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**Using vessel acoustics to detect diving patterns of krill foraging predators automatically: Development of a novel method for quantifying impact of krill fishing on seals and penguins**

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## **Using vessel acoustics to detect diving patterns of krill foraging predators automatically: Development of a novel method for quantifying impact of krill fishing on seals and penguins**

### Abstract

The aim of this work was to assess the possibilities of automatically generating a dataset of dive behaviour of air-breathing predators, based on acoustic data from a monitoring survey and from commercial krill fishing operations. Our results documents that some form of automatic detection of diving predators in the data is feasible. A relatively low detection probability of our algorithms compared to the manual detections, suggest that there is significant room for improvement. Given the caveats of an imperfect methodology, the results document the possibilities to automatically extract, with a reasonable level of precision, data on the dive behaviour of air-breathing predators from the echo-sounder data.

### Introduction

The commercial fishery for krill (*Euphausia superba*) in the Antarctic has in recent years shown an increasing trend, with annual catches around 200 000 tons (CCAMLR). An increasing number of nations and vessels have been notifying for the fishery, further increasing the concern that the trigger level might be reached. The present trigger level of 620 000 tons (CCAMLR (Conservation of Antarctic Marine Living Resources) CM 51-01), subdivided by area based on historic catch information, is restrictive compared to the estimated sustainable, and needs to be evaluated (Nicol et al. 2012). One of the main concerns of a potentially increasing fishery is the possible impacts on predators (*e.g.* seabirds, seals, whales, fish, squid) also utilizing the Antarctic krill as a food resource (Howard 1989, Croxall et al. 2002). Particular in focus is the potential impact on predators when major harvest activity overlap with energetically demanding feeding periods in concentrated areas, especially close to important breeding areas for land-base-dependant predators (Constable and Nicol 2002, Croxall et al. 2002). Knowledge about predator behavior is important in this context to identify the potential degree of conflict with fisheries.

CCAMLR has for more than 20 years aspired to develop the FeedBack Management (FBM) system (Constable et al. 2000). Combining fisheries data, research vessel data and modelling has been considered the main way forward to obtain enough information during the fishing season to regulate the spatial distribution of catches (CCAMLR WG-EMM 2014). However, in the CCAMLR discussions around the impact of fishing on krill predators the following prerequisite has been taken for granted: Fishing vessels negatively impact the feeding of krill predators by disturbing their feeding behaviour and/or by negatively impacting their prey field. The lack of documentation is

mainly due to the difficulties in establishing a reliable methodology to obtain data that can be used to evaluate this issue.

Knowledge about predator behavior is important in the context of predator-fisheries interactions as it may enable us to identify the potential degree of conflict. Commonly employed techniques to construct activity budgets, distribution patterns and diving activity include collection of data from biologging instruments that are attached to the animals (*e.g.* Gjertz et al 2002, Krafft et al 2000, 2002, Carlens et al 2006). Such data often provide detailed information on individual behavior, but also has its weaknesses such as highly labor intensive fieldwork and potential influence on behavior and energetics due to the instrumentation and handling (Blanchet et al. 2014). Typically, also instrumentation of land based predators occurs during periods when they aggregate on land, such as during reproduction and moult (Biuw et al. 2009). This increases the chance of under-representing the part of a population that is only short periods on shore, like those that do not participate in breeding activities, with likely different energetic needs and foraging behavior.

There is an increasing trend in exploring alternative methods for the surveillance of predator behavior, such as remote sensing (*e.g.* Schwaller et al. 2007), that may provide different results as well as reducing potential influence of instrumentation and costs. Recent interest has also been devoted employing acoustic data logged by echosounders and sonars from vessels (ICES joint research report). Previous studies have shown that it is possible to observe diving behaviour using data obtained by echosounders. These studies have shown or suggested that species as variable as whales (Doksæter et al. 2009, Godø et al. 2013), seals (Loshamn 2009) and birds (Brierley and Fernandes 2001) leave behind traces on the echograms, and that experienced operators are capable of recognizing these traces. These traces will usually only contain fragments of the total underwater dive profile, but have been used to extract data on behaviour (Godø et al. 2013), in-dive swimming speeds etc.

While performing a krill scientific assessment cruise in a high density krill area using the fishing vessel Saga Sea, we observed a number of telltale dive traces on echograms. Since these fishing vessels tend to concentrate in the same areas as those used for intensive feeding by marine predators, this opens the possibility of obtaining dive data from areas of ecologically important predator-prey interactions. However, the extraction of data on dives of marine predators usually requires a manual procedure, and as such is work-intensive and prone to a certain amount of subjectivity.

We explore the potential of using acoustic methodology during monitoring surveys as well as during commercial fishing to study this issue. These datasets represents two overarching advantages; we can observe the predators and the prey field simultaneously with the same method, and we can record data at the same spatial and temporal resolution as the commercial fishing. By using echosounders we are able to observe of the upper parts of the water column with a high spatiotemporal resolution. In the most common configuration, a hull-mounted echosounder transmits sound vertically into the ocean interior and records the timing and strength of echoes returned, thereby efficiently mapping the vertical distribution of sound scattering features underneath the vessel. As echosounders use sound for the observation, it is usually impossible to directly identify the recorded echo to species. In recent years multiple frequency acoustics methodology has been developed to deal with this problem (Kloser et al. 2002, Korneliussen and Ona 2002) as done to distinguish krill from other organisms (Watkins and Brierley 2002, Calise and Knutsen 2012). When combining frequency responses with ecological knowledge, it is often possible to identify the source of scattering with reasonable certainty.

The aim of this work is to assess the possibilities of automatically generating a dataset of dive behaviour of air-breathing predators, based on acoustic data from a monitoring survey and from commercial fishing operations. If successful, we further analyse the tracks with respect to behavioural characteristics and discuss how the method can be used to quantify impact of fishing on predators.

### **Methods:**

The data collection was carried out in the waters near and between the South Shetland Islands (62°0'S 58°0'W) and in South Orkney Islands (60°35'S, 45°30'W) during 2013 and February 2014. The vessel used was a Norwegian commercial trawler, the FV Saga Sea, using hull-mounted Simrad ES60 echosounders operating at 38 and 120 kHz. The data were collected during active commercial fishing operations or when in transit between fishing operations in the 2013 season, and in January and February 2014; referred to as the *fisheries data*. The same vessel was used to carry out a scientific survey in the South Orkney Islands area 24. - 30. January 2014, using the same transducers; and is referred to as the *scientific data*. During the period of the scientific cruise the vessel followed pre-set cruise-lines, designed to map krill distribution in the area around the South Orkney Islands. During daylight hours of the scientific cruise observers identified and counted seabirds and marine mammals along the cruise-lines.

By observing echogram traces identified from a manual inspection as diving predators, some

prominent features were selected as the basis for the automatic identification. First of all, the traces typically had stronger backscatter at 38 kHz than at 120 kHz. This is convenient, as it provides acoustical separation from euphausiids and other macroplankton, which typically show stronger backscatter on the higher of these frequencies (Calise & Knutsen 2012). Secondly, in the vertical domain the backscatter from the 2 frequencies often did not overlap. Both of these features suggest that using a filter that isolates areas with a low ratio in 120 kHz to 38 kHz backscatter should be effective in isolating the diving animals (Fig. 1). Unfortunately diving air-breathing predators are not the only organisms or features that give stronger backscatter at 38 than at 120 kHz. Features with a high 38 kHz backscatter compared to 120 kHz backscatter was quite often identified at very shallow ranges. This is probably a result of poor spatial overlap between pulse-volumes of the two transducers at close ranges (Korneliussen et al. 2008), as a first step we therefore filtered out all results shallower than 20 m. In order to further identify potential error sources, we investigated the results further wrt. areas of high relative backscatter at 38 kHz in the scientific survey data. We found that for this particular survey, larger patches of higher backscatter at 38 kHz were almost always associated with features identified as diving animals. For the patches that were not, they were either layers of relatively low total backscattering strength, or deep patches clearly associated with bottom features. To remove the latter category, we limited data to the upper 200 m, and excluded areas in proximity to the bottom from analysis.

Based on these considerations, we processed the data in the following way in KORONA (Korneliussen et al. 2006). First, spike noise (*e.g.* from other equipment (sonars and other acoustic instruments)) was filtered from the data. The acoustic data were then smoothed, primarily in the horizontal domain. Since the smoother operated on ping data, the actual horizontal spatial scale of smoothing will vary with ship speed and ping-rate. These smoothed data were then integrated at both frequencies (38 and 120 kHz) at a bin size of 5 m vertical and 30 seconds horizontal, at a threshold of -70 dB, these integration results are referred to as bin-values. Technically a mask was applied before integrating the data set, this mask was smoothed more than the NASC (Nautical Area Scattering Coefficient) values: If the (smoothed pixel) frequency response of the mask ( $rf$ , defined as  $NASC_{38kHz}/NASC_{120kHz}$ ) was  $< 1$ , the pixel backscattering strength was set to -120 (i.e. no echo), if  $\geq 1$ , the original echo strength was retained in the final data set. Antarctic krill is considered a weak scatterer, and the backscattering at 120 kHz is stronger than that at 38 kHz, typically be several dB (Calise & Knutsen, 2012). Scattering where 38 kHz is stronger is therefore indicative of some other species. In principle, this means that in the filter implemented in this study, prior to integration, we had echograms with values only where (smoothed) 38 kHz was stronger than (smoothed) 120 kHz, i.e. data where most of the krill backscatter was removed from the

echogram (Fig. 1). Backscattering strengths from the (30 s by 5 m vertical) bins form the basis for the automatic detection of the dives, for each bin we have a  $rf$  value, as well as a backscattering strength at 38 kHz. The automatic detection is based on  $rf$  values above a threshold ( $rf_t$ ,  $rf_t > 1$ ), and backscattering strengths also exceeding a threshold ( $NASC_{38_t}$ ).

In order to check the performance of the automatic detection, the entire scientific survey was also manually processed for dive events. In the manual detection, a box was drawn around backscatter interpreted as dives, all backscatter within these boxes were then assumed to be caused by diving predators. This produces an independent, but potentially biased (due to manual identification), estimate of dive events, but is in our case the “best” existing approach. In particular, it is unlikely that all actual dive-events are detected manually, so this can be considered a conservative measure, and it is also highly likely that the dive events manually observed is the subset of dive events leaving behind high backscatter traces, i.e. possibly the biggest animals, the animals closest to the center path of the vessel (which may be significant if vessel avoidance or attraction occur) etc.

From the bins, two metrics are extracted,  $rf$  and  $NASC_{38}$ , but these metrics are still noisy, i.e. there will be presence of random events giving 38 kHz stronger than 120 kHz, the influence of different threshold levels on the detection and error rates were therefore investigated. There is also the potential for vertical bias in the data. First of all the 120 kHz data is more influenced by noise than the 38 kHz data, and the deeper data is more affected than the shallow. Additionally, most of the traces left behind by diving animals will be of relatively short duration, due to a moving boat and the movements of the animal, unless the animal happens to swim in the same direction as the boat is moving. The levels of noise in the raw data (both caused by spikes and other noise) necessitated the use of a smoothing operator before especially  $rf$  is computed, but the both the spike removal algorithms and the smoother will tend to reduce the backscatter from dive events. This may lead to a vertical bias, especially at shallow depths, where the combined effects of ping rate and boat speed may imply that dives are only “hit” by single pings, dive events may be selectively removed.

To compare results from the automatic identification with the manually identified traces, a couple of parameters were calculated. Results are presented at two levels of aggregation: bin events are based on results obtained directly in the 30 second by 5 m vertical integration bins, but integration results were also collapsed to represent the water column total (i.e. 1 observation per 30 second time segment, referred to as segment data), a dive was accepted if any bin within a time segment had automatically detected dive-events.

Detection probability:  $\text{sum}(\text{AIE} \ \& \ \text{MIE})/\text{sum}(\text{MIE})$ ,

where AIE is Automatically Identified Events, and MIE is Manually Identified Events and  $\text{sum}(\text{AIE} \ \& \ \text{MIE})$  is the sum of AIE given concurrent MIE. A Manually Identified Event or trace is here defined as a time segment (200 m vertical by 30 sec) with a diving predator present. Note that a single dive from a predator may trigger events in 1 or more adjacent bins and segments. The detection probability was calculated for different thresholds of absolute backscattering strength at 38 kHz ( $\text{NASC}_{38\_t}$ ), i.e. the total 38 kHz backscatter needed in order to accept an event. In addition it was calculated for different values of the ratio ( $\text{rf}_t$ ) between 38 kHz and 120 kHz backscatter, with for instance a ratio of 2 implying that traces were only accepted where  $\text{NASC}_{38\text{kHz}} \geq 2 * \text{NASC}_{120\text{kHz}}$ .

In addition to the detection probability, we calculated the error rate, defined as:

Error ratio:  $\text{sum}(\text{AIE} \ \& \ !\text{MIE})/\text{sum}(\text{AIE})$

which is the ratio between “false” (in the sense of no concurrent manual observation) automatic identifications of dive events and the total number of automatic identifications.

The echosounder software display of positions interferes with the fishermen's use of the stored data, so for the fishery the acoustic data lacks gps-positions. The acoustic results from the fishery were therefore aligned with approximate positions from the catch reports, interpolation was used to assign positions to points in between reported trawls. The positions in the data from the fisheries operations are therefore only useful for obtaining the general area of the vessel, which is OK in this paper focusing on demonstrating the methodology.

Since the Simrad equipment onboard consists of split-beam echosounders, we also attempted to detect single echo events from the predator dives using LSSS. The single echo detections would allow us to map the 3 dimensional position of the organisms in relation to the transducer, and could potentially be used to study the 3 dimensional positions and swimming patterns of the animals relative to the vessel (Godø et al. 2013). The Simrad standard algorithm for echo detection is geared towards providing high quality target strength measurements, in order to obtain any detections an alternate method had to be used, with relatively lax echo detection criteria allowed.

## **Results:**

### Methodology:

Fig. 2 shows the effects of different settings of  $rf\_t$  on detection probability (black lines) and error ratios (red lines) plotted against  $NASC\_38\_t$ . At low values of the NASC threshold a relatively high proportion of actual dive events are detected (detection probability  $> 0.55$ , i.e. automatic detection of a dive event where dive events are also detected manually), but a high proportion of these events are false positives (i.e. detect a dive event where dive events are not detected manually). For high values of  $rf$  thresholds and NASC thresholds the proportion of false positives drop to 0, but the detection probability is also low (Fig. 2). The effect of increasing  $rf\_t$  above 2 was limited, so we chose a value of 2 for this parameter. For  $NASC\_38\_t$  we chose an intermediate value, 40, corresponding to a detection probability of  $< 0.2$ , but also a low error ratio (approaching 0 in the scientific cruise data), as a compromise. This should enable a reasonable detection rate for dive events, and at the same time keep the number of false positives low.

Using these settings on the material from the fishing operations, we obtained a total of 4,174 automatically detected dive events in the integration bins from the fishing data, but note that each actual animal trace may leave several dive events. Using the number of 30 second integration time-segments as a baseline, dive events were detected in a total of 1,523 out of 236,146 time segments (corresponding to  $\sim 0,006$  % of a total of  $\sim 82$  days of observation). During the seasons observed, the fishing effort was concentrated in 2 areas, with dive events registered in both these areas and during transit between them (Fig. 4,5). The data from the scientific survey had dive events more spread, with 1 particular cluster evident (Fig. 6).

The automatically detected dive events in the fishery data were spread out in time, with some degree of clustering indicated (Fig. 7). Analysis of the vertical distribution of predators in the fishery data set gave a bimodal distribution of backscatter, with most backscatter occurring in the upper 100 m, but also with the amount of predator backscatter increasing at depths larger than  $\sim 120$  m (Fig. 3). Based on this result, the “dive event” category was split in 2, with backscattering occurring shallower than 120 meters being designed as “shallow dive event” and deeper backscatter assigned as “deep dive event”. “Deep dive event” backscatter was absent in the scientific survey data.

The integration results for bins “rejected” by the automatic dive-detection, i.e. 30 second by 5 m vertical bins where  $NASC\ 120 > NASC\ 38$ , were treated as prey (krill) distribution. The plot of dive events vs time seems to indicate that temporal (or spatial) effects affects the data, and possibly also



indicates a progressively deepening of prey distribution in June, but variability is very high, and these patterns have not been statistically tested (Fig. 7). The data also show that the automatic detection of deep dive events is heavily influenced by observations in 1 area/time-slice.

Most dive events were shallow, the same was the case for the vertical distribution of prey backscatter, especially close to South Shetlands (fig. 8,9). Around the South Orkneys the data suggest that the vertical distribution of prey was bimodal in 30 second intervals where dive events were also registered (fig. 9). Both dive depths and prey depths (both measured as WMD) showed relatively small variations with time of day (fig. 10). The probability of observing dive events varied with time of day, approximately with a factor of 3 from the 2 hour period least likely to observe a dive event to the period with the highest probability (fig. 11), but there appeared to be no consistent pattern inside or between areas, so these data may be influenced by random noise or other factors (fig. 11). In both areas variations in dive depth (measured as weighted mean of events over the course of the day) were relatively small, on the other hand daily variations in weighted mean depths of krill backscatter were also moderate (fig. 10), with no consistent diel vertical migration pattern evident in the results.

Splitting the data from the scientific survey into the area where active fisheries take place (approximately north of 61 and west of 45) and areas without fisheries, it is evident that most of the dive activity takes place in the same area as the fishery. In the manual dive detection data 528 of a total of 579 bins associated with dive events occurred inside the “fisheries” area, integration bins from this area made up 49 % of total area covered during the scientific survey. Similarly, in the automatically detected dive events overwhelmingly occurred inside the “fisheries” area, more than 98 % of bins with dive events were registered here.

The prey distribution data suggest that prey distribution observed during the fishery was different from that observed during the scientific survey (Fig. 12), and also may indicate that slightly more time was spent over high density regions in the South Orkneys area than in the South Shetlands area (with 1 time unit equaling 30 seconds), but time spent above extremely high density areas (i.e. right hand side of the distributions) were nonetheless very small (fig. 12).

In order to explore the effects of prey backscatter on dive behaviour further, both dive behaviour and prey backscatter were binned over 1 hour. The resulting data show a trend where the probability of observing a dive event increases with increasing values of prey backscatter for these 1 hour bins, this is seen in both the scientific survey data, and the fisheries data (fig. 13).

The horizontal projection of detected echo positions from the split beam data in bins with detected dives shows hints of an x-pattern (fig. 14), which probably suggests that the relaxed criteria for echo detections produced biased positions. There is a slight overweight of detections in front of the vessel (fig. 14), with a second peak towards the stern of the vessel, but more work on the performance of the echo detection routine is needed before using these data.

## **Discussion:**

### Methods:

Overall our results document that some form of automatic detection of diving predators in the fisheries data is feasible. More advanced algorithms are possible, and the relatively low detection probability of our algorithm compared to the manual detection, suggest that there is significant room for improvement. In our case we chose relatively strict criteria for detecting the dives, in order to prevent the detection of “false dives”. During the scientific cruise we observed numerous penguins, fur seals and whales in the vicinity of the vessel (Krafft et al. 2014). We believe that in this particular data-set, for this particular area, the shallow dive events are likely to represent diving, air-breathing predators. Manual scrutiny of the acoustic data for the scientific survey suggested that the majority of events with stronger scatter at 38 kHz than at 120 kHz were caused by animals with high vertical mobility at shallow depths, and the interpretation is that these traces represent diving, air-breathing predators. While we have confidence in our interpretations especially around the South Orkneys, the automatic detection of deep “dive events” in the South Shetland/Bransfield Strait area suggests that alternative scatterers with frequency response similar to our dive events may exist there, more in-depth analysis is needed to investigate this.

The presence of the “deep dives”, particularly in some areas, suggests that we were not wholly successful in separating diving predators from other groups. Again this probably relates to the simplicity of our algorithm, in many areas there will be numerous other organisms that are capable of triggering “dive events” given our algorithm, but the relatively low rate of false detections in the data from the scientific survey suggests that at least for the area and depth ranges we covered, such alternative scatterers were scarce. It should also be noted that the manual detection of dives is prone to a certain amount of subjectivity, and that we're not sure that all dives actually present were detected in the scientific survey.

We attempted to use the data to assess the position of the dives relative to the vessel, but were hampered by relatively few detected echoes in data from the scientific survey. In addition there are

clear hints that the positions in the detections are biased (fig. 14), the performance of different echo detection routines on these extreme targets should be evaluated. If reliable positions for the dives are obtained, data from the echo-sounders onboard the fishing vessels could be used to study vessel influence on animal behaviour at close ranges. For fish, echo detection data from split-beam echosounders have previously been used to study details of behaviour, and the results have shown that fish can both exhibit avoidance to gear (Handegard and Tjostheim, 2005) and attraction to vessels (Rostad et al. 2006). Such data would complement data from sonar, which is capable of resolving marine mammal behaviour at longer ranges (Knudsen et al. 2008), but with less resolution.

#### Ecological results:

Given the caveats of an imperfect methodology, the results document the possibilities of using data from the fishery to study the ecology of predator-prey interactions between krill and diving predators. Most of the detected dives were shallow, with numbers of detections falling rapidly from ~50 to 100 m depth, but with some events detected quite deep (Fig. 3, 7, 8, 9). This probably has important consequences for the encounter rates of krill with predators, and therefore the vertical gradient in predation pressure. Previous studies of krill swarm behaviour have found that the behaviour of krill swarms are altered by the presence of diving predators (Cox et al. 2009), so predators clearly affects the krill behaviour. In a large-scale acoustic study covering areas from the South Orkneys to South Georgia, krill swarms were in general found distributed deeper in the water-column in areas closer to land (Klevjer, Tarling, and Fielding 2010), which in that case was interpreted as a response to changes in predation pressure from land-based, diving predators. In the areas sought out by the fishermen in this study, the prey field remained shallowly distributed despite the presence of predators, though there were indications that the average depth of the krill distribution increased slightly towards the end of the 2013 season (Fig. 7). Deeper dives in the later part of the season in the South Orkney Islands is also expected due to the deeper distribution of krill over the season (Godø et al. this meeting). A progressive seasonal deepening of krill distribution has previously been described in the Bransfield Strait (Lascara 1999), with adult krill maintaining a deep distribution while overwintering. So while previous studies have documented that krill are capable of changing their distribution and behaviour, both in response to the presence of predators as well as to a seasonally changing environment, the krill population in the areas sought out by the fishery appear to maintain a relatively shallow distribution during the seasons investigated, despite the presence of both human and natural predators. Our data may suggest that krill in the South Orkneys area respond to diving predators, since the prey vertical distribution was shifted downwards in areas with diving activity present (Fig. 9), but the vertical distribution in the South

Shetland area showed no such indications (Fig. 8). In the data from the South Orkneys there may also be a hint of a diel pattern in dive depths registered (Fig. 10), but the weighted mean depths of krill distributions show no indications of diel patterns, another indication that the overall krill vertical distribution in these areas are not primarily controlled by the presence of predators.

Since these data were collected during fisheries operations, care must be taken when transferring the results to “normal” conditions. For instance, from the plot of fraction of observation time spent at different prey densities (Fig. 12), it is clear that the fishing vessel spends a higher proportion of time at higher prey densities than the scientific cruise. Said in other words, the fishermen seek out areas of higher krill densities, but that also means that patterns observed from this platform does not necessarily represent patterns at “typical” or “normal” conditions. Also, fishing vessel are running their vessel with strong floodlight at night, which also might alter both krill distribution and feeding opportunities of predators (Godø et al. this meeting). Our data spans a biased subset of these “natural” conditions, binning dive events by prey densities (both summed over hourly intervals) suggests that the diving predators are more frequently seen at high prey densities. Understanding the spatial patterns of predators and prey is typically a goal of ecological investigations, while the data from the fishing operations is not suited for such studies of spatial distribution per se, they may give us the opportunity to study the predator-prey interactions in the areas where these are most likely to occur.

In summary the preliminary results here presented suggest that it is possible to automatically extract, with a reasonable level of precision, data on the dive behaviour of air-breathing predators from the echo-sounder data recorded during the commercial fishing operations. The algorithm used in this particular work was simple, and there are likely more efficient and accurate ways to go about technically. It may also be possible to use data from the echo-sounders to study behavioural interactions between the diving predators and the fishing vessel, especially if data on dive behaviour observed from the vessels are combined with data from “undisturbed” dives, for example dive behaviour observed from bottom-mounted, stationary platforms.

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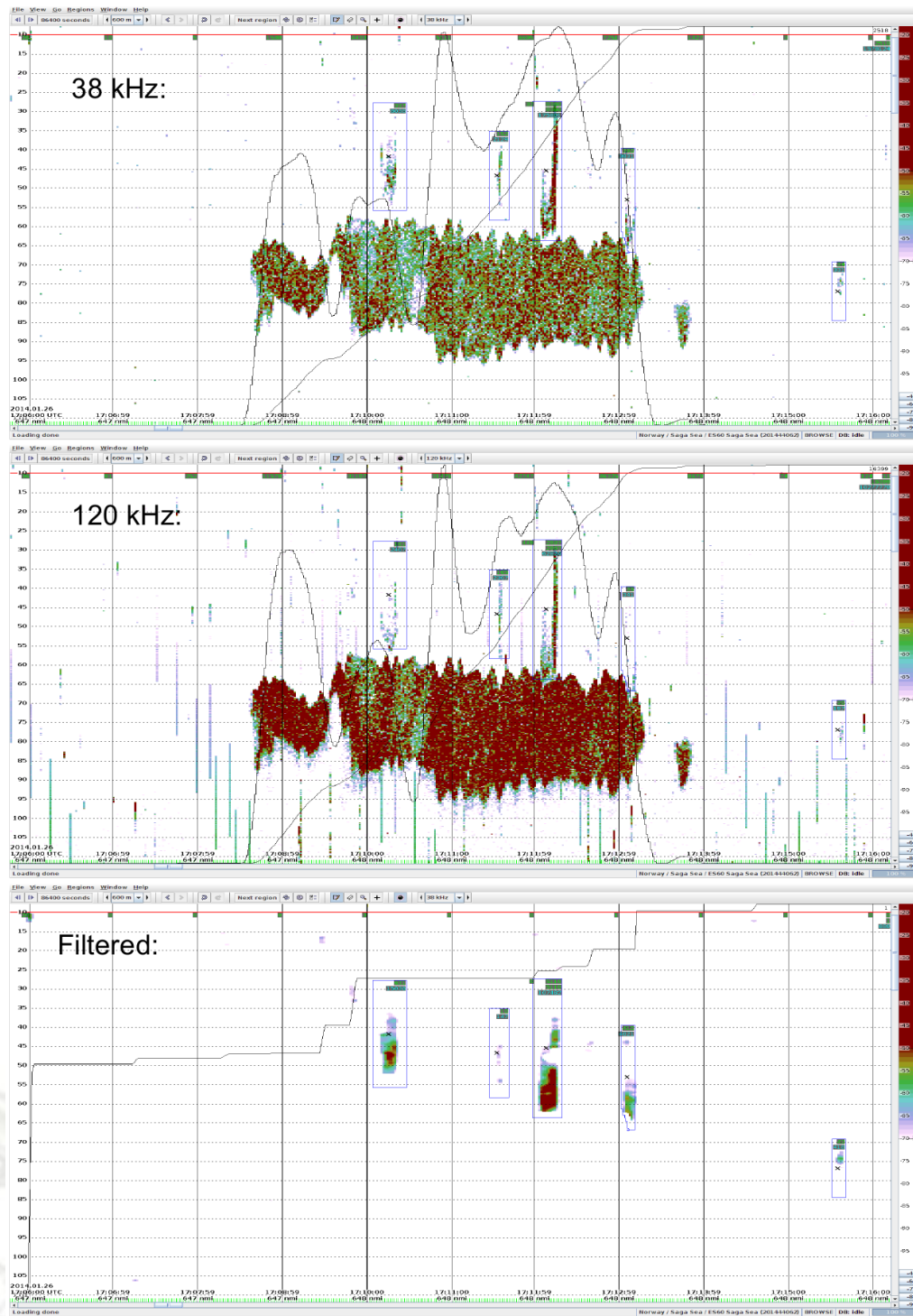
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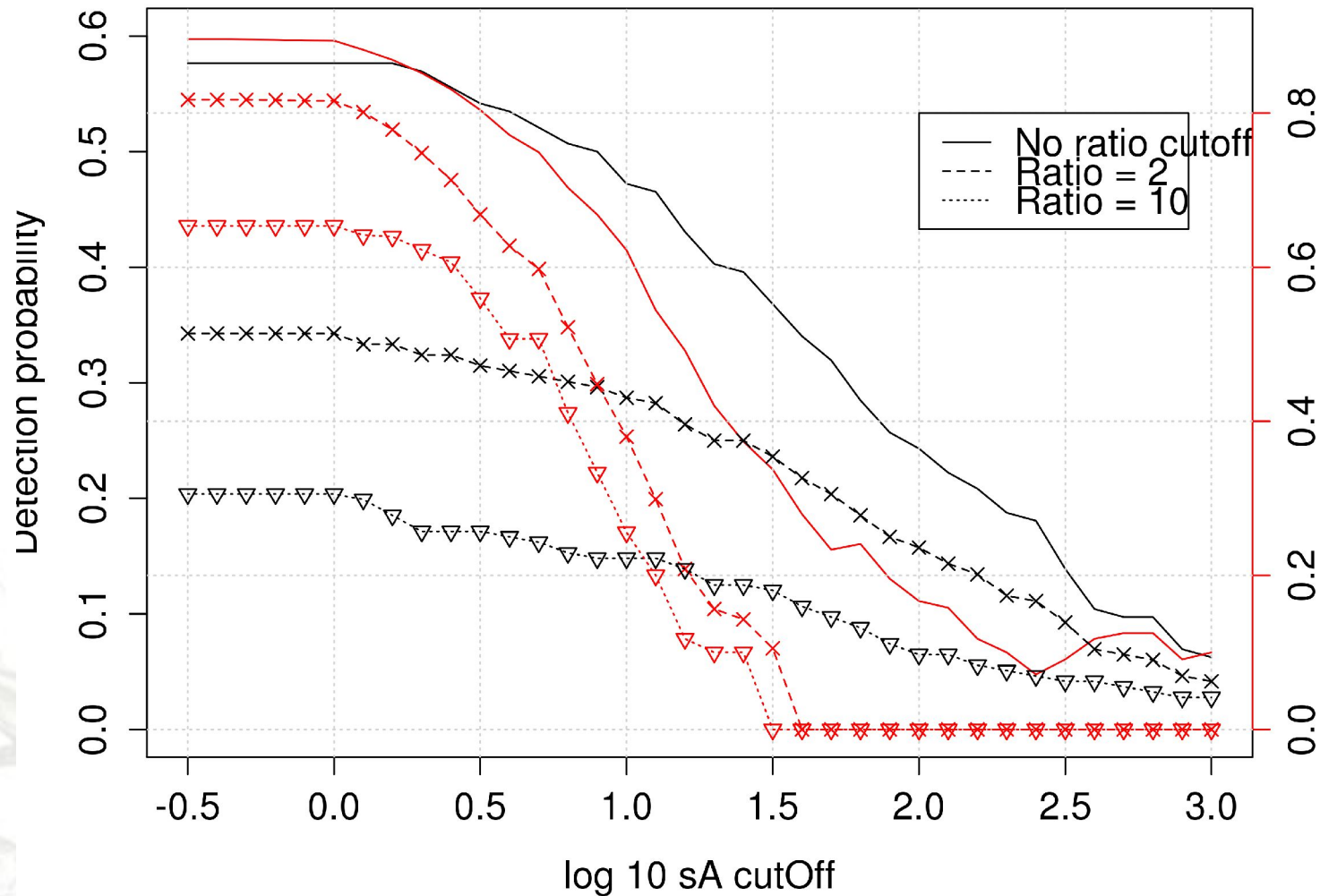
**Fig.1: Schematic representation of the results from the KORONA filter. The KORONA filter smoothed the original echograms, and then exported sections based on frequency response. The results from the echogram where  $NASC_{38} > NASC_{120}$  forms the basis for the rest of the dive detection algorithm (bottom panel), the remainder of the data were simply treated as «krill».**

**The blue boxes in the figures show regions with manually detected dive profiles (manual detection performed using variable thresholds).**

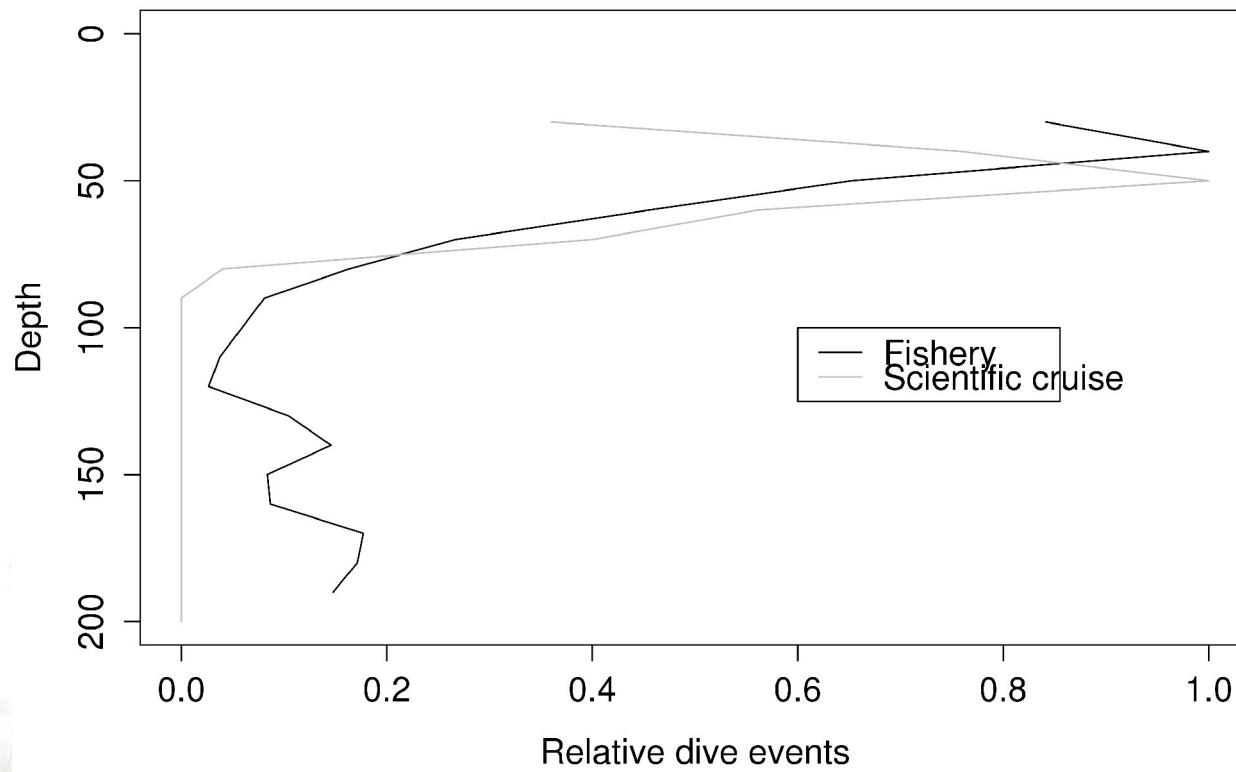




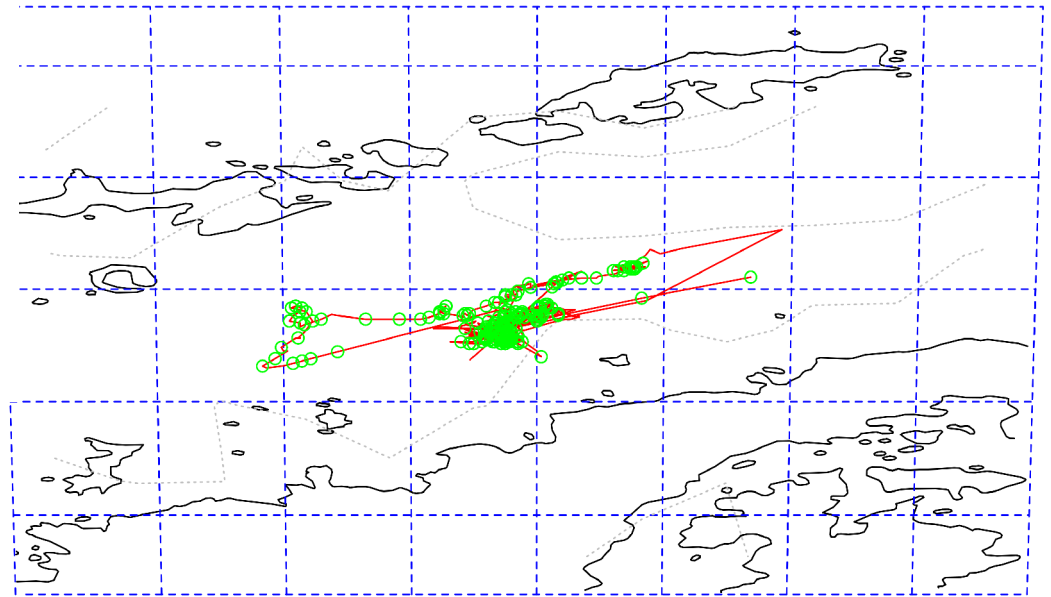
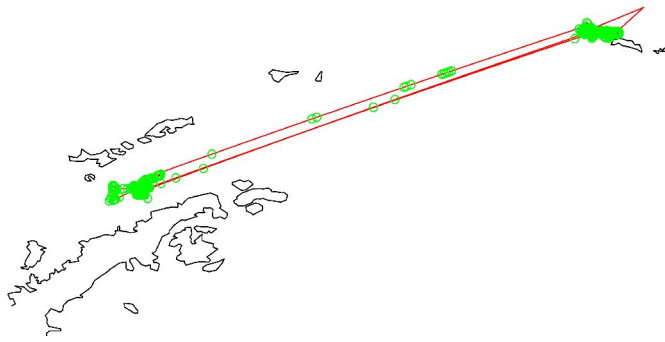
**Fig.2: Effects of different parameters on automated dive detection. Dives were detected by letting an operator manually go through the dataset from the scientific cruise, these dives were then compared to the output of the automated detection. Ratio refers to the ratio between NASC\_38 and NASC\_120, in 30 sec by 5 m vertical integration bins, where the KORONA filter has already found  $\text{NASC}_{38} \geq \text{NASC}_{120}$ . The x-axis is cutoff value for NASC\_38. Black lines and points give detection probability (left hand scale), while red lines and points give error rate (right hand scale). Error rate was defined as the number of false detections divided by the total number of automatic detections.**



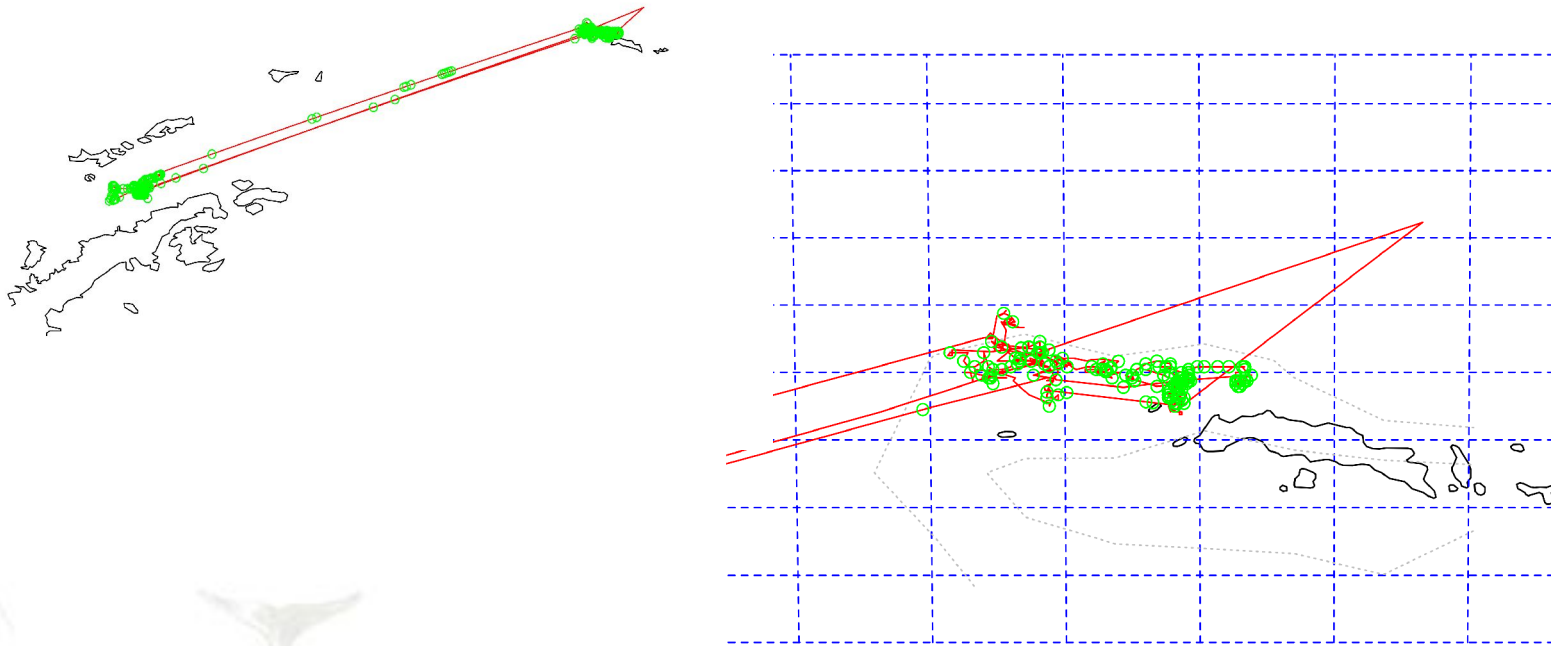
**Fig. 3: Vertical distributions of automatically detected dive events from the fishery data (black line) and the scientific cruise (grey line)**



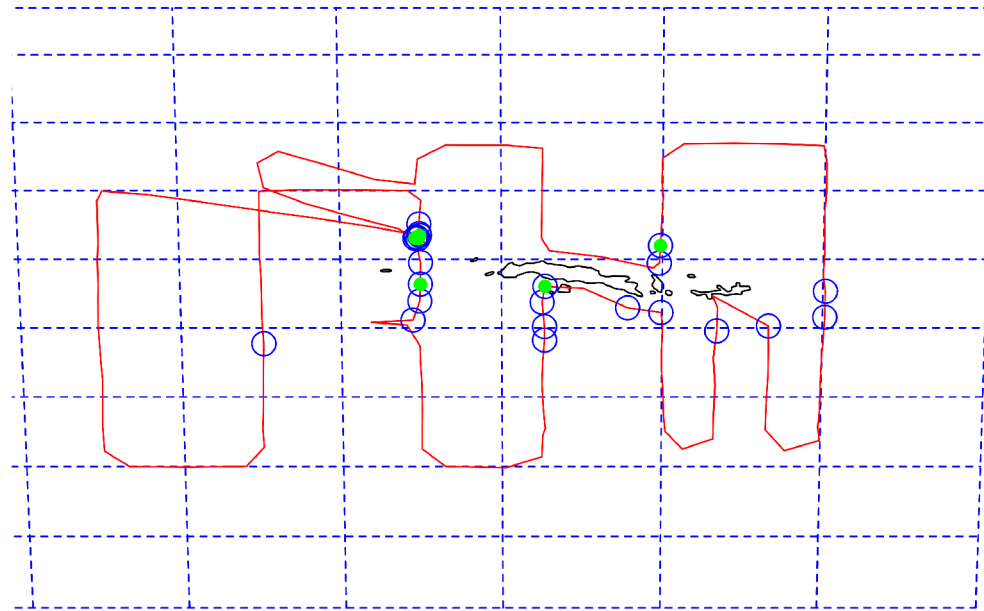
**Fig. 4: Overview areas and zoom on dive events in the Peninsula area.**



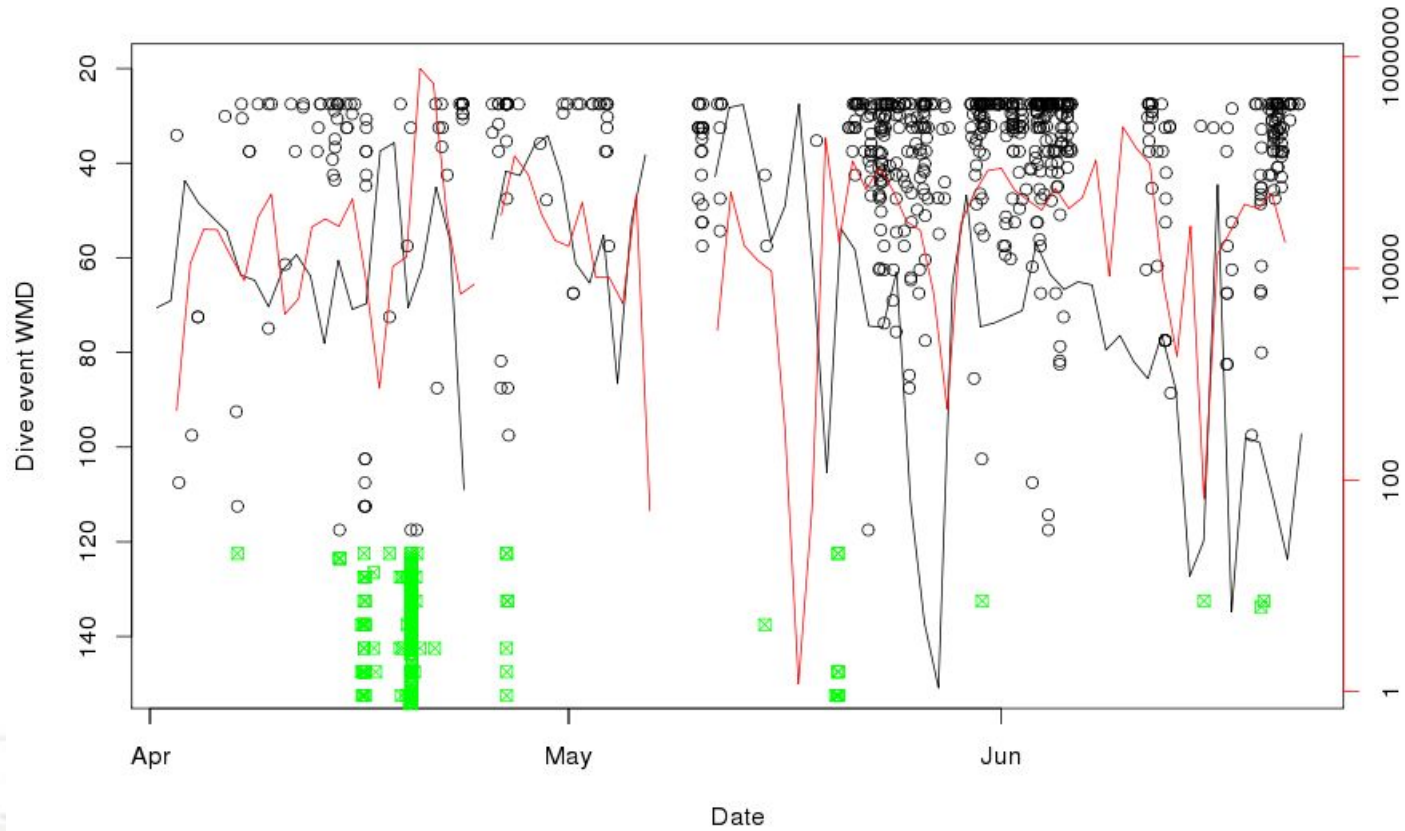
**Fig. 5: Overview areas and zoom on dive events in the South Orkneys area.**



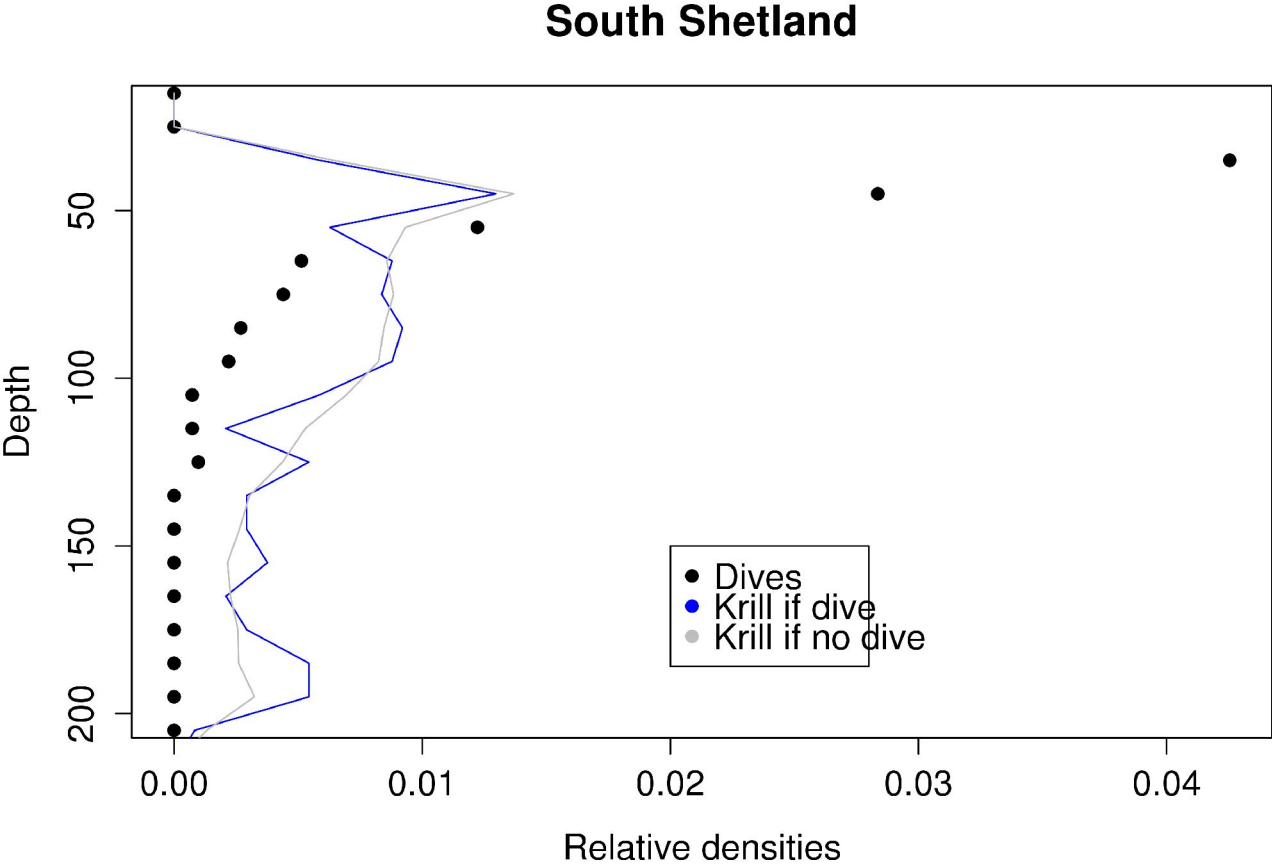
**Fig. 6: Distribution of dives from the scientific cruise. Red line is the cruiseline, blue rings show the locations of manually detected dives, green dots show the locations of automatically detected dive events.**



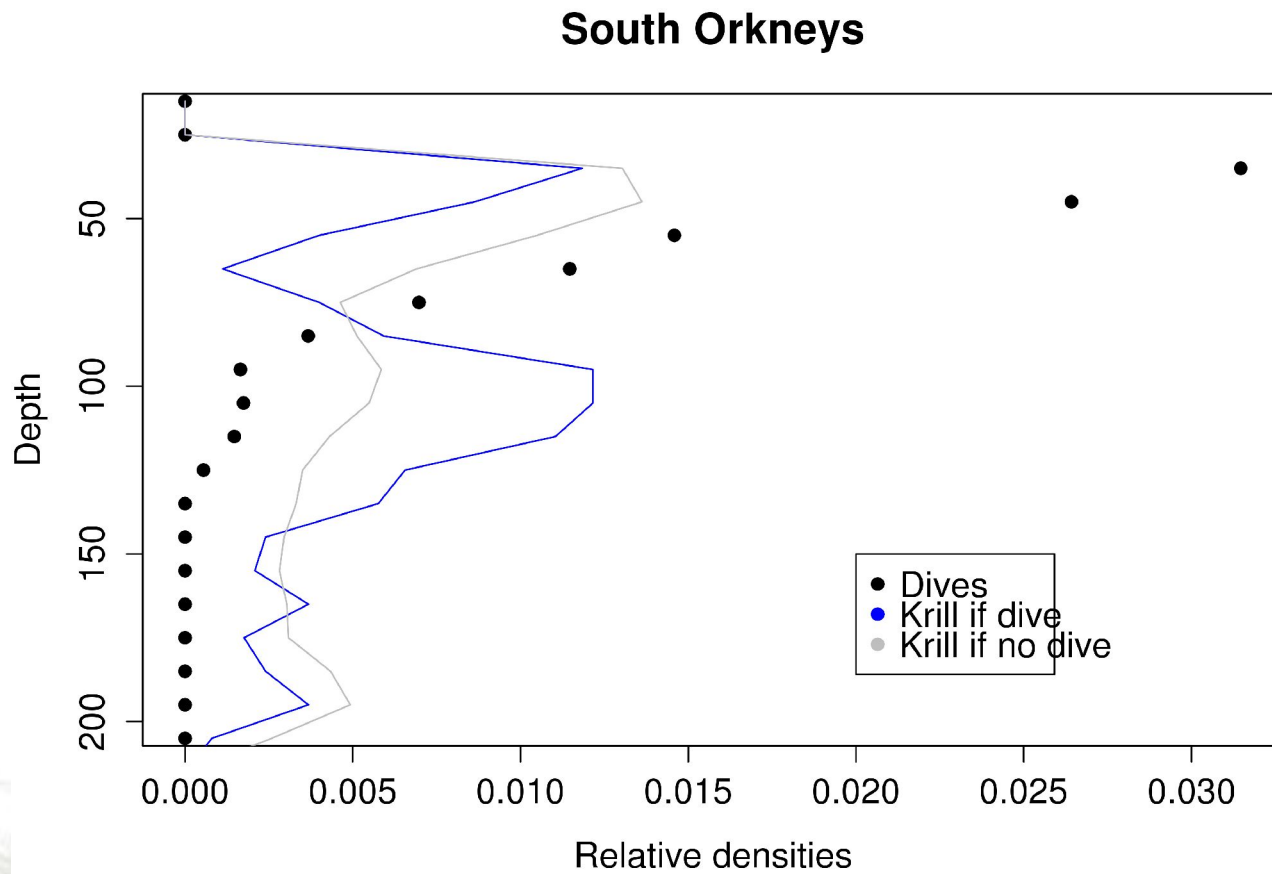
**Fig. 7: WMD of dive events vs date (black points) detected during fishing operations in 2013. WMD of deep dive events is indicated by green points, black line shows the daily WMD of prey distribution, and the red line is daily sum of NASC of prey (logarithmic scale, shown on right hand side).**



**Fig. 8: Depth distribution of dive events (black points, WMD of dive events per 30 sec interval with dives), prey vertical distribution (WMD) in intervals without dive events (grey line) and prey vertical distribution in intervals with concurrent dive events (blue line).**



**Fig. 9: Depth distribution of dive events (black points, WMD of dive events per 30 sec interval with dives), prey vertical distribution (WMD) in intervals without dive events (grey line) and prey vertical distribution in intervals with concurrent dive events (blue line).**





**Fig. 10: Depth distributions as a function of time of day. 2-hour averages of WMD of dives (points, South Orkneys in black, South Shetlands in grey) plotted against time (seconds relative to solar noon) over the entire sampling period. Lines show 2-hour averages of WMD of prey distributions.**

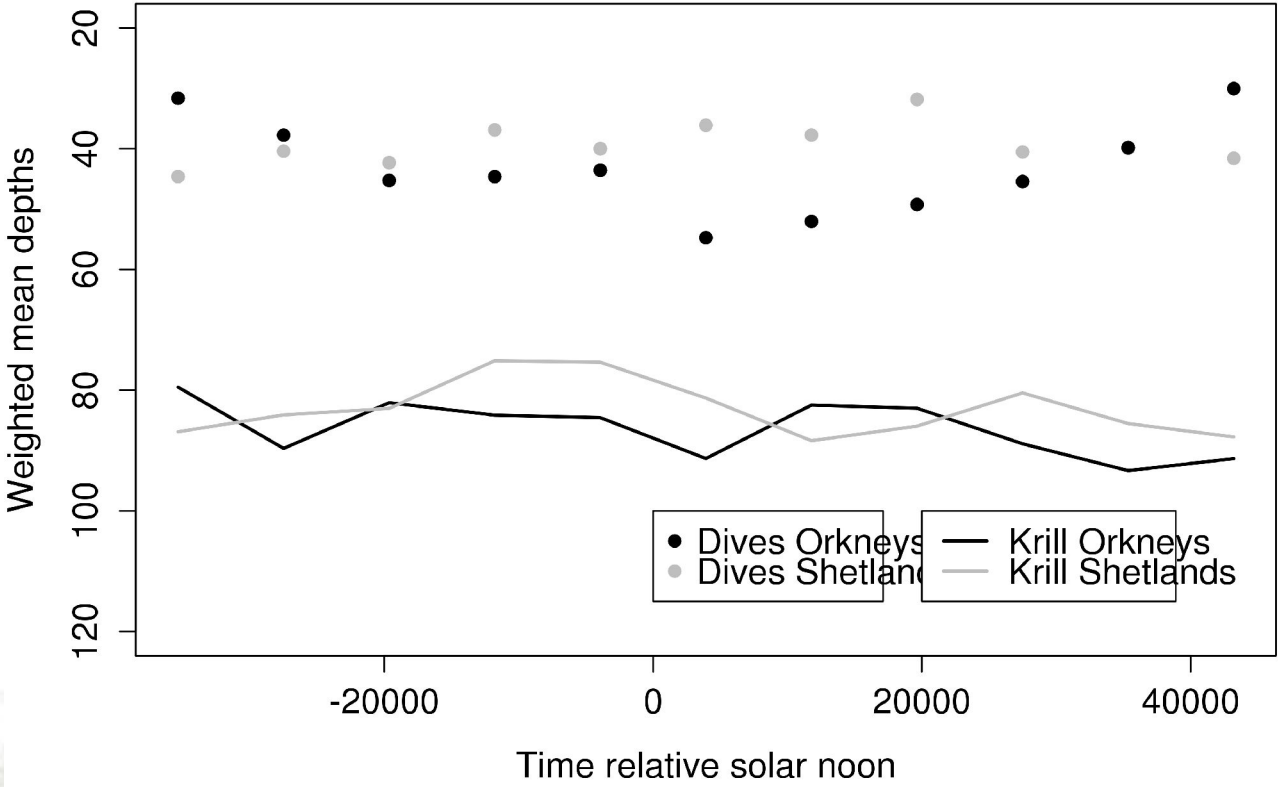
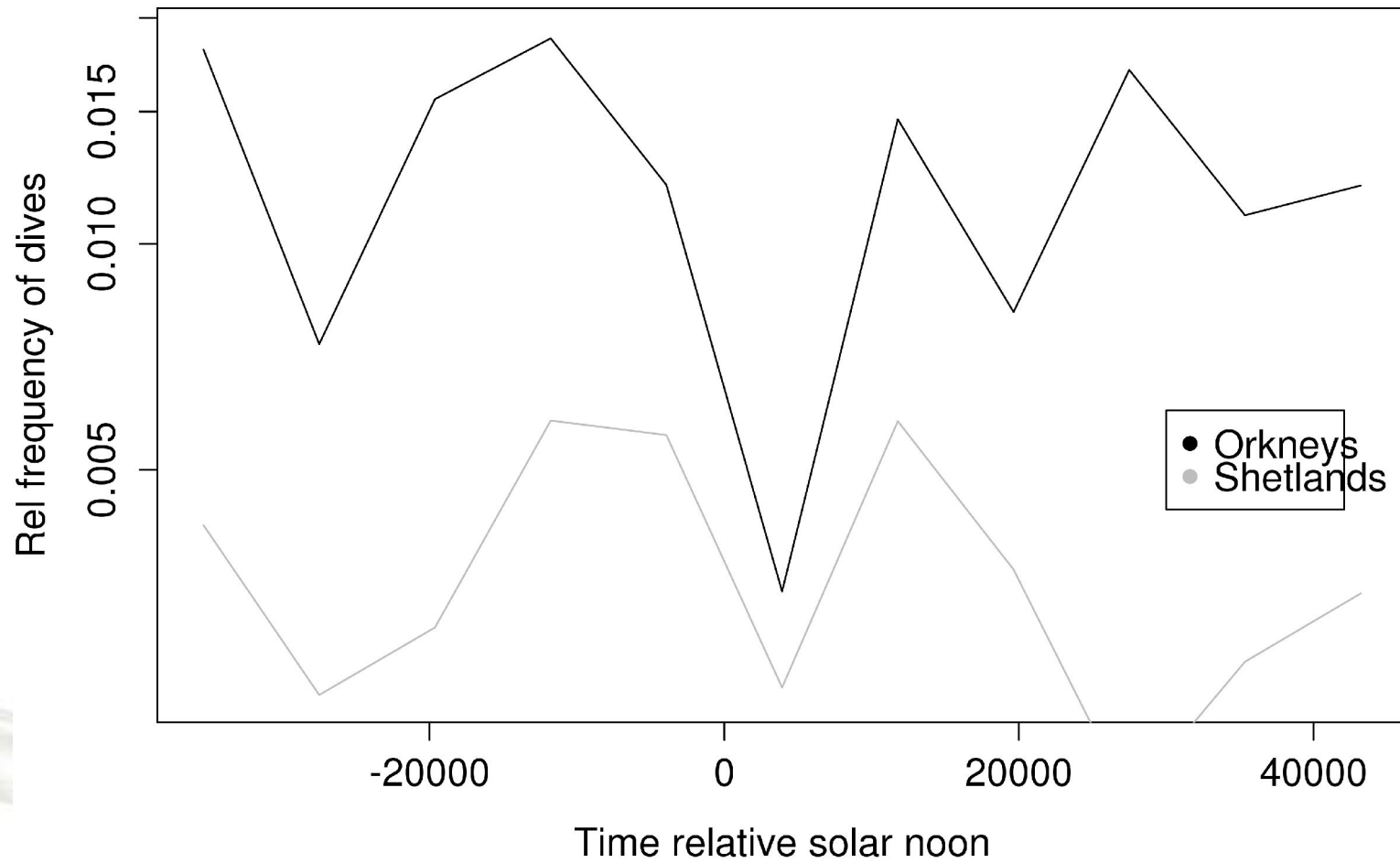
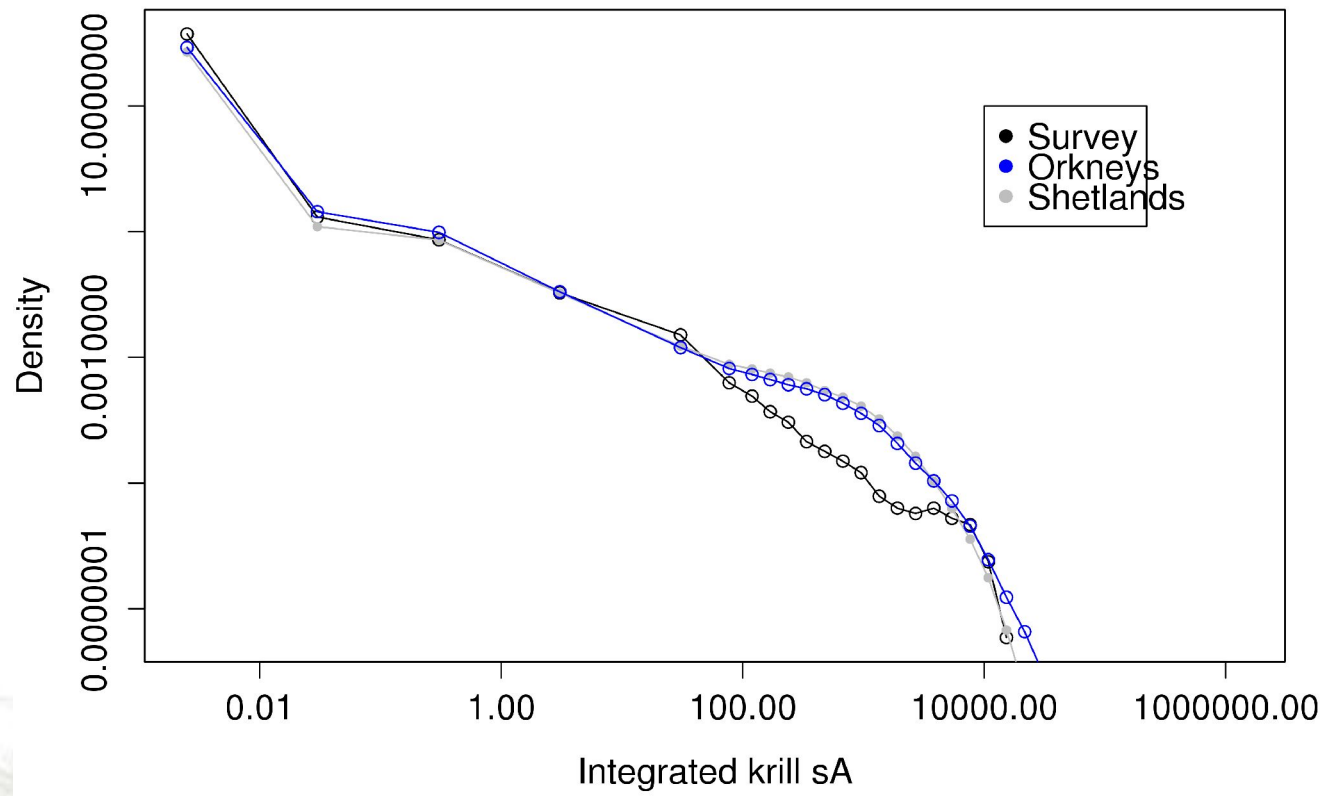


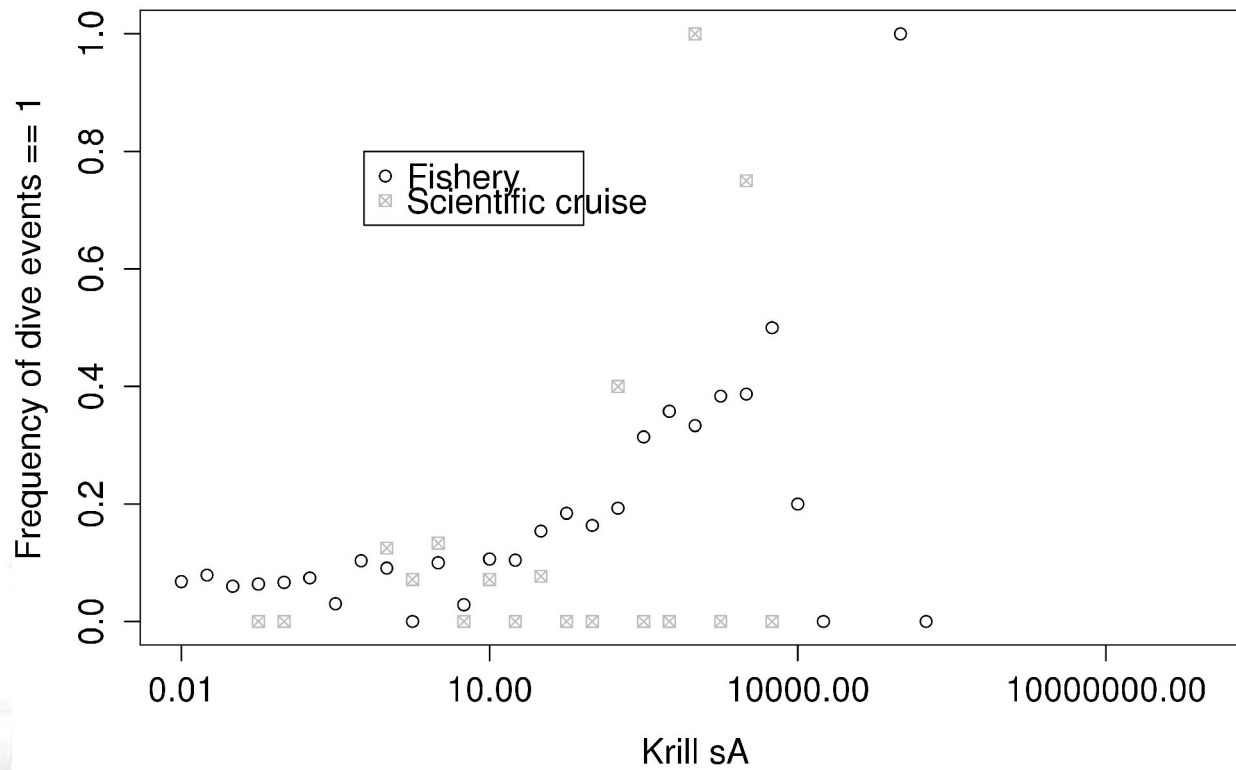
Fig. 11: Frequency of observations of dive events as a function of time of day, split according to area.



**Fig. 12: Relative time (in 30 sec intervals) spent above different prey densities, for the 2 areas and during the scientific survey.**



**Fig. 13: Probability of observing a dive event within a 1 hour time-slice, as a function integrated prey backscatter within the same time-slice. Shown both for data from the fishery (black dots) and the scientific survey (grey dots).**



**Fig. 14. Spatial distribution of detected single echoes in bins with dive events relative to the 38 kHz transducer. Left panel shows all detected echoes as seen from above, with the transducer at origo. Positive alongship is towards the bow of the vessel, positive athwartship is towards starboard. Right panel displays distribution projected onto a plane parallel with the axis of the vessel.**

