conclusion, there is some variation between localities, and it may be that there is greater potential for applying the method in some areas than others. One of the datasets analysed here (dataset C, Zone 1) shows some promise and should be examined in greater detail. WG-FSA has suggested that some further analysis may be warranted on the data from Subarea 48.3. There is clearly considerably more work to be done in the future exploring patterns in CPUE and the behaviour of the fishermen, and applying more powerful statistical techniques to the problem. However, WG-FSA has also pointed out that considerable time and effort has already been spent on the local depletion approach, including the imposition on the fishery in Subarea 48.3 of an experimental harvest regime in the 1993/94 season, with little return in terms of results on which to base management advice.

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Table 4: Series selected from the CCAMLR database for Chilean longliners in the 1991/92 season, Subarea 48.3. Dataset A.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | 9.6E-06 | 0.822 |
| 2 | -7.4E-06 | 0.064 |
| 3 | -2.5E-06 | 0.325 |
| 4 | -4.3E-06 | 0.307 |
| 5 | -2.0E-05 | 0.164 |
| 6 | -5.3E-06 | 0.444 |
| 7 | 8.3E-06 | 0.792 |
| 8 | -5.5E-06 | 0.215 |
| 9 | 9.3E-06 | 1.000 |
| 10 | 2.2E-05 | 0.833 |
| 11 | -4.0E-06 | *0.002* |
| 12 | 3.0E-07 | 0.441 |
| 13 | -3.5E-06 | 0.145 |
| 14 | -7.9E-06 | *0.014* |
| 15 | 1.1E-05 | 1.000 |
| 16 | 2.9E-07 | 0.332 |
| 17 | -8.6E-07 | 0.398 |
| 18 | -3.4E-06 | *0.047* |
| 19 | 2.7E-06 | 0.986 |
| 20 | 2.1E-06 | 0.982 |
| 21 | -2.8E-06 | 0.267 |
| 22 | 2.5E-06 | 1.000 |

Table 5: Series selected from the CCAMLR database for Chilean longliners in the 1992/93 season, Subarea 48.3. Dataset A.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | -7.8E-06 | 0.218 |
| 2 | 1.9E-08 | 0.502 |
| 3 | -1.7E-05 | 0.107 |
| 4 | -2.2E-05 | 0.081 |
| 5 | -7E-07 | 0.424 |
| 6 | 2.9E-07 | 0.505 |
| 7 | -1.7E-05 | 0.282 |
| 8 | -1.3E-05 | *0.090* |
| 9 | 7.4E-06 | 1.000 |
| 10 | -6.3E-07 | 0.473 |
| 11 | -1.2E-05 | *0.006* |
| 12 | 2.2E-05 | 0.911 |
| 13 | 3.9E-06 | 0.817 |
| 14 | 1.3E-05 | 0.998 |
| 15 | -4.4E-06 | *0.020* |
| 16 | -1.1E-07 | 0.351 |
| 17 | 1.3E-05 | 0.935 |
| 18 | -5.5E-06 | 0.475 |
| 19 | -1.1E-05 | *0.011* |
| 20 | -2.8E-05 | 0.038 |
| 21 | -1.2E-04 | *0.049* |
| 22 | 7.6E-06 | 0.797 |
| 23 | -3.2E-05 | 0.073 |
| 24 | 1.5E-05 | 0.641 |
| 25 | 8.3E-07 | 0.876 |
| 26 | 7.1E-07 | 0.842 |

Table 6: Series selected from the CCAMLR database for Chilean longliners in the 1992/93 season, North Bank. Dataset A.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | -6.8E-07 | 0.276 |
| 2 | 5.4E-06 | 0.990 |
| 3 | -4.8E-07 | 0.426 |
| 4 | -1.3E-06 | 0.102 |
| 5 | 5.7E-06 | 0.911 |
| 6 | 1.5E-06 | 0.659 |
| 7 | 4.1E-06 | 0.979 |
| 8 | 1.6E-05 | 0.989 |
| 9 | 7.0E-06 | 0.778 |
| 10 | 4.2E-06 | 0.997 |
| 11 | 8.3E-07 | 0.605 |
| 12 | -3.4E-06 | 0.063 |
| 13 | 1.2E-05 | 0.899 |
| 14 | -1.0E-05 | 0.110 |
| 15 | 1.3E-05 | 0.915 |
| 16 | -3.0E-06 | *0.046* |
| 17 | 4.3E-07 | 0.644 |
| 18 | 5.8E-06 | 0.997 |
| 19 | 2.4E-06 | 0.877 |

Table 7: Series selected from the CCAMLR database for Chilean longliners in the 1992/93 season, Rhine Bank. Dataset A.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | -1.3E-06 | 0.319 |
| 2 | 2.8E-06 | 0.914 |
| 3 | -7.4E-06 | 0.133 |
| 4 | 1.9E-06 | 0.797 |
| 5 | 2.5E-06 | 0.705 |
| 6 | -4.2E-06 | 0.408 |
| 7 | 6.5E-06 | 0.876 |
| 8 | -2.1E-05 | *0.017* |
| 9 | -1.3E-06 | 0.380 |
| 10 | 2.4E-06 | 0.864 |
| 11 | -1.4E-06 | *0.050* |
| 12 | 2.4E-05 | 0.737 |
| 13 | -1.2E-05 | 0.095 |
| 14 | 1.1E-05 | 0.590 |
| 15 | -6.4E-06 | 0.072 |

Table 8: 1991 artisanal fishery off Valdivia (Chaihuin submarine canyon). Dataset B.

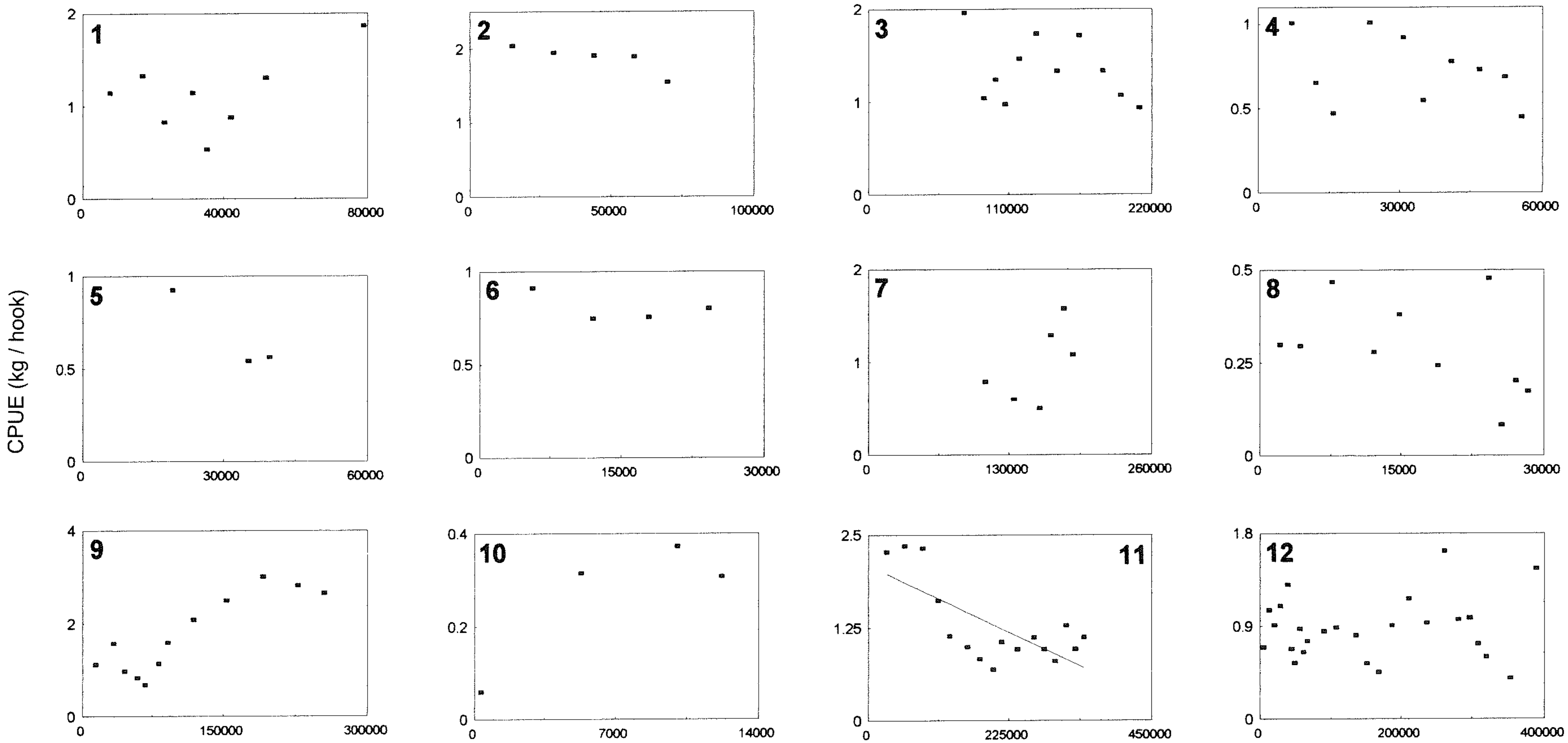
| Series | Gradient | *P* Value |
|---|---|---|
| 1 | -0.00306 | 0.846 |
| 2 | -0.01994 | 0.405 |
| 3 | 0.00413 | 0.433 |
| 4 | 0.01001 | 3.235 |

Table 9: 1991/92 industrial longline fishery off southern Chile, Zone 1. Dataset C.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | 3.2E-07 | 0.584 |
| 2 | -2.7E-06 | *0.003* |
| 3 | -4.2E-06 | 0.124 |
| 4 | -1.1E-05 | *0.004* |
| 5 | 4.4E-07 | 0.550 |
| 6 | -3.9E-06 | 0.065 |
| 7 | -1.6E-05 | *0.030* |
| 8 | -1.2E-05 | *0.001* |

Table 10: 1991/92 industrial longline fishery off southern Chile, Zone 2. Dataset C.

| Series | Gradient | *P* Value |
|---|---|---|
| 1 | 3.2E-06 | 0.770 |
| 2 | 2.9E-06 | 0.874 |
| 3 | 6.1E-06 | 0.962 |
| 4 | 1.4E-06 | 0.783 |
| 5 | -9.1E-06 | *0.016* |
| 6 | 1.6E-06 | 0.656 |
| 7 | -1.6E-06 | 0.223 |


CPUE (kg / hook)
1
2
3
4
5
6
7
8
9
10
11
12
0
40000
80000
50000
100000
110000
220000
30000
60000
15000
130000
260000
150000
300000
7000
14000
225000
450000
200000
400000
0.5
0.25
0.2
0.4
1.25
2.5
0.9
1.8

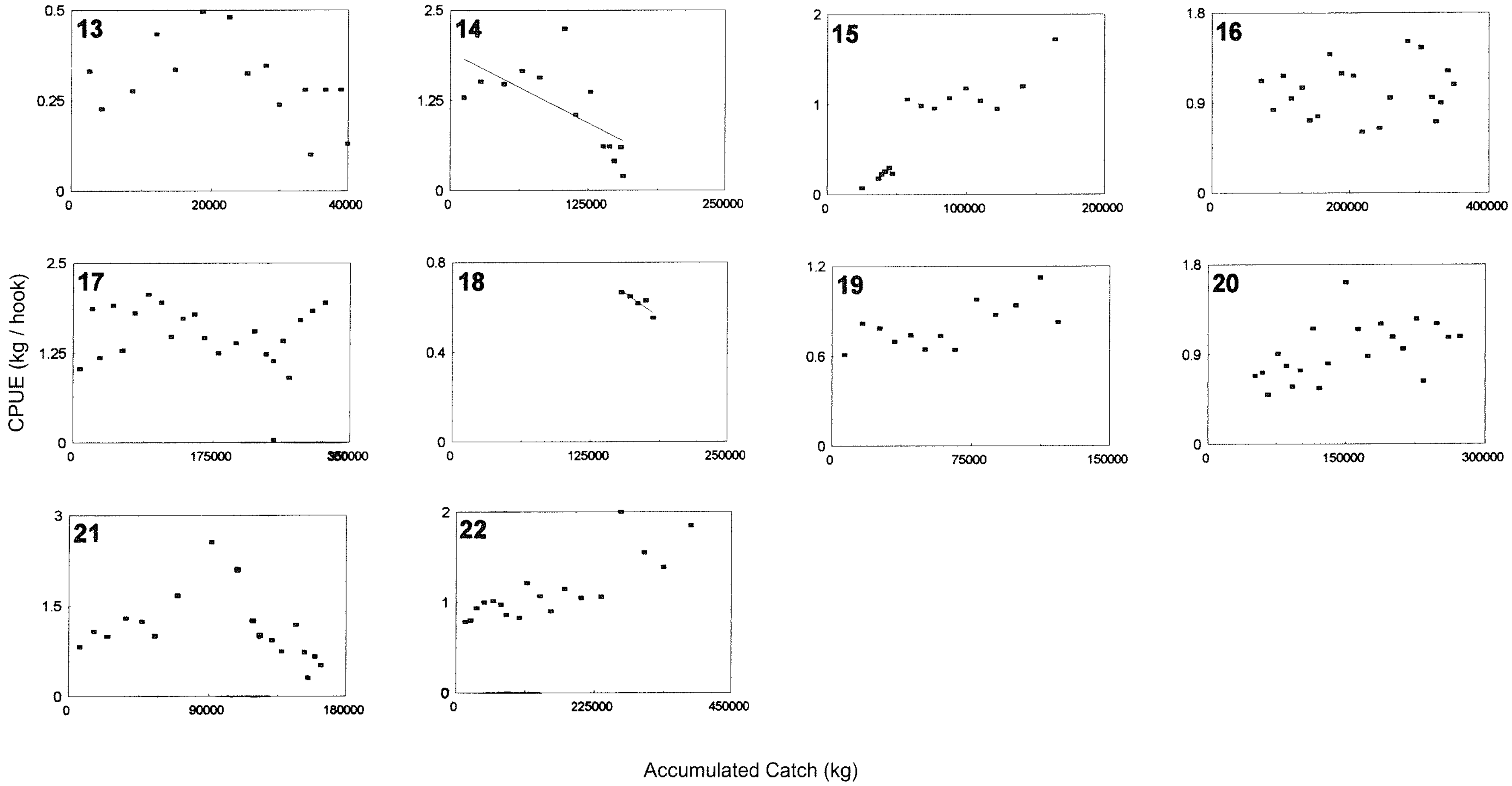
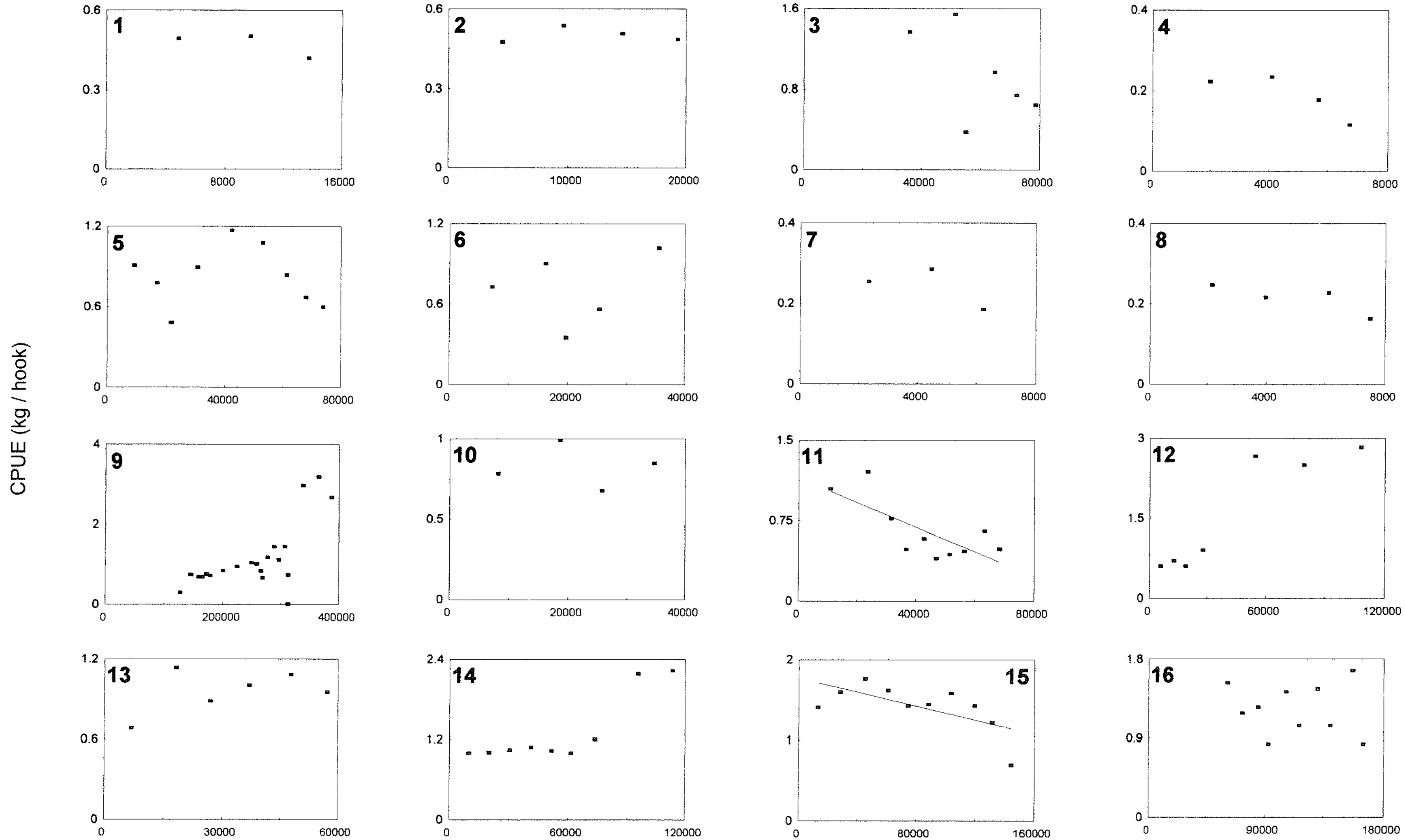



Figure 2: Series selected from CCAMLR database for Chilean longliners in the 1991/92 season, Subarea 48.3. Dataset A.


CPUE (kg / hook)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0.6
0.3
0
8000
16000
10000
20000
1.6
0.8
40000
80000
0.4
0.2
4000
1.2
0.6
20000
4
2
200000
400000
1
0.5
1.5
0.75
3
60000
120000
30000
2.4
160000
1.8
0.9
90000
180000

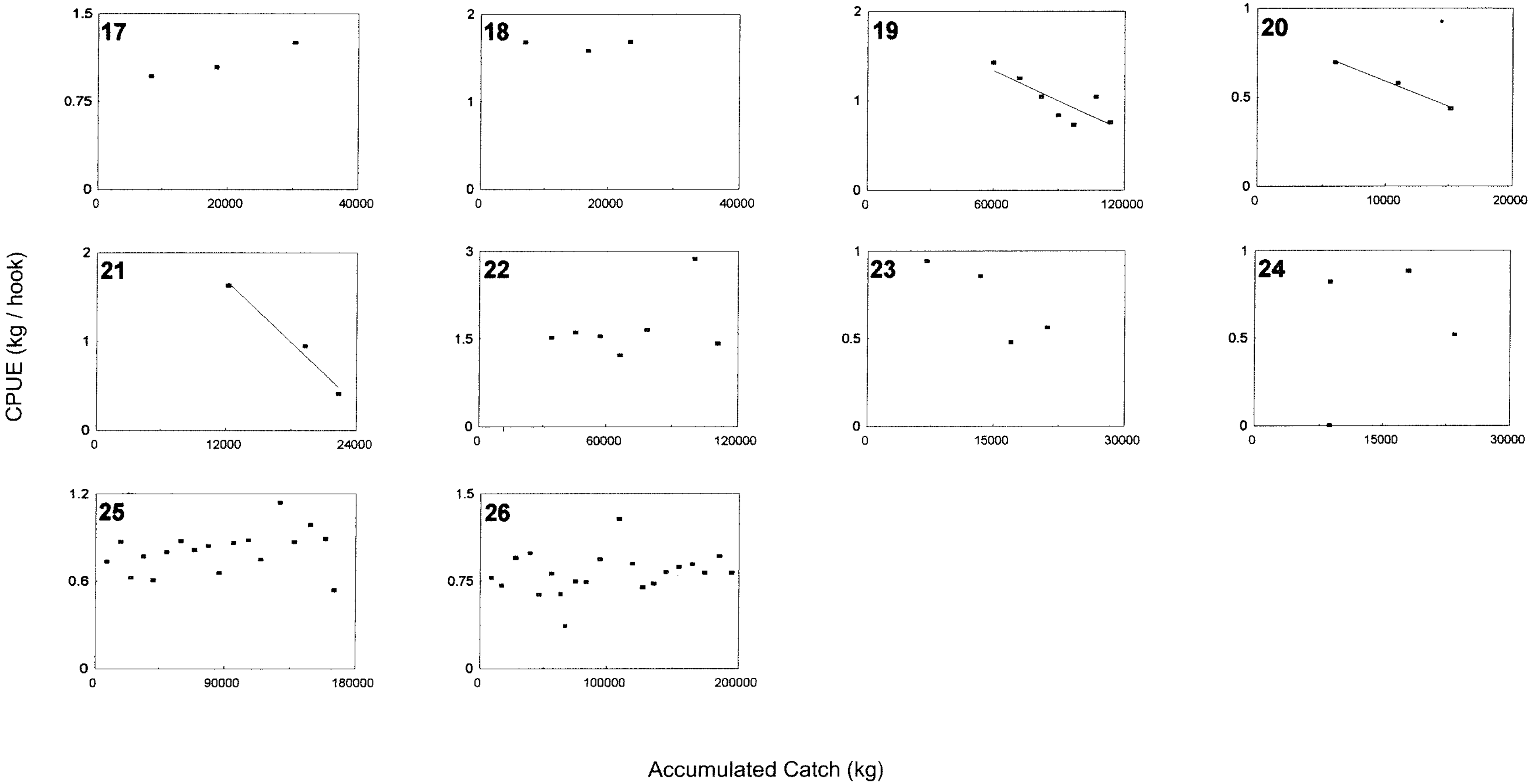
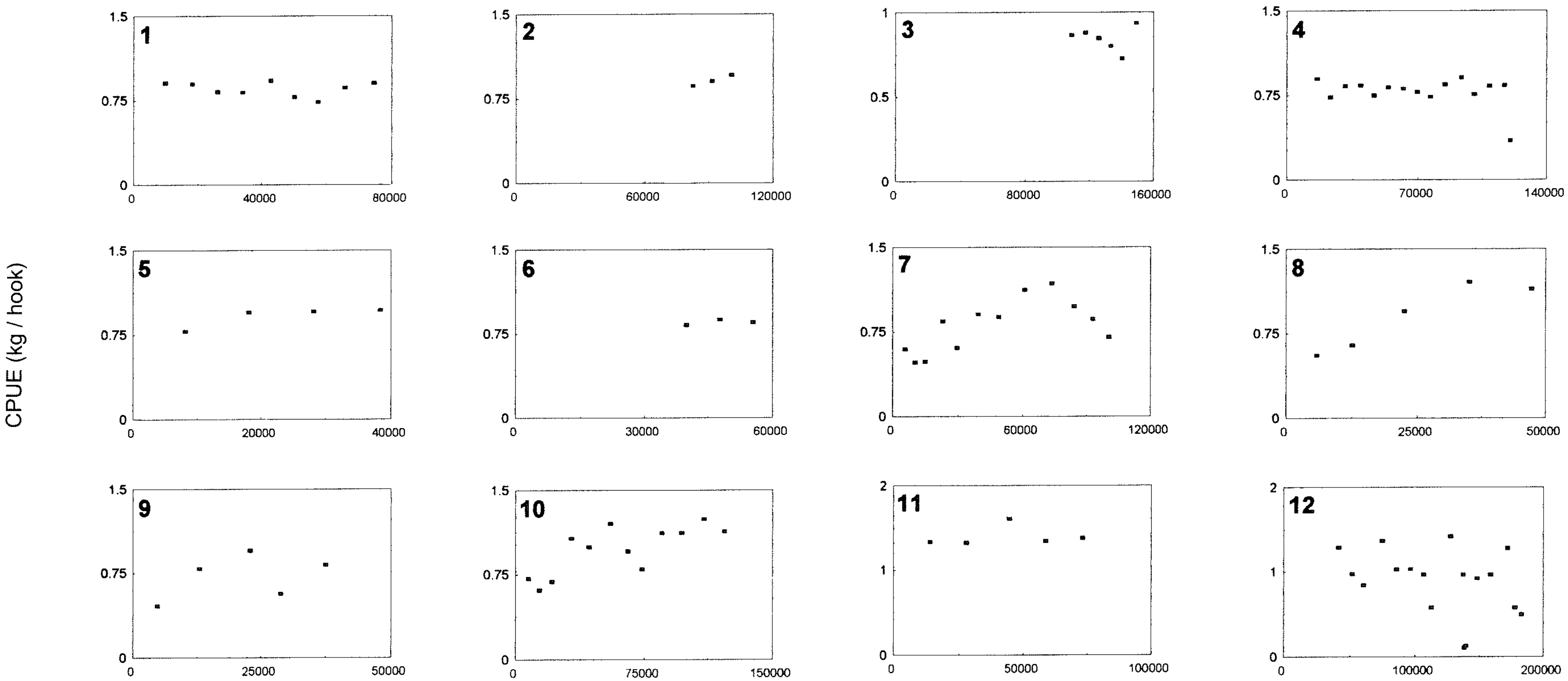



Figure 3: Series selected from the CCAMLR database for Chilean longliners in the 1992/93 season, Subarea 48.3. Dataset A.


CPUE (kg / hook)
1
2
3
4
5
6
7
8
9
10
11
12

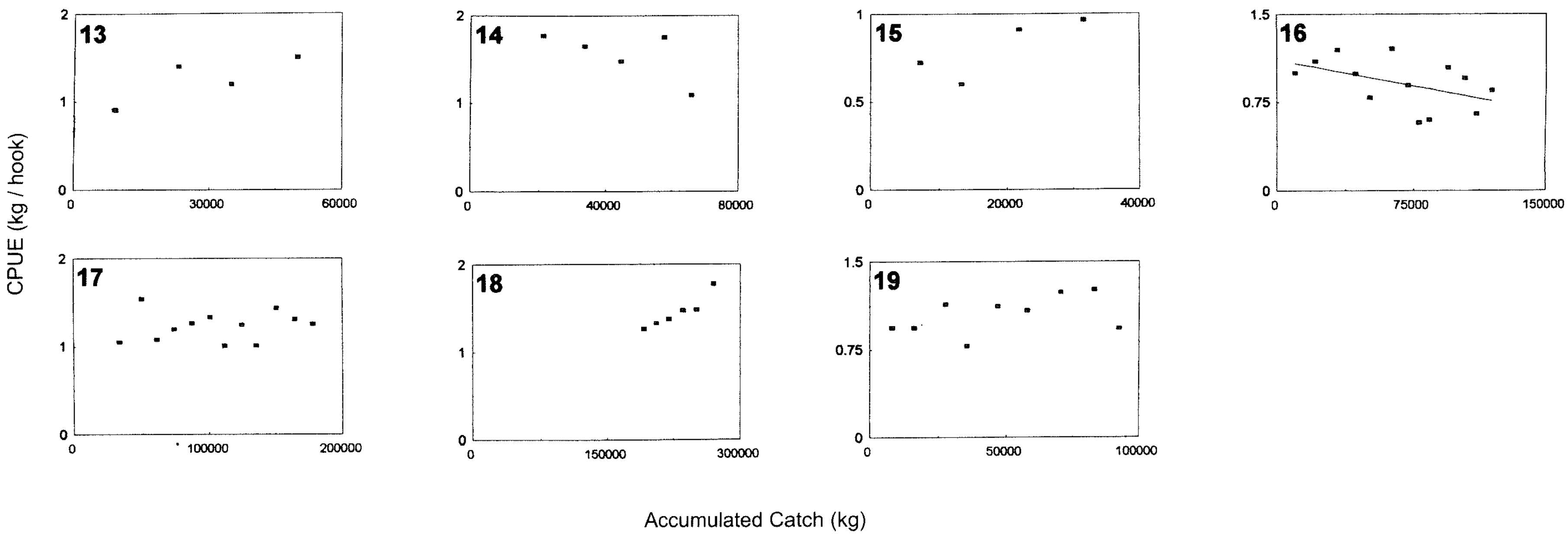



Figure 4: Series selected from the CCAMLR database for Chilean longliners in the 1992/93 season, North Bank. Dataset A.

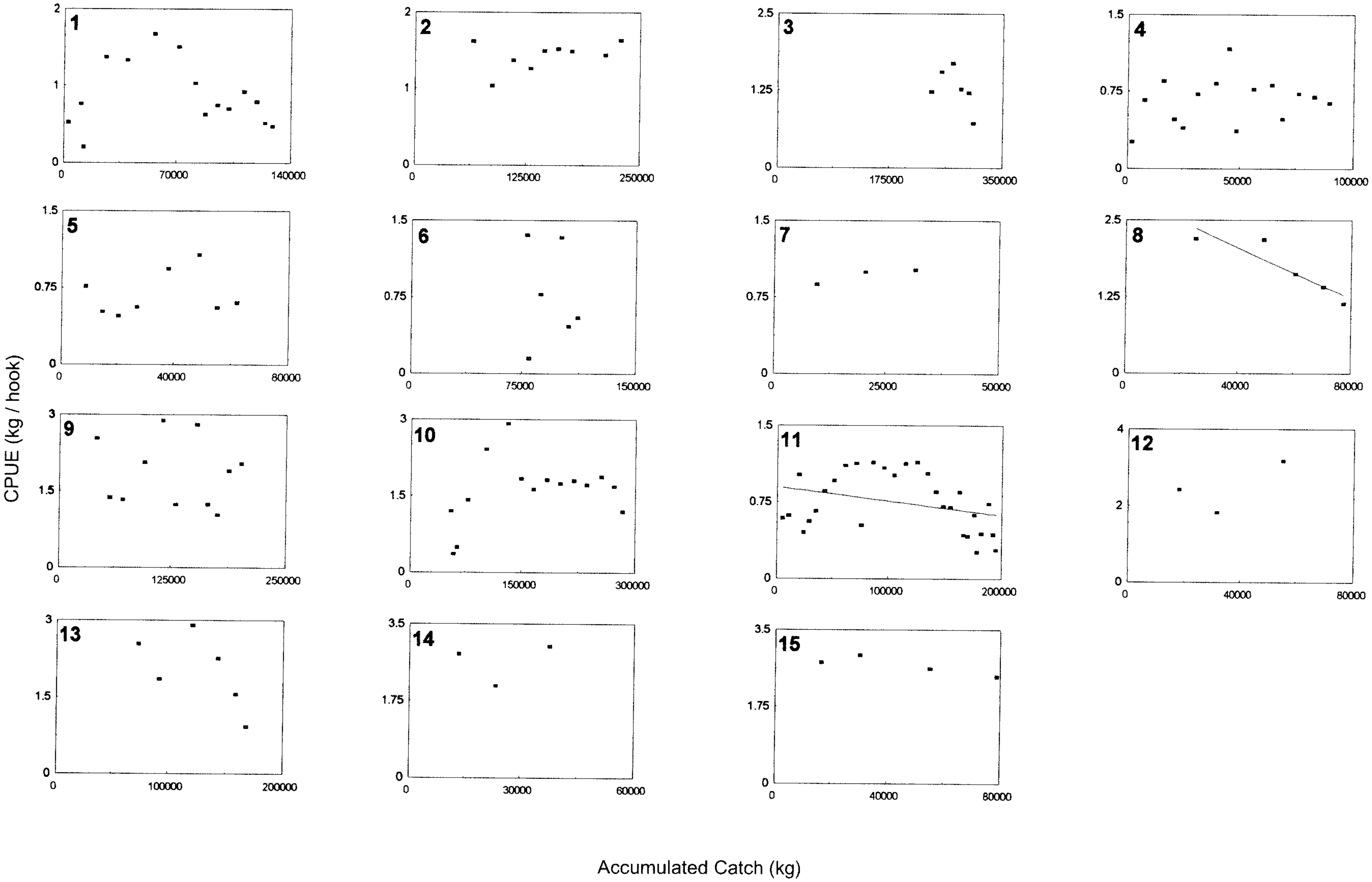



Figure 5: Series selected from the CCAMLR database for Chilean longliners in the 1991/92 season, Rhine Bank. Dataset A.

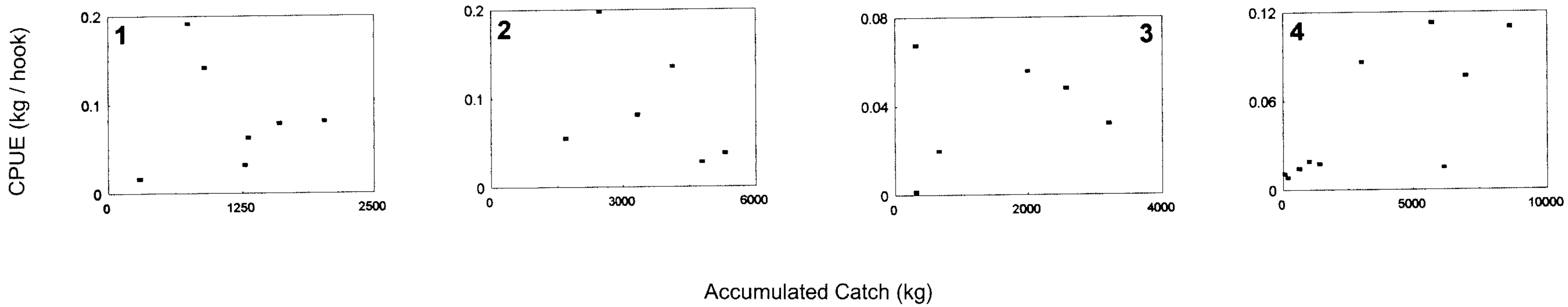



Figure 6: 1991 artisanal fishery off Valdivia (Chaihuin submarine canyon). Dataset B.

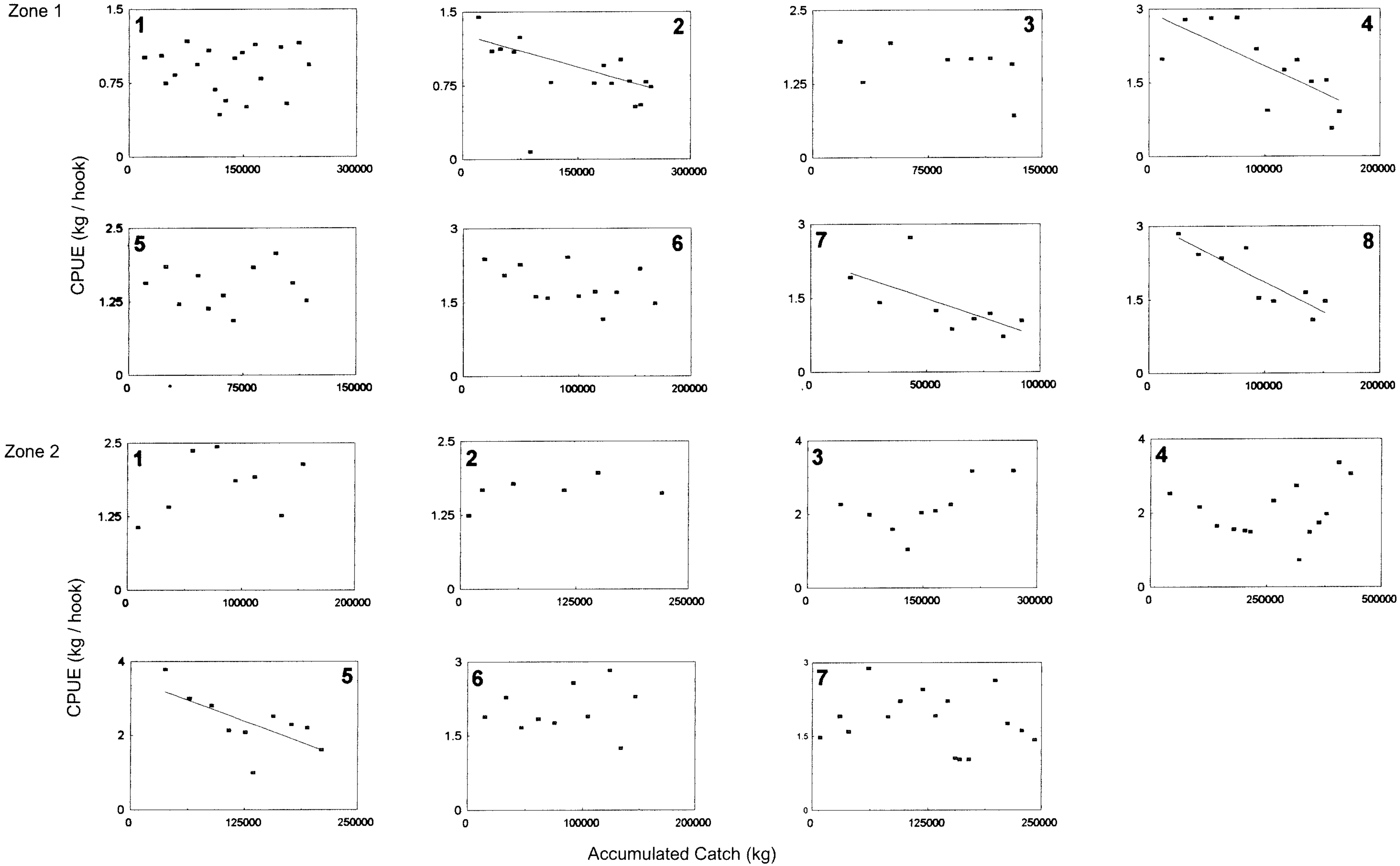



Figure 7: 1991/92 industrial longline fishery off southern Chile, Zones 1 and 2. Dataset C.

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