NOT TO BE CITED WITHOUT PRIOR REFERENCE TO THE AUTHOR

International Council for the Exploration of the Sea ICES CM 2006/Q:10

# Vertical distribution and variable mortality rates of adult cod (*Gadus morhua*) in Icelandic waters.

**(data from tagging with conventional tags and electronic archival tags combined)**

Vilhjálmur Thorsteinsson and Kristinn Sæmundsson

The vertical distribution of adult cod in Icelandic waters and availability to fisheries is studied by tagging experiments using conventional tags along with electronic archival tags (DSTs), releasing tagged adult cod on spawning grounds during the spawning season. The Releases have been relatively large numbers of cod with conventional tags and a sub-sample double tagged with additional DST. This way it becomes possible to have more recaptures for each release group, obtaining more information on the distribution of the fishery, as well as migrations within and outside the area of fishery indicated by the time series from the DSTs. For analyses data is grouped by tagging locality and time of the year. The vertical distribution of the fishery is shown by depth information from recapture data. This is compared to time spent at depth shown by archived electronic data. The results show considerable time spent by the fish at deeper levels than is indicated by the distribution of the fishery. This difference in availability varies between areas of release. Results indicate that there is a tendency for temporal stability in the behaviour of selection of depth and ambient temperature in feeding migrations and the more time cod spends in deeper waters, the lower the probability of capture. Occurrences of deep types of feeding migrations vary between spawning components. Feeding migrations of adult cod from the continental shelf to deeper waters (below 200 m.) should therefore influence fishing mortalities.

keywords: Gadus morhua, double tagging, migrations, availability, mortality

Contact author: Vilhjálmur Thorsteinsson, Marine Research Institute, Skulagata 4 ,

121 Reykjavík, Iceland. Tel: +354 575 2000; Fax: + 354 575 2001; Tel(direct) +354 575 2107;

GSM +354 863 5442; E-mail: villi@hafro.is

# Introduction

This paper reports a continued effort to study the behaviour of cod in Icelandic waters using tagging experiments. From the beginning of these experiments (Thorsteinsson 1995) the release strategy has been to release a relatively large number of cod with CTs (conventional tags) with a sub sample double tagged with a Data Storage Tag DST. The data on releases and recaptures pf the CT is fishery dependent data, which is compared to the fishery independent data from the DST's. The main objective of this paper is to use data from two tag types to examine whether behaviour patterns such as selection of depth and ambient temperature during feeding migrations can influence availability of cod to the fishery.

Availability and accessibility are terms used to describe how variability in behaviour could affect fisheries or CPUE (Harden Jones 1974), and frequently the objectives of research with DSTs is to explain the variability of CPUE and efficiencies of fishing gear in surveys (Arnold et al, ; Greer-Walker et al. 1990; Arnold 1992; Arnold et al, 1997; Godö and Michalsen 1997; Metcalfe, Hunter et al. 1999; Arnold and Dewar 2000; Godö and Michalsen 2000).
**Previously,** we used Data Storage Tags to study migration patterns, ambient temperature, and growth (Pálsson and Thorsteinsson 2003). In our first approach we pooled DST data recaptured from releases in experiments from 1995 to 1999, on traditional spawning grounds of cod off the South West coast of Iceland. The result from 60 DSTs showed patterns in behaviour based on choice of depth as **Shallow**, where cod in feeding migrations showed vertical movements to lesser depth than 200 m and **Deep** where the cod showed mostly vertical migrations to more depths than 200 m during feeding migrations. Evidence was found for different growth rate of the two behaviour types associated with depth and seasonality in that average depth increased during winter, before the cod started spawning migrations, in February. Further we became aware of the affinity of deep migrations with thermal fronts.
**The present approach** differs from the earlier one in that we use behaviour categories or selection by the fish of depth and ambient temperature as characteristics to visualise and classify behaviour patterns as well as descriptive statistics. We have extended the study period to the year 2005 and use 278 DST data series long enough to study summer and winter feeding migrations. We have also increased the spread of the investigation. In former (Pálsson &Thorsteinsson, 2003) work we had only data from release sites off the South West coast. Whereas now we are also using data from other release areas which likewise are traditional spawning grounds around Iceland.

In this paper we look at the behaviour as it appears in post spawning migrations in selections of depth and ambient temperature. Among the behaviour examples and characteristics which have to be defined are the relative frequency among individuals in populations or stock. The duration of events: that is does the behaviour last for seconds, minutes, hours, days or years, stability of behaviour types within a given year. In addition, how multi annual time-series show long term stability in behaviour, from releases in various regions of Icelandic waters how common the varieties of behaviour is and then make a comparison of DST data, which is fisheries independent and the data from the release of conventional tags from the same experiments to find the influence of the behaviour on availability to the Fisheries. What is the possible effect of the behaviour on catchability, availability, accessibility

# Materials and Methods

## Locations

Tagging was carried out in Icelandic coastal waters. In Figure 1 are regions of the continental shelf that show collections of sampling areas, marked with lines, e.g. off the West, South West, South-Middle, on a map of Iceland and the surrounding waters.
**Release localities** within regions are shown by central points of localities of combined releases of Data Storage Tags (DSTs) and conventional tags (CTs) indicated by abbreviations of local names. These are on traditional spawning grounds and are also on traditional gill-net fishing grounds (Marteinsdottir, Gudmundsdottir et al. 2000).

**Release Groups**, are similar to Groups as defined by Robinchaud (Robichaud 2004), i.e. a sampling unit of cod tagged together at a common location, In our case all trials with a fishing gear to collect cod to release with tags on the same locality (area) within a two day period. These do not, however, necessarily refer to isolated population units.

## Tags

We use the abbreviation CT for Conventional Tags and DST for electronic tags that go by the names of Data Storage Tags or archival tags. The types of the DST's in the MRI tagging database are DST200, DST300, used in the period from 1995 to 1999. Their max capacity is 4050 records of temperature and depth, with 8 bit microprocessors and 0.4% resolution of measurement range. From 2000-2003, DST-milli, with a capacity of 10,000 to 21,000 records of temperature and depth. Since 2003, DSTcenti-ex, with capacity up to 130,000 records of temperature and depth. The DSTmilli, and DSTcenti-ex have 12 bit microprocessors and the resolution in data collection is 0.06% of the measurement range. The electronic tags were all produced by Star Oddi, Iceland. For technical information on the DSTs, see the website http://www.Star-Oddi.com.

## Tagging

Tagging was carried out annually during the period from the 25$^{th}$ of March to the 30$^{th}$ of April. Months of liberty were counted from 1$^{st}$ of May. When capturing cod for tagging off the west coast and south coast we used mainly gillnets, with 12 nets per each setting with mixed mesh sizes (Thorsteinsson et al 1996; Gudmundsdottir et al 1998). Off the North Coast Danish seine was used to capture the cod. The CTs (Conventional Tags) were attached with clothes marking guns near the first dorsal fin. The DSTs were surgically attached in the peritoneal cavity (for information on method see Website: http://www.hafro.is/catag/b-fish_tags_tagging/b13-methods_section/b1302-conv-double-cod.html).
All surgical operations for DSTs work was carried out by V. Thorsteinsson, (the author) with license No.0304-1901, issued by the Icelandic Committee for Welfare of Experimental Animals from the Chief Veterinary Office at Ministry of Agriculture, Reykjavik Iceland. Same method is used in Thorsteinsson, 1995, Thorsteinsson & Marteinsdóttir 1998, Pálsson & Thorsteinsson 2003. For further information on tagging method see Website http://www.hafro.is/catag/.

## Data

For the study we used both time series from DSTs and data from releases and recaptures of CTs. The DST data used is limited to DST time-series that reach 9 months of duration with some exceptions in areas with low recapture rates. Summary information about the data is displayed in Table 1. Each record entry consists of: ID of release area, ID of DST, the type of summer migration (depth character, temperature character), the type of winter migration (depth character, temperature character) and minimum and maximum temperature for both summer and winter migrations.

At present there are more than 2000 DSTs releases and close to 700 recaptures, with database entries of up to 8 million records of temperature and depth. The DST tags have been in rapid development during the period of this project. The latest products of DSTs have much higher measurement resolution and are capable of measuring much greater depth and temperature range, which makes comparisons between old and new DSTs difficult. By using simple classification of data based on depth (Shallow versus Deep) and temperature (coastal water temperatures range versus temperature characteristics found at current fronts) we can use DSTs with different resolution in measurements without problems of comparison, in the same study.

**Strategy and assumptions**

It is important that all data used in the study comes from tagged adult cod in the spawning season on traditional spawning grounds. The mixed release method used in the study, i.e. releasing a sub-sample of the cod tagged with CT, also tagged with DSTs (Double tagged), produces two kinds of data in relation to fisheries dependence.

**Fisheries-dependent data.** All recaptures from tagging experiments in Icelandic waters are recovered through the fishing industry either by the fishermen, by employees of fish factories or institutions that are active in research or monitoring. Such data is therefore fisheries-dependent where the recapture location and depth shows the distribution of the fishery, rather than the distribution of a population or release group.

**Fisheries-independent data.** The data collected by the measurement devices and stored in memory of the DSTs is fishery independent since it is collected equally within and outside the area were fishery is conducted. The position and depth at recapture is, however, fishery-dependent.

**Analysing the time-series for behaviour patterns**

Each time-series is divided into three (nominal) seasons,4 months each, Behaviour-period See the descriptions below and Figures 2 and 3.

Seasons definition

| | | |
|---|---|---|
| Season 1 | February – May, | Spawning migrations |
| Season 2 | June – September, | Summer feeding migrations |
| Season 3 | October – January, | Winter feeding migrations |

**Behaviour characters based on vertical migration or ambient temperature selection**

Dominant character type among possible combinations (Shallow-Coastal, Shallow-Frontal, Intermediate-Coastal, Intermediate-Frontal, Deep-Coastal and Deep-Frontal) is given to each season using the criteria below. See also Figures 2 and 3 for illustrations on division of time-series into seasons and explanations of characters used to describe the behaviour.

| | |
|---|---|
| Coast(al)- temp. (C) | Normal annual cycle of temperature rising towards maximum in late summer and declining during winter |
| Front(al)-temp.(F) | Not an annual cycle but very variable going frequently between extremes found at thermal fronts, min temperature reaching close |

| | |
|---|---|
| | to or below 0°C (-Front) and max temperature reaching 8+ |
| Shallow migr. (S) | Shallow migrations: fish that spends virtually all of their time in shallower waters, less than 200 m depth |
| Intermediate migrations (I) | Intermediate depth migrations: behaviour where the range is variable but spending considerable time at around 200 m dept |
| Deep migr. (D) | Deep water migrations: fish that spend most of the time in deeper waters than 200 m |

Depth class definition used in Palsson & Thorsteinsson (2003) was Shallow migrations for those vertical migrations that were clearly shallower than 200 m and Deep Migrations for all others. There are however a number of time-series among the usable data that have vertical migrations overlapping the theoretical 200 m boundary. To verify the former grouping based on depth (Shallow and Deep) or define a new category if necessary we use a temporary definition of "Intermediate depth" when initially grouping behaviour patterns or types in feeding migrations.

**Temporal stability**

Fo wihin a year stability we calculate the probability of a migration pattern such as Shallow/Coastal or Deep/Frontal that are found in Summer Season 2, will be repeated in following Winter Season 3.

Some time-series of 1.5 to 3 years of length showing graphical presentation of real multi seasonal data are also provided.

**Comparison of fisheries-dependent and fisheries-independent data**

For this part, data from the South West region is used because that region has the longest history of tagging experiments with double tagged releases of CTs and DSTs.

For indices of availability we use the proportion of Shallow/Coastal behaviour pattern in each release location (Knarr, Krys, Selv).

The effect of availability of the tagged fish to the fisheries is estimated from total recaptures of CTs as % of total releases of CTs in each release area (Knarr, Krys, Selv) in the study period.

The fisheries independent data in Figure 7 displays averages from 25 DST200 tags with 11 to 13 month time-series, 100,000 data points in total. Because of regularity in sampling intervals the number of data points per season in the DST data are approximately the same.

The data points in the recapture data (fisheries dependent) however vary in numbers by seasons depending on seasonal recapture rate as shown in Table 4.

The behaviour as depth and ambient temperature selection is in association with feeding migrations of seasons 2 and 3. The recapture data is therefore limited to the same seasons.

# Results

## Behaviour patterns in feeding migrations

Analysis of behaviour types was carried out on 195 DSTs tags that included at least 1 summer season and 1 winter season, selected from the 279 available DST tags . Thus, the 390 "Behaviour-Season units) make 6 possible types of depth temperature selection: Shallow-Coastal, Shallow-Frontal, Intermediate-Coastal, Intermediate-Frontal, Deep-Coastal, Deep-Frontal. These are summarised in table 1.

**Shallow water migrations.** Cod that stay in shallow waters with a temperature change within the range of the coastal waters, were 199 or 51 %. Shallow water cod stayed in shallow water throughout the year, and seldom went into areas with the characteristics of temperature fronts. There was 1 season with Shallow/Frontal characteristics found in the selected data. This was found in release locality "Thist" in the North East region.

**Deep water migrations.** Deep water migrations were 157 or 38% of the total. Most of the cod that migrated to depths >200m encountered frontal areas. Number of seasons with temperature fronts were 118 or 89 %, within the deep migration type. The seasons of the Deep migration types with Coastal temperature characteristics were only 13 or 3% of the total.

**Migrations at intermediate depths.** Vertical migrations at intermediate depths were 41 of 390 or 11% in total. Further grading by temperature characteristics, gave 21 (6%) intermediate depth with coastal temperature characteristics and 20 (5%) intermediate depth and frontal characteristics. It seems that intermediates with coastal temperature ranges should be counted as the tail end of the distribution with shallow types and likewise the intermediate with fronts as tail the end of distribution of deep types. In remaining studies of temporal stability of behaviour types in depth/temperature selection, the intermediate depth with constant or coastal temperature was grouped with Shallow-Coastal types and the intermediate depth with frontal characters with Deep-Frontal types.

**The association of cold minimum temperatures with Deep type migrations.** Of the selected Deep types, 150 or 90% reach temperature fronts with minimum temperatures below 1 °C. Thereoff, 123 or 72% reach minimum temperature less than 0 °C. Further, 112 or 65% of the deep types were found to spend variable length of time in sub zero temperatures down to -1°C (N = 172). In comparison the Shallow types where the temperature minimum is <= 1 °C were only found in 5 cases or 2.25 % of the total investigated DSTs and those were in DSTs released off the North coast.

Results of grouping behaviour types as combinations of depth/temperature characteristics, indicate two dominant or main groups: Shallow/Coastal and Deep/Frontal. In further analysis in this paper we only use the two dominant types Shallow/Coastal and Deep/Frontal. Other combinations, Shallow with characters from temperature fronts and Deep with characters from coastal waters, accounted for less than 5% of seasons analyzed.

## Temporary stability of behaviour in feeding migrations (Shallow/Deep and Coastal/Frontal)

### Temporal stability of behaviour pattern within a year

Time-series with summer and winter feeding seasons were used for this part. Table 2 shows the result of counting behaviour types from Appendix 1. This is used to calculate the probability of shallow types in summer continuing as shallow types in winter versus shallow types in summer changing over to deep type in winter. In the same way the probability of deep types in summer continuing as deep in the winter versus deep types of summer migrations changing over to shallow migrations in winter were calculated.

The results indicate that more than 90% of individuals are likely to keep to the same behaviour category or depth selection throughout the time of the annual feeding migrations (Table 2).

### Temporal stability of behaviour characteristics between years

Presently the available data for more than 13 months at large are rather few but we have some to show as examples of multi annual stability. Figure 4 shows averages of depth for successive feeding seasons where cod has been at large for up to 3 years. There are two time-series with the Shallow/Coastal type in all seasons, for two years (2C0645 and 1C0444). Three time-series are identified as Deep/Frontal during 3 and 4 seasons for two years (1C0621, 1C0593, 1C0605). They are feeding in very typical thermal fronts and part-time in sub-zero temperatures in all feeding seasons. The 6$^{th}$ time-series (1C0611) with 6 seasons for three years, is of the type Shallow/Coastal summer and the winter seasons are of the type Deep/Frontal. Thus in 1C0611 the behaviour Shallow/Coastal summer Deep/Frontal winter is repeated for 3 years. All shown examples repeat the vertical migration patterns within the first year migration range either Shallow/Coastal, Deep/Frontal or alternating Shallow/Coastal-Deep/Frontal.

Figure 5 shows the temperature averages per feeding season, using the same data as in Figure 4. There is an obvious difference in temperature ranges of the two behaviour types based on Shallow and Deep. The Shallow/Coastal time-series show higher summer temperatures in rhythm with seasonal temperature cycle which is characteristic for coastal waters. DST 2C0645 was released off the West coast and 1C0444 released off South-East coast. The change in average temperatures is not as prominent in the South-East region as in the West region.

The Deep water time-series show much lower average temperatures than the shallow water types (Figures 5). Unlike the averages for the shallow water types, which reflect the temperature cycle in the coastal waters the temperature averages of the Deep/Frontal types are influenced by time spent at variable temperatures which can be found at the polar water fronts in North West and East of Iceland see Figure 9 (Pálsson & Thorsteinsson, 2003; Hansen & Österhus, 2000, http://www.hafro.is/Sjora/). The longest time-series in this group, 1C0611 shows a trend towards lower temperatures with increasing number of seasons at liberty (Figure 5). This is probably to be caused by longer time spent at low temperature with increase in size or age.

## The migration patterns, Shallow/Coastal and Deep/Frontal in different release localities around Iceland

The 11 Release Locations of tagged cod in the study are widespread among the spawning grounds and are within all regions except the East Coast, Figure 1. Table 3 shows the actual numbers of Shallow-Coastal and Deep-Frontal types grouped by release locations (see Figure 1). In this part all time-series that reach 5 months and longer are included as well as all seasons.

The relative magnitude of Shallow/Coastal types and Deep/Frontal types for each of the 11 release localities is shown in Figure 6. The phenomenon of Shallow/Coastal and Deep/Frontal division in feeding migration of adult cod is widespread in the Icelandic spawning stock of cod.

The Shallow/Coastal types are more common among those belonging to the release locations: Breid, Fax, Knarr, Ingo, Hals, Huna, Eyja (or 60% to 84 %).The Deep/Frontal are more common among cod relesed in: Selv and Thist (or 75% and 64%, respectively). In the areas Krys and Medal the proportions between Shallow/Coastal and Deep/Frontal are nearly equal. All release localities with combined releases of CTs and DSTs have both Shallow/Costal and Deep/Frontal migration types within them, the proportions between types of migration varies however between the release locations.

## The effect of the migration patterns Shallow/Coastal and Deep/Frontal on availability to fisheries of adult cod in South West Region

Figure 7 shows a comparison of the fisheries independent data and fisheries dependent data. The horizontal-columns histogram show in percentages the vertical distribution in 50 m depth intervals down to 400 m and >400 m (Figure 7). Black horizontal columns are time-series from DSTs (fishery independent) and white horizontal columns are recaptures from CT tagging experiments (fishery dependent). Table 4 shows fisheries-dependent data, as a summary of releases and recaptures of CTs and DSTs from tags released at the South-West region from 1995 to 2003.

**Release locality Knarr (80% Shallow)**

In the period of spawning migrations and spawning (season 1) DST data and CT recapture data have the very same distribution and the maximum values coincide.

During feeding migrations (seasons 2 and 3) DST data and CT recapture data are quite similar except that DST data has a secondary mode down at 300 to 400 m depth range caused by small proportion of the cod released in Knar that are of the deep type.

**Release locality Krys (54% Shallow)**

The period of spawning migrations and spawning (season 1) DST data and CT recapture data have the very same distribution and the maximum values coincide like in Knarr. When it comes to season 2, there are two modes in the DST data of nearly equal size, one above 200 m and the other from 250 to 400 m. The recapture data shows that most of the fishery goes on in lesser depth than 200 m. The same can be said for both types of data in season 3.

**Release locality Selv (25 % Shallow)**

The vertical distributions in Selv are different from the others in that there is obviously more deep trend in the data. The DST data is already bimodal in season 1. This is likely to be caused that deep going cod that spawn in Selv are spending less time on the spawning grounds and are either later to leave the feeding grounds or return back earlier . In season 2 and 3 there is less and less time spent by the fish at depths of the fishery shown by the recaptures.

**Availability and recaptures**
The proposed method is to compare variability in behaviour patterns (Shallow/Coastal versus Deep/Frontal) to variability in total recaptures as percent of total releases. The data selected for this is from the South-West region from the 3 release localities (Knarr, Krys, Selv) grouped by 3 seasons (February-May, June-September, October- January).

In figure 7 and Table 4 We have established that the more DST data and CT recapture data coincides in vertical distribution the more availability in the form of recaptures. This happens when the fish is in shallow waters. Therefore a proposed **availability index**, for the purpose of this present work is the relative number of **Shallow** type adult cod within a release locality.

Referring to Figure 3, such an index for the three areas, would be: Knarr = 80 %, Krys =54% and Selv = 25%, and this should be compared to relative numbers of recaptures of CT releases in the same release localities in seasons 2 and 3. The total recaptures in seasons 2 and 3 as percent of the total releases are: Knarr = 12%, Krys = 8%, and Selv = 4%.

Figure 8 shows the relationship between the proposed indices of DSTs in three release localities (Knarr, Krys and Selv) and the total recaptures of CTs released in same localities.

# Discussion

**Definitions of behaviour patterns**

Observations and definition of behaviour structure in commercial stocks is important for utilisation of resources. The suggestion of two types of behaviour of adult cod in Icelandic waters in relation to vertical movements in feeding migrations (Palsson and Thorsteinsson, 2003) was tried by creating an extra group between deep and shallow. That is cod showing vertical migrations in around the 200 m depth that was defined as the boundary between Shallow and Deep. The results indicated that of the 6 possible combinations of depth and temperature, there are two dominant types of behaviour. The other 4 possible combinations were ca 15% of the total and could possibly be ignored as tail end of temperature distributions but not comfortable solution.

We have been using depth characters as leading in the definitions by first looking at depth and then temperature.

**Reversing the classification – first grouping by temperature type then depth**

Noticing that the Shallow-Frontal type exist in small populations off the North coast (near cold surface waters) but is rare in release groups from South regions. We might get a simpler (picture?) situation by using the temperature characters as dominant. The characters of coastal waters are easily defined and separated from the characters of temperature fronts. Then we have two groups:

Coastal Cod that stays in waters with coastal characteristics (as we have defined in methods) mostly in shallow waters but with some of the distribution down to deep.

Frontal Cod that migrates to temperature fronts and utilises the food source associated with them. The south limits of the Polar fronts are off the East coast and the West coasts of Iceland at 400 -500 m depth but comes to surface waters far north (see figure 9). This explains that migrant cod off the South coast hit the fronts at greater depths >300m but cod that spawn off the north coast of Iceland may hit the fronts at less that 200 m depth. See Figure 9.

We need the depth dimension however for explaining the differential mortality by depth.

**Temporal stability in behaviour**

Temporal stability is observed in behaviour of individual cod. More than 90% show the same behaviour of depth–temperature selection in summer and winter. Interestingly, the other 10% may also have temporal regularity, because we have annual repetition of Shallow Summer - Deep Winter behaviour in that group. The graphs, in figures 4 and 5 show temporal stability. There are also indications of temporal stability in spawning grounds that is release groups in the same locality tend to have similar ratios of Deep to Shallow behaviour types over a decade. The fidelity to choice of depth and ambient temperature in feeding migrations should be of importance for fisheries management.

**Distributions of the dominant behaviour types among regions**

Concerning distribution among spawning grounds these two groups were found within all major spawning grounds and release group of CTs & DSTs tagging experiments around Iceland but in variable proportions at each locality Table 3. The relative numbers of Deep and Shallow at spawning site could be related to depth and (?) distance from shore. In the South West region the spawning ground with the highest percentage of Deep was furthest from the shore in the South West region.

In this work no attempt is made to quantify the proportions in the regions. For that information on population indices of the spawning grounds involved is needed.

An example of this would be Marteinsdottir et al. (2000) using data from the MRI gill-net survey for 1997 made indices of relative abundance of female cod on these spawning grounds. The sizes of areas Knarr and area Selv have been estimated from commercial fishery data showing where gill-nets have been set by fishermen. From this information the release area Knarr is 135 km2 and Area Selv 157 km2. from indices obtained from Gill-net survey relative indices of females Knarr: 6.01, Selv: 40.9 (relative index of females).

**The effect on availability** depending on whether the cod migrates shallow or deep or choice of temperature regimes as coastal waters or temperature fronts is considerable as shown in Figure 8. The **differential Fishing mortality** by depth which this tagging data shows between shallow and deep fishing grounds has also been shown by (Begg and Marteinsdottir 2003). They used data from " MRI ground fish spring surveys" and log book data from the Icelandic fisheries, to investigate the effect of fishing on the compositions of adult cod in Icelandic waters. The South West region in this paper corresponds to 9.1 and 9.2 regions of Begg & Martinsdottir 2003 where the mean relative fishing mortality was F = 2.3 for shallow 0 to 125m depth and F= 0.4 for deeper than 125 m (125 – 500m).

## Acknowledgements
We would like to thank for support granted by.
The Icelandic Ministry of fisheries,
Nordic Counsel of Ministers
Projects supported by European Commission: CODYSSEY, METACOD

## References

**Arnold, G. P. (1992). The depth of neutral buoyancy in cod: vertical migrations and systematic variation in target strength. ICES Fast Working Group, Bergen.**

**Arnold, G. P. and H. Dewar (2000). Electronic tags in marine fisheries research: a 30-year perspective. Symposium on Tagging & Tracking Marine Fish with Electronic Devices, Honululu.**

**Arnold, G. P., M. Greer-Walker, and B.H. Holford (1990). "Fish behaviour: achievements and potential of high-resolution sector-scanning sonar." Rapports et Procés-Verbaux Réun. Cons. int. Explor. Mer. 189: 112-122.**

**Arnold, G. P., J. D. Metcalfe, B.H. Holford and A. A. Buckley (1997). Availability and accessability of demersal fish to survey gears: new observations of 'natural' behaviour obtained with electronic data storage tags. ICES.**

**Begg, G. A. and G. Marteinsdottir (2003). "Spatial partitioning of relative fishing mortality and spawning stock biomass of Icelandic cod." Fisheries Research 59: 343-362.**

**Godö, O. R. and K. Michalsen (1997). The use of data storage tags to study cod natural behaviour and availability to abundance surveys in the Barents Sea. ICES Annual Science Confernce, Baltimore, Mariland, U.S.A.**

**Godö, O. R. and K. Michalsen (2000). "Migratory behaviour of north-east Arctic cod, studied by use of data storage tags." Fisheries research 48: 127-140.**

**Harden Jones, F. R. (1974). Objectives and problems related to research into fish behaviour. Sea fisheries research. F. R. Harden Jones. London, Elek Science: 261-275.**

**Marteinsdottir, G., A. Gudmundsdottir, et al. (2000). "Spatial variation in abundance, size composition and viable egg production of spawning cod (Gadus morhua L.) in Icelandic waters." ICES Journal of Marine Science 57: 824-830.**

**Metcalfe, J. D., E. Hunter, B.H. Holford and G.P. Arnold (1999). The application of electronic data storage tags to spatial dynamics of fish populations. ICES C.M. 1999/AA:01.**

**Pálsson, Ó. K. and V. Thorsteinsson (2003). "Migration patterns, ambient temperature, and growth of Icelandic cod (Gadus morhua L.): evidence from storage tag data." Canadian Journal of Fisheries and Aquatic Sciences 60: 1409-1423.**

**Robichaud, D., Rose, George A. (2004). "Migratory behaviour and range in Atlantic cod: inference from a century of tagging." Fish and fisheries 5: 185-204.**

**Thorsteinsson, V. (1995). Tagging experiments using conventional tags and electronic data storage tags for the observations of migration, homing and habitat choice in the Icelandic spawning stock of cod. ICES.**

# Tables

***Table 1.*** ***Numbers of behaviour types in 4 month periods (seasons) of summer and winter migrations (Behaviour-Seasons). Periods of time series from DSTs identified on the bases of depth and temperature characteristics. Only time series that show both summer (June-September) and winter (October - January) migrations are included.***

| | Coastal | % Coast | Frontal | % Front | total | % |
|---|---|---|---|---|---|---|
| Shallow | 199 | 51 | 1 | 0 | 200 | 51 |
| Intermediate | 21 | 5 | 20 | 5 | 41 | 11 |
| Deep | 13 | 3 | 137 | 35 | 150 | 38 |
| total | 233 | 60 | 157 | 40 | 390 | 100 |

**Table 2. Repetitive behaviour of individuals. Within year temporal stability of behaviour as selection of depth level. All data with time series showing summer and winter feeding migrations**

| Migration pattern | numbers | proportion |
|---|---|---|
| Shallow summer followed by shallow winter | 103 | 93% |
| Shallow summer followed by deep winter | 8 | 7% |
| Deep summer followed by deep winter | 78 | 93% |
| Deep summer followed by shallow winter | 6 | 7% |
| total | 195 | |

**Table 3. Numbers of "Behaviour-Seasons" by Localities of two the most common behaviour types based on vertical migration and ambient temperature (Shallow-Coastal and Deep-Frontal)**

| Release Localities | Shallow coastal | Deep frontal | Total |
|---|---|---|---|
| **Breid** | 20 | 7 | 27 |
| **Fax** | 26 | 6 | 32 |
| **Knarr** | 76 | 18 | 94 |
| **Krys** | 43 | 37 | 80 |
| **Selv** | 16 | 47 | 63 |
| **Med** | 18 | 16 | 34 |
| **Ingo** | 26 | 10 | 36 |
| **Hals** | 25 | 5 | 30 |
| **Hun** | 5 | 2 | 7 |
| **Eyja** | 10 | 5 | 15 |
| **Thist** | 22 | 42 | 64 |
| **Totals** | 287 | 195 | 482 |

*Table 4. Releases and recaptures of conventional tags by relese locality and season, in tagging experiments with adult cod 1995 to 2005 in the South West region*

| Release-Locality | Summary Releses | Recaptures Season 1 | Recaptures Season 2 | Recaptures Season 3 | Total Recap. | Recapt % Total release |
|---|---|---|---|---|---|---|
| Knarr | 2503 | 401 | 183 | 128 | 712 | 28 |
| Krys | 2335 | 306 | 97 | 82 | 485 | 21 |
| Selv | 2772 | 185 | 65 | 43 | 293 | 11 |

# Figures

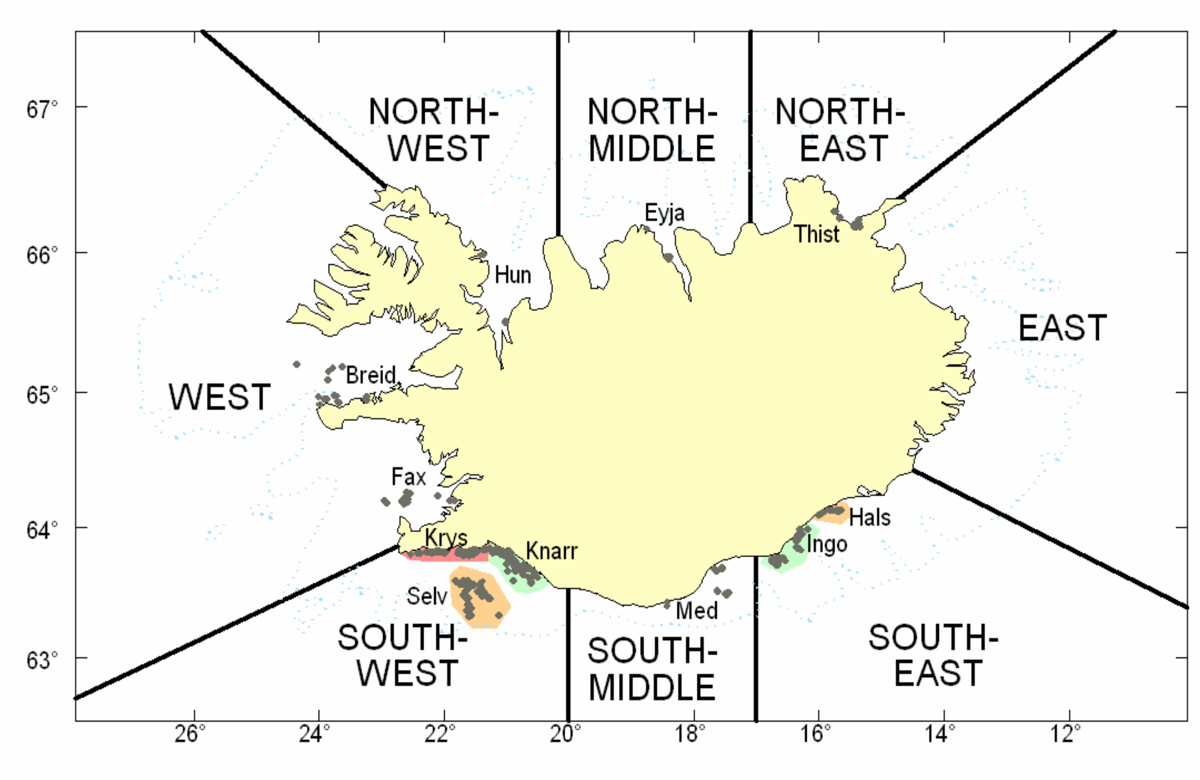



**Figure 1. Release areas of DST tags and conventional tags for adult cod on spawning grounds 1995 2005. 200 m depth contours are shown in blue.**

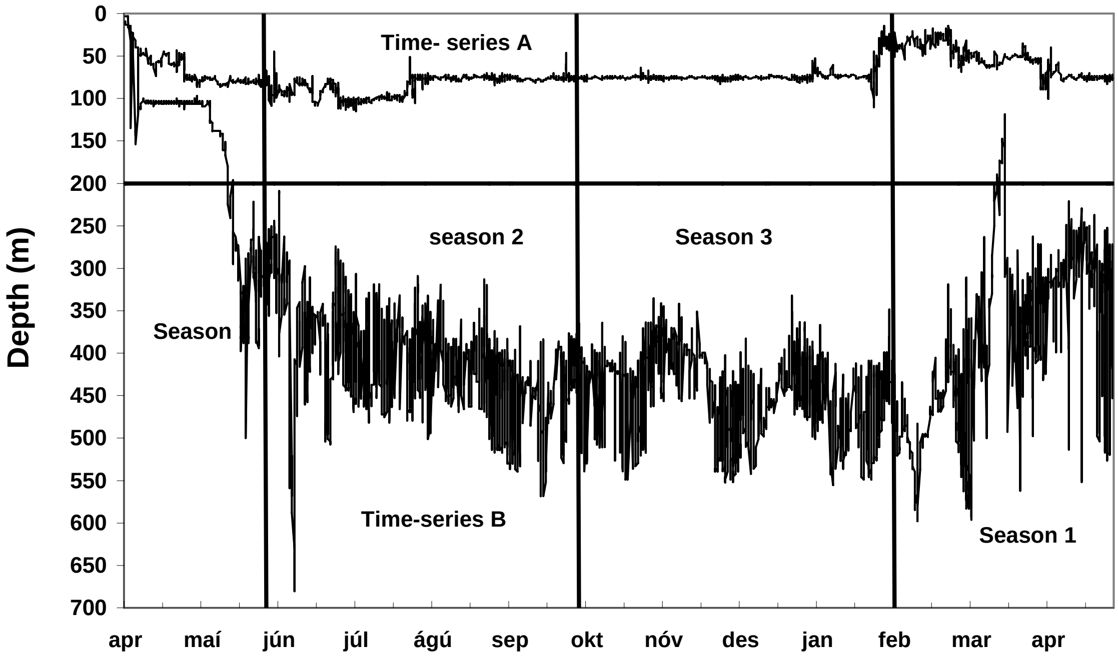



Figure 2. Examples of depth selection among adult cod with DSTs. Time-series A is a Shallow type of feeding migration. Time series B is a Deep type of feeding migration. Horizontal line marks boundary at 200 m. Vertical lines mark seasons: Season 1, Spawning migration and spawning, Season 2: Summer feeding migrations, Season 3: Winter feeding migrations.

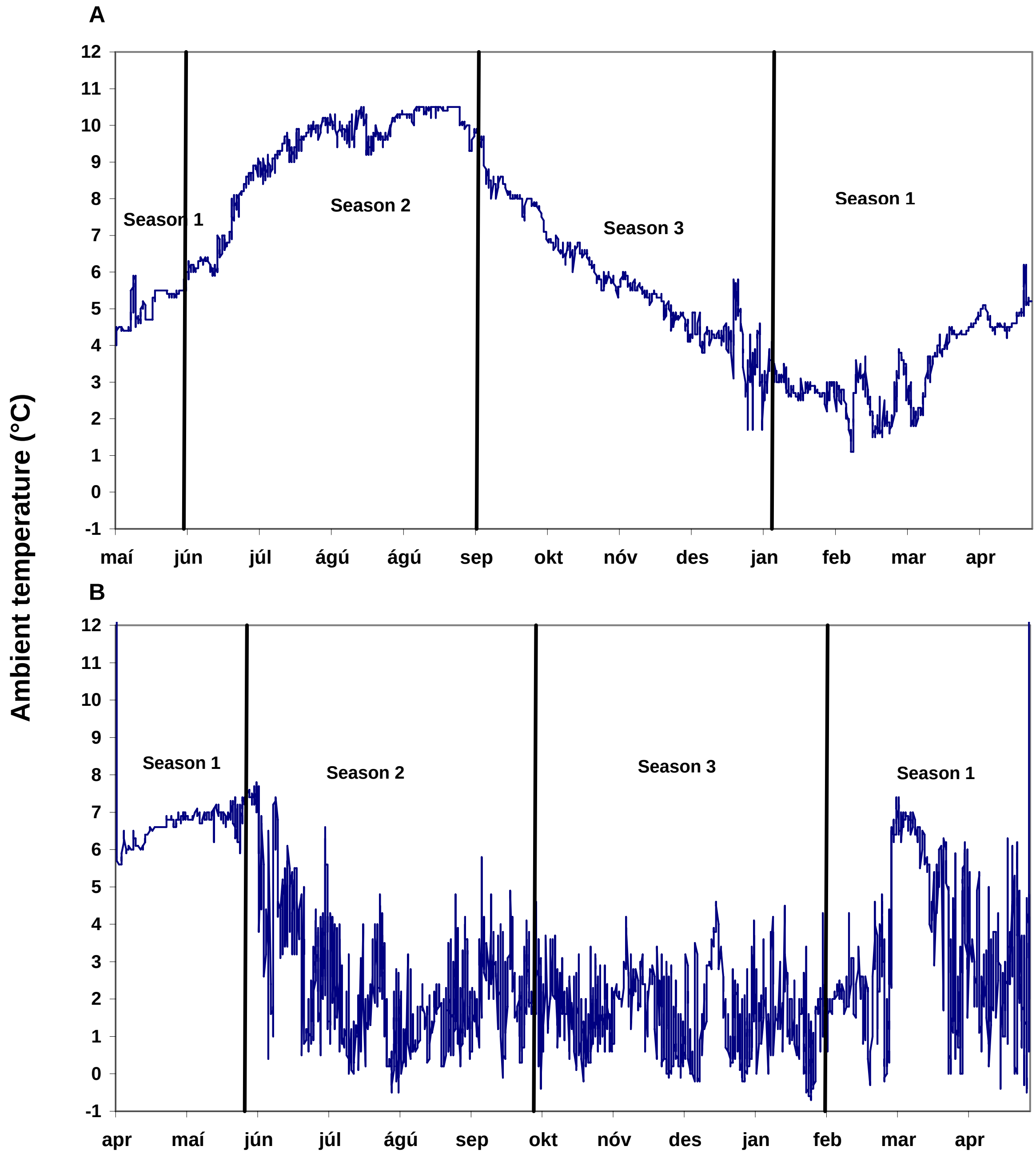



Fig 3. Examples of behaviour types as selection of ambient temperature of adult cod with DSTS. A) Typical annual temperature cycle and range where the cod is feeding in shallow coastal areas. B) Typical annual temperature variation where the cod is feeding at a temperature front. Vertical lines mark seasons: Season 1: Spawning migration and spawning. Season 2: Summer feeding migrations. Season 3: Winter feeding migrations.

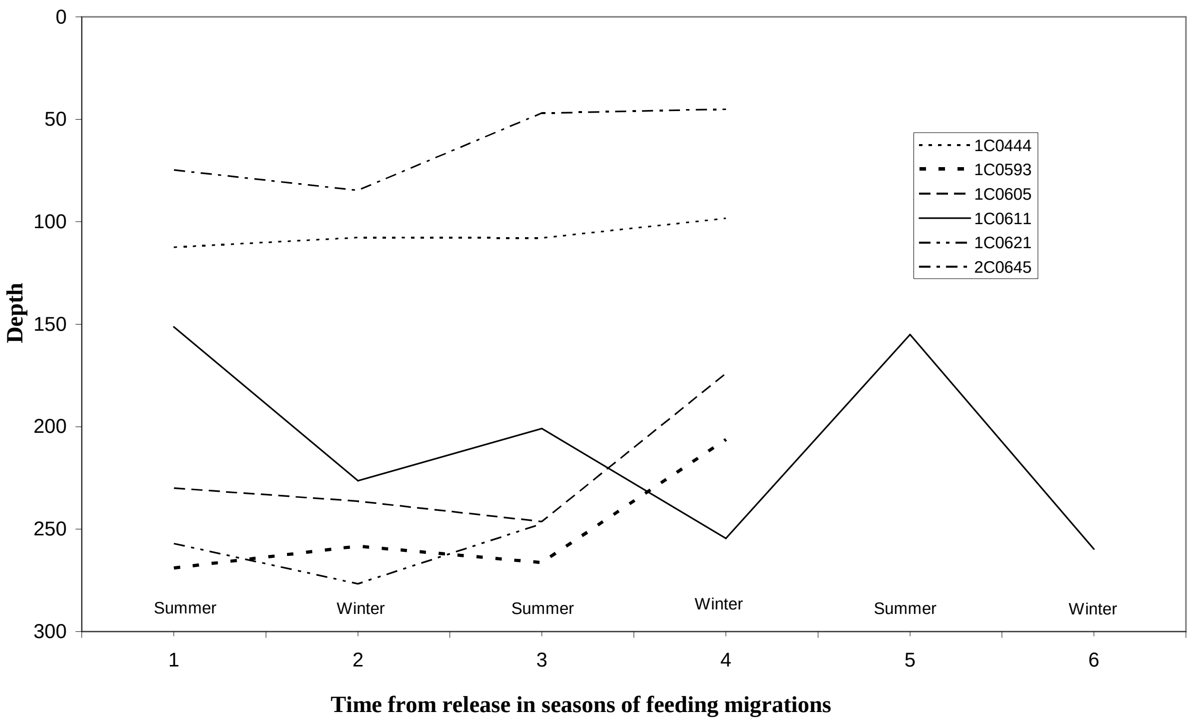



Figure 4. Average depth over 4 month seasons summer and winter over 1.5 to 3 years time series of DST data. Stability in behaviour of adult cod in feeding migrations

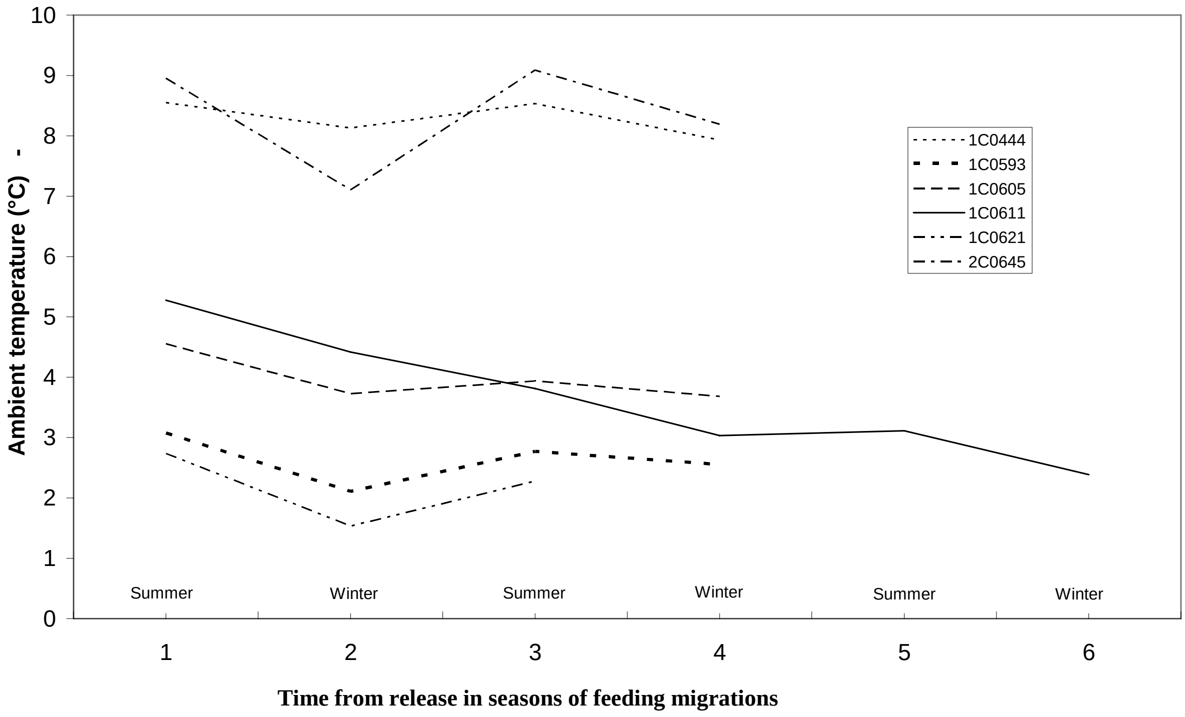



Figure 5. Average temperature over 4 month seasons summer and winter in 1.5 to 3 years time series of DST data. Stability in behaviour in feeding migration as selection of ambient temperature.

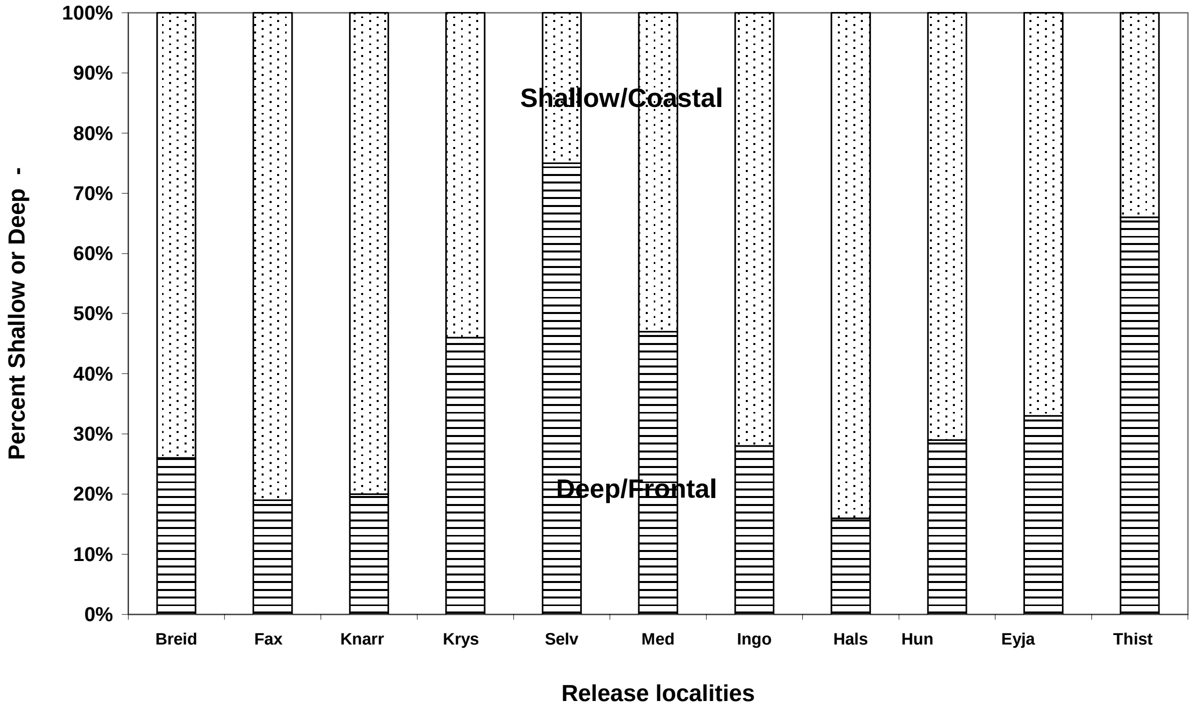
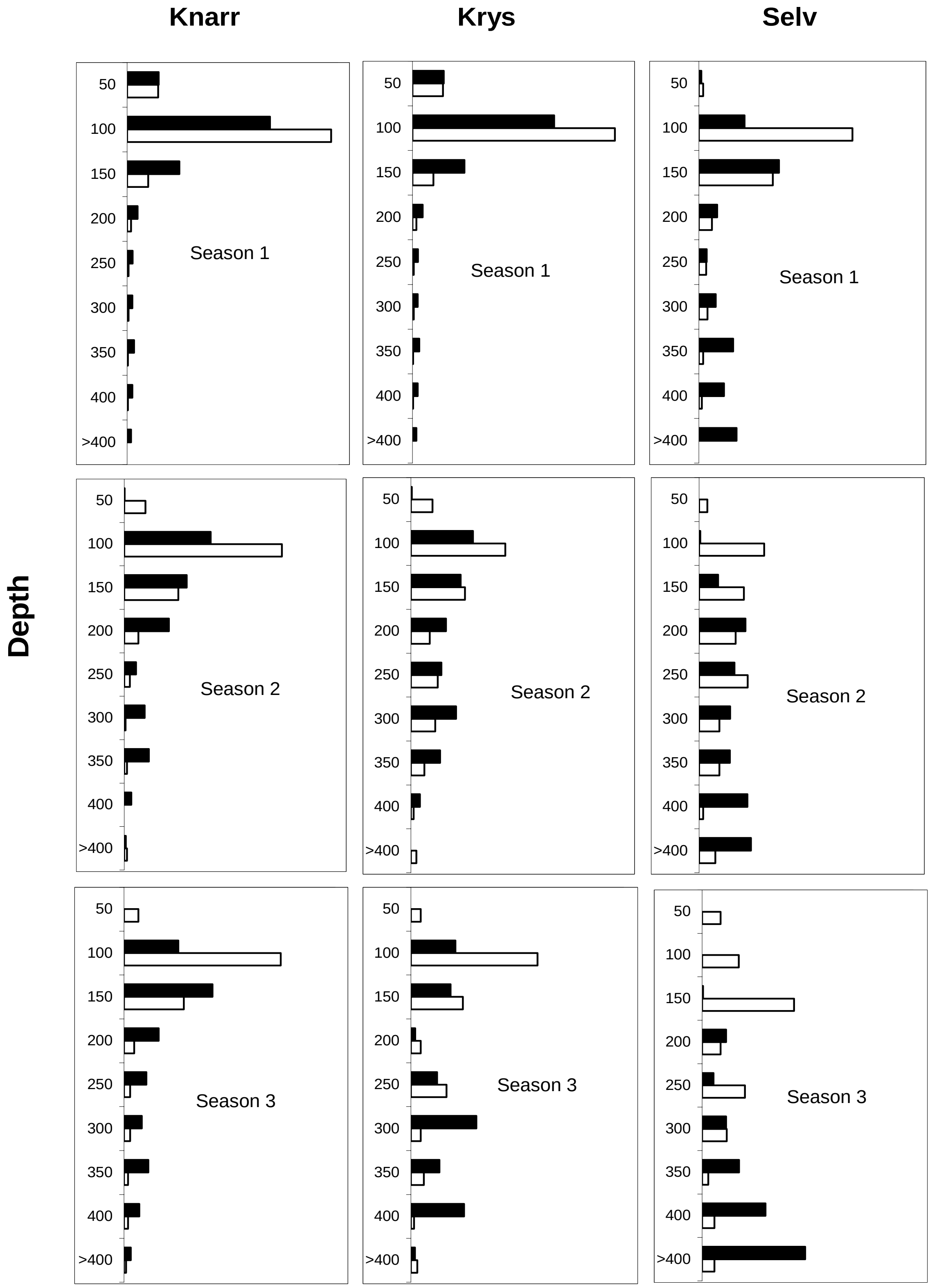



**Figure 6. The relative numbers of the two most common behaviour types based on depth and ambient temperature selection (Shallow-Coastal and Deep-Frontal) found in various release locations around Iceland**




DST data % and recaptures % by Locality, Season and Depth

Figure 7.  Horizontal-columns histograms showing vertical distribution in 3 seasons of the year, for 3 localities in 50 m depth intervals down to 400 m and > 400 m.  Black columns are time series from DSTs as percent measurements within 50 depth interval (fisheries-independent). White columns are CTs recaptures (fisheries dependent) from the same tagging experiments as the DSTs. The data is from 3 release localities in South West region (Knarr, Krys, Selv) 1995 to 2004 divided by 3 seasons.

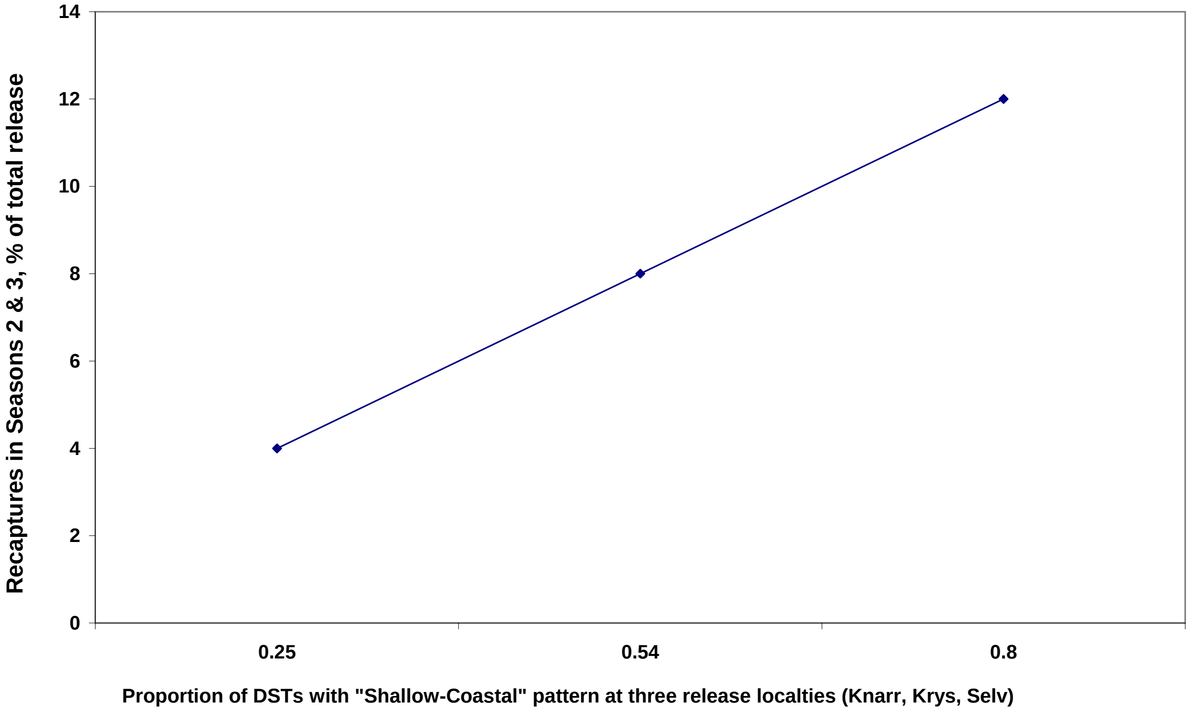



Figure 8. The relationship between CT recaptures as percent of total release of CTs in three release localities in the region southwest of Iceland and percent of recaptured DSTs in same release localities with Shallow / Coastal type pattern in feeding migrations

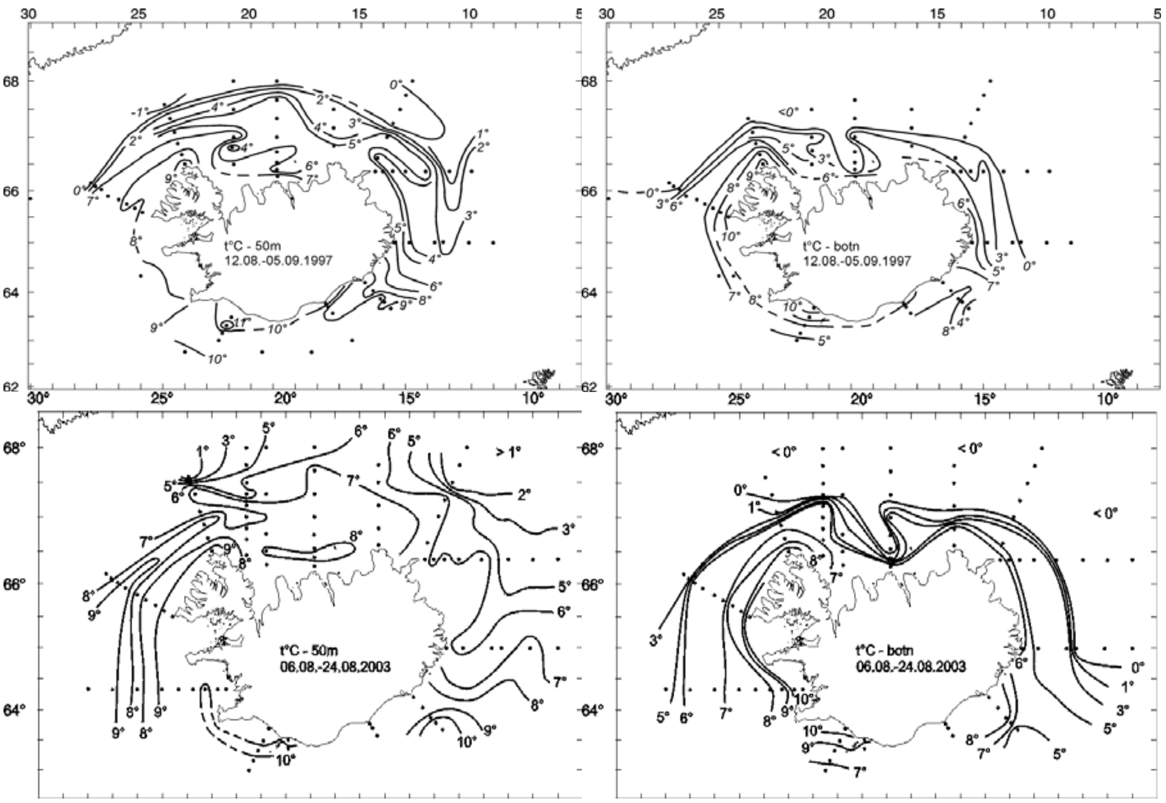



Figure 9. August temperature conditions, in Icelandic waters at 5o m depth and bottom, in 1997 and 2003 (http://www.hafro.is/Sjora/).