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Links between climate variation and the year class strength of hoki: an update

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Final Research Report for Ministry of Fisheries Research Project HOK1999/01 Objective 1

National Institute of Water and Atmospheric Research

December 2000

Final Research Report

Report Title	Links between climate variation and the year class strength of hoki: an update.
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1. Date:	December 2000
2. Contractor:	National Institute of Water and Atmospheric Research Limited
3. Project Title:	Hoki population modelling and stock assessment
4. Project Code:	HOK1999/01
5. Project Leader:	Dr R. Hurst
6. Duration of Project:	
Start date:	1 December 1999
Completion date:	1 December 2000

7. Executive Summary

Hoki (*Macruronus novaezelandiae* Hector) year class strength varies substantially from year to year. We examine associations between hoki year class strength and climate variables including the Southern Oscillation Index (SOI), satellite sea surface temperatures (SSTs), synoptic weather patterns, wind speeds, and the depth of the West Coast mixed layer. The long-term goal is to be able to predict hoki year class strengths (YCS) using climate data. If accurate YCS estimates could be produced using climate data, they would add considerable information to the stock assessment process.

This report updates an earlier report submitted in 1999 under Ministry of Fisheries project HOK9701 which studied the relationship between climate variables and the recruitment success of hoki. We test the predictions of the models described in that report. The models correctly predicted that both western and eastern stock YCS in 1996 would be below average, but underestimated the departure from the norm. Predictions of 1995 YCS were too optimistic for both stocks.

New predictive models are developed using updated data and a revised statistical methodology. Strong year classes of the western hoki stock are associated with cooler SSTs, a negative SOI, and westerly or south-westerly flow along the west coast of the South Island. We accordingly predict a moderately strong 1997 year class and weak 1998 and 1999 year classes for the western stock of hoki. The current model cannot predict eastern stock YCS with confidence.

Future research investigations that may improve understanding of hoki year class strength could include more extensive surveying of areas adjacent to the Chatham Rise to estimate juvenile hoki abundance there; a more comprehensive study of upwelling in Cook Strait in relation to hoki larval distribution throughout Cook Strait, and the local hydrological and meteorological patterns that give rise to it; a more comprehensive investigation of other possible variables that may be useful in predicting YCS.

8. Objectives

Overall objective:

To determine biomass, long-term sustainable yields and optimum exploitation rates of hoki (*Macruronus novaezelandiae*) stocks and to model the response of hoki stocks to exploitation.

Specific objective:

To determine relationships between environmental variables and year class strength in the western and eastern hoki stocks.

9–11. Methods, Results, Conclusions

See attached draft manuscript for submission to NZ Journal of Marine and Freshwater Research.

We deviated from the methods set down in the tender in two regards. Firstly, we have not redone the analysis using the trawl survey abundance estimates of 2+ hoki on the Chatham Rise as a measure of hoki year class strength (YCS), because the 2+ abundance estimates were found to be highly correlated with the stock assessment estimates of YCS that were actually used, and cover a much shorter time span.

Secondly, we have not presented estimates of the stock-recruitment relationship parameters, because it was found in preliminary analysis that the YCS were highest when the stock size was low, and even after attempting to correct for the effects of climate on recruitment, the stock-recruitment relationship was decreasing rather than increasing. This could indicate a Ricker stock-recruitment relationship rather than the Beverton-Holt relationship traditionally used for hoki. However, we believe instead that this indicates that not all the effects of climate have been removed from the recruitment time series, and hence that it is not yet possible to assess the stock-recruitment relationship.

12. Publications

See attached draft manuscript.

13. Data Storage

Data are stored on the primary author's PC.

14. References

See attached draft manuscript.

Links between climate variation and the year class strength of New Zealand hoki (*Macruronus novaezelandiae*): an update

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Abstract Hoki (*Macruronus novaezelandiae* Hector) year class strength varies substantially from year to year. We examined associations between hoki year class strength and climate variables including the Southern Oscillation Index (SOI), satellite sea surface temperatures (SSTs), synoptic weather patterns, wind speeds, and the depth of the West Coast South Island mixed layer. We evaluated the predictions of a model developed two years ago to predict year class strengths of the western and eastern New Zealand hoki stocks from similar climate variables. New predictive models were developed using updated data. Strong year classes of the western hoki stock were associated with cooler SSTs, a negative SOI, and westerly or south-westerly flow along the west coast of the South Island. We accordingly predict a moderately strong 1997 year class and weak 1998 and 1999 year classes for the western stock of hoki. The current model cannot predict eastern stock year classes strengths with confidence.

Keywords hoki; recruitment; climate

INTRODUCTION

Research has been carried out worldwide to assess the influences of environmental factors on the recruitment success of fish species (Glantz & Feingold 1990). Typically, these studies collect a set of environmental data, form estimates of the strengths of recruiting year classes, and look for correlative relationships between the two. If a relationship between recruitment and environmental variables can be established, then the possibility of estimating recent year class strengths from environmental data arises. The effect of the environment on recruitment can potentially be separated out from other effects, which in turn may allow the effect of reduced stock size on recruitment to be assessed. However, this is easier said than done. Commonly a relationship is found which explains the data well, but is then found to have little or no predictive ability (Shepherd et al. 1984). The only valid test of a recruitment/environment study is the ability to predict data not used in the original analysis (Walters & Collie 1988).

This paper is a sequel to that of Livingston (2000), which studied the relationship between climate variables and the recruitment success of hoki (*Macruronus novaezelandiae*). Here we test the predictive ability of Livingston's (2000) model, and update her analysis with two more years of data and a revised statistical methodology. The long-term goal is to predict hoki year class strengths (YCS) using climate data. Current stock assessments of hoki cannot estimate YCS for the three years prior to the assessment, since the earliest age for which abundance estimates are included is 2.5 years. If accurate YCS estimates could be produced using climate data, they could extend up to the year prior to the assessment and would add considerable information to the assessment process.

New Zealand hoki are assessed as two stocks (Annala et al. 2000) referred to as the western and eastern stocks. The western stock consists of mature fish mostly inhabiting the Sub-Antarctic, while the eastern stock consists of mature fish mostly inhabiting the Chatham Rise (Figure 1). Hoki spawn during winter on two main spawning grounds, West Coast South Island (WCSI) and Cook Strait, which are believed to be used by the western and eastern stocks respectively. The timing of the spawning migrations from the Chatham Rise to Cook Strait and from the Sub-Antarctic to WCSI is uncertain, but Livingston *et al.* (1997) concluded that most western stock hoki began the spawning migration from late May to early June. Peak spawning occurs in July and August. Eggs are spawned in 250–750 m depth along the shelf edge and slope, and larvae advect inshore as they get older (Zeldis 1993, Zeldis et al. 1998). They feed initially on phytoplankton, tintinnids, and copepod larvae, and later on copepod adults and copepodites (Murdoch 1990). Juveniles of both stocks move along the coast to reach the Chatham Rise nursery ground between one and two years old (Livingston & Schofield 1996a, Livingston 1997). As hoki reach maturity, they move to deeper water, with some remaining on the Chatham Rise as eastern stock fish and others moving south to the Sub-Antarctic to join the western stock.

Livingston (2000) studied the relationship between hoki recruitment and climate variables including sea surface temperature (SST), the Southern Oscillation Index (SOI), synoptic weather patterns, wind speeds, and the depth of the mixed layer off the WCSI. She classified synoptic patterns according to the seven-class system of Kidson (1997) which represented daily weather variability over New Zealand in terms of seven objectively-defined synoptic weather classes. Climate variables were aggregated by season. Data covered the period from 1980 to 1994. Recruiting hoki YCS were estimated from the two-stock assessment model of Cordue (1999). The relationships between YCS and individual climate variables were investigated by bivariate plots and correlations. Multiple regression analysis was then used to model the combined effects of climate variables on recruitment. A fully linear model was assumed, with no transformation of the response variable. Best subsets regression in Sigmastat was used to select a parsimonious set of explanatory variables.

Strong associations between YCS and some climate variables were found by Livingston (2000), with some correlations of $r = 0.8$ and above. Strong western stock YCS were associated with El Niño years with low temperatures off the West Coast, with deep mixing off the West Coast in July, SW synoptic weather patterns in winter, NW weather patterns in summer, and the absence of NW weather patterns in spring. Strong eastern stock YCS were associated with NW and SW weather patterns and strong westerly winds through Cook Strait in winter, and with low temperatures on the Chatham Rise in winter. These results were in accord with the earlier findings of Blagoderov (1978), Shuntov et al. (1981), Livingston & Schofield (1996b), and Bradford-Grieve et al. (1996). A number of hypotheses were discussed to explain possible underlying mechanisms of cause and effect.

In this paper, the predictive success of the regression models of Livingston (2000) is tested, using updated climate and recruitment data from 1995 and 1996. The regression models are refitted using revised climate and recruitment data, covering the 1982–1994 time period, using the same predictor variables. The regression models are then used to predict YCS in 1995 and 1996 and these are compared with the actual 1995 and 1996 YCS from the stock assessment model. We also compare them with the "naive" prediction of the mean YCS over the 1980–1994 period. This is the best prediction in the absence of any climate information. For a recruitment/climate model to be successful, its predictions need to be more accurate than the naive predictions.

The analysis of Livingston (2000) is also updated, using the revised climate and recruitment data, incorporating new data from 1995 and 1996 and using a revised statistical methodology. Correlations between YCS and climate variables are presented. Regression models of YCS on climate variables are fitted, and their predictive power is assessed using a cross-validation technique. As a method of assessing model success, we prefer the cross-validation procedure to other approaches such as significance testing and partitioning variance, on the basis that prediction is the best test of a recruitment / environment study. Prediction within the data set is not as convincing as external prediction on completely new data, but still provides a useful criterion for assessing the model. Finally, the regression models are used to predict YCS for 1997–1999, since climate data are now available for this period. The accuracy of these predictions can be tested when the stock assessment YCS for 1997–1999 become available.

METHODS

Recruitment data

Hoki YCS were indexed separately for the western and eastern stocks of hoki (Table 1). The YCS were derived from the two-stock assessment model of Cordue (2000), in which they were estimated by the MIAEL method. They denote the numbers of hoki larvae recruiting in each year, relative to the expected number according to the currently assumed Beverton-Holt spawning stock-recruitment relationship. These recruitment data cover the period from 1980 to 1996.

Livingston (2000) used similar data from the previous year's stock assessment (Cordue 1999), which employed similar methodology but with a less complex estimation technique and two years less data. Both stock assessments include separate model runs, one including catch-per-unit-effort data and one including acoustic survey data, since the two data series are not considered to be compatible; both this paper and Livingston (2000) use the runs including acoustic data. The YCS in this paper agree with those of Livingston (2000); the correlations between the two YCS series over 1980–1994 are 0.95 for the western stock and 0.85 for the eastern stock.

Climate data

WCSI mixed layer depth data were calculated using a one-dimensional ocean mixed layer model applied to the point 42°S, 170°E, with surface fluxes calculated using a meteorological dataset derived from land stations at Hokitika (42.72°S, 170.99°E) and Farewell Spit (40.55°S, 172.02°E) (Hadfield 2000). It has been run from 1980 to 1999 and verified against satellite-derived SST data and occasional subsurface observations. The model's treatment of the ocean below the mixed layer is simple; it neglects oceanographically-driven variability.

Monthly mean climate data were aggregated by season, with autumn defined as April-June, winter as July-September, and spring as October-December. Most variables assessed were local to the New Zealand region, apart from the SOI, which is a measure of the state of the El Niño/Southern Oscillation system, taken as the normalised mean sea-level pressure difference between Tahiti and Darwin. Approximately, values of the SOI above +10 indicate La Niña conditions, while values less than −10 indicate El Niño.

Sea surface temperatures were interpolated from a global 1°×1° data set (Reynolds and Smith 1994) at three locations of interest: WCSI (43°S 170°E), Cook Strait (41.5°S 174.5°E), and Chatham Rise (44°S 180°). Near-surface wind components at the same three sites were interpolated from NCEP/NCAR reanalysis fields (Kalnay et al. 1996). The usual meteorologically standard westerly and southerly Cartesian wind components were rotated to derive southwesterly and northwesterly wind components, which are approximately parallel and normal (respectively) to the South Island mountain chain.

General weather conditions over New Zealand were taken from the cluster analysis of Kidson (2000), where daily weather patterns are assigned to one of 12 objectively-defined weather "classes". The monthly frequency of occurrence of each class indicates the type and variety of weather systems observed over the New Zealand region as a whole. The 12 class means and their associated acronyms are shown in Fig 2. Note that the analysis of Livingston (2000) instead used the earlier seven-class set of synoptic patterns of Kidson (1997).

Statistical methods

Predictive testing of the models of Livingston (2000)

The best subset regression models of Livingston (2000) were refitted using the revised climate and YCS data from 1982–1994. The YCS for 1995 and 1996 were predicted using the climate data from 1995 and 1996 in the above models. The predictions were compared with the actual values from the stock assessment model.

The best subset model of western stock recruitment in Livingston (2000) included the following predictors: the incidence of NW weather patterns in spring, the WCSI mixed layer depth at 1 July, the SOI in autumn, and the WCSI SST in spring. Because of the high collinearity among the climate variables, this small subset of variables encapsulated most of the explanatory power of the climate data, with an R^2 of 0.87. The model of eastern recruitment included the incidences of

NW and SW weather patterns in winter and the mean southwest wind velocity in Cook Strait. The explanatory power of this set of variables was high, with an R^2 of 0.78.

The models were hence:

$$\begin{aligned}
\text{western YCS} = \beta_0 &+ \beta_1 \cdot \text{proportion of NW weather patterns in spring} \\
&+ \beta_2 \cdot \text{WCSI mixed layer depth at 1 July} \\
&+ \beta_3 \cdot \text{mean SOI in autumn} \\
&+ \beta_4 \cdot \text{WCSI mean SST in spring} \\
\text{eastern YCS} = \theta_0 &+ \theta_1 \cdot \text{proportion of NW weather patterns in winter} \\
&+ \theta_2 \cdot \text{proportion of SW weather patterns in winter} \\
&+ \theta_3 \cdot \text{Cook Strait mean SW wind velocity in winter.}
\end{aligned}$$

The NW and SW weather patterns belong to the seven-class set of synoptic patterns of Kidson (1997) which has been superseded by the twelve-class set of Kidson (2000). The seven-class patterns are no longer generated and do not cover the 1995–1996 forecasting period. For this analysis only, the seven-class data were approximated using the new twelve-class data. The old SW class corresponds to the new SW and HNW classes, and so the occurrence of SW weather patterns was replaced in the model by the occurrence of SW and HNW patterns. Similarly, the old NW class corresponds to, and was replaced in the model by, the new TNW, HE, and W classes.

New models

For the full dataset covering 1980–1996, correlations between YCS and climate variables were calculated. Regression models of western and eastern YCS on climate variables were fitted. The YCS were log-transformed in the correlation and regression analyses, to reduce the influence of the strongest year classes, and because the residuals in the regression analysis were found to be more normally distributed when the log-transform was used. The climate variables included for the western stock were the depth of the West Coast mixing layer at July 1 and, for each of the autumn, winter, and spring quarters of that year, the mean SOI, the mean WCSI SST and northwest and southwest wind velocities, and the proportions of each of the twelve synoptic weather patterns. The climate variables included for the eastern stock were, for each of the autumn, winter, and spring quarters, the mean SOI and the proportions of each of the twelve synoptic weather patterns; for the autumn and winter quarters only, the mean Chatham Rise SST and northwest and southwest wind velocities; for the winter and spring quarters only, the mean Cook Strait SST and northwest and southwest wind velocities.

The regression model for each stock was therefore

$$\log(\text{YCS}) = \beta_0 + \sum_i \beta_i \cdot \text{climate variable}_i + \varepsilon$$

where ε is a normally distributed random error with constant variance. Because of the log transformation of YCS, this is a multiplicative model: the joint effect of two climate variables is the product of the individual effects. The normal random error on log(YCS) with constant variance is equivalent to a lognormal random error on YCS with constant coefficient of variation (c.v.). The models were fitted using forwards stepwise selection, with variables added if the F-test for their inclusion gave a significant result at the 5% level.

The predictive powers of the regression models were tested by cross-validation. For each year *i* of the 17 years in the dataset, the regression coefficients were re-estimated using data from all years except *i*, the YCS for year *i* was predicted, and the prediction was compared to the actual YCS in year *i*. The performance of the predictions was evaluated on the basis of root mean squared error (RMSE) in log(YCS). For comparison, the same procedure was carried out using the 'naive' model where the predicted YCS in year *i* was simply the geometric mean of the YCS in the other 16 years.

YCS for the western and eastern stocks in 1997–1999 were predicted using the new regression models.

RESULTS

Predictive testing of the models of Livingston (2000)

Refitting the best-subsets regressions of Livingston (2000) with revised climate and recruitment data resulted in decreased explanatory power of the models for both stocks. The R-squared statistic decreased from 0.87 to 0.84 for the western stock and from 0.78 to 0.40 for the eastern stock. Revised parameter estimates are given in Table 2. The refitted regressions correctly predicted below-average YCS (ie. below the naive prediction) in 1996 for both stocks, though the actual YCS in 1996 were even lower than predicted (Table 3). However, the regressions incorrectly predicted substantially above-average YCS in 1995 for both stocks. According to the stock assessment, the western 1995 year class was only slightly above average size, and the eastern 1995 year class was weaker than that of 1996.

New models

Western YCS in 1980–1996 were strongly correlated with autumn SOI (r = –0.84), and with WCSI SSTs in spring (r = –0.80) and to a lesser extent winter and autumn (r = –0.70, –0.59) (Table 4). Eastern YCS were correlated most closely with the occurrence of the TNW synoptic pattern in autumn (r = –0.56) and the TSW synoptic pattern in winter (r = –0.52). There were moderate to weak correlations (–0.50 < r < 0.50) between YCS and a range of SST, SOI, wind velocity, and synoptic pattern variables.

The stepwise regression fit of western YCS included a number of climate predictors; SOI in autumn, WCSI SST in winter, and the occurrences of the T synoptic pattern in autumn, the TNW pattern in winter, and the H pattern in spring (Table 5). The regression fit of eastern YCS, however, included only one predictor; the occurrence of the TNW synoptic pattern in autumn.

The predictive power of the western stock model was a great improvement on the naive model which includes no climate data. The cross-validation analysis showed a reduction in RMSE from 0.89 in the naive model to 0.24 in the regression model. However, the eastern stock model has little predictive power. The RMSE is reduced from 0.75 in the naive model to 0.69 in the regression model.

The regression model for the western stock predicted an above-average YCS of 1.48 in 1997 but weak YCS of 0.46 and 0.23 in 1998 and 1999 (Table 6). The prediction for 1997 was high because of the very negative autumn SOI of –22.7, but was reduced by the low incidence of synoptic pattern TNW in winter. The 1998 year had an average autumn SOI of –5.3 but otherwise adverse conditions, including a slightly higher than average SST in winter and low occurrences of synoptic patterns T in autumn, TNW in winter and H in spring. The low prediction for 1999 was driven by a combination of a high autumn SOI of 8.0 and a high winter SST (14.2 compared to an average of 12.7 in 1980–1996), and was also decreased by low incidence of synoptic pattern TNW in winter and increased by high incidence of T in autumn and H in spring. For the eastern stock, the regression model predicted above-average YCS of 1.49 and 1.30 in 1997 and 1999 and an average YCS of 1.01 in 1998, on the basis of the occurrence of the TNW synoptic pattern in autumn.

DISCUSSION

The new correlation and regression results for the western stock presented in this paper are similar to those of Livingston (2000). Western YCS were very strongly correlated (absolute r = 0.7–0.85) with autumn SOI and winter and spring WCSI SST. The explanatory power of the western stock regression model was high.

However, the results for the eastern stock differ from those of Livingston (2000). As Livingston noted, the distribution of eastern YCS is highly skewed, with two outlying year classes (1988 and 1994) having a strong influence on the correlation and regression analyses. Log-transformation of YCS values reduced the influence of these high values resulting in much lower associations between climate variables and YCS, and reduced explanatory power of the regression model. This problem of non-normality of untransformed values is common in analyses of recruitment vs environmental factors (Shepherd et al. 1984).

As well as the original climate variables, western YCS was also inversely correlated with SOI in winter and spring, and SST in autumn. This is not surprising, considering the strong collinearity between SOI and SST in consecutive seasonal quarters. For example, there was a correlation of 0.86 between winter and autumn WCSI SSTs in our dataset, so that a genuine correlation between western YCS and winter SST could lead to a spurious correlation between YCS and autumn SST, or vice versa. Western YCS were associated negatively with synoptic patterns including NE in autumn and TSW, HSE, (both with southeasterly flows over the South Island) and HW (zero or northeasterly flow) in winter, and positively with SW (southwesterly flow) in winter. However, the regression analysis selected only those synoptic pattern variables which provided significant information not already included in autumn SOI or winter SST, which included T in autumn, TNW in winter, and H in spring. In summary, the western stock model associated strong YCS with cooler SSTs, a negative SOI, and west or south-west flow along the west coast of the South Island.

Eastern YCS were also correlated negatively with TSW and HW in winter and TNW in autumn, and positively with HNW in winter. Only TNW in autumn was included in the regression model. The results for the eastern stock are quite different from those identified by Livingston (2000). In the present work, the only important variable selected by the regression procedure was autumn TNW, suggesting a negative relationship between the occurrence of conditions with northwest flow in autumn and YCS. Correlation between other variables and eastern YCS followed the pattern identified by Livingston, i.e., a positive association between eastern YCS and westerly flow. Interpretation of these results is difficult. The inconclusive results may be caused by problems with the data. Eastern YCS are not estimated as well as western YCS, because the abundance of the eastern stock is relatively poorly estimated (Annala 2000). Further, the hydrodynamics of Cook Strait and how weather systems affect Cook Strait are highly complex and may not be well summarised by the variables used here.

The work in this paper uses stock assessment model estimates of YCS, rather than direct observations, which introduces error into the data. Process error in the model may have introduced bias. Also, the model YCS are merely a single least-squares estimate and the uncertainty of that estimate is not incorporated in this analysis. These problems are unavoidable in the absence of direct observations of larval abundance.

We agree with Walters & Collie (1988) and Shepherd *et al.* (1984) that the only valid test of a recruitment/environment analysis is the ability to predict data not used in the original analysis. This has not yet been demonstrated for New Zealand hoki. The best-subsets regression models of

Livingston (2000) correctly predicted that both western and eastern YCS in 1996 were below average, but underestimated the departure from the norm. Predictions of 1995 YCS were too optimistic for both stocks, and in fact the naive prediction of the mean historical YCS would have been more successful. The poor western stock prediction for 1995 may have been due to seasonal climate fluctuation: the SOI in autumn 1995 and the WCSI SST in winter 1995 were both low, resulting in a high YCS prediction, but the mean SOI and SST in the rest of the 1995 year were both above average.

It is possible that the 1995 YCS was underestimated by the stock assessment model. The 1995 year class, for both stocks, had some notable features which it shared with the 1989 year class. Both year classes were relatively weak and followed very strong year classes spawned in 1994 and 1988. Their low estimated abundances in the bottom trawl surveys carried out on the Chatham Rise from *RV Tangaroa* annually in summer suggest that they were very weak (Horn 1994; Schofield 1997), yet their representation in the commercial catch in spawning areas suggests much higher abundance (Annala et al. 2000). One explanation is that their apparent presence in the spawning catch is due to ageing error, and indeed re-reading of some otoliths has led to a drop in the spawning catch-at-age of the 1995 and 1989 year classes. An alternative hypothesis was suggested by data on the relative abundance of 1+ hoki in inshore surveys carried out from *RV Kaharoa* on the east coast of the South Island. A review of this time series reports the 1995 hoki year class as standing out as a strong year class (Beentjes & Stevenson 2000). This result is questionable in that the 1+ fish are not well sampled by the bottom trawl. However, it is not inconceivable that the preceding strong 1994 year class had occupied available habitat on the Chatham Rise, thereby forcing the 1995 year class to occupy less favorable habitat on the East Coast. The 1995 year class would then have been inadequately covered by the Chatham Rise trawl survey, and appeared less abundant than it actually was.

We will be able to evaluate the predictions made in this paper in several years, when the stock assessment model YCS for 1997–1999 have been estimated. The cross-validation analysis suggests that we can be relatively confident in our predictions of a moderately strong 1997 western year class and weak 1998 and 1999 year classes. We also predict above-average 1997 and 1999 eastern year classes and an average 1998 eastern year class, but our ability to predict eastern year classes is poor. This prediction for the 1997 year class is particularly interesting because its estimated abundance on the Chatham Rise as 2+ fish in January 2000 was lower than expected given its abundance as 1+ fish in the previous survey in January 1999. Several explanations were suggested, including early maturation, early migration to the Sub-Antarctic and high mortality (Stevens et al. in press).

The understanding of the processes of upwelling and inshore movement of larval hoki off the WCSI and Cook Strait and their links with weather conditions is incomplete. This limits our ability to identify the effects of weather conditions on the movements of juvenile hoki and of their food supply. Another problem is that the stock-recruit relationship of hoki is unknown.

In her paper, Livingston (2000) concluded that a negative SOI probably had an indirect effect on recruitment by producing conditions favorable to hoki larval survival, including cool temperatures and westerly flow. Hoki have a cold-water distribution in New Zealand waters, with the bulk of the biomass found in association with or south of the Subtropical Front. Cooler SSTs are associated with a negative SOI. Further, the extent of deep mixing in winter, postulated as promoting the growth of zooplankton species important in the diet of hoki larvae (Bradford-Grieve et al 1996), is greater under negative SOI conditions. Newly hatched hoki larvae are adapted to feed in low food density conditions typically found in the spawning locations (Murdoch 1990). As they grow, they tend to concentrate inshore from the spawning sites where productivity is higher (Zeldis et al. 1998). Southwest weather conditions (another feature of negative SOI) are also known to cause upwelling off Westland which results not only in increased productivity but could provide a means of directly transporting larvae inshore (Bradford 1983). Since YCS is generally believed to be driven primarily by survival success in the first year, it is reasonable to propose that climate conditions which transport hoki larvae from the low density food environment in which they first hatch to a high density one will improve survival rate and result in higher YCS.

In Cook Strait there is direct evidence that newly hatched hoki larvae are upwelled from the Cook Strait Canyon to the shallows of Cloudy Bay on the eastern side of the northern end of the South Island (Murdoch et al. 1990). Upwelling of nutrient rich water has been observed in Cook Strait during periods of northwesterly wind flow (Bradford et al. 1986), in areas where young hoki occur in abundance (Murdoch et al. 1990). Southwesterly flow over the South Island can result in localised northwesterly flow through Cook Strait (Reid 1996), so either northwesterly or southwesterly conditions over the country could result in favorable conditions for young hoki in Cook Strait. The re-analysis in this paper found little correlation between climate variables and YCS. This does not of course mean that they are necessarily unconnected. The difficulties associated with linking broad-scale climatic trends to the complex hydrology of Cook Strait are not trivial. Further, the YCS of the eastern stock of hoki are more uncertain than those of the western stock (Annala et al 2000).

Future research investigations that may improve understanding of hoki YCS could include more extensive surveying of areas adjacent to the Chatham Rise to estimate juvenile hoki abundance there; a more comprehensive study of upwelling in Cook Strait in relation to hoki larval distribution throughout Cook Strait, and the local hydrological and meteorological patterns that give rise to it; a more comprehensive investigation of other possible variables that may be useful in predicting YCS.

ACKNOWLEDGMENTS

We are grateful to Jim Renwick for providing assorted climate data and for his contributions to the text of this paper. We thank Patrick Cordue for assistance with hoki recruitment data, John Kidson for synoptic weather pattern data and Mark Hadfield for WCSI mixed layer depth data. This research was funded by the New Zealand Ministry of Fisheries (project HOK1999/01).

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Table 1: Year class strength indices (YCS) for the western and eastern hoki stocks, as estimated in the stock assessment model of Cordue (2000).

	YCS	
Year	Western	Eastern
1978	0.73	1.86
1979	2.22	0.05
1980	0.34	0.39
1981	0.79	0.37
1982	0.55	0.74
1983	1.04	0.89
1984	1.17	1.21
1985	1.25	0.41
1986	0.35	0.30
1987	2.37	2.28
1988	5.30	0.53
1989	0.66	0.13
1990	0.32	0.55
1991	0.88	2.54
1992	1.48	2.63
1993	0.59	2.00
1994	2.98	3.67
1995	0.70	1.38
1996	0.76	0.76

Table 2: Parameter estimates for the best-subsets regression models of Livingston (2000), refitted using revised climate and recruitment data from 1980 to 1994.

Variable	Coefficient
Western stock	
Constant	10.86
Proportion of NW weather patterns in spring	-3.05
WCSI mixed layer depth at July 1	0.008
Mean autumn SOI	-0.048
Mean spring SST on WCSI	-0.716
Eastern stock	
Constant	-2.21
Proportion of NW weather patterns in winter	7.38
Proportion of SW weather patterns in winter	10.27
Mean winter SW wind velocity in Cook Strait	-0.142

Table 3: Predictions from the refitted models of Livingston (2000) for 1995 and 1996 YCS, compared to the actual YCS from the stock assessment model, and the "naive" predictions of the mean YCS during the 1980–1994 period.

		Western stock	Eastern stock
1995:	Model prediction	2.15	1.77
	Actual YCS	1.38	0.70
	Naive prediction	1.24	1.34
1996:	Model prediction	1.10	0.92
	Actual YCS	0.76	0.76
	Naive prediction	1.24	1.34

Table 4: Correlations between log-transformed YCS and climate variables, ordered in decreasing order of magnitude, and excluding any correlations of absolute value less than 0.30.

Variable	Correlation
Western stock	
SOI, autumn	-0.84
WCSI SST, spring	-0.80
WCSI SST, winter	-0.70
WCSI SST, autumn	-0.59
NE synoptic pattern, autumn	-0.53
SOI, winter	-0.50
SW synoptic pattern, winter	0.46
TSW synoptic pattern, winter	-0.44
HSE synoptic pattern, winter	-0.42
HW synoptic pattern, winter	-0.40
WCSI mean SW wind velocity, autumn	0.37
TNW synoptic pattern, spring	0.37
T synoptic pattern, autumn	0.36
WCSI mean SW wind velocity, winter	0.35
SOI, spring	-0.34
HNW synoptic pattern, autumn	0.33
R synoptic pattern, autumn	0.31
SW synoptic pattern, spring	0.30
Eastern stock	
TNW synoptic pattern, autumn	-0.56
TSW synoptic pattern, winter	-0.52
HNW synoptic pattern, winter	0.44
HW synoptic pattern, winter	-0.42
Cook Strait mean NW wind velocity, winter	0.35
HSE synoptic pattern, spring	0.35
SOI, spring	0.33
W synoptic pattern, autumn	-0.33
Chatham Rise SST, winter	-0.32
Cook Strait mean NW wind velocity, spring	0.31
HE synoptic pattern, winter	0.31

Table 5: Parameter estimates for the regressions of log(YCS) on climate and recruitment data from 1980 to 1996.

Variable	Coefficient
Western stock	
Constant	4.08
SOI, autumn	-0.062
WCSI SST, winter	-0.44
T synoptic pattern, autumn	2.15
TNW synoptic pattern, winter	6.08
H synoptic pattern, spring	3.02
Eastern stock	
Constant	0.60
TNW synoptic pattern, autumn	-12.11

Table 6: YCS for the western and eastern stocks in 1997, 1998, and 1999, predicted from the regression models in Table 5.

Year	Western YCS	Eastern YCS
1997	1.48	1.49
1998	0.46	1.01
1999	0.23	1.30

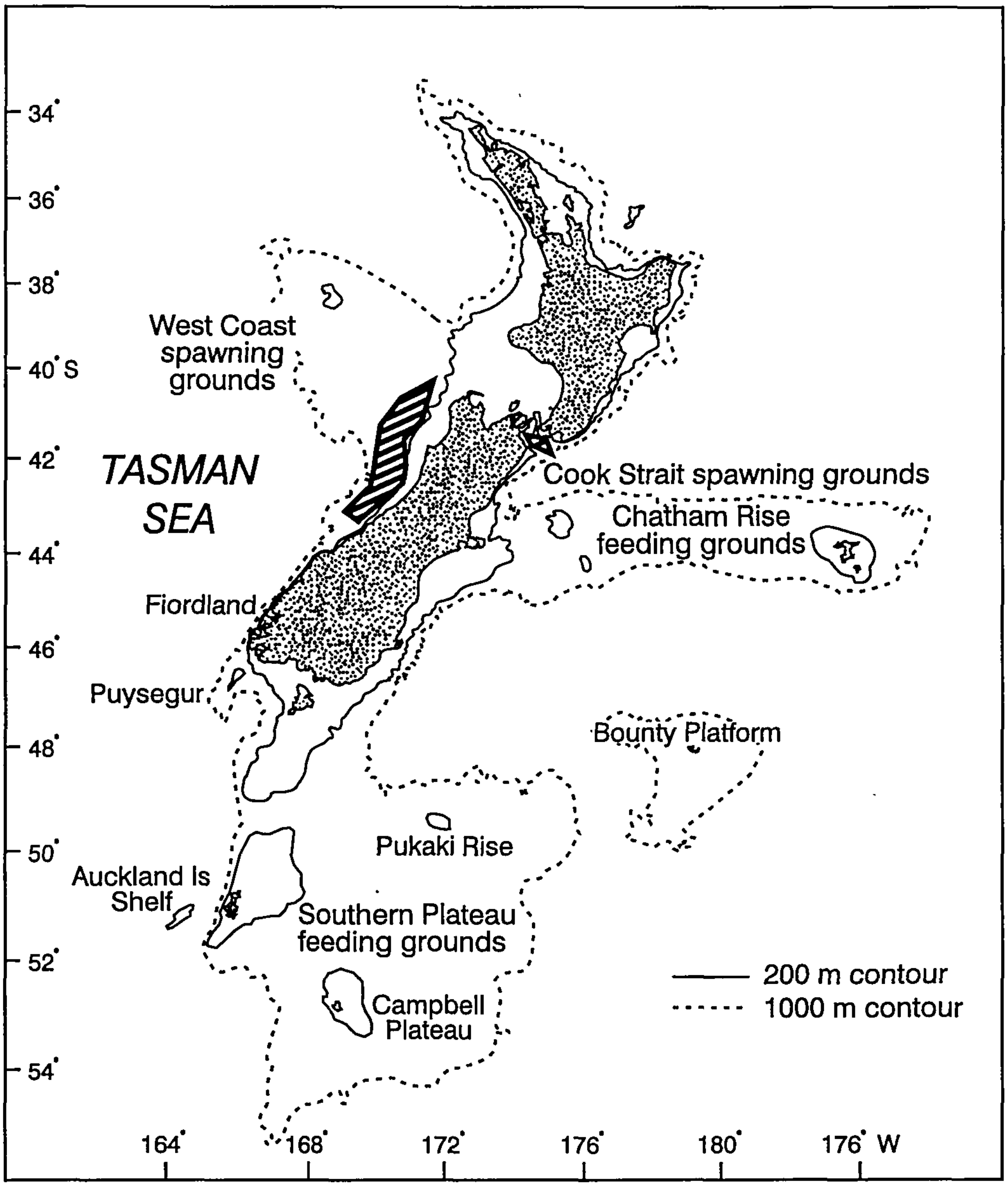

Figure 1: Distribution of hoki (*Macruronus novaezelandiae*) in New Zealand waters.

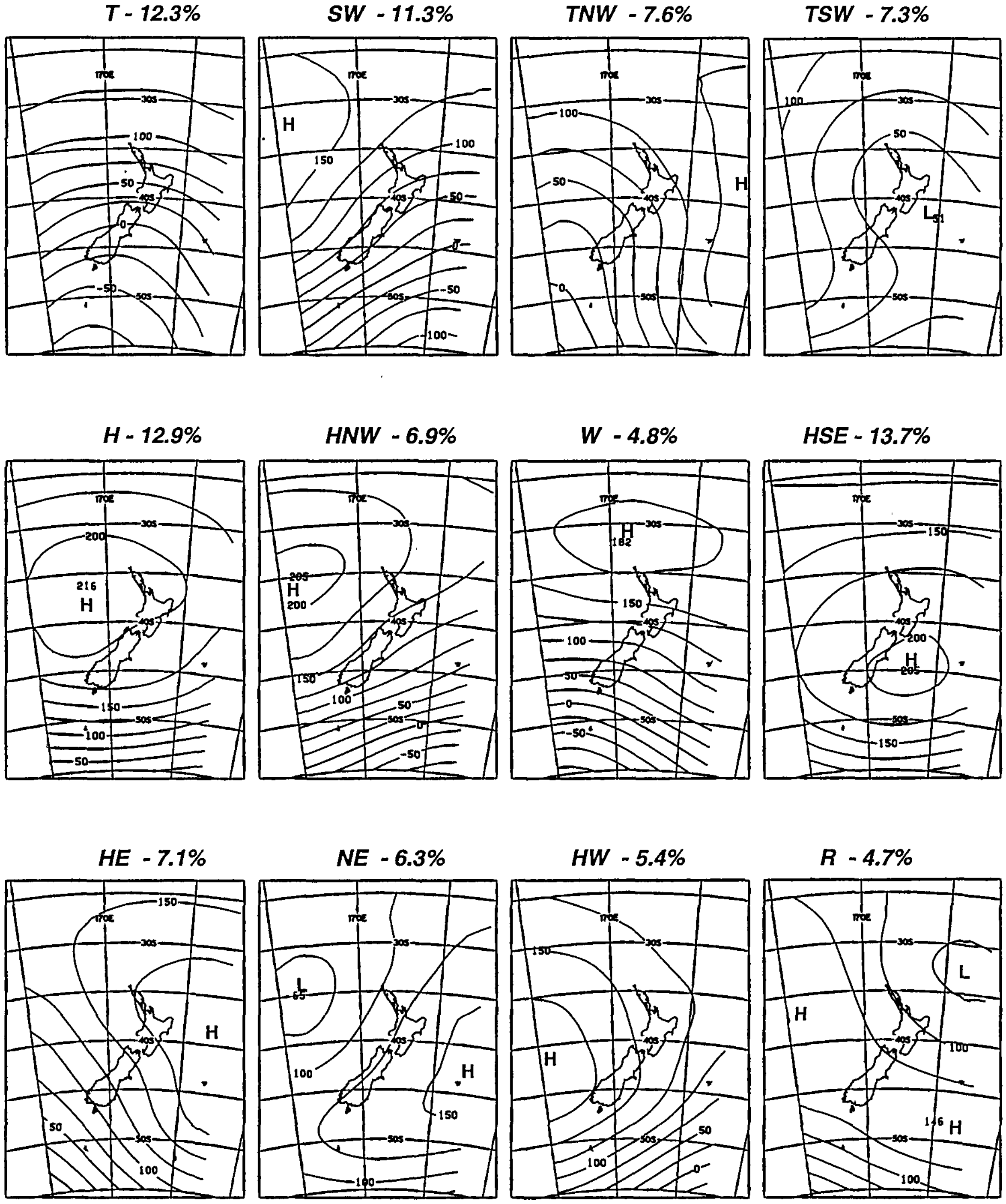

Figure 2: Cluster-mean (height of the 1000 hPa surface) flow patterns used to categorise daily weather types, after Kidson (2000). The contour interval is 25 m. Each day's circulation pattern was categorised as one of the types shown, based on a distance similarity measure. The overall mean percentage frequency of occurrence of each weather pattern is shown above each map, along with the abbreviated label used in the analyses. Abbreviations are: T, trough; SW, southwesterly; TNW, trough/northwesterly; TSW, trough/southwesterly; H, high; HNW, High to northwest; W, westerly; HSE, High to southeast; HE, high to east; NE, northeasterly; HW, high to west; R, ridge.