# Catch Intention in the Chilean Industrial-Longline Fishery

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## Acknowledgements

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## Abstract

Fishing tactics employed for a given catch intention may change in relation to the spatial and seasonal dynamics of the population, and are likely to impact stocks in a particular way (Pelletier and Ferraris, 2002). Left unaccounted for, these effects may cause biases in CPUE time series. It is therefore important to understand the impact these decisions have on the effectiveness of fishing effort units as well as the factors driving them. These factors were investigated in the Chilean industrial-longline fishery for the period of 1997-2008 across two management zones, North and South, during which time the fishery was regulated by two differing management strategies, Total Allowable Catch (TAC) from 1997-2000 and Individual Transferable Quotas (ITQ) from 2001-2008. Catch intention was estimated using a Principal Components Analysis (PCA) and Cluster Analysis which yielded three main catch intentions: pink cusk-eel (*Genypterus blacodes*), southern hake (*Merluccius australis*), and Patagonian toothfish (*Dissostichus eleginoides*) for the Chilean industrial-longline fishery. This study investigates the impact of catch intention on the effectiveness of fishing effort units as well as the factors influencing catch intention using Generalized Linear Models (GLM).

## Introduction

Catch-per-unit-effort (CPUE) data forms the basis of many stock assessments and population trend analyses, and is assumed to be proportional to the abundance of a species (Hilborn and Walters, 1992). However, biases in CPUE time series indicate that such a parallel is not always sound (Hilborn and Walters, 1992; Horwood and Millner, 1998). Bias may be caused by several factors, one of which is catch intention. Catch intention refers to the desired target species per haul in terms of type(s) and quality, and may vary throughout the year in response to fluctuating factors such as species availability and market demand (Pelletier and Ferraris 2002). Likewise, the fishing tactics employed for a given target species may change in relation to the spatial and seasonal dynamics of the population, and are therefore likely to impact stocks in a particular way (Pelletier and Ferraris, 2002). It is therefore important to understand both the impact these decisions have on the effectiveness of fishing effort units and the factors driving them.

Fisher knowledge is thought to play an important role in both target species selection and decisions made regarding fishing tactics. Two main factors might be expected to influence target species selection. The first is species availability, a relative concept dependent on knowledge of the spatial/temporal dynamics of a species and its accessibility in terms of a vessel's fishing scope. For the purposes of this study, fishing scope is defined as where, what, when, and how a fisher can fish. The fishing scope of a vessel can be restricted by a number of factors, including weather conditions, physical limitations, vessel range, and both informal and formal management regulations (e.g., informal social mores per Acheson, 1988, and Maurstad, 1998; also zones, licenses, closed seasons, gear regulations, etc.). These may be viewed in terms of ultimate and proximate causes. The second is market demand. In a cash-driven fishery where a fisher's main aim is to maximise profit, market demand may be viewed in terms of expected returns and their variability (which take into account other factors such as operational and opportunity costs). Fishers are predicted to target either the most abundant species at a fishing ground or the species providing the profit-maximising catch (Tsitsaki and Maravelias, 2008; Mediterranean purse seine fleet).

Catch intention has previously been identified using both direct means (e.g., fisher interviews) and indirect means (input- and output-based as per Marchal *et al.*, 2006). Input-based methods use fishing tactics to infer catch intention. Alternatively, output-based methods define catch intention retrospectively, in terms of catch composition, but this has a number of limitations (see discussion of Model and Variable Assumptions below). Despite such flaws, indirect, output-based methods remain the main tool used to identify catch intention in mixed fisheries where target species per haul/trip are not easily identifiable on the basis of fishing tactics, and where direct measures are either costly or unavailable (e.g., from historical data).

A fisher's knowledge of the spatial/temporal dynamics of a species is thought to be based on both past and present experience and may be aided by fish-finding technologies. A fisher uses this knowledge to select the most efficient combination of gear, mode of deployment, and location (i.e., fishing tactics) to maximize catch within the fishing scope (Pelletier and Ferraris, 2000). This knowledge is constantly being updated and may be modified by catch rate values from the previous haul (Tsitsaki and Maravelias, 2008). In the schema of the fisher knowledge process that Grant and Berkes (2006) present, learning took place at the end of each haul and fishing trip when Grenadian pelagic longline fishermen reflected on their observations of ecological cues and the fishing tactics they had employed, as compared against their own and others' catches. Based on conclusions arising from this process, a fisher might change either the target species selected or the fishing tactics employed. Thus, comparison of the actual to the intended or expected catch appears to be a key part of a fisher's decision-making process, occurring after each haul and at the end of each fishing trip. This theory may be tested by including catch rates from the previous haul for each potential target species in the catch intention model.

The Chilean pink cusk-eel industrial-longline fishery provides a good model for investigating the effect of catch intention on CPUE and for exploring the factors that drive it. The pink cusk-eel, *Genypterus blacodes,* is a benthic-demersal fish which inhabits the continental shelf and slope in the southern hemisphere (Ward *et al.*, 2001). Relatively little is known about its ecology except that individuals are characterized by medium longevity, low fecundity, and a sedentary lifestyle, with the majority of adults living in the soft bottom sediment (Ward *et al.*, 2001). The species sustains important fisheries in Australia, New Zealand, Argentina, and Chile (Wiff *et al.*, 2008). In Chilean waters the fishery for pink cusk-eel is part of a mixed species fishery developed between Talcahuano (36°44'S) and south of Cape Horn (57°00'S). However, fisheries data indicate that catches take place mostly in the austral zone between 41°28.6'S and 57°00'S (Wiff *et al.*, 2007). The fishery is exploited by both industrial and small-scale (artisanal) fishing fleets. Of these, the industrial fleet is composed of trawling and longline vessels limited to an area of offshore waters outside the interior baselines, subdivided into two zones: a Northern zone (41°28.6-47°00.0'S out to 60NM), and a Southern zone (47°00.0'S-57°00.0'S out to 80NM). The artisanal fleet is composed of longline vessels only, operating in interior waters (fjords and channels of the austral Pacific) between 41°28.6'S and 57°00'S, subdivided into three regions: X, XI, and XII.

In 1992 the fishery was declared a “fully exploited regime” under the Chilean General Law of Fishing and Aquaculture (Aguayo *et al.*, 2000). Such a declaration empowers the management authority to introduce, among other things, an annual quota (Wiff *et al.*, 2008). From 1992 through 2000, the fishery was managed by means of Total Allowable Catch (TAC), with catches set specific to each fishing fleet as well as to each zone. In 2001, individual transferable quotas (ITQ) were introduced for both industrial and small-scale fisheries, with the aim of permitting companies to self-regulate catches (pers. comm. Rodrigo Wiff). This change in management strategy during the period of the current study, 1997 through 2008, affords a unique opportunity to explore the effects of management decisions on the probability of a given catch intention. Based on prior knowledge of the fishery (pers. comm. Rodrigo Wiff), it was hypothesised that prior to 2001, when the fishery was managed based on TAC, fishers will have operated in a time race to get the “biggest slice” of the quota before their competitors. In contrast, from 2001 onwards, fishers will have been trying to get the “best slice” given their portion of the allocated quota. If so, we would expect different seasonal and spatial distributions of fishing operations under the two management conditions.

The fact that target species and the fishing tactics employed are likely to change throughout a given year opens up a couple of interesting questions for the current study. First, what is the impact of catch intention on the effectiveness of fishing effort units? Second, what factors influence catch intention? Specifically, what are the effects of season, market conditions, fishing scope, catch rates from the previous haul, and, finally, management conditions?

Preliminary answers to these questions were sought in the current study using the Chilean industrial-longline fishery as a case study. The first question was investigated by including pink cusk-eel catch intention as a potential factor in the CPUE model. The second question was explored by using a binomial model of the probability of the catch intention being pink cusk-eel, as a function of the following variables:

- Previous catch rates-
  - A fisher's indicator of profitability
- Previous location-
  - Measure of fishing scope (vessel range) which may limit the potential target species available
- Day
  - Environmental abundance
  - Measure of fishing scope (proximate- quota)
  - Market prices
- Year-
  - Measure of fishing scope (ultimate- quota)
  - Environmental abundance
- Management zone
  - Measure of fishing scope (ultimate- quota and spatial zone)
  - Indirect measure of between-vessel competition
- Management regulation (ITQ or TAC)
  - Hypothesised to affect fishing strategies

## Materials and Methods

Catch and effort data were analysed for the industrial-longline fleets operating in the Northern (41°28.6'S-47°00'S) and Southern (47°00'S-57°00'S) zones from 1997 through 2008 using logbooks registered by the Instituto de Fomento Pesquero (Chile). The majority of data was recorded by fishers, with only a small portion collected by scientists (pers. comm. Rodrigo Wiff). Further details of the sampling procedure may be found in Tascheri *et al.* (2005). During the period studied, 16,184 hauls and 31 vessels were recorded. Vessels during this period had an average length of 46.1m (ranging from 26.6-53.4m), average engine power of 1186 hp (ranging from 750-2000hp), and average gross tonnage of 569.1T (ranging from 292-753T). In all, 83 species were recorded, of which 12 species appeared in >1% of hauls. The most common species, sorted by frequency of appearance, were: 1) pink cusk-eel (*G. blacodes*), 2) southern hake (*Merluccius australis*), 3) Patagonian toothfish (*Dissostichus eleginoides*), 4) white warehou (*Seriolella caerulea*), 5) southern rays bream (*Brama australis*), 6) Patagonian grenadier (*Macruronus magellanicus*), 7) tadpole codling (*Salilota australis*), 8)Patagonian redfish (*Sebastes oculatus*), 9) South Pacific hake (*Merluccius gayi gayi*), 10) silver warehou, 11) southern blue whiting (*Micromesistius australis*), and 12) chancharro (*Heliocolenus lengerichi*).

### 1.1 Data Editing

The location of each haul was checked using the polygon outlined above. Although industrial-longline vessels are banned from fishing in interior waters (the fjords and mouths of channels, which are reserved for artisanal fishers), considerable fishing is known to take place in certain hotspots inside the area (pers. comm. Rodrigo Wiff). Therefore, the eastern boundary of the polygon was drawn in such a way as to include them. Location of hauls and fishing depths were also checked against bottom depths estimated from ETOPO1 (Amante and Eakins, 2009), and hauls where the location recorded was on land or where reported line depth exceeded known bottom depth by >200 m were excluded. Records that met the following criteria were also excluded from further analysis: any records missing entries for the start and/or finish time of the haul, or for number of hooks, latitude, longitude, depth, day, and year; any records with soak time ≤ 0 and >2 days, with differences between max. and min. depth <0, with depths >2500m, with speed over ground between starting and ending locations >10kts, with number of hooks ≤200 or ≥25,000, or with total catch weights >55,000kg. Finally, duplicate hauls were excluded, and obvious mistypes in dates identified and corrected.

## 2. Data Analysis

Data analysis was carried out in three steps: 1) Estimation of catch intention using PCA and cluster analysis, 2) Modelling the factors affecting CPUE of pink cusk-eel, and 3) Modelling the factors influencing catch intention. Models were chosen by forward stepwise selection with the model with the lowest AIC chosen (Aikaike's Information Criterion; Aikaike, 1973). Although models where the difference between AIC was <2 were considered to have equivalent support from the data (Burnham and Anderson, 1998), in such cases the model with the lowest AIC was chosen.

### 2.1 Estimation of Catch Intention

Because spatial/temporal dynamics for a species may vary between biogeographic regions, catch intention was estimated separately for the Northern and Southern zones and the results combined for the final dataset. Catches were grouped based on similarities in species composition and percentage species contribution (by weight) using principal components analysis (PCA) and cluster analysis. Each cluster was then assigned a catch intention named after the dominant species (largest species contribution). All statistical analysis for this study was carried out using the package *R* (*R* Development Core Team, 2009).

#### *2.1.1 Principal Components Analysis (PCA)*

PCA is a useful way of reducing the dimensionality of a large dataset with many interrelated variables while retaining as much as possible of the original variation present (Jolliffe, 2009). To determine the catch intention associated with each haul, a PCA was performed on a dataset containing the percentage contribution by weight of each species (i.e., the catch profile) to the total catch per haul. Catch profiles were used, as opposed to catch rates, to remove any differences between hauls which could be linked to time or vessel size (Pelletier and Ferraris, 2002). Hauls with a total catch rate of zero were excluded from the analysis, yielding a dataset containing 96 species, with 2537 hauls and 9601 hauls for the Northern and Southern zones, respectively. In contrast to a prior study by Wiff *et al.* (2008), species occurring in <1% of hauls were included, as rarer species are thought to be the most discriminating (Biseau, 1998). Principal components which cumulatively explained >85% of the total variance in the catch profiles were retained. Biplots of the first two components, corresponding to the x and y axes respectively, were constructed for each zone. Distances away from the origins, representing the "loadings" of the variables on the first two components, were used to assess the importance of each species in explaining the catch composition seen (Jolliffe, 2002). In addition, the cosine of the angle between the lines was used to approximate the correlation between the species, with angles closer to 0° or 180° showing a strong correlation, and angles closer to 90° or 270° showing only a small correlation (Jolliffe, 2002).

*2.1.2 Cluster Analysis*

Cluster analysis was applied to the principal components retained from the PCA analysis. Due to differences in the file sizes, separate clustering techniques were applied to each zone. In the Northern zone, clusters of hauls were built using agglomerative hierarchical analysis (AHA) by successive pairwise agglomerations of elements using the Euclidean distance as a similarity measure (Ward, 1963). As the Southern zone was not directly tractable using AHA, a two-step approach recommended by He *et al.* (1997) was used. First, a non-hierarchical agglomerative analysis (K-mean) was performed to obtain 2500 homogenous groups (centroids). Then hierarchical clustering methods (AHA) were applied to the centroids generated in the previous step.

As observed in other studies, the number of clusters selected using AHA is highly subjective, and the criteria range (Wiff *et al.*, 2007; He *et al.,* 1997; Pelletier and Ferraris, 2002). In this study, clusters were selected based on prior knowledge of the fishery, results of the PCA analysis, and visual inspection of the dendrogram. After the cluster analysis, the mean percentage contribution of each of the identified target species was calculated and compared between clusters. Each cluster was then named after the dominant species (by weight).

## 2.2 CPUE Model

A generalized linear model (GLM) (McCullagh and Nelder, 1989) was applied to explore the variables effecting CPUE for the pink cusk-eel. The effort unit was defined as the number of hooks multiplied by the soak time (days), with catch being the total amount (kg) of pink cusk-eel in each haul. Soak time was calculated from the time the line was set to the time the line started to be hauled. After unsuccessful attempts to fit a model of all hauls, including those with a CPUE for pink cusk-eel of zero, in the end those hauls not containing pink cusk-eel were excluded from the analysis, as in previous studies (Pelletier and Ferraris, 2002; Wiff *et al.*, 2008). Unsuccessful attempts were also made to fit a model to the entire study area covered, but in the end the data was split into Northern and Southern spatial zones. The Gamma distribution was selected in both cases to describe the response variable (expected catch rate) following inspection of the distributional properties of the residuals.

**Table 1.** Variables and their polynomial transformations considered during the model building process for the factors influencing CPUE. (:) indicates an interaction term.

| Variable | Linear | Quadratic | Cubic | Interactions |
|---|---|---|---|---|
| Depth | X | X | X | Depth^3:Year<br>Depth^3:Longitude^3<br>Depth^3:Latitude^3 |
| Day | X | X | X | Day^3:Year<br>Day^3:Latitude^3<br>Day^3:Longitude^3 |
| Longitude | X | X | X | Longitude^3:Latitude^3 |
| Latitude | X | X | X | |
| | Factor | | | |
| Year | X | | | |
| Catch Intention | X | | | |
| Vessel | X | | | |

The explanatory variables listed in Table 1 constitute the *a priori* CPUE model for both analyses and provided the ceiling for the model's complexity. The ceiling model included catch intention along with proxies of environmental processes (e.g., longitude, latitude, depth, day, and year) and an indicator of vessel capacity (vessel), all of which could impact catch size. Description and units of each variable may be found in Table 2.

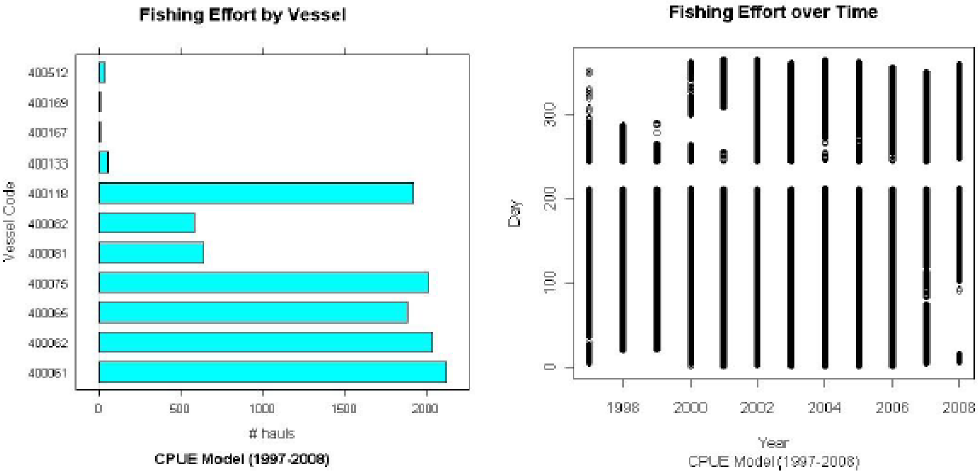


Figure 1. Fishing effort in the CPUE Model (1997-2008): by vessel (a), over time (b).

Histograms and scatterplots of all variables were inspected prior to the analysis to check for any patterns or colinearity within the model. Inspection of the plots revealed a number of interesting patterns. First, some vessels fished at a much greater frequency than others (Figure 1a). Second, a clear drop in fishing effort is observed in August of each year. This corresponded to a closed season occurring during the southern hake's spawning season (pers. comm. Rodrigo Wiff). In addition, there is a gap in effort at the start of 2008 for which the cause (likely to be missing data) is unknown at this time (Figure 2a). The unequal weighting of effort by vessel and over time may influence the model results (see discussion of Model and Variable Assumptions below).

| Table 2. Description and Units of Variables used in the Project Analyses | |
|---|---|
| **Variable (units)** | **Description** |
| Catch Intention | The catch intention assigned to each haul using PCA and Cluster Analysis. Where: 1=southern hake, 2=pink cusk-eel, 3=Patagonian toothfish. |
| Vessel | Unique code assigned to each vessel. |
| Depth (m) | Calculated as: $\frac{Maxium - Minimum\ Depth\ (m)}{2}$ |
| Longitude (decimal degrees) | Calculated as the midpoint of the Start and End Longitude of each haul. |
| Latitude (decimal degrees) | Calculated as the midpoint of the Start and End Latitude of each haul. |
| Day | Day of the year ranging from 1-365. Where 1=January 1st. |
| Year | Year ranging from 1997-2008. |
| prevLatitude (decimal degrees) | Latitude from the previous haul. |
| prevLongitude (decimal degrees) | Longitude from the previous haul. |
| CPUE (Kg/hooks*Days) | Catch-per-unit-effort of pink cusk-eel. Calculated from the following equation: $\frac{Total\ Catch\ of\ Pink\ Cusk\ Eel\ (Kg)}{\#\ of\ Hooks\ x\ Soak\ Time\ (Days)}$ |
| prev_CPUE(cusk) (Kg/hooks*Days) | CPUE of pink cusk-eel from the previous haul. |
| prev_CPUE(hake) (Kg/hooks*Days) | CPUE of southern hake from the previous haul. |
| prev_CPUE(toothfish) (Kg/hooks*Days) | CPUE of Patagonian toothfish from the previous haul. |
| cusk_pa | Probability the catch intention is pink cusk-eel. Where:<br>-Catch intention is pink cusk-eel=1<br>-Catch intention is not pink cusk-eel=0 |
| Speed over ground (Knots) | Distance between start and end locations calculated using the Great Circular Distance Method. $\frac{Distance\ (km)}{Time\ End\ Haul - Time\ Started\ Laying\ Line\ (hours)}$ |
| Bottom depth (m) | Extracted from: http://www.ngdc.noaa.gov/mgg/global/global.html. Only depths within 2 NM of the mid coordinates of each haul were used. |
| Soak Time (Days) | Calculated as: $Time\ Started\ Hauling - Time\ End\ Laying\ Line.$ |

### 2.3 Catch Intention Models

The same criteria used in the first analysis were applied to the dataset in second analysis, with the exception that hauls not containing pink cusk-eel were retained. In order to test the hypothesis that location and catch rates from the previous haul may be important factors determining catch intention, the first haul of each trip were excluded, along with hauls for which data on the prior hauls were missing. This resulted in a starting dataset of 14,508 hauls. In the absence of readily available information on fishing licenses, management zone (north or south) was assigned to each vessel based on the spatial zone, Northern (41°28.6'S-47°00'S) or Southern (47°00.0'S-57°00.0'S), where the majority of hauls took place. Hauls occurring outside the appropriate management zone but within the polygon defined above were retained, since zones are not heavily enforced (pers. comm. Rodrigo Wiff), and decisions of what to catch were assumed to be driven by the official management zone.

To explore the effects of varying management conditions on catch intention, the dataset was subdivided into four subsections by management zone and strategy: Northern TAC (1997-2000), Northern ITQ (2001-2008), Southern TAC (1997-2000), and ITQ (2001-2008). A logistic regression model with a binomial error structure and logit link function was used to model the probability that the catch intention was pink cusk-eel (1) vs. another target species (0).

**Table 3.** Variables and their polynomial transformations considered during the model building process for the factors influencing the probability a catch intention is pink cusk eel. (:) indicates an interaction term.

| Variable | Linear | Quadratic | Cubic | Interaction |
|---|---|---|---|---|
| Day | X | X | X | Day^3:Year |
| prevLongitude | X | X | X | prevLongitude^3:prevLatitude^3 |
| prevLatitude | X | X | X | |
| prev_CPUE(cusk) | X | X | X | |
| prev_CPUE(hake) | X | X | X | |
| prev_CPUE(toothfish) | X | X | X | |
| | Factor | | | |
| Year | X | | | |
| Vessel | X | | | |

The explanatory variables listed in Table 3 constitute the *a priori* catch intention model and provide the ceiling for the model's complexity. Variables considered in the ceiling model include previous latitude; previous longitude; and day, vessel, year, and catch rates from the previous haul for the three main catch intentions: southern hake, pink cusk-eel, and Patagonian toothfish. Description and units of these variables may be found in Table 2.

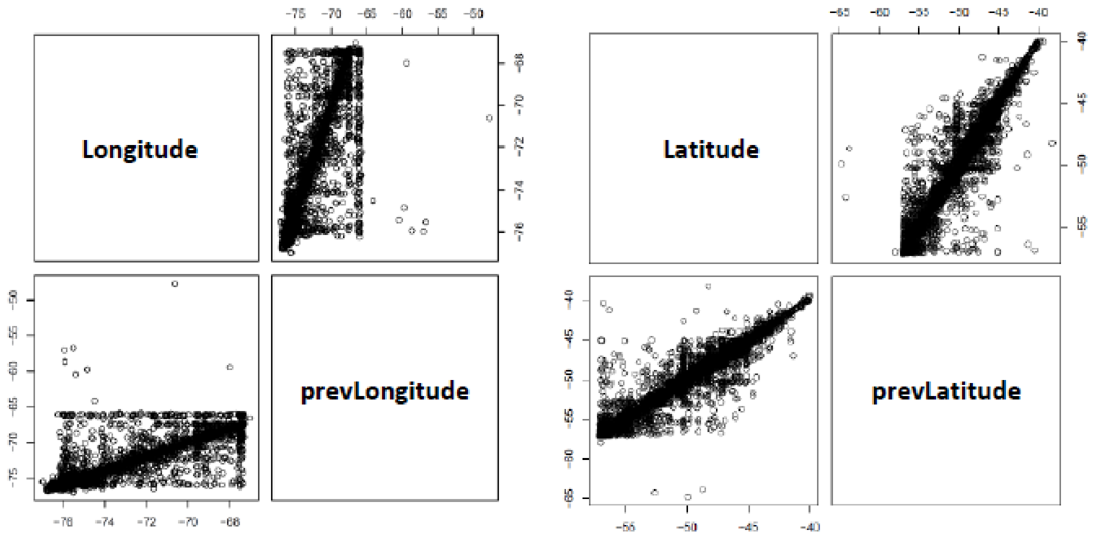


**Figure 2.** Location of hauls (a) longitude vs. previous longitude, (b) latitude vs. previous latitude.

Prior to the analysis, variable scatterplots and histograms were inspected to check for colinearity within the model. Similar patterns in fishing effort over time were observed to those in Figure 1a of the previous model. Figure 2 indicates that the majority of hauls do not occur far from their starting longitude (a) or latitude (b).

## Results

### 1. PCA and Cluster Analysis

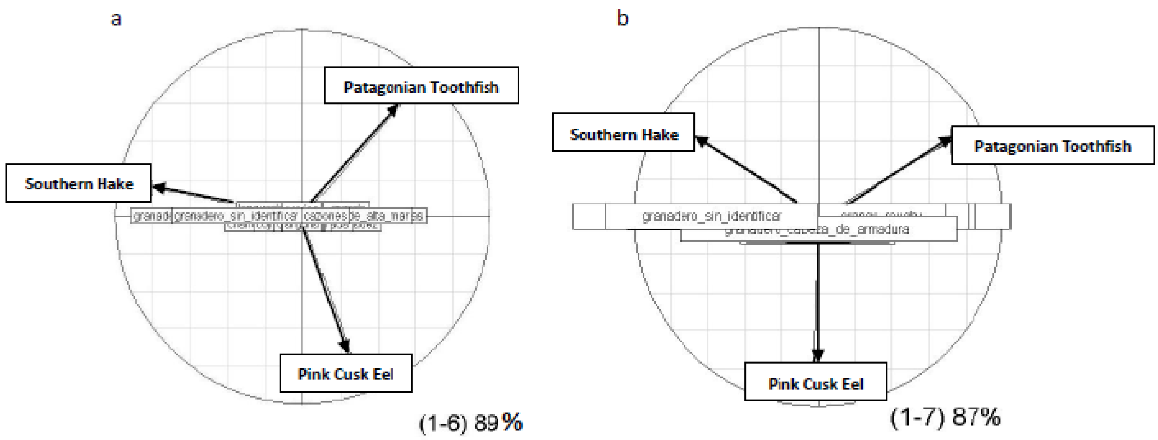


**Figure3.** Results of the principal component analysis for the Northern (a) and Southern Zone (b).

The application of PCA to catch species composition yielded six components which together explained 89% of the total variance in catch for the Northern zone, and seven components which together explained 87% of the total variance for the Southern zone. At least three key target species can be distinguished in each zone from the biplot of the first two components, Fig. 2, where components 1 and 2 correspond to the x and y axes, respectively. In both zones the target species identified by the analysis were southern hake, pink cusk-eel, and Patagonian toothfish. The other species appear close to the centre of the biplot, indicating that these species were not dominant in explaining the catch composition for either zone.

In the Northern zone, Fig. 3a, the species contributing most significantly to the first component, as indicated by the distance from the origin, was southern hake, followed by Patagonian toothfish, then pink cusk-eel. For the second component, the largest contributor was pink cusk-eel, followed by Patagonian toothfish, then southern hake. The three catch intentions are relatively distinct, as evidenced by the cosine of the angles between them, showing only slight correlations between Patagonian toothfish and pink cusk-eel for the first principal component and between southern hake and Patagonian toothfish for the second.

In the Southern zone, Fig. 3b, the species contributing most significantly to the first component was Patagonian toothfish, followed by southern hake, then pink cusk-eel. For the second component, the dominant species was pink cusk-eel, followed by Patagonian toothfish, then southern hake. The three catch intentions are distinct, showing only slight correlations between southern hake and Patagonian toothfish in the first component.

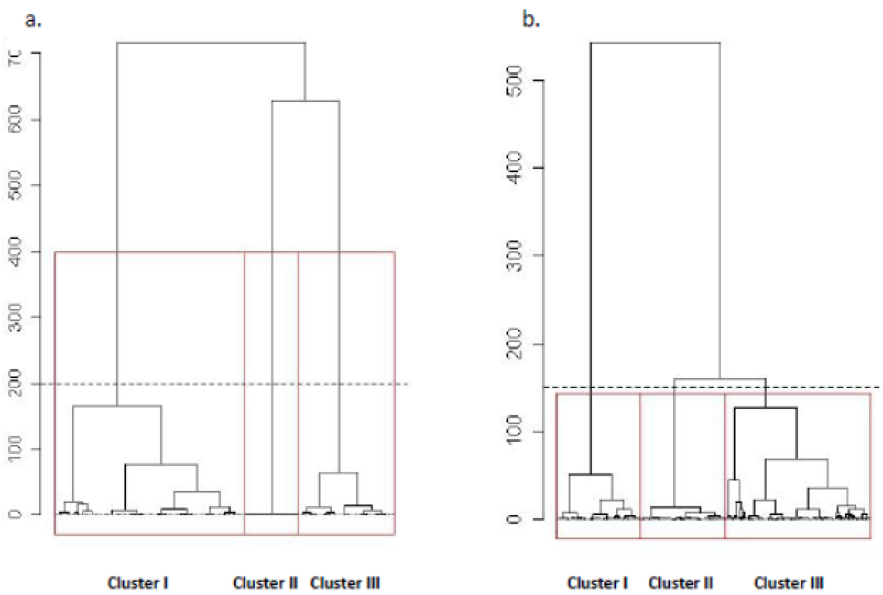


**Figure 4.** Results of the agglomerative hierarchical analysis for the Northern (a) and Southern (b) Zones from 1997-2008. The red boxes indicate the dendrogram cut and corresponding clusters.

The dendrograms resulting from the AHA for the Northern (a) and Southern (b) zones are presented in Figure 4. Three main clusters (catch intentions) emerge, based on the proportion of the species in the hauls, in both analyses. This finding fits with both the PCA and prior knowledge of the fishery; consequently, the dendrogram cut (indicated by the red boxes) was set to three groups. In the Northern zone, Cluster I contained the largest proportion of the hauls (57.6%), in which the dominant species was southern hake ( 77.15% average weight in kg/haul). This cluster was characterised by an average pink cusk-eel catch rate of 0.28kg per effort unit (kg/# of hooks x soak time). Cluster II accounted for the smallest proportion of hauls (15.8%), for which the main species was Patagonian toothfish (99.47% average weight in kg/haul). The average pink cusk-eel catch rate for this cluster was 0.0006kg per effort unit. Cluster III contained a relatively small proportion of the hauls (27.6%), in which the dominant species was pink cusk-eel (85.6% average weight kg/haul). This cluster was characterised by an average pink cusk-eel catch rate of 0.90kg per effort unit.

In the Southern Zone, Cluster 1 contained a relatively small proportion of the hauls (17.3%), in which the dominant species was pink cusk-eel (81.9% average weight in kg/haul). This cluster was characterised by an average pink cusk-eel catch rate of 0.748kg per effort unit. Cluster 2 contained 35% of the hauls, in which the dominant species was southern hake (94.39% average weight in kg/haul). This cluster was characterised by an average pink cusk-eel catch rate of 0.043kg per effort unit. Cluster 3 accounted for the largest proportion of hauls (47.7%), for which the main species was Patagonian toothfish (49.23% average weight in kg/haul). The average pink cusk-eel catch rate for this cluster was 0.1104kg per effort unit.

**2. CPUE Model**

The study area, including fishing zones, considered in the analysis is shown in Figure 5. Each point represents a fishing haul containing pink cusk-eel scaled to CPUE of pink cusk-eel colour coded by catch intention. The resulting "best model" for the Northern zone included the two variables catch intention and day, with an explained deviance of 34.14% (Table 4). Catch intention was the most influential variable, entering the model first and accounting for 99.9 % of the explained deviance.

**Table 4.** The resulting 'best' model (GLM with Gamma error structure, link=log) of factors influencing the CPUE of pink cusk-eel for the Northern Zone (1997-2008).

| Term | Estimate | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|
| Intercept | -1.7513 | 0.03253 | -53.840 | <2e-16 *** |
| as.factor(Catch Intention) | | | | |
| 2 | 1.432 | 0.0345 | 41.485 | <2e-16 *** |
| 3 | -1.467 | 0.4371 | -3.355 | 0.000802*** |
| Day | 0.0001768 | 0.0001578 | 1.120 | 0.262598 |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ''
Null deviance: 4760.5 on 3361 degrees of freedom
Residual deviance: 3135.2 on 3358 degrees of freedom
AIC: -44.725

It being suspected that the exclusion of other variables from the model might be the result of catch intention being "too good" a predictor, the selection process for the Northern zone was repeated, this time excluding catch intention. The result was a model of greater biological interest (Appendix A: Table 1). However, that model was not pursued further, as this did not fall within the aims of the current project.

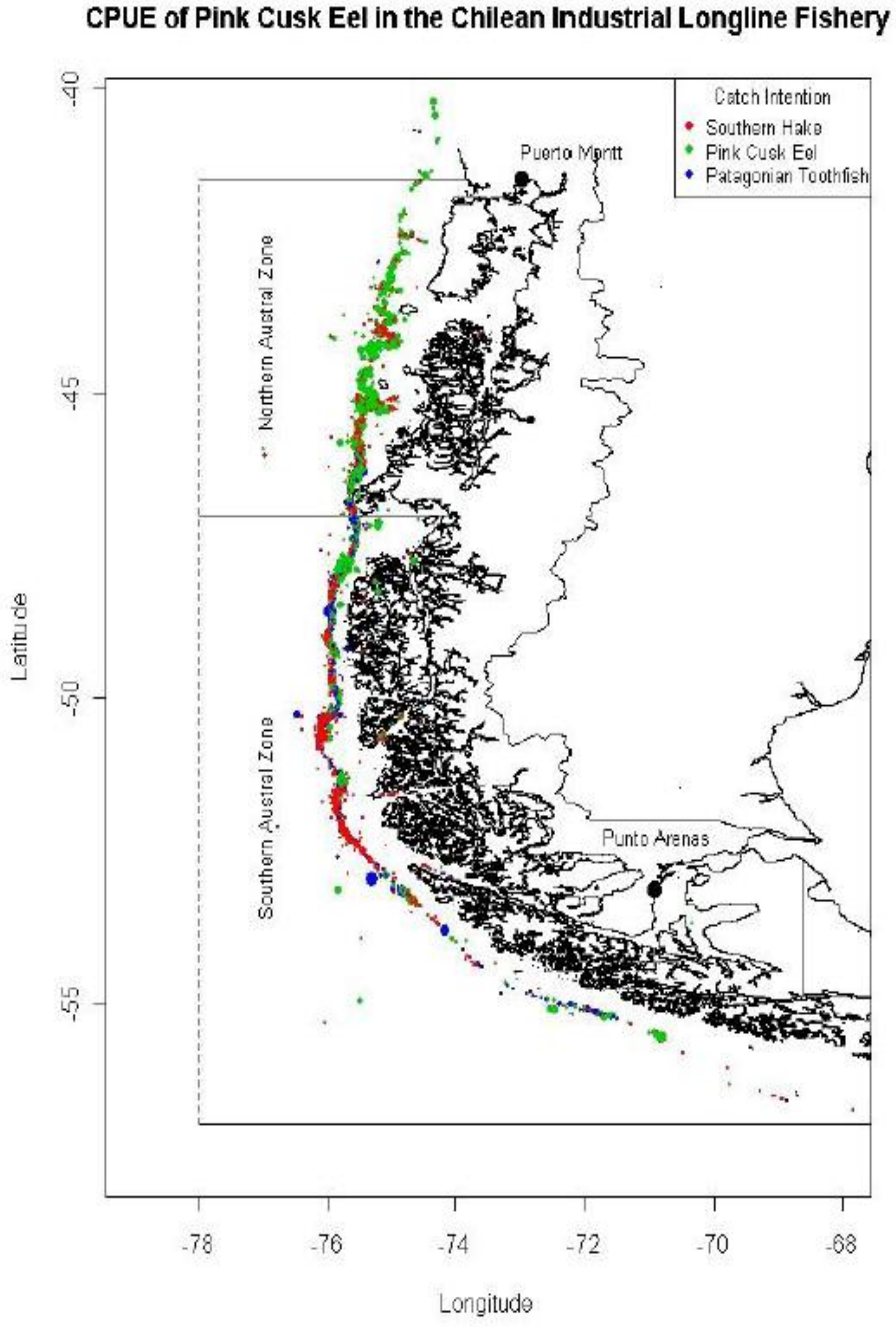


**Figure 5.** Location of the study area, indicating fishing zones, for the CPUE model. Each point represents a fishing haul containing pink cusk-eel and is weighted by CPUE of pink cusk-eel and colour coded by catch intention.

A CPUE model was also fitted to hauls in the Southern zone. However, inspection of the distributional properties and the deviance explained (1.8%) indicated it to be a poor fit (Appendix A Table 2). Therefore, conclusions cannot be drawn regarding the effect of catch intention on CPUE of pink cusk-eel in the Southern zone. Despite this, the factors influencing catch intention may still be explored in the Southern zone, as the analysis is not conditional on catch intention having a significant effect on CPUE.

### 3. Catch Intention Models

The study area considered in the binomial model, including fishing zones, is shown in Figure 6, where each point represents one fishing haul colour coded by catch intention. It is clear from visual inspection of the plot that catch intention differs markedly between the Northern and Southern zones, with a catch intention of pink cusk-eel occurring more commonly in the Northern zone than in the Southern zone. Details of the binomial model selection process may be found in Appendix B.

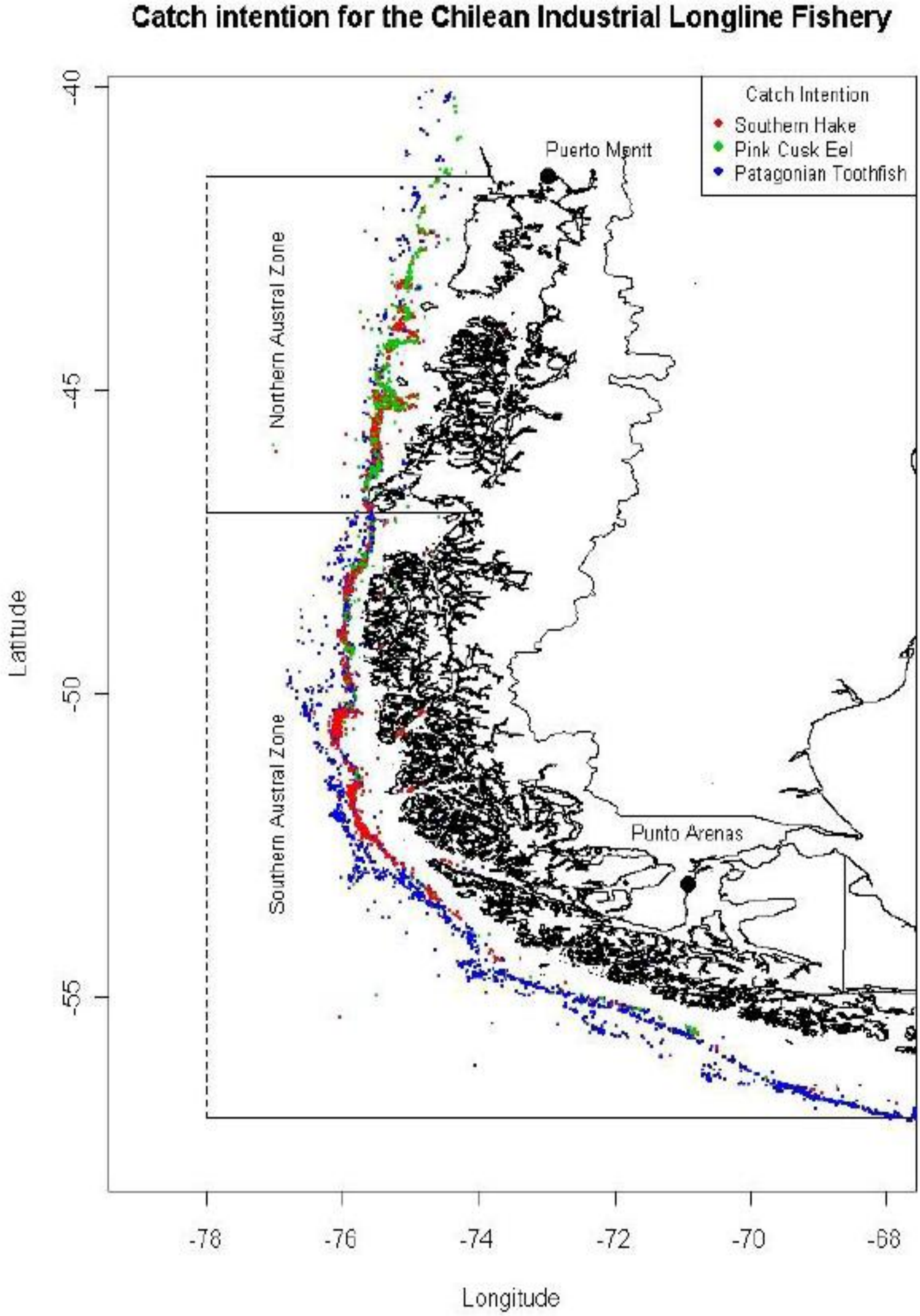


**Figure 6.** Location of the study area indicating fishing zones for the Binomial Model. Each point corresponds to one fishing haul and is colour coded by catch intention.

### 3.1 Northern Zone TAC (1997-2000)

The resulting “best model” for the Northern TAC included the variables vessel, previous latitude, day, and previous catch rates for both pink cusk-eel and southern hake. Together these variables explained 55.65% of the deviance in the model (Table 5a). CPUE of pink cusk-eel from the previous haul was the most influential variable, entering the model first and making up 53.76 % of the explained deviance. The probability of the catch intention being pink-cusk eel increased with catch rates for the species from the previous year, and decreased with previous catch rates for southern hake and advancing day of year. The model predicts a negative quadratic relationship between previous latitude and the probability of a catch intention being pink cusk-eel, its highest probability occurring with a previous latitude of approximately 43°00'S.

Table 5a. The resulting 'best' model (GLM with Binomial error structure, link=logit) relating variables to the probability of a catch intention of pink cusk-eel for the Northern TAC (1997-2000).

| Term | | logit $\beta$ | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|---|
| Intercept | | -2.041e+00 | 3.154e-01 | -6.471 | 9.75e-11 *** |
| as.factor(Vessel) | | | | | |
| | 400081 | -5.295e-01 | 2.420e-01 | -2.187 | 0.028712* |
| | 400128 | -1.979e+01 | 2.408e+03 | -0.008 | 0.993443 |
| | 400130 | -1.982e+01 | 1.823e+03 | -0.011 | 0.991324 |
| | 400132 | -2.022e+01 | 2.773e+03 | -0.007 | 0.994181 |
| | 400133 | 1.810e+01 | 1.809e+03 | 0.010 | 0.992019 |
| | 400136 | -1.947e+01 | 4.716e+03 | -0.004 | 0.996706 |
| | 400138 | -1.966e+01 | 3.761e+03 | -0.005 | 0.995829 |
| | 400139 | -1.975e+01 | 1.520e+03 | -0.013 | 0.989634 |
| | 400140 | -1.990e+01 | 4.773e+03 | -0.004 | 0.996673 |
| | 400151 | -1.978e+01 | 3.038e+03 | -0.007 | 0.994804 |
| | 400152 | -1.983e+01 | 2.280e+03 | -0.009 | 0.993061 |
| | 400153 | -2.014e+01 | 3.386e+03 | -0.006 | 0.995254 |
| | 400155 | -1.984e+01 | 4.390e+03 | -0.005 | 0.996393 |
| | 400157 | -2.021e+01 | 1.075e+04 | -0.002 | 0.998500 |
| | 400163 | -2.010e+01 | 1.075e+04 | -0.002 | 0.998509 |
| | 400164 | -1.957e+01 | 6.067e+03 | -0.003 | 0.997426 |
| | 400165 | -1.993e+01 | 5.371e+03 | -0.004 | 0.997040 |
| | 400166 | -1.960e+01 | 5.377e+03 | -0.004 | 0.997091 |
| | 400167 | -1.995e+01 | 6.209e+03 | -0.003 | 0.997436 |
| | 400169 | -2.021e+01 | 5.370e+03 | -0.004 | 0.996997 |
| | 400174 | -1.952e+01 | 4.684e+03 | -0.004 | 0.996675 |
| | 400511 | -1.951e+01 | 4.809e+03 | -0.004 | 0.996762 |
| | 400152 | 2.745e-02 | 6.813e-01 | 0.040 | 0.967868 |
| prev_CPUE(cusk) | | 5.121e+01 | 4.937e+00 | 10.372 | < 2e-16 *** |
| prevLatitude | | 9.282e+01 | 1.387e+01 | 6.690 | 2.23e-11 *** |
| prevLatitude^2 | | -2.763e+01 | 1.067e+01 | -2.590 | 0.009597 ** |
| Day | | -1.812e+01 | 5.450e+00 | -3.324 | 0.000887 *** |
| prev_CPUE(hake) | | -5.492e+01 | 5.583e+00 | -9.836 | < 2e-16 *** |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Null deviance: 1515.9 on 1420 degrees of freedom
Residual deviance: 672.3 on 1392 degrees of freedom
AIC: 730.3

## 3.2 Northern Zone ITQ (2001-2008)

The resulting "best model" for the Northern ITQ included the variables latitude, previous catch rates of pink cusk-eel, and the interaction between day and year. Together these variables explained 50.88% of the deviance (Table 5b). Day was the most influential variable, entering the model first and accounting for 33.14% of the deviance explained. The probability of a catch intention being pink cusk-eel increased with decreases in previous latitude (i.e., moving further north) and with increases in the species' catch rates from the previous haul. Model predictions of the interactive effects of day and year on the probability of a catch intention being pink cusk-eel are shown in Figure 7. That probability was highest overall in 2003, and also at the start and end of each year (summer).

**Table 5b.** The resulting 'best' model (GLM with Binomial error structure, link=logit) relating variables to the probability of a catch intention of pink cusk-eel for the Northern ITQ (2001-2008). (:) indicates an interaction term.

| Term | | logit $\beta$ | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|---|
| Intercept | | -1.413 | 0.294 | -4.803 | 1.56e-06 *** |
| as.factor(Year) | | | | | |
| | 2002 | 0.3381 | 0.377 | 0.896 | 0.370 |
| | 2003 | 0.9246 | 0.344 | 2.689 | 0.0072** |
| | 2004 | 0.1851 | 0.3991 | 0.464 | 0.6428 |
| | 2005 | -0.0797 | 0.3856 | -0.207 | 0.8363 |
| | 2006 | 0.1423 | 0.413 | 0.344 | 0.7305 |
| | 2007 | 0.541 | 0.3801 | 1.423 | 0.155 |
| | 2008 | -2.825 | 3.401 | -0.831 | 0.406 |
| Day | | 22.29 | 15.68 | 1.421 | 0.1552 |
| Day^2 | | 6.016 | 11.84 | 0.508 | 0.611 |
| Day^3 | | -7.083 | 3.653 | -1.939 | 0.052 . |
| prev_CPUE(cusk) | | 52.687 | 5.425 | 9.713 | <2e-16 *** |
| prev_CPUE(cusk)^2 | | -25.872 | 3.8679 | -6.689 | 2.25e-11 *** |
| prevLatitude | | 24.792 | 4.617 | 5.369 | 7.90e-08 *** |
| as.factor(Year):Day | | | | | |
| | 2002 | 11.283 | 18.302 | 0.617 | 0.5376 |
| | 2003 | 11.455 | 17.270 | 0.663 | 0.5071 |
| | 2004 | 30.766 | 17.769 | 1.731 | 0.0834 . |
| | 2005 | 8.949 | 18.246 | 0.490 | 0.6238 |
| | 2006 | 55.223 | 23.670 | 2.333 | 0.0196 ** |
| | 2007 | 6.224 | 19.222 | 0.324 | 0.746 |
| | 2008 | 162.672 | 137.06 | 1.187 | 0.235 |
| as.factor(Year):Day^2 | | | | | |
| | 2002 | 4.426 | 15.60 | 0.284 | 0.777 |
| | 2003 | 24.97 | 14.0796 | 1.773 | 0.0762 . |
| | 2004 | 38.165 | 15.467 | 2.468 | 0.0136 ** |
| | 2005 | 31.6256 | 15.584 | 2.029 | 0.0424 ** |
| | 2006 | 90.346 | 24.108 | 3.748 | 0.00018 *** |
| | 2007 | 38.924 | 16.816 | 2.315 | 0.021 ** |
| | 2008 | -4.06 | 72.524 | -0.056 | 0.955 |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Null deviance: 2298.8 on 1803 degrees of freedom
Residual deviance: 1073.2 on 1776 degrees of freedom
AIC: 1129.2

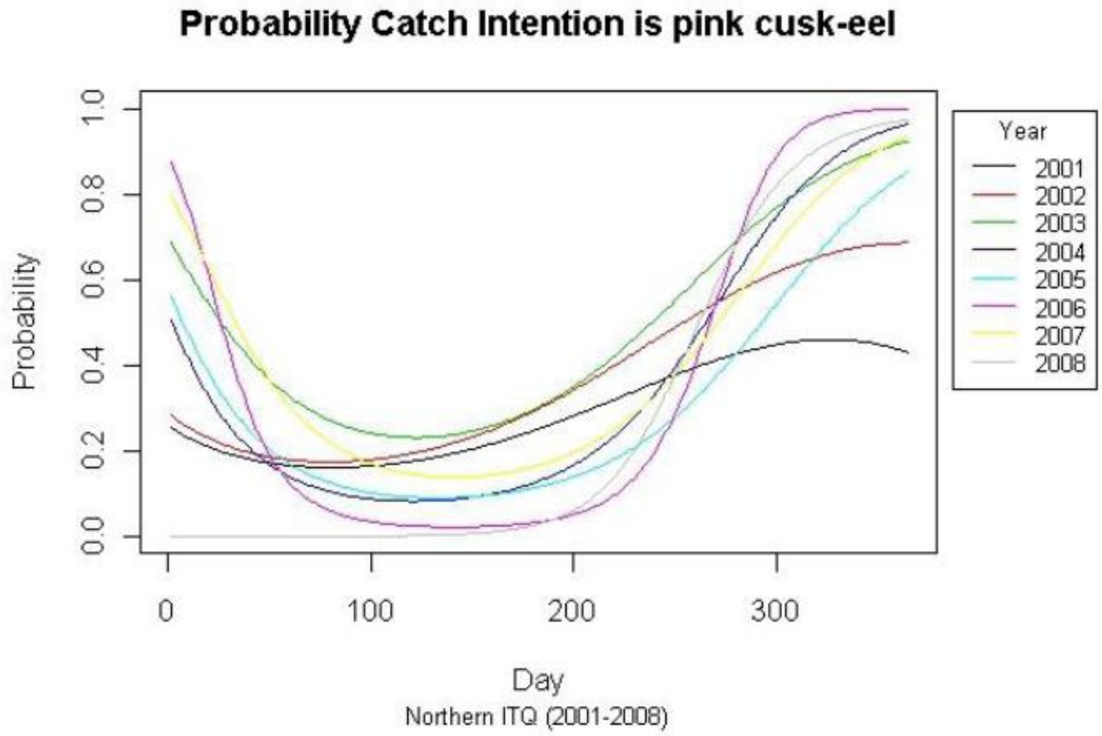


**Figure 7.** Model predictions for the Northern ITQ (2001-2008) of the interactive effect of Day and Year on the probability of a catch intention being pink cusk-eel.

### 3.3 Southern Zone TAC (1997-2000)

The resulting "best model" for the Southern TAC condition included year, vessel, day, previous latitude, and previous catch rates both for pink cusk-eel and for southern hake. The model selected explained 56.37% of the deviance (Table 5c). Previous catch rate of pink cusk-eel was the most influential variable, entering the model first and making up 65.38% of the deviance explained. The probability of a catch intention being pink cusk-eel increased with decreases in previous latitude (moving further north) and with catch rates for the species from the previous haul. The probability decreased with advances in both day and year and also with increases in catch rates for southern hake from the previous year.

Table 5c. Results of the "best" catch intention model (GLM with binomial error structure and logit link function) relating variables to the probability of a catch intention of pink cusk-eel for the Southern Zone TAC (1997-2000).

| Term | logit $\beta$ | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|
| Intercept | -4.3967 | 0.2934 | -14.985 | < 2e-16 *** |
| prev_CPUE(cusk) | 78.2176 | 6.8435 | 11.429 | < 2e-16 *** |
| prev_CPUE(cusk)^2 | -11.2055 | 7.9053 | -1.417 | 0.156 |
| prev_CPUE(cusk)^3 | 36.1088 | 9.7150 | 3.717 | 0.000202 *** |
| prevLatitude | 99.5094 | 10.8951 | 9.133 | < 2e-16 *** |
| prev_CPUE(hake) | -74.9334 | 7.3177 | -10.240 | < 2e-16 *** |
| prev_CPUE(hake)^2 | 36.8407 | 8.6444 | 4.262 | 2.03e-05 *** |
| prev_CPUE(hake)^3 | -25.0458 | 6.1503 | -4.072 | 4.66e-05 *** |
| Day | -18.5558 | 7.2351 | -2.565 | 0.010326 * |
| As.factor(Year) | | | | |
| 1998 | -0.4019 | 0.2598 | -1.547 | 0.121805 |
| 1999 | -0.5127 | 0.2449 | -2.093 | 0.036308 * |
| 2000 | -0.7486 | 0.2470 | -3.030 | 0.00244 ** |
| As.factor(Vessel) | | | | |
| 400065 | -0.3872 | 0.3451 | -1.122 | 0.261878 |
| 400075 | 1.0905 | 0.2558 | 4.263 | 2.02e-05 *** |
| 400079 | -14.6741 | 655.6270 | -0.022 | 0.982 |
| 400082 | 0.6658 | 0.3054 | 2.180 | 0.029238 * |
| 400088 | -11.8782 | 432.3224 | -0.027 | 0.978081 |
| 400118 | 0.5067 | 0.2547 | 1.989 | 0.046679 * |

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Null deviance: 2417.2 on 3733 degrees of freedom
Residual deviance: 1054.7 on 3716 degrees of freedom
AIC: 1090.7

### 3.4 Southern Zone ITQ (2001-2008)

The resulting "best model" for the Southern ITQ condition included interactions between previous latitude and longitude and also day and year. Together these variables explained 37.03% of the overall deviance (Table 5d). Model predictions of the effects of these interactions on the probability of a catch intention being pink cusk-eel are shown in Figure 8. The probability was highest at more northerly latitudes and showed a negative quadratic relationship with longitude, with probability highest at more easterly longitudes. The model predicts probability of the catch intention being pink cusk-eel to be greatest at the start and end of the year. The probability varies by year, with the highest probability overall occurring in 2001. Previous latitude was the most influential variable, entering the model first and explaining 50.32% of the deviance explained.

**Table 5d.** Results of the "best" catch intention model (GLM with binomial error structure, link=logit) relating variables to the probability a catch intention being pink cusk-eel for the Southern ITQ (2001-2008). (:) indicates an interaction term.

| Term | | logit $\beta$ | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|---|
| Intercept | | -2.970e+00 | 1.720e-01 | 17.265 | < 2e-16 *** |
| prevLatitude | | 1.268e+02 | 5.869e+00 | 21.600 | < 2e-16 *** |
| prevLongitude | | 2.154e+01 | 1.880e+01 | 0.251829 | 0.251829 |
| prevLongitude^2 | | -1.735e+01 | 5.418e+00 | 3.202 | 0.001363 ** |
| prevLongitude^3 | | 2.464e+01 | 7.450e+00 | 3.307 | 0.000943 *** |
| prevLatitude:prevLongitude | | -1.758e+03 | 1.056e+03 | -1.664 | 0.096119 |
| as.factor(Year) | | | | | |
| | 2002 | 1.687e-01 | 1.807e-01 | 0.934 | 0.350488 |
| | 2003 | 6.279e-01 | 1.730e-01 | 3.630 | 0.000283 *** |
| | 2004 | 1.205e+00 | 1.666e-01 | 7.229 | 4.86e-13 *** |
| | 2005 | -2.365e-01 | 2.315e-01 | -1.022 | 0.306883 |
| | 2006 | 3.319e-01 | 2.180e-01 | 1.523 | 0.127791 |
| | 2007 | 9.704e-02 | 2.781e-01 | 0.349 | 0.727146 |
| | 2008 | -1.558e+00 | 7.633e-01 | -2.040 | 0.041303 * |
| Day | | 5.221e+01 | 8.677e+00 | 6.017 | 1.78e-09 *** |
| Day^2 | | 8.771e+01 | 9.385e+00 | 9.346 | < 2e-16 *** |
| Day^3 | | 1.623e+00 | 9.284e+00 | 0.175 | 0.861214 |
| as.factor(Year):Day | | | | | |
| | 2002 | -4.174e+01 | 1.250e+01 | -3.341 | 0.000836 *** |
| | 2003 | 5.492e+00 | 1.099e+01 | 0.500 | 0.617182 |
| | 2004 | 2.027e+01 | 1.116e+01 | 1.816 | 0.069299 |
| | 2005 | 1.387e+01 | 1.329e+01 | 1.044 | 0.296573 |
| | 2006 | -1.302e+01 | 1.296e+01 | -1.005 | 0.314995 |
| | 2007 | 3.518e+01 | 1.458e+01 | 2.414 | 0.015793 * |
| | 2008 | 1.433e+02 | 6.868e+01 | 2.087 | 0.036904 * |
| as.factor(Year):Day^2 | | | | | |
| | 2002 | -6.892e+00 | 1.287e+01 | -0.536 | 0.592275 |
| | 2003 | -7.807e+00 | 1.300e+01 | -0.601 | 0.548031 |
| | 2004 | -6.348e+01 | 1.240e+01 | -5.119 | 3.07e-07 *** |
| | 2005 | -3.127e-01 | 1.456e+01 | -0.021 | 0.982870 |
| | 2006 | 6.053e+00 | 1.521e+01 | 0.398 | 0.690611 |
| | 2007 | 4.068e+01 | 1.776e+01 | 2.291 | 0.021945 * |
| | 2008 | -4.230e+01 | 5.108e+01 | -0.828 | 0.407586 |
| as.factor(Year):Day^3 | | | | | |
| | 2002 | 7.937e-01 | 1.303e+01 | 0.061 | 0.951430 |
| | 2003 | -2.216e+01 | 1.198e+01 | -1.851 | 0.064208 |
| | 2004 | -1.387e+01 | 1.226e+01 | -1.132 | 0.257757 |
| | 2005 | -3.617e+01 | 1.352e+01 | -2.676 | 0.007456 ** |
| | 2006 | -1.240e+01 | 1.470e+01 | -0.843 | 0.399128 |
| | 2007 | -5.627e+01 | 1.788e+01 | -3.146 | 0.001655 ** |
| | 2008 | -6.589e+01 | 2.692e+01 | -2.448 | 0.014360 * |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ''
Null deviance: 4760.5 on 3361 degrees of freedom
Residual deviance: 3079.6 on 3301 degrees of freedom
AIC: 0.48061

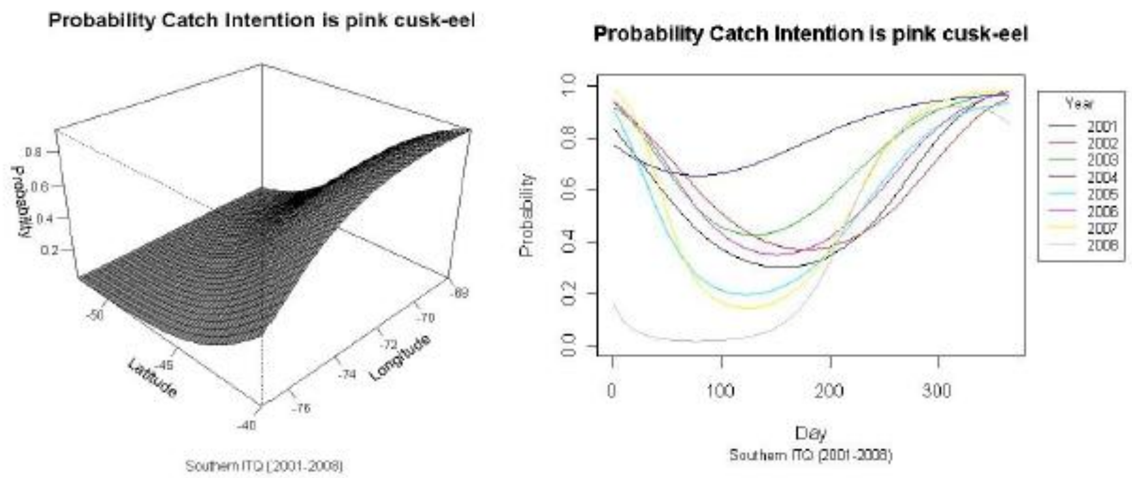


**Figure 8.** Model predictions for the Southern ITQ (2001-2008) of the interactive effects of previous latitude and longitude (a), and day and year (b), on the probability of a catch intention being pink cusk-eel.

## Discussion

### 1. Model and Variable Assumptions

*1.1 Estimation of Catch Intention*

The identification of catch intention is easiest for fisheries where there are few potential target species, with relatively little overlap between them, and where the gear is highly selective. The first two criteria are met in the Chilean industrial-longline fishery, where the fishery is characterised by three main target species with relatively little overlap, with the exception, in some cases, of southern hake and pink cusk-eel.

Still, there exist a number of criticisms associated with the use of catch composition to estimate catch intention. For one thing, estimates from landings often ignore the discard fraction, which may affect the estimated catch composition (Marchal *et al.*, 2006). Two key types of discards exist: (1) those arising from high-grading, whereby a fisher selects only the largest or best-quality fish, a practise common in fisheries where quotas are a limiting factor; and (2) discards of non-marketable species, i.e., species of little commercial importance, or those which cannot be landed (e.g., after a quota has been filled). Of these, high-grading is not considered a potential bias in the Chilean industrial-longline fishery, which is comprised of factory vessels, where local and international markets exist predominantly for whole fish and fish fillets respectively (pers. comm. Rodrigo Wiff). It is highly likely that discarding of non-commercially profitable catch occurs, particularly in cases where there is no scientific observer. The impact this may have on estimations of catch intention is conjectural. Even with bycatch regulations set to allow up to 20% of the catch after a quota for that species has been filled (Aguayo *et al.* 2000), we can assume that *any* target species is potentially marketable and therefore unlikely to be among the species discarded. However, unless discarding practises are similar between vessels and across years, discards could still present potential bias in the use of catch composition to estimate catch intention.

Catch composition may also vary due to differences in the spatial/temporal dynamics of a species. This was controlled in the analysis to some extent by splitting the hauls into two spatial zones. However, a species distribution is likely to change on a much finer spatial and temporal scale, and future studies might consider splitting their data further. There remain many complicating factors. For example, hauls may not be included in the appropriate cluster in cases where a decline in fish abundance has occurred (He *et al.*, 1997). Furthermore, changes in the underlying species assemblage due to fishing pressure and environmental conditions can affect catchability by altering the interactions both within and between species, which can lead to changes in the competitive dynamics of a fishery. Exploitation not only alters the abundance of species in an area but may also remove the most vulnerable fish, as was found by Walters and Bonfil (1999) to be the case for groundfish fished by the trawling fleet in British Columbia. As a result, the underlying species composition may no longer accurately reflect the ecological community, which may further widen the discrepancy between "intended" and "actual" catch. Likewise, environmental conditions could affect a species escape probability, as was the case in the southwestern North Sea, where an unusually cold season induced abnormal catches of sole (Horwood and Millner, 1998). Finally, our method assumes that what was caught is what was intended to be caught. This is flawed, as it implies perfect knowledge and ability on the part of the fisher, and has also never been ground-truthed. Finally, the method provides no way of estimating catch intention for hauls in which no catch occurs.

### *1.2 CPUE and Catch intention Models*

One of the assumptions of the CPUE and catch intention models used is that effort is allocated evenly within and across years and also between vessels. However, this is not the case for the Chilean industrial-longline fishery, and consequently vessels and years in which the majority of fishing took place are likely to be over-represented in the data. While currently beyond my statistical abilities, this skew may be taken into account through the proper application of weighting factors, and these should be incorporated in any further analyses of the data. Likewise, both models could be improved by using Generalized Additive Models (GAMs). One advantage of GAMs is that they are very flexible and allow the natural variation in the data to be fitted. This would be especially advantageous for the variable day of year, which could be fitted as a cyclic smooth, since day 1 and day 365 are thought to be very similar in terms of environmental processes. In addition, a major potential bias not addressed by this study is spatial autocorrelation, which is likely to exist as a given haul lacks independence from neighbouring hauls in space and time (Augustin *et al.* 1996).

### *1.2.1 CPUE model*

It is important to mention that there is some circularity involved in the inclusion of catch intention for a species in the CPUE model, since catch intention is estimated from catch composition, which is itself proportionate to CPUE of the entire haul. In addition, conclusions drawn from the CPUE model are limited, since the model includes only hauls in which pink cusk-eel was caught. However, knowing where a species is not found is just as important as knowing where it is, and it is possible for a catch intention of pink cusk-eel to be assigned to a haul containing no pink cusk-eel, in cases where the species making up the haul and their percentage contributions are otherwise similar, therefore the sample used may not be an accurate representation of a catch intention. In addition, the exclusion of hauls not containing pink cusk-eel is likely to disproportionately eliminate some catch intentions to a great extent than others, in particular those for which the target species was Patagonian toothfish as hauls suggest that relatively little overlap between the species occurs.

### *1.2.2 Catch Intention Model*

One of the main assumptions associated with the catch intention model is that each vessel is an independent unit. However, this is not the case as a vessel may be one of many owned by a company. The impact this has on the dynamics of the fishery is one for speculation, as just because two vessels belong to the same company does not necessarily mean they can be viewed as a single unit, yet neither are they independent. The vessels might be expected to be constrained by similar factors, such as the quota, and their catch intentions related, though not necessarily the same, at a given point in time. This characteristic of the fishery leads to a number of interesting questions: Do vessels belonging to the same company share knowledge of good fishing grounds? How does a company decide what vessel targets which species? what vessel goes out when? The answers to these questions are likely to provide important insight towards understanding the factors driving catch intention.

## 2. Findings

### *2.1 The Effect of Catch Intention on CPUE*

Catch intention was found to have a significant effect on the CPUE of pink cusk-eel in the Northern zone. While this suggests catch intention is an important factor determining CPUE of pink cusk-eel, it was also "too good" a predictor in the sense that it resulted in the exclusion of variables which held the greatest biological interest. Therefore, although it was able to explain a large proportion of the deviance in the data, it was difficult to pinpoint exactly the impacts and relative importance of the fishing tactics employed in response. Likewise, it is unclear whether the significance of catch intention is in fact the result of the circularity involved in its estimation.

### *2.2 The Factors influencing Catch Intention*

#### Previous catch rates

The previous catch rate of pink cusk-eel was found to be the most influential variable in both the Northern TAC and Southern TAC condition, and was also an important variable in the Northern ITQ condition. In each, the probability of a catch intention being pink-cusk eel increased with catch rates of pink cusk-eel. This may be the result of a number of causes: (1) a catch intention may be the same for a series of hauls, (2) higher catch rates of pink cusk-eel may induce a fisher to change target species and fish for pink cusk-eel. These arguments also apply to the previous catch rate of southern hake which was found to be a significant factor in the Southern TAC condition. What is most interesting, however, is that previous catch rates of pink cusk-eel was not an important variable in the Southern ITQ. This could be due perhaps to the fact that a catch intention of pink cusk-eel was relatively rare in the Southern zone, which was dominated by southern hake and Patagonian toothfish.

Fishing Scope

*Location*

The significance of latitude in each of the models and the interaction between longitude and latitude in the Southern ITQ condition model suggest that previous location has an important effect on the catch intention selected. Two possible explanations may be: vessels are constrained by the potential target species available at a given location, which could be tied to habitat, such that even if fishing for that particular target species is poor they are limited in terms of options of what they can catch. Second, as a vessel is limited in it's range, a false significance of previous latitude may result simply from the fact that catch intention for a certain species, while varying within a trip, may still occur either in a series or in close sequence. This however is only speculation and needs to be formally tested.

The fact that latitude was found to be a significant predictor of the probability of a catch intention being pink cusk-eel in all four models, compared to only one model for longitude could be tied to the fact that latitude is a better predictor of changes in the biogeography of the region (Camus, 2001).

*Season, Management condition, and Market prices*

It is difficult to interpret the effect of day and year on catch intention, as both represent a multitude of potentially important variables in the model including: status of the quota, species abundance/availability, and market prices. In the Northern TAC, the probability of a catch intention being pink cusk-eel decreased with day in a linear relationship which suggests it might be representative of the status of the quota (which in this condition decreases over time in response to fishing pressure). However, one must be cautious in one's interpretation of day of year as it provides only a rough measure of quota status as the rate at which a quota is depleted is not constant. In addition, as two separate quotas are set within a given year for the Chilean longline fishery, corresponding to Jan. 1-31 and Feb. 1-Dec. 31 respectively, (Aguayo *et al.* 2000). If as hypothesised, fishers in the TAC condition operate in a race to get the "biggest slice" of the allocated quota, one would expect the greatest effort to be seen at the start of the year, or otherwise related to the proportion of the quota that is left, which is likely to be the best predictor of this relationship. In its absence, days since the start of the quota may be used and should be incorporated into future analyses. It should be noted also that the aforementioned hypothesis is conditional on the assumption that the quota is a limiting factor, or at least perceived to be one.

In the Northern ITQ an interaction between day and year was found to be significant. However, in this case the relationship observed appears to be driven predominantly by environmental factors, as a negative quadratic relationship is observed between day and the likelihood of catch intention being pink cusk-eel is highest at the start and end of the year. As day 1 is likely to be very similar environmentally to day 365, this suggests an environmental relationship is at work.

While from this study it is unclear how market conditions effect catch intention, this area warrants further research.

**Conclusions**

Any interpretations drawn from this study are conditional on the accuracy of the method used to estimate catch intention as well as the statistics applied. Under the pretense that these conditions hold true, this study provides evidence that catch intention can have a significant impact of effectiveness of fishing effort units, and may be influenced by a number of dynamic factors which are affected by management conditions. This study also shows that the effect of catch intention and the factors which influence it, are important areas within fisheries science which warrant further research.

# Appendix A

Table 1. The resulting 'best' model (GLM with Gamma error structure, link=log) of factors influencing the CPUE (not including catch intention) of pink cusk-eel for the Northern Zone (1997-2008).

| Term | | Estimate | Std. Error | t value | Pr (>\|t\|) |
|---|---|---|---|---|---|
| Intercept | | -0.3837 | 0.12975 | -2.957 | 0.003126 ** |
| as.factor(Vessel) | | | | | |
| | 400062 | -1.1410 | 1.5098 | -0.991 | 0.32158 |
| | 400065 | 0.30811 | 0.10284 | 2.996 | 0.002755** |
| | 400075 | -0.29684 | 0.08330 | -3.564 | 0.000371*** |
| | 400081 | 0.18485 | 0.07122 | 2.595 | 0.009493** |
| | 400082 | 0.15806 | 0.07493 | 2.109 | 0.034983* |
| | 400118 | -0.49315 | 0.06743 | -7.314 | 3.25e-15*** |
| | 400133 | 0.18608 | 0.28603 | 0.651 | 0.515360 |
| | 400167 | -5.19034 | 0.83600 | -6.209 | 6.01e-10*** |
| | 400169 | -1.47639 | 0.81767 | -1.806 | 0.071069 . |
| | 400512 | 0.08074 | 0.27292 | 0.296 | 0.767381 |
| as.factor(Year) | | | | | |
| | 1998 | 1.18501 | 0.28956 | 4.092 | 4.37e-05*** |
| | 1999 | 0.93873 | 0.74616 | 1.258 | 0.208449 |
| | 2000 | -0.42305 | 0.15179 | -2.787 | 0.005349** |
| | 2001 | -0.70299 | 0.15199 | -4.625 | 3.89e-06*** |
| | 2002 | -0.84090 | 0.14435 | -5.825 | 6.25e-09*** |
| | 2003 | -0.89332 | 0.14565 | -6.133 | 9.62e-10*** |
| | 2004 | -1.53673 | 0.15070 | -10.198 | <2e-16 |
| | 2005 | -1.12238 | 0.16655 | -6.739 | 1.87e-11*** |
| | 2006 | -1.04015 | 0.16212 | -6.416 | 1.60e-10*** |
| | 2007 | -1.6053 | 0.19161 | -6.057 | 1.55e-09*** |
| | 2008 | -1.05576 | 1.83055 | -0.577 | 0.564152 |
| Day | | 10.02684 | 7.70863 | 1.301 | 0.193442 |
| Day^2 | | -18.11617 | 9.60228 | -1.887 | 0.059295 . |
| Day^3 | | -6.55497 | 5.38625 | -1.217 | 0.223698 |
| Longitude | | -5.43117 | 1.61876 | -3.355 | 0.000802 *** |
| Longitude^2 | | 0.19871 | 1.30012 | 0.153 | 0.878535 |
| as.factor(Year):Day | | | | | |
| | 1998 | 159.98703 | 27.53652 | 5.810 | 6.84e-09 |
| | 1999 | 119.75468 | 67.4770 | 1.775 | 0.076032 |
| | 2000 | -44.11182 | 8.48054 | -5.202 | 2.10e-07 *** |
| | 2001 | 13.91356 | 9.23553 | 1.507 | 0.132028 |
| | 2002 | 7.71321 | 8.52255 | 0.905 | 0.365513 |
| | 2003 | 11.03123 | 8.54438 | 1.291 | 0.196776 |
| | 2004 | 22.0114 | 8.5036 | 2.588 | 0.009683 ** |
| | 2005 | 23.02894 | 9.59065 | 2.401 | 0.016397 * |
| | 2006 | 19.49561 | 9.01929 | 2.162 | 0.030725 * |
| | 2007 | 7.24119 | 10.22068 | 0.708 | 0.478695 |
| | 2008 | 0.94329 | 113.54256 | 0.008 | 0.993372 |
| as.factor(Year):Day^2 | | | | | |
| | 1998 | 134.824 | 18.851 | 7.152 | 1.05e-12 *** |
| | 1999 | 97.743 | 41.1624 | 2.375 | 0.017626 * |
| | 2000 | 21.97 | 10.227 | 2.148 | 0.0318 * |
| | 2001 | 77.95 | 10.51 | 7.419 | 1.49e-13 *** |
| | 2002 | 65.226 | 10.092 | 6.463 | 1.18e-10 *** |
| | 2003 | 70.42 | 10.52 | 6.697 | 2.49e-11 *** |
| | 2004 | 68.825 | 10.312 | 6.674 | 2.90e-11 *** |
| | 2005 | 37.033 | 10.381 | 3.568 | 0.000365 *** |
| | 2006 | 41.195 | 10.723 | 3.842 | 0.000124 *** |
| | 2007 | 57.904 | 12.284 | 4.714 | 2.53e-06 *** |
| | 2008 | 42.150 | 73.364 | 0.575 | 0.566 *** |
| as.factor(Year):Day^3 | | | | | |
| | 1998 | 95.49 | 15.32 | 6.233 | 5.15e-10 *** |
| | 1999 | 65.73 | 22.60 | 2.91 | 0.00366 ** |
| | 2000 | 0.982 | 6.937 | 0.142 | 0.8874 |
| | 2001 | 28.40 | 6.805 | 4.174 | 3.08e-05 *** |
| | 2002 | -9.1773 | 6.526 | -1.406 | 0.1597 |
| | 2003 | -10.533 | 6.504 | -1.620 | 0.105 |
| | 2004 | -17.62 | 6.518 | -2.703 | 0.0069 ** |
| | 2005 | 5.381 | 7.011 | 0.768 | 0.443 |
| | 2006 | -10.648 | 6.947 | -1.533 | 0.1254 |
| | 2007 | -20.32 | 9.272 | -2.191 | 0.029 * |
| | 2008 | -16.56 | 28.98 | -0.572 | 0.568 |
| Day:Longitude | | -16.433 | 80.316 | -0.205 | 0.838 |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '
Null deviance: 4760.5 on 3361 degrees of freedom
Residual deviance: 3079.6 on 3301 degrees of freedom
AIC: 0.48061

# Appendix A

Table 2. The resulting 'best' model (GLM with Gamma error structure, link=log) of factors influencing the CPUE of pink cusk-eel for the Southern Zone (1997-2008).

| Term | | Estimate | Std. Error | t value | Pr (>ltl) |
|---|---|---|---|---|---|
| Intercept | | -1.231 | 0.0783 | -15.720 | <2 e-16 *** |
| as.factor(Year) | | | | | |
| | 1998 | -0.267 | 0.102 | -2.623 | 0.0087 ** |
| | 1999 | -0.069 | 0.1054 | -0.656 | 0.512 |
| | 2000 | -0.0732 | 0.10296 | -0.711 | 0.477 |
| | 2001 | -0.018 | 0.0983 | -0.187 | 0.8519 |
| | 2002 | 0.203 | 0.1059 | 1.920 | 0.0549 . |
| | 2003 | -0.1051 | 0.0958 | -1.096 | 0.273 |
| | 2004 | 0.1175 | 0.0957 | 1.23 | 0.22 |
| | 2005 | -0.319 | 0.097 | -3.289 | 0.001 ** |
| | 2006 | -0.568 | 0.0984 | -5.78 | 7.87e-9 *** |
| | 2007 | -0.642 | 0.102 | -6.307 | 3.00e-10 *** |
| | 2008 | -0.479 | 0.104 | -4.621 | 3.88e-06 *** |

Sig. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Null deviance: 15486 on 7439 degrees of freedom
Residual deviance: 15013 on 7428 degrees of freedom
AIC: -7470

# Appendix B

### Binomial Model Selection Process:

Table 1. Model Selection for the Catch Intention model in the Northern Zone during the period 1997-2000

| Term | Action | Res. Deviance | AIC | Δ AIC |
|---|---|---|---|---|
| Intercept | starting | 1515.9 on 1420 df | | |
| Prev_CPUE(cusk) | added | 1062.4 on 1419 df | 1006.4 | -- |
| As.factor(Vessel) | added | 917.47 on 1396 df | 967.74 | 38.66 |
| prevLatitude | added | 825.39 on 1395 df | 877.39 | 90.1 |
| PrevLatitude^2 | added | 812.74 on 1394 df | 866.74 | 10.65 |
| Prev_CPUE(hake) | added | 683.75 on 1393 df | 739.75 | 126.99 |
| Day | added | 672.3 on 1392 df | 730.3 | 9.45 |
| **Models within 2 of the lowest AIC** | | | | **Difference** |
| prevLongitude | added | 672.07 on 1391 df | 732.07 | 1.77 |

Table 2. Model Selection for the Catch Intention model in the Northern Zone during the period 2001-2008

| Term | Action | Res. Deviance | AIC | Δ AIC |
|---|---|---|---|---|
| Intercept | starting | 2298.8 on 1803 df | | |
| Day | added | 1911.2 on 1802 df | 1915.2 | -- |
| prevLatitude | added | 1641.6 on 1801 df | 1647.6 | 267.6 |
| As.factor(Year) | added | 1611.1 on 1794 df | 1631.1 | 16.5 |
| As.factor(Year):Day | added | 1565.9 on 1787 df | 1599.9 | 31.2 |
| Day^2 | added | 1321.1 on 1786 df | 1357.1 | 242.8 |
| Prev_CPUE(cusk) | added | 1114.9 on 1785 df | 1152.9 | 204.2 |
| As.factor(Year):Day^2 | added | 1083.9 on 1778 df | 1135.9 | 17 |
| Prev_CPUE(cusk)^2 | added | 1076.9 on 1777 df | 1130.9 | 5 |
| Day^3 | added | 1073.2 on 1776 df | 1129.2 | 1.7 |
| **Models within 2 of the lowest AIC:** | | | | **Difference** |
| Prev_CPUE(cusk)^2 | or | 1076.9 on 1777 df | 1130.9 | 1.7 |

Table 3. Model Selection for the Catch Intention model in the Southern Zone during the period 1997-2000

| Term | Action | Res. Deviance | AIC | Δ AIC |
|---|---|---|---|---|
| Intercept | starting | 2417.2 on 3733 df | | |
| Prev_CPUE(cusk) | added | 1526.4 on 3732 df | 1530.4 | -- |
| prevLatitude | added | 1350.3 on 3731 df | 1356.3 | 174.1 |
| Prev_CPUE(hake) | added | 1212.5 on 3730 df | 1220.5 | 135.8 |
| Prev_CPUE(hake)^2 | added | 1204.8 on 3729 df | 1214.8 | 5.7 |
| Prev_CPUE(cusk)^2 | added | 1157.9 on 3728 df | 1169.9 | 44.9 |
| Prev_CPUE(cusk)^3 | added | 1117.3 on 3727 df | 1131.3 | 38.6 |
| as.factor(Vessel) | added | 1081.3 on 3721 df | 1107.3 | 24 |
| Prev_CPUE(hake)^3 | added | 1068.3 on 3720 df | 1096.3 | 11 |
| Day | added | 1064.1 on 3719 df | 1094.1 | 2.2 |
| as.factor(Year) | added | 1054.7 on 3716 df | 1090.7 | 3.4 |
| **Models within 2 of the lowest AIC** | | | | **Difference** |
| Day^2 | added | 1054.1 on 3715 df | 1092.1 | 1.4 |
| PrevLatitude^2 | added | 1052.9 on 3715 df | 1090.9 | 0.2 |
| prevLongitude | added | 1054.7 on 3715 df | 1092.7 | 2.0 |

## Appendix B

Table 4. Model Selection for the Catch Intention model in the Southern Zone during the period 2001-2008

| Term | Action | Res. Deviance | AIC | Δ AIC |
|---|---|---|---|---|
| Intercept | starting | 7135.8 on 7548 df | | |
| prevLatitude | added | 5806.1 on 7547 df | 5810.1 | -- |
| Day | added | 5357.4 on 7546 df | 5363.4 | 446.7 |
| Day^2 | added | 4842.8 on 7545 df | 4850.8 | 512.6 |
| as.factor(Year) | added | 4758.7 on 7538 df | 4780.7 | 70.1 |
| Day^3 | added | 4705.4 on 7537 df | 4729.4 | 51.3 |
| prevLongitude | added | 4671.0 on 7536 df | 4697 | 32.4 |
| PrevLongitude^2 | added | 4663.0 on 7535 df | 4661 | 36 |
| as.factory(Year):Day | added | 4588.5 on 7528 df | 4630.5 | 30.5 |
| as.factor(Year):Day^2 | added | 4514.8 on 7521 df | 4570.8 | 59.7 |
| as.factor(Year):Day^3 | added | 4493.6 on 7514 df | 4563.6 | 7.2 |

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