The effects of bycatch relationships on quota lease prices

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Abstract

Because some species are caught jointly, fishers who want to catch one must own quota for the other. This has both ecological and economic implications. Previous literature on the economics of bycatch includes (Boyce 1996), (Larson, Brett et al. 1998), (Squires, Cambell et al. 1998), (Neher 1988) and (Squires and Kirkley 1995). Most existing literature either theoretically models bycatch relationships or discusses the problems and approaches to management when there are significant bycatch relationships. We focus instead on the market implications. A joint production relationship means that the lease prices of the quota should be related. We test this idea using a specific instance where the bycatch relationship is clear and simple. We use observer data to identify the relationship between hoki and hake catches, both spatially and temporally. This offers a simple 'natural experiment' where the level of bycatch varies across space and time and we can study the effect of this variation on the relationships between the quota lease prices. We first develop a more formal model of the joint determination of lease prices. We use this to develop testable hypotheses about lease price relationships. We then develop the dataset on bycatch intensity and link these data to our other data on quota lease prices and their determinants. Finally we test our hypotheses.

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1 Introduction

Since 1986, New Zealand has managed its commercial fisheries using an individual transferable quota system. Total catches are limited for each fish stock (species in an area). The rights to harvest are allocated to fishers in the form of shares of the total catch. Quotas are allocated in perpetuity but can be leased on an annual basis. For more detail on the history and operation of the system see (Straker, Kerr et al. 2002). This paper is part of a research programme empirically analysing the operation of the system.[1] It builds directly on (Newell, Sanchirico et al. Forthcoming 2004) which looks broadly at the determination of sale and lease prices and features of market operation.

Because some species are caught jointly, fishers who want to catch one must own quota for the other. This makes it more complex for fishers to comply with a quota system because they may catch species that they did not intend to catch and therefore need quota they do not own. If the market worked perfectly, fishers would costlessly buy the quota they need to match their bycatch when they come into port. The market lease prices would reflect good estimates of future needs for and availability of bycatch quota so would allow them to plan their future harvest effort efficiently. Bycatch makes management of a quota system more complex because special rules need to be defined to balance the need to limit the catch of both species while also making it relatively easy and cheap for fishers to comply so that they are not tempted to cheat by discarding or not reporting some bycatch.

The bycatch relationship means that the prices of the two quota would be related in an efficient market. In many situations one species is the more valuable and/or abundant so is generally the ‘target’ species while another (or a group) is the ‘bycatch’. If the bycatch species is attractive to catch in its own right because its export price is high relative to its lease price, the bycatch relationship can improve the value of the target species quota. If in contrast, the bycatch is of low value or the total allowable catch limit is set very low so that it is binding and the bycatch lease price is very high even though the export price is low, then the target species is less valuable than it would be without the bycatch relationship.

[1] For more information on the general programme see Kerr et al (2003) and www.motu.org.nz/nz_fish.htm

When the management problem is simply high transaction costs of acquiring quota, if the market works efficiently, the bycatch management problem is ameliorated. Where the management problem arises because of unfavourable bycatch relationships, the market cannot replace strong enforcement.

We explore the efficiency of the market in responding to bycatch relationships using a broad database on the determinants of lease prices and one specific instance where the bycatch relationship is clear and simple. We use observer data to give the relationship between hoki and hake catches.[2] This offers a simple natural experiment where the level of bycatch varies across species, fish stocks and time and we can study the effect of this variation on the relationships between the quota and export prices.

We first develop a more formal model of the joint determination of lease prices. We use this to motivate testable hypotheses about export price and quota lease price relationships.[3] Then we describe our data on quota lease prices and their determinants with particular emphasis on the data on bycatch intensity. In section 4 we discuss both time series and panel analysis of the data. We conclude in section 5.

1.1 Literature review

Previous literature on the economics of bycatch includes (Boyce 1996), (Larson, Brett et al. 1998) and (Squires, Cambell et al. 1998). Bycatch is due to the fact that most fishing gear and practices are not perfectly selective for target species and is also a consequence of overlap in the range and distribution of target and other fish species.

(Boyce 1996) uses a theoretical model to show how bycatch TACs can be set optimally. He also shows that both species can be optimally fished under an individual transferable quota system if both the target species and the bycatch species have tradable quotas. In the case we study, Hoki and Hake, both species are included in the QMS. (Larson, Brett et al. 1998) use data from the Bering

[2] Hoki and Hake are often caught as part of a mixed trawl but we focus on the relationship among these two only.
[3] Our period of analysis ends before the ACE system is implemented so we always refer to leases rather than ACE transactions.

Sea/Aleutian Islands region of the North Pacific Ocean to estimate "optimal" bycatch rules using a multispecies joint production model.

(Annala 1996), (Squires, Cambell et al. 1998) and (Batstone and Sharp 1999) discuss the problems associated with bycatch in the New Zealand context and the solutions that have been used. (Annala, Sullivan et al. 1991) discusses the problems encountered in the first couple of years of the QMS, particularly the issue of bycatch with reference to Hoki/Hake, Alfonsino/Bluenose and Flatfish fisheries. In the early period of the QMS, bycatch problems were mostly experienced in inshore fisheries because the TACs set initially in 1986 were not set in proportion to pre-QMS landing levels and because of natural variation in stock size ((Annala, 1996). The occurrence of TAC overruns has decreased since the late 1980s. (Annala 1996) suggests that this has resulted from fishers adjusting their catch mix and methods of operation as they have become more experienced with the QMS. Industry has also actively encouraged the reduction of TAC overruns for bycatch species by introducing codes of practice in some fisheries ((Annala, 1996).

In contrast to earlier work, our paper empirically examines the effects on quota lease markets of the bycatch relationship between two species.

1.2 Bycatch rules

Under the Fisheries Act 1983 five defences were available to fishers who caught catch in excess of 10% of the value of their quota holdings:

1. Purchase or lease additional quota to cover the catch (by the end of the month); or
2. Record the catch against another's quota; or
3. Catching up to 10% in excess of their ITQ for a given species for a given year or carrying over up to 10% of their ITQ to the following year; or
4. Trade-off quota against other species, where possible[4]; or
5. Surrender the catch to the Crown and default the value or a proportion of it to the Crown.

[4] This scheme operates only for selected inshore species in certain areas and is not permitted in the deep-water fisheries Annala, J. H. (1996). "New Zealand's ITQ system: have the first eight years been a success or a failure?" Reviews in Fish biology and Fisheries **6**(1): 43-62.

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The bycatch trade-off scheme allowed fishers who caught in excess of their quota holdings to legally sell the catch, and in exchange lease back to the government an economically equivalent quantity of unfished ITQ for another species. The use of the catch/quota trade-off provisions increased rapidly in 1987-1988 and was the main reason that the number of fishstocks in which TACs were exceeded increased ((Annala, Sullivan et al., 1991). The inclusion in the ITQ system of some species with a high TAC and a large amount of uncaught quota resulted in “quota banks” which could be used to overfish other species.

The option of surrendering 100% of the port price paid for the bycatch to the government provided no incentive for fishers to land the catch, prompting the 1990 amendment that provided for ‘deemed values’ to be set at a percentage of the port price. Since 1990, if a fisher lands bycatch he can either buy quota to match his catch or pay a deemed value set by the government. The purpose of the deemed value system is to give fishers an economic incentive to land and sell excess catch rather than dumping it. Fishers are billed for the deemed value of the fish. Because of the distorting effect that the deemed value could have on the quota market, it is set higher than the quota lease price. The difference between the market price received by the fisher and the deemed value paid to the government is known as the incentive price. In effect, the deemed value places an upper bound on the quota lease price.

The Fisheries Act 1996 introduced a new catch balancing regime. However this did not come into operation until 2000/2001 and so is not relevant to our study period. This system is designed to provide incentives for fishers to cover all their catch of QMS fishstocks with an Annual Catch Entitlement (ACE). Each quota share generates an annual right to catch a specified amount of the relevant fishstock. This legislation requires annual balancing with monthly reporting of catch and balancing of catch within the month. If a fisher does not have enough ACE on the 15th of each month the Ministry of Fisheries will send a bill for the deemed value. The fisher has the rest of the year to acquire ACE to cover this overage. If this is achieved, the fisher receives back the deemed value and if not, the money remains with the government ((Clement & Associates, 2003).

2 Theory

Two species are caught jointly because they have similar geographic distribution and behavioural characteristics. This makes harvesting like a joint production function where one species is a byproduct of the production process of another. The 'Target species' is the species the fisher focuses effort on that because he believes he will get the most value from it. It may not be most valuable per ton; it may be more abundant. In reality, in many cases the fisher may jointly optimise so neither is strictly the target. This is particularly true when the fisher can influence the rate of bycatch by choosing the location, timing and technology used to harvest. In the experiment we are studying, Hoki is usually the target species. Hoki is not the target because it is most valuable per tonne but because it is much more abundant. In Table 1 we see that Hake is sometimes targetted but nearly all Hoki and most Hake is caught when Hoki is targetted.

2.1 Two species bycatch model

2.1.1 Simple deterministic model

We focus on a simplified problem that approximates our empirical situation. The catch of the bycatch species is determined by the chosen level of catch of the target. α_{ij} is a measure of the intensity of jointness of production relationship equal to catch of bycatch per unit of catch of target. The fisher cannot alter these relationships. We assume that the ITQ market works perfectly. It is competitive and has no transactions costs. Thus we can assume there is one representative fisher solving the market problem with no loss of generality. $\overline{Q}_i$ is the TAC for species i. λ_i are the shadow values on each TAC limit. l_i is the lease price for species i which in a deterministic world is equal to the shadow value (Montgomery 1972).

The representative fisher solves the following problem.

$$Max_{q_i,q_j}\ p_i q_i + p_j \alpha_{ij} q_i - c_i q_i + p_j q_j + p_i \alpha_{ji} q_j - c_j q_j \qquad (1)$$

$$\text{s.t.} \quad \begin{aligned} \overline{Q}_i &\geq q_i + \alpha_{ji} q_j \\ \overline{Q}_j &\geq q_j + \alpha_{ij} q_i \end{aligned}$$

p_i =export price for species i

q_i =quantity of species i caught when i is target

c_i = marginal cost of catching species i when i is target.

α_{ij} = ratio of bycatch j to target species i.

From the Lagrangean the first order conditions tell us that

$$\frac{\partial L}{\partial q_i} = p_i - c_i - \lambda_i + p_j \alpha_{ij} - \lambda_j \alpha_{ij} \geq 0 \qquad (2)$$

$$\frac{\partial L}{\partial q_j} = p_j - c_j - \lambda_j + p_i \alpha_{ji} - \lambda_i \alpha_{ji} \geq 0 \qquad (3)$$

From these we can infer that either $\lambda_i = 0$ or

$$\lambda_i = p_i - c_i + \alpha_{ij}(p_j - \lambda_j) \qquad (4)$$

and either $\lambda_j = 0$ or

$$\lambda_j = p_j - c_j + \alpha_{ji}(p_i - \lambda_i) \qquad (5)$$

Thus, from (4), if the total allowable catches are binding it seems that we should observe that, for a fixed lease price, the export price of hake (j) should positively affect the hoki lease price. The effects of i on j is symmetric.

From (5), however, we see that there is a direct relationship among λ_j, p_j and c_j. We can substitute (5) into (4) to find:

$$\lambda_i = p_i + \frac{(c_j \alpha_{ij} - c_i)}{(1 - \alpha_{ij}\alpha_{ji})} \qquad (6)$$

If the target is binding, the partial derivative $\frac{\partial \lambda_i}{\partial p_i} = 1$ which is the same as in a world with no bycatch. $\frac{d\lambda_i}{dp_j} = 0$ because any change in p_j is perfectly offset by a change in λ_j. In this simple world, export prices of the target species should not affect the bycatch species lease price.

The effects of changes in costs are more complex.

$$\frac{\partial \lambda_i}{\partial c_i} = -\frac{1}{(1 - \alpha_{ij}\alpha_{ji})} \qquad (7)$$

If there is no bycatch relationship in either direction, costs are reflected one-for-one in lease prices. As the strength of either bycatch relationship grows, the negative effects of costs are exacerbated. Intuitively, when c_i rises it becomes relatively more attractive to catch i as bycatch rather than target and to catch j as target rather than bycatch. Targetting j will tend to increase the catch of j and reduce the catch of i.

Given that total catches are limited (assuming the TACs are binding) quota prices must adjust to restore the balance in catches between the species. The response of the lease price of j to the cost of targetting i is the opposite in sign and proportionately smaller.

$$\frac{\partial \lambda_j}{\partial c_i} = \frac{\alpha_{ji}}{(1-\alpha_{ij}\alpha_{ji})} > 0 \tag{8}$$

Higher costs for one species raise the value of the quota of the other species. Overall, the quota lease price for j rises and the quota for i tends to fall.

Several realistic complications to our model alter these conclusions. Three complexities arise relative to this simple model: targets may not be binding; expected export prices may differ from current prices; there may be competition for resources across species. Unobservable cost shocks may also create a non-causal relationship between lease prices and export prices of interrelated species.

2.1.2 Non-binding targets

First, the lease market operates during the year and is based on expectations about future export prices and catches. Fishers need to form some expectation about whether the target is likely to bind. It is relatively rare to find zero lease prices even where the targets are consistently non-binding. Thus the actual lease price might reflect a weighted average of its non-binding value (zero) and its binding value where the weights depend on the expected probability of binding.

To explore this we define l_i as the lease price. $l_i = \rho_i \lambda_i$ where ρ_i is the probability that the TACC for species i is binding. $\rho_i \le 1$ and $\rho_i = \rho_i(\lambda_i)$ and $\frac{\partial \rho_i}{\partial \lambda_i} > 0$. Equation (6) becomes

$$l_i = \frac{\rho_i [p_i(1-\rho_j \alpha_{ji}\alpha_{ij}) + \rho_j \alpha_{ij} c_j - c_i + p_j \alpha_{ij}(1-\rho_j)]}{(1-\rho_i \rho_j \alpha_{ji}\alpha_{ij})} \tag{9}$$

If the target species quota becomes more binding for any reason unrelated to export prices or costs (such as a fall in TACC), i.e. ρ_i rises with no change in other variables, we would expect the hoki lease price to rise. If the bycatch species quota becomes more binding, the target lease price will fall.

If we now consider the response of l_i to a change in p_i, if $\alpha_{ij} = \alpha_{ji} = 0$ then it is equal to ρ_i <1. If α_{ij} and α_{ji} are positive, the own-price response is even lower.

$$\frac{\partial l_i}{\partial p_i} = \frac{\rho_i (1 - \alpha_{ji}\alpha_{ij})}{(1 - \rho_i \alpha_{ji}\alpha_{ij})} \tag{10}$$

When we take into account the fact that ρ_i depends on λ_i we find that the total response of l_i to p_i is larger than the partial effect.

$$\frac{dl_i}{dp_i} = (1 + l_i \frac{\partial p_i}{\partial \lambda_i})\frac{\partial l_i}{\partial p_i} \tag{11}$$

The partial effect of the bycatch export price, p_j, on the target lease price, p_i, is

$$\frac{\partial l_i}{\partial p_j} = \frac{\rho_i \alpha_{ij} (1 - \rho_j)}{(1 - \rho_i \rho_j \alpha_{ji}\alpha_{ij})} > 0 \tag{12}$$

because the positive effect of higher valued bycatch is not fully offset by the higher lease price for bycatch. The total differential is higher still because of the positive feedback through the higher probabilities of the target species TACC being binding.

$$\frac{dl_i}{dp_j} = (1 + l_i \frac{\partial p_i}{\partial \lambda_i})\frac{\partial l_i}{\partial p_j} \tag{13}$$

The possibility of non-binding quota also alters the marginal effects of costs. The absolute value of the own-cost response is smaller when there is uncertainty about whether the TACC binds.

$$\frac{\partial l_i}{\partial c_i} = -\frac{\rho_i}{(1 - \rho_i \rho_j \alpha_{ij}\alpha_{ji})} > \frac{\partial \lambda_i}{\partial c_i} \tag{14}$$

It becomes smaller in absolute value than ρ_i as the strength of the bycatch relationship grows. Again, taking the total differential amplifies the effect through the indirect effect on the probability that the target finds.

$$\frac{\partial l_i}{\partial c_j} = \frac{\rho_i \rho_j \alpha_{ij}}{(1 - \rho_i \rho_j \alpha_{ij}\alpha_{ji})} < \frac{\partial \lambda_i}{\partial c_j} \tag{15}$$

The effect of the bycatch cost on the target species is still positive but is lower when there is uncertainty about whether quota binds. It does not matter which quota species is potentially non-binding. Again the total differential is amplified.

2.1.3 Changes in expected export prices

The value of the lease does not respond only to current export prices but depends on expected profitability in the remaining part of the year.[5] The export prices that affect lease prices are a combination of export prices that have already been observed and export prices that are expected later in the year. If there are correlated export price shocks, and price changes are correlated over time then there might be an effect of one species export price on another's lease price purely through an expectations effect. We might expect that average export prices are an indicator of future export prices for this stock as well. If the Hoki export price is a strong 'indicator price' in the sense that its current export price shock is strongly correlated with future export price shocks for other species then it could have an effect on the lease prices of other stocks.

2.1.4 Competition for resources

The third complication is that although there may be no bycatch relationship between hoki and any other species, the production processes may still be interrelated. Hoki and Hake are offshore species. Thus they compete for a stock of capital and labour for offshore fishing that is relatively fixed in the short term. A short term shock to Hoki export prices that leads to higher Hoki harvests could raise the costs of catching other fish. This would suggest that a higher Hoki export price would lower the quota value of other offshore species.

More generally, if the average export price rises for all stocks, then we would expect that, controlling for the stock's own export price, the lease price will fall.

[5] For more analysis of this see Hendy, J. and S. Kerr (2003). How do catch patterns respond to changes in international prices for different species? Wellington, Motu Economic and Public Policy Research.

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2.1.5 Lease prices relative to export prices as indicator of common cost shocks

Finally, an econometric issue makes relationships between lease prices and export prices likely. Fishing costs are driven by factors such as diesel prices, labour costs, weather and fish abundance. Changes in costs are probably correlated across species.

We observe lease prices and export prices but not costs. Thus if one species' lease price rises relative to the export price for that species, it probably indicates not only that the cost of harvesting that species has fallen, but also that the cost of harvesting others has fallen. This effect will be strongest on species with similar cost structures. For example changes in hoki costs are likely to most highly correlated with the costs for other offshore species such as orange roughy. Thus we might expect that, holding 'own export price' constant, a rise in hoki lease prices might raise the value of other lease prices and that this effect would be more pronounced for offshore species.

3 Data

The unit of observation for this analysis is quarterly by stock for the period 1986-2001. Most data comes from (Newell, Sanchirico et al. Forthcoming 2004) and is described in more detail below. Also discussed below is additional catch effort data for hoki and hake was obtained from the Ministry of Fisheries.

Hoki/hake bycatch data

Hoki is a long-tailed hake found around New Zealand and Australia. The fish aggregate during winter (July-August) on spawning grounds on the west coast of the South Island (QMA7). The TAC for hoki was increased to 250,000t in 1986, which resulted in the rapid development of the fishery. With the increase in hoki catches in recent years, the bycatch of other non-target species (particularly hake, ling and silver warehou) has become a problem. The proportion of bycatch species is usually less than 5% of the total catch in the hoki fishery. Scientific observers aboard trawlers have measured the bycatch of hake during the hoki spawning season. The rate of bycatch varies, but averaged 2-3% over the whole season ((Annala, Sullivan et al., 1991). The TAC for hake increased in 1987 to 3,000t as it was considered undesirable to constrain the development of the hoki fishery by the level of by-catch of hake. Hoki quota holders were given a realistic quantity of hake quota to cover genuine bycatch. A certain amount of target fishing for hake is likely to occur, as this is a preferred high-value species ((Annala, Sullivan et al., 1991).

The observer catch effort data shows the amount of catch of hoki and hake by trawl on a daily basis for the period 11 May 1986 through to 29 November 2002 and which species was being targetted. This data was aggregated by month and two bycatch intensity ratios were constructed; one showing the catch of hake when hoki was the target, the other showing the catch of hoki when hake was the target. In instances where the bycatch was greater than the stated target the presumed target has been reversed, hence the bycatch intensity variables takes a value between zero and one. Table 2 presents the bycatch intensity variable and Figures 7 through to 9 show the ratio of hake (bycatch) to hoki (target). As expected, the bycatch of hake averages 12% of the hoki catch in QMA7 which is the hoki spawning ground. Figures 10 to 12 show the ratio of hoki caught in each QMA when hake is the target.

The following discusses the (Newell, Sanchirico et al. Forthcoming 2004) dataset that contains data acquired from the New Zealand Ministry of Fisheries on all individual leases between quota holders from when the program began in late 1986 through 2001 – more than 170,000 transactions altogether.

Lease transaction prices

The transactions dataset contains the price per ton of quotas leased, the relevant fish stock, and the transaction date; lease prices were available for 151,835 leases. Some of the lease price data were unreliable because the transaction was not arms-length or was misreported. In all, we omitted 30% of lease observations that did not represent 43 reliable market transactions.[6] After adjusting for inflation using the PPI, we calculated the quarterly average lease

[6] We omitted all prices for transactions that were not between economically distinct parties, and for leases from the Treaty of Waitangi Fisheries Commission (which are deliberately discounted). We also omitted lease prices less than $1 per ton, sale prices less than $20 per ton, as well as a small number of prices that were unreasonably high (which likely contain other assets). We also omitted prices for bundled transactions involving multiple types of quota, where the reported price was simply a constant average value for all quota. In any event, whether or not we omitted observations did not alter the qualitative results, and it changed the quantitative magnitudes only to a small degree.

price for each fish stock. We also counted the number of transactions used in the creation of each quarterly average for use in our econometric estimation, which employs this number of underlying transactions as a statistical weight. Due to a number of missing observations in the dataset, it was necessary to assign values to 2,319 missing observations in the lease price series.[7] This was achieved by interpolating the missing values using a regression on a time trend and quarterly dummies for each fish stock. Any stock with more than six interpolated values was then excluded. The following stocks were also dropped from the analysis due to a lack of export price data: Dredge Oysters (OYS), Bass (HPB) and Stargazer (STA). Table 4 presents the average quota lease prices for hoki and hake over the period 1986-2001. Figure 2 and Figure 3 show real and logged monthly trends in the hoki and hake lease prices respectively. Figures 4, 5 and 6 show the variation in the monthly lease price of hake in each QMA as well as the hoki lease price.

Export Prices

As a measure of the value of each fish species, we calculated its export price per greenweight ton using data from Statistics New Zealand over the period 1986–1999. After adjusting for inflation using the PPI, we created a quarterly export price by dividing the FOB revenue for each species by the greenweight tonnage of product. We computed the greenweight tonnage by multiplying exported tonnages—by product type (e.g., whole, fillets, lobster tails)—by official Ministry of Fisheries conversion factors ((Clement & Associates, 2003), and then summing these for each species. Table 5 shows the average export prices for hoki and hake for the 1986-2001 period.

Fishing Costs

Using data from Statistics New Zealand, we constructed an index of New Zealand fishing costs over time using the rates of change in real (PPI-deflated) labor and material (including fuel) costs for fishing, weighted by their shares in total variable costs (25% labor and 75% materials (including fuel), according to New Zealand fishing industry contacts).

TAC and Actual Catch

[7] Many of these missing values were attributable to species that had not entered the quota system at a point in time.

Both the total allowable commercial catch and the actual catch for each fish stock over time are from the New Zealand Ministry of Fisheries. The variable *pcatch* is the percentage of the TAC caught in the previous year. The variable *pqcumulcatch* is the year-to-date percentage of the TAC caught above the previous year. The variable *lnqexpricepcat* is a interaction term between the logged export price and the percentage of the TAC caught in the previous year.

Real GDP

The real GDP growth rate for New Zealand is from Statistics New Zealand.

Ecological Variables

As a measure of climate variation, we obtained monthly values for the Southern Oscillation Index from the Australian Bureau of Meteorology, from which we computed quarterly averages (http://www.bom.gov.au/climate/current/soihtm1.shtml). We classified fish stocks as to whether they faced significant initial catch reductions under ITQs by using historical information on catch rates, TAC levels, and references in the literature ((Annala, Sullivan et al. 2000);(Clark, Major et al. 1988); (Major 1999); (Clement & Associates 1997)). The following 33 fish stocks were so classified: CRA1-5, CRA7-8, BNS2, ELE3-5, JDO1, MOK1-3, ORH2B, SCH1-3, SCH5, SCH7-8 SKI3, SNA1-2, SNA8, SPO1-3, SPO7-8, TRE1, HPB2-3.

3.1 Time series analysis of lease price data

In this section, we focus on the long-run properties of quota lease prices. We examine the long-run links between hoki and hake quota lease prices across QMA. If the lease price series exhibit stationarity then we can legitimately use the data in the subsequent panel models. In contrast, if the data were found to be non-stationary, then its use in panel regressions would give spurious results.

3.1.1 Univariate Time Series Properties

We examine the univariate time series properties of the lease price data. We do this by conducting unit root tests to establish whether the series are stationary, i.e. integrated of order zero [I(0)], or non-stationary, i.e. integrated of order one [I(1)]. If the former, this suggests that the effects of shocks are transitory; if the latter, the effects of shocks are permanent. Stationarity is tested for in both an average (across the three QMA) hake lease price, and the hake lease price in QMA1, QMA4 and QMA7.

Table 8 tests for the order of integration of the quota lease prices. The four columns test for stationarity for each series respectively in: levels with deterministic trend and constant, levels with constant only, first difference with constant, and first difference without constant. The Augmented-Dickey Fuller (ADF) test is used in conjunction with SIC for selecting the lag length. The figures for the ADF test are p-values on the test to reject the null hypothesis of a unit root (i.e. non-stationary). Overall the tests indicate that the lease price series are I(0) (i.e. stationary) with a deterministic trend.

4 Estimation and Results

We identify the effects of bycatch on lease price relationships by using species that do not have a bycatch relationship with Hoki as a control group.

4.1.1 Econometric Specification

We use the same general econometric specification and error structure as (Newell, Sanchirico et al. Forthcoming 2004). We also include all the stock-specific variables they use to predict lease prices. We include fixed effects for seasonal effects (months) and fish stocks. We include species specific controls for quarters (within a fishing year) and years. Thus we do not include their variables where they change only across time or across stocks.

To explore the effects of other species export prices on lease prices we include the average quota export price for the whole industry (weighted by volume). This should capture the effects of export price expectations and competition for resources. We then include the hoki export price on its own as well as interacted with offshore species, because the competition should be more acute there, and hake, because of the bycatch relationship.

We cannot directly observe costs but do observe lease prices. We know that lease prices respond negatively to costs and given that the effects of export prices and other own-species effects are already controlled for, we assume that the remaining effect of lease prices results from cost shocks. Thus a negative coefficient on lease prices should be interpreted as a positive coefficient on costs. We include average lease prices for the industry to account for common export price shocks. We then include the hoki lease price on its own as well as interacted with the offshore species, because costs should be more highly correlated, and with hake, because of the bycatch relationship.

Finally we control for the direct effect of an increase in the probability that the Hoki quota binds. We also interact this with Hake because of the bycatch relationship.

4.1.2 Results

The results largely accord with our theoretical expectations and are shown in Table 3. Own export price and own probability-of-binding effects are positive. Other export prices have a negative effect which suggests that competition for resources outweighs any expectations effects. Curiously the hoki export price has a positive effect on all lease prices. This disappears and in fact goes negative (though insignificant) when looking at offshore species where the competition with hoki for resources is likely to be most acute. The effect of the hoki export price on the hake lease price is positive and in one specification significant. This is as expected.

Average lease prices seem to increase lease prices which is consistent with our idea that they reflect a fall in costs that might be correlated across species. The Hoki lease price has a stronger positive effect, and the strongest effect still on offshore species where we would expect costs to be highly correlated with hoki costs. The effect of the Hoki lease price on hake is lower than on other species (though insignificantly). This is consistent with theory though a very weak result.

When the hoki catch seems more likely to bind all lease prices seem to fall. This affect is more acute on Hake, as we would expect from the theory.

5 Conclusion

We find clear evidence on interactions among stocks in the quota lease market. Some of these relationships seem to relate to bycatch relationships. Both the theory and empirical results support a positive effect of bycatch export prices on the target species lease price; a positive effect of a fall in bycatch costs on target lease prices; and a negative effect of an increase in the probability that the TACC of the bycatch binds on target lease prices.

This suggests that the markets are responding appropriately to bycatch relationships. This may suggest that they are relatively optimally allocating bycatch across fishers and even time. It suggests that using price and market signals to control bycatch may have efficiency advantages.

- ## Tables

Table 1 Hoki-Hake Bycatch relationship

	Hoki is target	Hake is target
Hoki catch	790m tonnes	2.5m tonnes
Hake catch	21m tonnes	9.3m tonnes

Source: Ministry of Fisheries Observer Data

Table 2 Bycatch intensity variable by QMA

Variable	Mean	Std. dev.	Min.	Max.
Bycatch of hake when hoki is the target:				
QMA1	0.07	0.12	0	1.00
QMA4	0.05	0.10	0.00009	1.00
QMA7	0.12	0.19	0.00002	1.00
Bycatch of hoki when hake is the target:				
QMA1	0.40	0.30	0.002	1.00
QMA4	0.38	0.29	0.02	1.00
QMA7	0.40	0.31	0.0003	1.00

Table 3 Regression results

Variables		(1)	(2)
Own fish stock	Logged fish export price	0.248***	0.244***
		(5.86)	(5.78)
	Logged fish export price, squared	0.069***	0.071***
		(3.74)	(3.85)
	(Logged export price)*(prior year % caught of TAC)	0.131***	0.134***
		(4.53)	(4.61)
	Prior year %caught of TAC	0.396***	0.400***
		(11.67)	(11.81)
	Prior year %caught of TAC, squared	-0.207***	-0.210***
		(9.06)	(9.20)
	Year-to-date %caught of TAC above prior year	0.078*	0.076*
		(1.85)	(1.79)
	Year-to-date %caught of TAC above prior year, squared	-0.042	-0.039
		(0.90)	(0.84)
Other stock export prices			
Expectations and competition for resources	Logged average quota export price	-0.378***	-0.406***
		(3.91)	(4.18)
	Logged hoki export price	0.143**	0.112*
		(2.48)	(1.90)
	(Logged hoki export price)*(offshore species)	-0.151	-0.164
		(1.42)	(1.55)

Bycatch	(Logged hoki export price)*(hake)	0.565**	0.363
		(2.09)	(1.30)
Effects of cost			
Costs falling	Logged average quota lease price	0.079**	0.039
		(2.51)	(1.17)
	Logged hoki lease price	0.049***	0.057***
		(2.58)	(2.95)
Cost of similar species falling	(Logged hoki lease price)*(offshore species)	0.125***	0.127***
		(3.37)	(3.42)
Cost of bycatch falling	(Logged hoki lease price)*(hake)	-0.055	-0.047
		(0.51)	(0.44)
Extent to which bycatch quota binds	(hoki catch/TACC)*(hake)		-1.491***
			(2.95)
	hoki catch/TACC		-0.239***
			(2.59)
Controls for season, year and stock fixed effects	Seasonal effects	*jointly significant*	*jointly significant*
	Fish stock fixed effects	*jointly significant*	*jointly significant*
	Annual fixed effects	*jointly significant*	*jointly significant*
	Species specific quarterly dummy	*jointly significant*	*jointly significant*
	Species specific annual dummy	*jointly* significant	*jointly* significant
Constant		6.386***	6.938***
		(6.01)	(6.45)
Observations		5933	5933
R-squared		0.97	0.97
F		255.33	255.28

Absolute value of t statistics in parentheses
significant at 10%; ** significant at 5%; *** significant at 1%

Table 4 Average quota lease prices for Hoki and Hake (1986-2001)

Variable	Mean	Std. dev.	Min.	Max.
Hoki lease price	220	170	21	880
Hake lease price (QMA1)	494	233	12	1240
Hake lease price (QMA4)	521	168	82	972
Hake lease price (QMA7)	822	415	64	1868

Table 5 Average export prices for Hoki and Hake (1986-2001)

Variable	Mean	Std. dev.	Min.	Max.
Hoki export price	1,885	475	783	3,415
Hake export price	3,392	933	933	7,533

Table 6 Catch as a percent of TACC

Fishstock	Catch as a percent of TACC
Hoki	91
Hake1	85
Hake4	74
Hake7	115

Table 7 Descriptive statistics for determinants of quota prices

Variable	Mean	Std. dev.	Min.	Max.
Lease price ($/ton)	1,725	4,289	1	43,663
Export price ($/ton)	8,450	11,587	312	60,263
Catch (tons/year)	1,892	4,459	0	53,872
Total allowable commercial catch (tons/year)	2,759	7,240	1	75,815
Percentage catch	-0.29	0.39	-1.00	4.10
Percentage cumulative catch over prior year	0.01	0.14	-1.07	4.71
Southern Oscillation Index	-2.6	10.3	-23.7	15.5
Fishing cost index	0.86	0.05	0.79	1.00
GDP annual growth rate	0.02	0.02	-0.02	0.07
Number of leases per quarter	12	17	0	194
HokipriceXhake	0.11	0.74	0	6.68
HokiexpriceXhake	-0.03	0.22	-2.10	0
HokipriceXoffshore	1.56	2.38	0	6.68
HokiexpriceXoffshore	-0.47	0.72	-2.10	0

Table 8 Unit Root tests on Ln(Lease Quota Prices)

Fish stock	Level (Trend & Constant)	Level (Constant)	1st Difference (Constant)	1st Difference
*ADF**	SIC	SIC	SIC	SIC
Hoki	0.074	0.029	0.000	0.000
Hake	0.000	0.000	0.000	0.000
Hake (QMA1)	0.000	0.698	0.000	0.000
Hake (QMA4)	0.000	0.000	0.000	0.000
Hake (QMA7)	0.000	0.000	0.000	0.000

* p-value for augmented Dickey-Fuller test using the Shwartz Information Criterion (SIC) to select lag length.

Figures

Figure 1 Summary of hypotheses from theory

	$\frac{\partial l_i}{\partial p_i}$	$\frac{\partial l_i}{\partial p_j}$	$\frac{\partial l_i}{\partial c_i}$	$\frac{\partial l_i}{\partial c_j}$	$\frac{\partial l_i}{\partial \rho_i}$	$\frac{\partial l_i}{\partial \rho_j}$
Binding targets: no bycatch	1	0	-1	0		
Binding targets: bycatch	1	0	$-\frac{1}{(1-\alpha_{ij}\alpha_{ji})}$	$\frac{\alpha_{ij}}{(1-\alpha_{ij}\alpha_{ji})} > 0$		
Non-binding targets: no bycatch	ρ_i $\frac{dl_i}{dp_i} = (1 + l_i \frac{\partial p_i}{\partial \lambda_i})\rho_i$	0	$-\rho_i$ $-(1 + l_i \frac{\partial p_i}{\partial \lambda_i})\rho_i$	0	$p_i - c_i$	0
Non-binding targets: bycatch	$\frac{\rho_i(1-\alpha_{ji}\alpha_{ij})}{(1-\rho_i\alpha_{ji}\alpha_{ij})} < 1$	$\frac{\rho_i\alpha_{ij}(1-\rho_j)}{(1-\rho_i\rho_j\alpha_{ji}\alpha_{ij})} > 0$	$-\frac{\rho_i}{(1-\rho_i\rho_j\alpha_{ij}\alpha_{ji})}$	$\frac{\rho_i\rho_j\alpha_{ij}}{(1-\rho_i\rho_j\alpha_{ij}\alpha_{ji})}$	$\lambda_i + \frac{\rho_j\alpha_{ij}\alpha_{ji}}{(1-\rho_j\alpha_{ij}\alpha_{ji})^2}$	Complex <0
Expected prices	>1	>0				
Competition for resources		<0				
Correlated costs				<0		
Overall	>0 and around 1	Ambiguous More negative with similar stocks	<0	Ambiguous More negative with similar stocks	>0	Ambiguous Close to zero

Figure 2 Trends in quota lease prices for hoki and hake

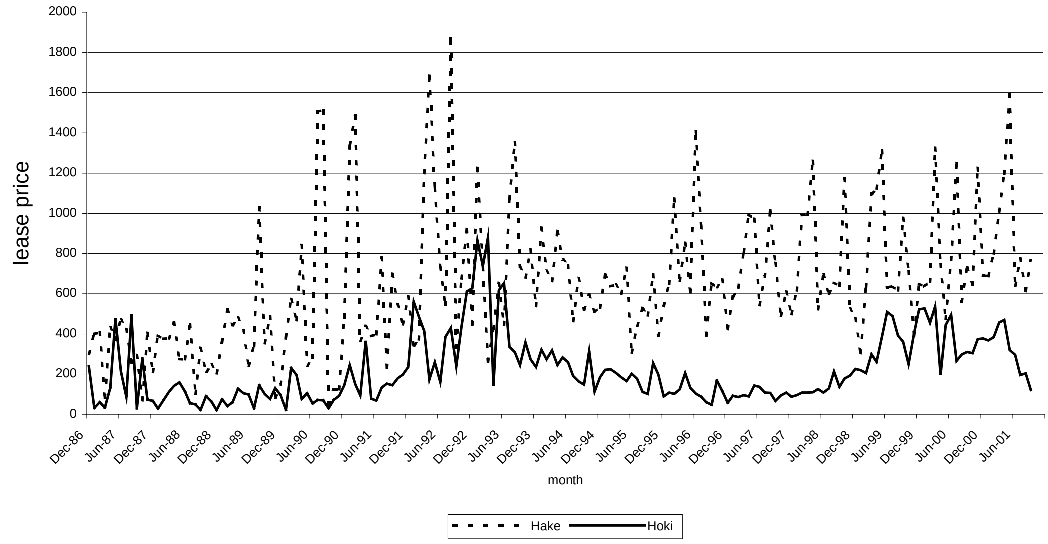


Figure 3 Trends in quota lease prices for hoki and hake (log)

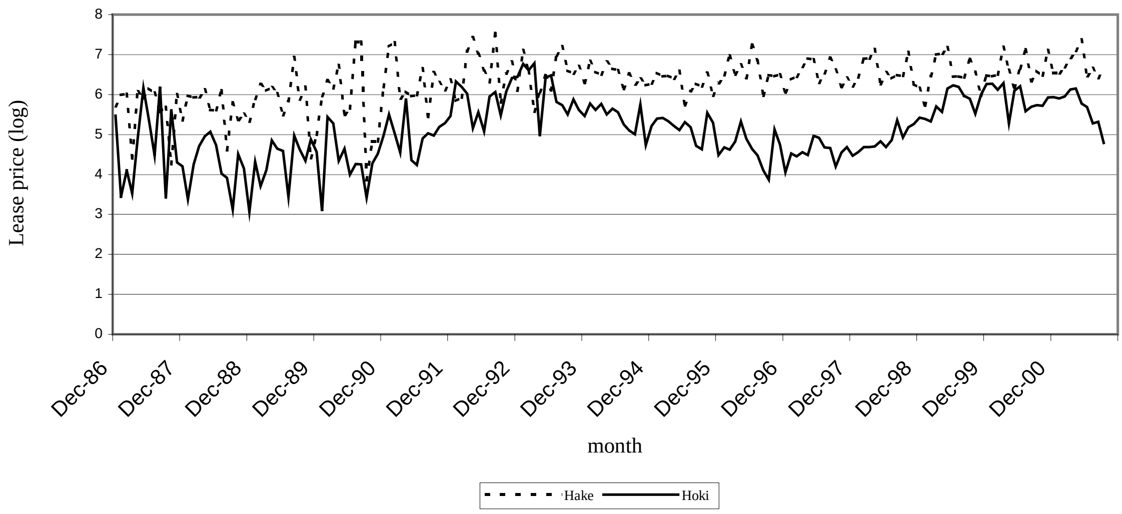


Figure 4 Trends in quota lease prices for hake (QMA1) and hoki

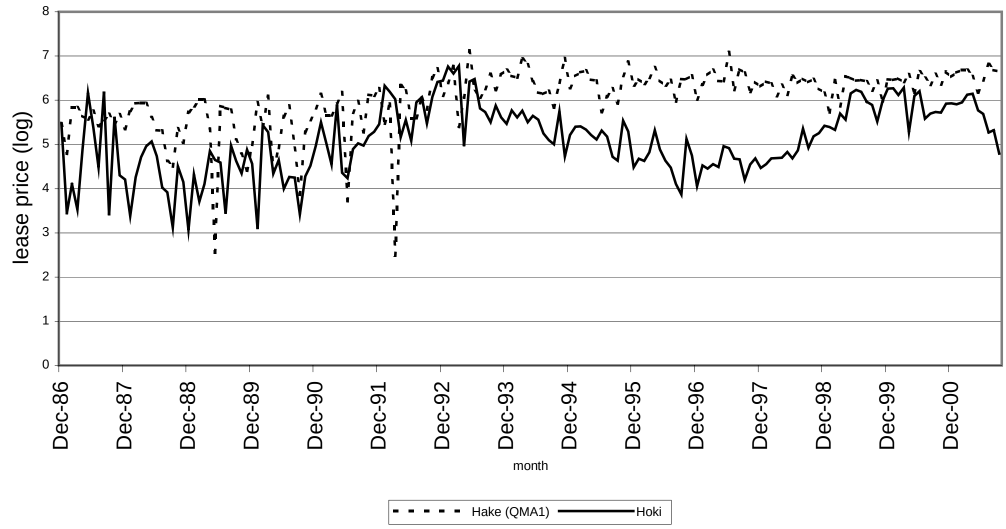


Figure 5 Trends in quota lease prices for hake (QMA4) and hoki

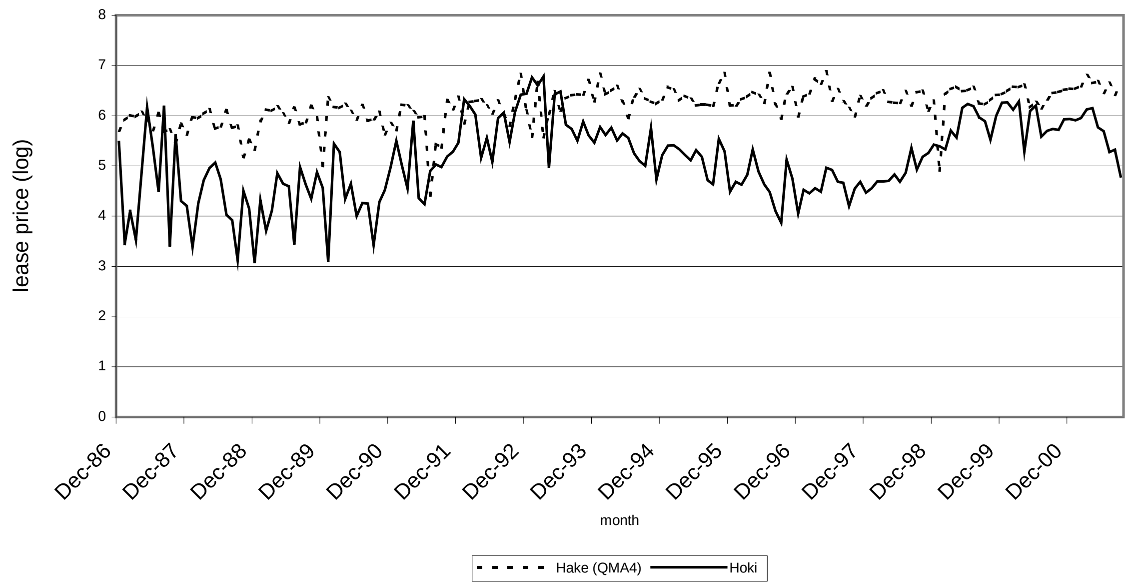


Figure 6 Trends in quota lease prices for hake (QMA7) and hoki

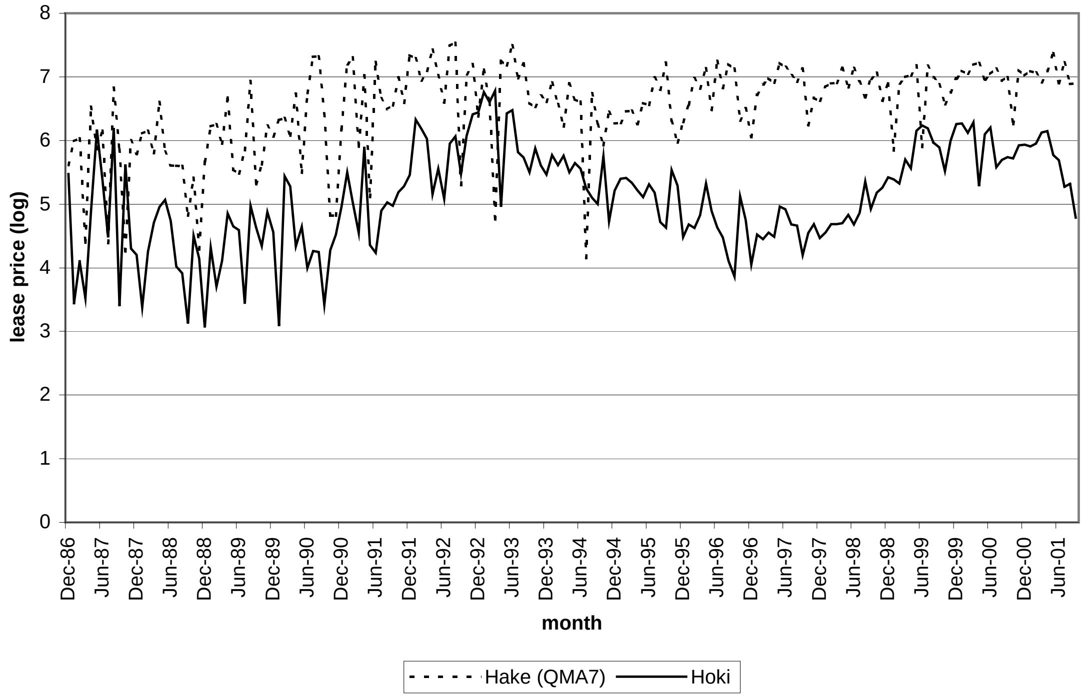


Figure 7 Bycatch of hake in QMA1 when hoki is the target

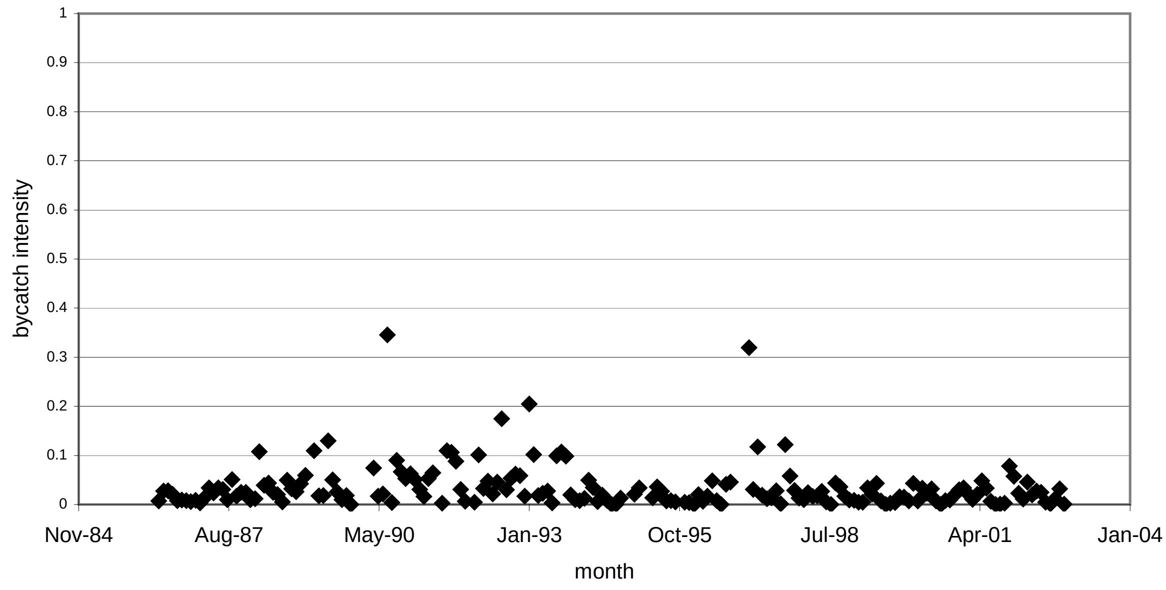


Figure 8 Bycatch of hake in QMA4 when hoki is the target

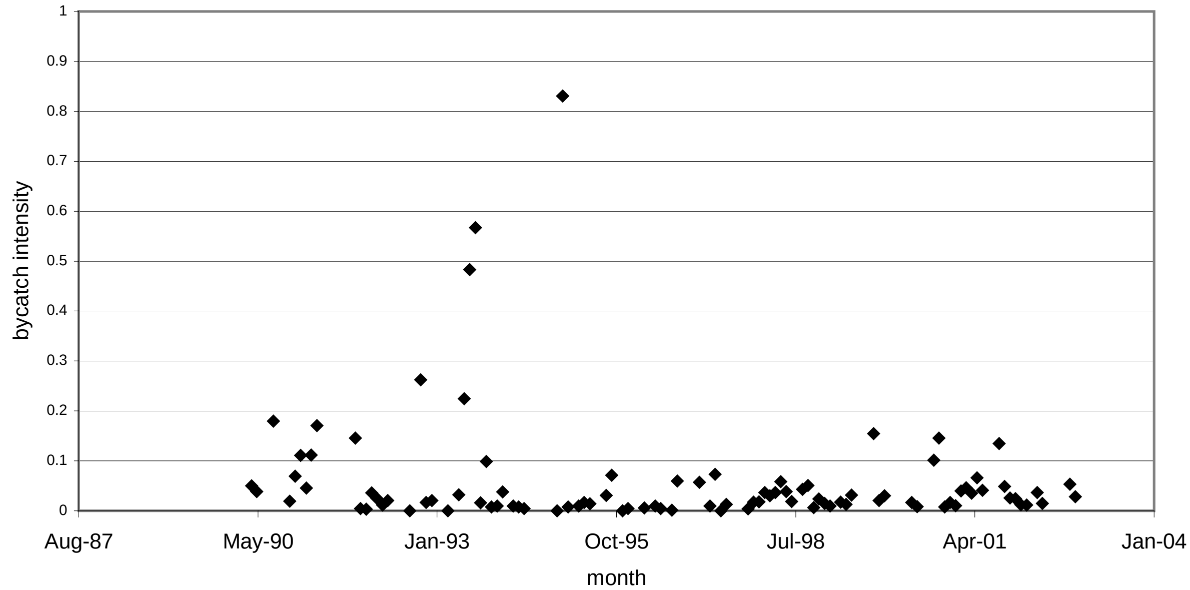


Figure 9 Bycatch of hake in QMA7 when hoki is the target

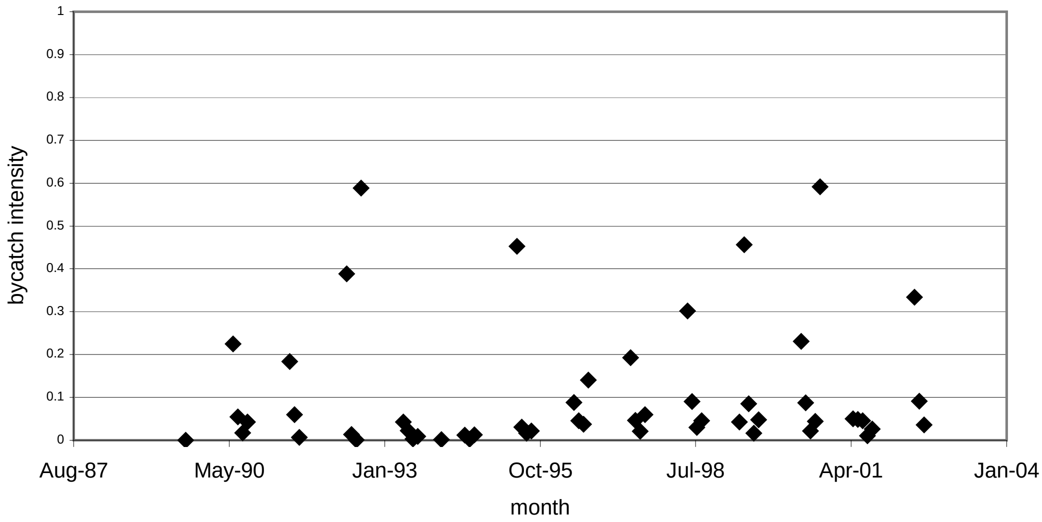


Figure 10 Bycatch of hoki in QMA1 when hake is the target

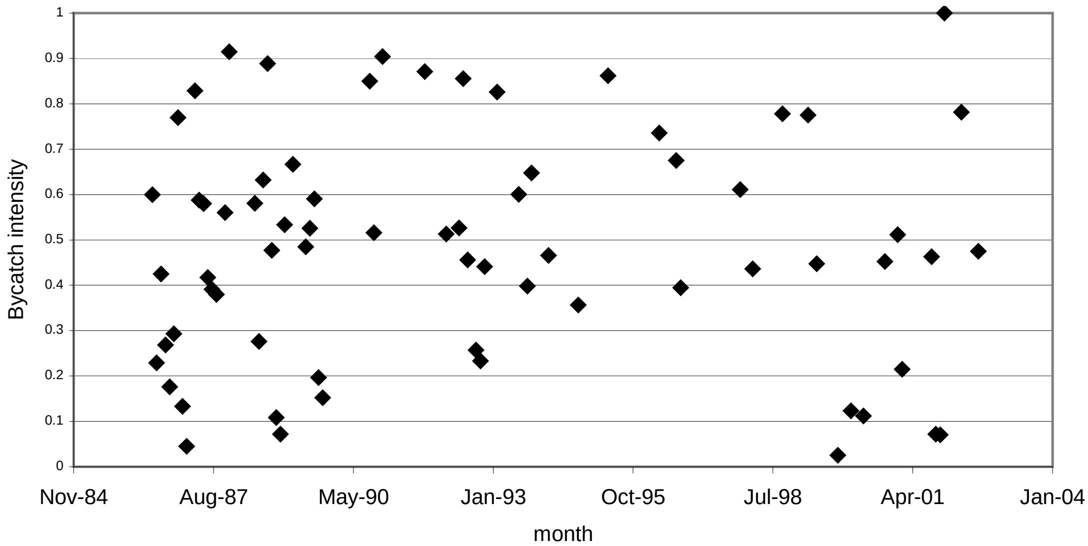


Figure 11 Bycatch of hoki in QMA4 when hake is the target

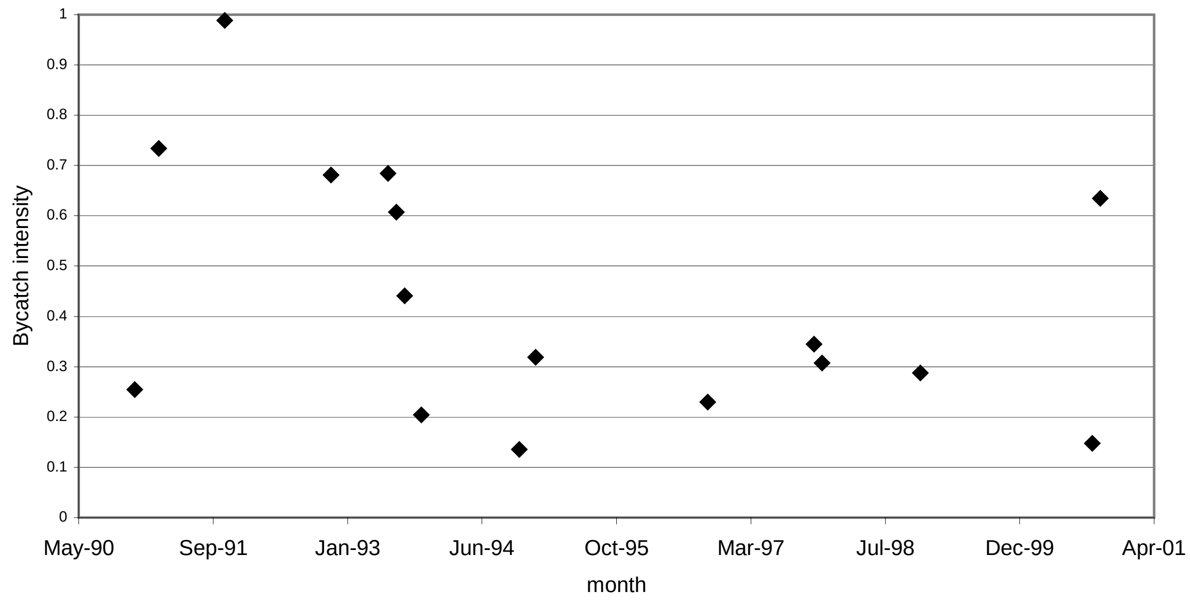
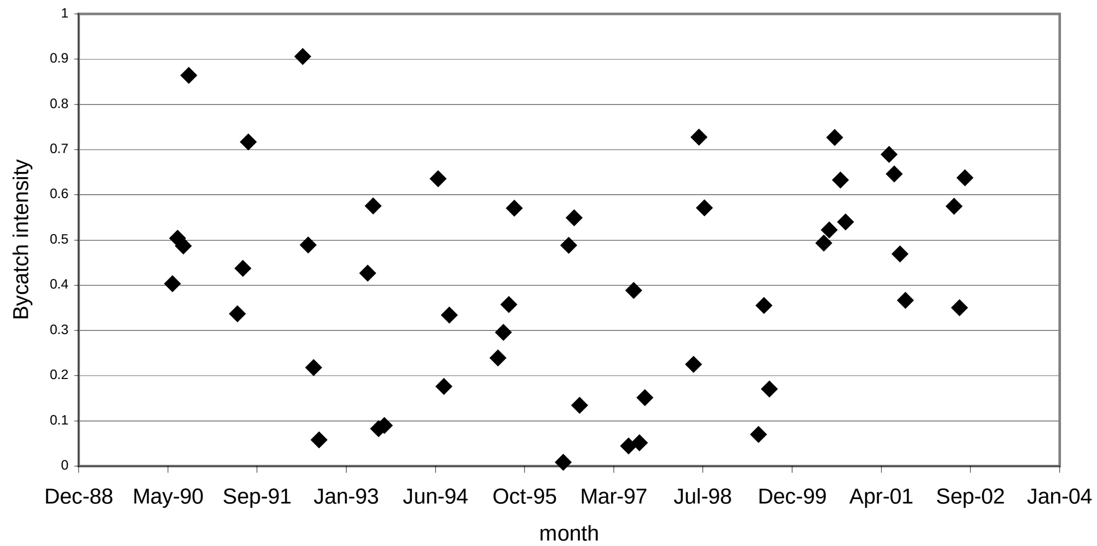


Figure 12 Bycatch of hoki in QMA7 when hake is the target



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