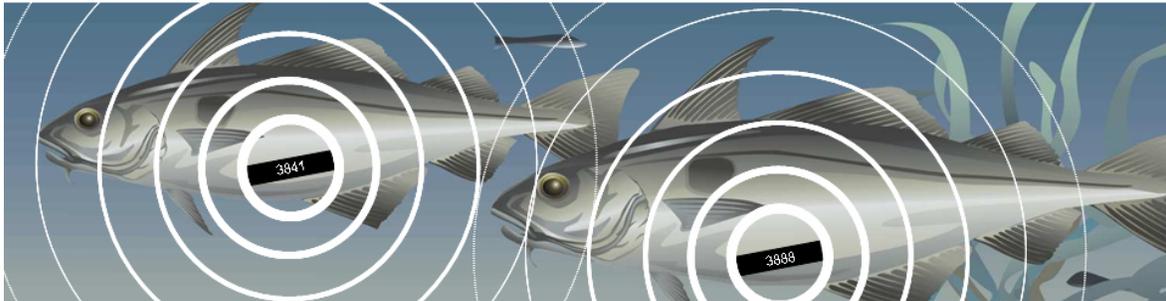


Is Closed Area I serving as a refuge for haddock? A study of fine-scale behavior through the use of ultrasonic tagging techniques



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¹ Note: This is a draft final report and contains one completed manuscript outlining the results of tag effects experiments, and one draft manuscript (an executive summary and completed figures) detailing the results of the monitoring experiment in Closed Area I. A completed final report containing both manuscripts in completed form, as well as an introductory section linking the two manuscripts, will be submitted to the NEC by October 31, 2009.

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Effects of intraperitoneal acoustic tag implantation on haddock
(*Melanogrammus aeglefinus*) survival and condition

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Abstract

The effects of intraperitoneal acoustic tag implantation was examined on long-term (6 week) haddock survival and condition (Fulton's condition factor and liver-somatic index) in the laboratory, and on short-term (3 day) survival in the field. Haddock responded well to clove oil anaesthesia ($40 \text{ mg} \cdot \text{L}^{-1}$; mean \pm SD time to induction was 249 ± 23 seconds, and mean time to full recovery was 1055 ± 40 seconds). Six-week survival rates for haddock that underwent surgical tag implantation and control haddock were 50% and 86%, respectively; survival rate of implanted haddock corrected for control mortality was 58% and 30 day survival was 62.5%. Fulton's condition factor (FCF) was significantly lower for haddock that underwent surgery and survived the duration of the experiment compared to control haddock that also survived 6 weeks; FCF did not differ among implanted and control haddock that died prematurely. Liver-somatic index (LSI), on the other hand, did not differ among treatment groups (i.e., implanted versus control haddock) but was lower in haddock that died prematurely compared to haddock that survived the entire experiment. These condition index results suggest that haddock suffered increased stress associated with tag insertion (which was likely compounded by tank effects, most notably increased infection) and that mortality was associated with cessation of feeding which was most likely due to infection (a tank effect). Field trials showed that haddock can survive the capture, surgery, release experience under realistic field conditions (i.e, 90 m depth); survival rate at this depth after 3 days for implanted and control haddock was 83% and 75%, respectively. Results from this experiment support further use of intraperitoneal acoustic tag implantation as a means of acoustic tracking of haddock in the wild with the acknowledgement that some mortality and sublethal effects may be unavoidable.

1. Introduction

Acoustic tagging, or telemetry, is becoming a popular method for tracking fish in their natural environments. A great deal can be learned about fish migration (Welch et al. 2002), population structure (Comeau et al. 2002), foraging behaviors (Klimley et al. 2001) and habitat associations (Lindholm et al. 2007) using this method which does not rely on recapturing the tagged fish, an important constraint for conventional tagging studies (Bolle et al. 2005). Although powerful for inferring fishery-independent movement patterns, limitations to acoustic tagging technology include high unit costs, field logistics (i.e., being able to locate tagged fish either on fixed receivers or with mobile telemetry units) and the potential for these larger tags to cause adverse effects on survival and physiology of the fish being studied. Thus, prior to commencing any acoustic telemetry study, great care should be given to choosing the proper tag placement protocol and, whenever possible, ensuring that the tags themselves have minimal impact on fish movement and biology.

Bridger and Booth (2003) reviewed three methods of electronic tag placement on/in fish – external attachment, intragastric insertion, and surgical implantation – and concluded that the choice of method depends on a variety of factors including species, fish and transmitter size, and duration of study. Based on a range of possible tag induced effects, including reductions in swimming performance (e.g., Counihan and Frost 1999) and growth (e.g., Greenstreet and Morgan 1989), and increases in abrasion related injuries (e.g., Thorstad et al. 2000), Bridger and Booth (2003) concluded that external tagging may be most suitable for short-term research in environments that lack high velocities and physical obstructions (due to the potential for snagging). Similarly, intragastric insertion, although with minimal effects on swimming (e.g., McCleave and Stred 1975), should be considered mostly for short-term studies (Bridger and Booth 2003) due to possible effects on feeding (e.g., Jepsen et al. 2001) and concerns regarding tag expulsion; for cod, 50% regurgitation may take place between 5 (Lucas and Johnstone 1990) and 32 days (Winger and Walsh 2001). Finally, surgical implantation, while much more involved in terms of deeper anaesthesia and longer handling times (Bridger and Booth 2003), may be the only method suitable for studies where long-term tag deployments are required. Effects on growth and survival of surgically implanted tags in

salmonids and Atlantic cod have been observed to be minimal (Adams et al. 1998, Cote et al. 1999, respectively). Furthermore, there is very little evidence of effects of surgical implantation on swimming performance in a variety of species (see Bridger and Booth 2003).

This study is part of a larger project to examine haddock residency and movement behavior in an offshore closed area (Closed Area I, ~ 30 miles southeast of Cape Cod, Massachusetts; see Sherwood, unpublished, for details). Thus, given the goals of the study for which this tagging trial was initiated (i.e., long-term monitoring) and the fact that the majority of telemetry studies on cod (closely related to haddock) have used surgical implantation as a means of tag attachment (e.g., Cote et al. 1999, Robichaud and Rose 2001, Windle and Rose 2005), the purpose of this study was therefore to examine the possible effects of surgical tag implantation (including anaesthesia) on haddock survival and physiological condition. This study represents the first such trial with haddock which are expected to tolerate surgical implantation of acoustic tags as readily as cod.

2. Methods

2.1. Field sampling and laboratory facilities

A total of 18 haddock ranging in size from 46 to 62 cm were captured by hook and line in April of 2007 at the southern end of Jeffreys Ledge in the Gulf of Maine (approx. lat and long) and brought back to holding facilities at the University of New England's Marine Science Education and Research Center. Haddock were divided among two circular tanks each 2 m in diameter and 1.5 m deep and supplied with flowing seawater. Opaque covers were fitted to each tank to minimize stress from overhead lights. Haddock were allowed to acclimate to their new surroundings for a period of two weeks prior to commencing anaesthesia and surgery trials. Haddock were considered fully acclimated when normal feeding and swimming behavior resumed, which for the majority of individuals took place within one week. During this initial acclimation period, 2 haddock died. Haddock were fed a mixture of clam and herring cut up into bite size pieces. Water temperature for the duration of the experiment ranged from 8°C to 12°C.

2.2. Anaesthesia trials

A number of different anaesthetic agents are available for use in fish surgery (see Bowser 2001 for a review). Given that the purpose of this study was to explore acoustic tag implantation techniques for haddock to be released in the wild, MS222 (3-aminobenzoic acid ethyl ester methanesulphate, for which the U.S. Food and Drug Administration, or FDA, mandates a 21 day withdrawal period) was ruled out in favor of clove oil (active ingredient eugenol) which is considered non-mutagenic and a safe substance by the FDA (Woody et al. 2002). Anaesthesia trials using clove oil were conducted on haddock following protocols outlined in Woody et al. (2002). Specifically, haddock were introduced to an anaesthetic bath (in a 50 L cooler) containing $40 \text{ mg} \cdot \text{L}^{-1}$ of clove oil. This concentration was at the low end of the range of concentrations tested by Woody et al. (2002) for adult sockeye salmon and was chosen to ensure both short induction and recovery times for haddock. Since clove oil does not completely dissolve in water below 15°C , and water temperatures for the field component of this study were expected to be around 7°C , clove oil was mixed with ethanol in a 1:9 ratio (Anderson et al. 1997) to facilitate mixing (Woody et al. 2002). Thus, to achieve $40 \text{ mg} \cdot \text{L}^{-1}$ of clove oil in a 50 L bath, 1.86 ml of clove oil was added to 16.7 ml of ethanol, which was added to the bath. Anaesthesia trials were conducted on 4 haddock where time to 4 stages of anaesthesia (Woody et al. 2002) were measured: stage 2 (sporadic loss of equilibrium and difficulty maintaining position); stage 3 (complete loss of equilibrium and inability to regain upright position); stage 4 (no reaction to handling or a sharp prod to peduncle); and recovery (ability to remain upright, normal swimming behavior). A stopwatch was started at the moment haddock were introduced to the anaesthetic bath.

2.3. Surgery trials (laboratory)

Surgeries to implant “dummy” V16 acoustic tags (Vemco Inc.) were conducted on 9 haddock and the remaining 7 haddock were left as controls. The study for which these trials were conducted (Sherwood, unpublished) required long battery life and high detection range. V16 tags are the second largest tag produced by Vemco (and hence fulfill these requirements since battery life and detection range are related to tag size

among other factors), measure 68 mm long, and weigh 11 g in water and 25 g in air. Dummy V16s are designed to replicate the real tag in every way including weight, which, in water for the V16, represented 1.3% of the body weight of the smallest sized haddock (46 cm and 829 g) used in this experiment (i.e., well within the “2% rule”; Brown et al. 1999). The standard operating procedure for tag implantation was adapted from Fabrizio et al. (2005) and is described as follows: Prior to commencing surgery, the entire surgical area (top of cart and cradle, Figure 1) was disinfected with Wavecide ® spray and wiped dry with clean paper towels. All surgical instruments were cold sterilized for at least 10 minutes in a stainless steel tray containing Envirocide ® (glutaraldehyde), removed, rinsed with distilled water and placed on sterile guaze pads in an easily accessible area. Haddock were placed in the anaesthetic bath (see above) and were transferred dorsal side down to the surgery cradle (Figure 2) after stage 4 anaesthesia set in (Woody et al. 2002); a flow system (small submersible pump with 3/4” tubing) was turned on to ensure proper irrigation of the gills. The incision site (ventral, about 2 cm anterior to the anus and slightly off to the side; Figure 2) was dabbed dry with sterile gauze and scales were removed. A small incision (~ 2 cm) was made with a fresh #12 scalpel blade cutting from front to back. Care was taken when making the incision to not puncture the intestinal tract which underlies the incision site. Once the incision was made, a dummy tag, sterilized (by immersion in the glutaraldehyde solution for at least 1 hour) and coated in triple antibiotic ointment, was inserted into the body cavity and massaged into place so that it lay lengthwise and did not cause any outward pressure under the incision. The incision was closed in a simple interrupted pattern (Wagner et al. 2000) with 2-3 non-absorbable nylon sutures (Ethilon ® 3-0, fs-1 cutting) and 3 surgeons knots per suture. A thin layer of Vetbond ® was applied to the incision to ensure full closure and the entire incision area was covered with a layer of triple antibiotic ointment. Finally, a numbered T-bar tag (Hallprint Pty Ltd.) was inserted into the dorsal musculature for identification purposes before returning the haddock back to the water for recovery (control haddock were also tagged with T-bar tags). Haddock (both dummy tagged and control) were left alone for a period of 6 weeks (42 days) during which time they were fed to satiation once per day and monitored for any infections and abnormalities. Haddock deemed to be in failing condition (e.g., fin rot and/or abnormal swimming) were euthanized by an overdose with

MS-222. At the end of 6 weeks, all haddock were euthanized by an overdose with MS-222, weighed (nearest g), measured (nearest mm), gutted and weighed again (nearest g) and liver weight was also measured (nearest g). All protocols for this study were reviewed and approved by the University of Southern Maine's and the University of New England's Institutional Animal Care and Use Committees (IACUC # 031207-01 and UNE09-2007, respectively)

2.4. Sub-lethal effects monitoring (laboratory)

In addition to survival, which was monitored over the course of the six week experiment, potential indicators of sub-lethal effects were also considered in the form of biological condition indices. Specifically, Fulton's condition factor (K) and the liver-somatic index (LSI), both indicators of energetic fitness and energy reserves (Lambert and Dutil 1997), were measured and are given as follows:

$$FCF = \frac{W_{guttred}}{L^3} \cdot 100$$

where $W_{guttred}$ is gutted weight (g) and L is total length (cm), and

$$LSI = \frac{W_{liver}}{W_{guttred}} \cdot 100$$

Where W_{liver} is liver weight (g) and $W_{guttred}$ is gutted weight (g). Effects monitoring for tag insertion trials typically considers growth either in terms of length or weight gain (e.g., Cooke et al. 2003). The duration of this experiment and small sample size limited the ability to use growth in this way since very little growth in length occurred (although FCF is analogous to weight gain, or loss, in the absence of length gains). To the author's knowledge, no other study has considered liver index as an endpoint in this type of study. Liver index, in addition to FCF, may provide useful information on energy stores which should be related to recent feeding levels (Adams and McLean 1985) as well as stress. Fulton's condition factor and liver-somatic index were compared among haddock from

surgery and control groups and survivors versus non-survivors by analysis of variance (ANOVA).

2.5. Surgery trial (field)

In addition to conducting surgery trials with dummy acoustic tags in the laboratory, it was also important to investigate whether haddock can survive the entire capture/surgery/release experience in the wild. Specifically, this project is part of larger study to examine haddock movements and behavior in Closed Area I (CAI, western Georges Bank) about 30 miles southeast of Cape Cod, Massachusetts. Haddock tend to select depths of about 90-150m in this area (Cape Cod Commercial Hook Fishermen's Association, CCCHFA, personal communication). Therefore capture/surgery/release trials took place within this depth range on a total 30 haddock (16 surgery and 14 control) in July of 2007. Haddock were captured by hook and line and transferred to holding tanks which were cooled to 7°C (to approximate bottom temperature) with ice (seawater). Surgery to implant dummy acoustic tags was conducted on haddock that were deemed in good condition (responsive and swimming near bottom of holding tank) following the same protocol as used in the laboratory (see previous sections). Following surgery, haddock were held for ~ 1 hour to monitor recovery and, if in good condition, were transferred to a holding cage (1.5 m diameter × 1 m high; Figure 3) which was slowly lowered to the bottom. Two such trials, each with 4 cages (trial 1: 8 surgery and 8 control; trial 2: 6 surgery and 8 control), were conducted for a duration of 5 and 3 days in the western portion of CAI, respectively at 150 and 90 m depth (haddock were divided equally among cages). The intention was for both trials to last only 3 days, however, weather impeded returning to the first trial until day 5. At the end of each trial, cages were lifted off the bottom and survival of surgery and control haddock was recorded and compared.

3. Results

3.1. Anaesthesia trials

Anaesthesia trials, using clove oil, were conducted on four haddock prior to commencing surgery trials to ensure that haddock could be immobilized during surgery and to ensure that they recover fully from anaesthesia. Figure 4 shows the results of these trials. Mean (± 1 SD) time to stage 2 anaesthesia (sporadic loss of equilibrium) was 125 ± 22 seconds, mean time to stage 3 anaesthesia (complete loss of equilibrium) was 178 ± 33 seconds, mean time to stage 4 anaesthesia (not reactive) was 277 ± 60 seconds, and mean time to full recovery was 1166 ± 225 seconds. An increasing trend in time to all stages of anaesthesia was apparent by order of haddock in the experiment (i.e., haddock 4 took the longest to be induced and to recover). If haddock 4 is removed, mean times to the 4 stages of anaesthesia for the remaining 3 haddock become 117 ± 20 , 165 ± 26 , 249 ± 23 , and 1055 ± 40 seconds. Mean time from full induction (stage 4) to full recovery for the first 3 haddock was 806 ± 26 seconds or about 13 minutes. Recovery, despite taking 13 minutes, was very rapid once it set in and haddock resumed normal activity almost immediately when they “came to”.

3.2. Surgery trials (laboratory)

Survival results of the laboratory surgery trials are shown in Figure 5. Four of the 9 haddock that underwent surgery survived the duration of the experiment (6 weeks). One haddock had to be euthanized immediately following surgery due to complications; the remaining 4 had to be euthanized at later dates following surgery as a result of failing condition (erratic swimming and/or cessation of feeding) due primarily to infection by fin rot; 3 of these 4 succumbed in a 3 day window at about 2 weeks following surgery. There was no significant difference in size of haddock that survived (mean ± 1 SD length = 51.4 ± 3.6 cm) and those that died (54.5 ± 6.2 cm). In contrast, 6 of the 7 control haddock survived. Associated survival rates for surgery versus control haddock were therefore 50% (when haddock that died due to complication during surgery is removed) and 86%, respectively. Sample sizes were too small to test for significance. Survival rates for surgery haddock, corrected for control survival (86%) may have been 58%. Similarly, if

only the first 30 days are considered, survival rate for surgery haddock increases to 62.5%.

Sub-lethal endpoints (Fulton's condition factor and liver somatic index) were also measured at the end of the experiment and are shown in figures 6 and 7. FCF (figure 6) was significantly lower for haddock that underwent surgery than for controls (Table 1). There was also a significant interaction effect between treatment group (surgery vs. control) and whether fish survived the duration of the experiment or not (Table 1). In other words, FCF was significantly lower for haddock that underwent surgery and survived the duration of the experiment (mean \pm 1 SD FCF = 0.67 ± 0.08) compared to control haddock that also survived the entire experiment (mean FCF = 0.85 ± 0.05), but there was no difference in FCF between haddock of either treatment group that died prematurely (the 2 haddock that died during the acclimation period were included in the control group for this analysis). LSI (figure 7) was not significantly different among treatment groups, but did differ significantly among haddock that survived the duration of the experiment and those that did not (Table 1). In contrast to the situation with FCF, there was no significant interaction effect for LSI as a function of treatment group and survival to the end of the experiment.

3.3. Surgery trials (field)

To test whether haddock could survive the entire capture/surgery/release experience, surgery trials were conducted in the field. An initial trial with 8 surgery haddock and 8 control haddock (captured and released to cages without surgery) resulted in 100% mortality for both treatment groups. This first trial was conducted at 150 m depth and lasted 5 days; the plan to return in 3 days was hampered by bad weather (the site was about 30 miles offshore). Haddock in this trial were not only dead but completely scavenged suggesting that they may have succumbed to a sand flea infestation. A second trial, conducted at 90 m depth and lasting only 3 days, yielded much better results (figure 8). Five of the 6 surgery haddock and 6 of the 8 control haddock survived for survival rates of 83% and 75%, respectively. The 3 dead haddock were not completely scavenged suggesting an absence of sand fleas in this location.

4. Discussion

The purpose of this study was to determine whether haddock can survive intraperitoneal acoustic tag implantation, similar to Atlantic cod (Cote et al. 1999, Robichaud and Rose 2001, Windle and Rose 2005), and whether there are any sub-lethal effects associated with this procedure. While there was certainly mortality associated with the surgery protocol, the 6 week-long experiment did indeed reveal that haddock can survive acoustic tag implantation in the laboratory at a rate of 58% (corrected for control mortality; 30 day survival was 62.5%). This rate compares well with 20-day survival rates for transmitter implantation in juvenile largemouth bass (between 42 and 65%; Cooke et al. 2003). Although the mortality rate for surgery haddock is already corrected for mortality in control haddock, there remains the possibility that mortality in surgery haddock may have been magnified as a result of multiple stressors (i.e., the combined stress of holding and surgery). In other words, surgery in the absence of tank effects (e.g., when fish are released back to nature) may not have led to as high as 42% mortality. Indeed, field estimates of long-term survival for Atlantic cod implanted with acoustic tags, based on telemetry tracking over a year, have been as high as 84% (Windle and Rose 2005). As such, the level of mortality observed in the lab here (potentially artificially magnified) was deemed to be acceptable for further testing in the field through long-term telemetry tracking (see Sherwood, unpublished).

Further reason to pursue long-term tracking studies of haddock in the field came from a successful short-term caging trial. Although the first cage trial was a failure (100% mortality), the second trial showed that haddock can have very high short-term (3 day) survival rates following capture, surgery and release (83%). This short-term survival rate compares very well to short-term (5-10 days) survival rates for Atlantic cod tagged with external t-bar tags (88%; Brattey and Cadigan 2004) suggesting that in the short-term, at least, surgery is no more invasive for haddock than t-bar tags are for cod. Total mortality in the first trial may have been due to multiple factors: 1) the location may have been too deep (150 m); 2) the trial may have been too long (5 days); and 3) due to the length of the trial and the location, the caged haddock may have succumbed to a sand flea (parasitic amphipods) infestation, which can be a common cause of mortality in caging studies of this kind (e.g., Tallack and Slifka 2007). The success of the second trial may have been

due to attempts to mitigate one or all of these factors: 1) the trial was moved to a shallower depth (90 m); 2) the trial lasted only 3 days; and 3) the new location may have been far enough away from sand fleas which tend to be located in patches (CCCHFA, personal communication). The fact that implanted haddock were not only living, but thriving, when they were brought back to the surface in the second trial, suggests that they had overcome the initial stress of capture, surgery and release. For this reason, the experiment was considered a success.

In addition to survival, this study also considered sub-lethal effects of acoustic tag implantation in haddock. The two endpoints, Fulton's condition factor (FCF) and liver somatic index (LSI) were included to provide information on the energetic well-being of haddock over the course of the 6 week-long laboratory holding experiment. These indices provided interesting results on their own (figures 6 and 7) and may also be useful for interpreting survival results in the lab. Growth has been observed to both decrease for fish tagged in various ways with electronic devices (Bégout Anras et al. 2003, Jepsen et al. 2008, Thorstad et al. 2009) or to be relatively unaffected (Adams et al. 1998, Cote et al. 1999). Whether or not fish growth is affected likely has something to do with relative tag size (Thorstad et al. 2009). While growth may provide insights on energetic well-being of a fish, perhaps better measures of this are condition factor and liver index. This is because, unless one examines otoliths or other hard parts, determining growth requires size information at the beginning and end of a time interval (i.e., at the time of tagging and at the time of recapture). This information may either be lacking in many studies or error prone. Condition indices (like FCF and LSI), on the other hand, require measurements only at the end of an experiment or at the time of recapture. Additionally, the relative size of different organs versus the whole body in relation to length can provide information on different physiological processes which may respond to different environmental conditions on different time frames. For example, LSI may respond more quickly to starvation than FCF (Arndt et al. 2005). Thus, FCF could conceivably be an indicator of long-term stress and LSI an indicator of a short-term energy deficit. In this light, it is interesting to speculate how haddock may have responded to the stresses of surgery and holding in the laboratory trials. The fact that there was a significant interaction effect between treatment (surgery vs. control) and survival to the end of the

experiment on FCF suggests that it took the entire duration of the experiment for the stress of tag implantation, perhaps compounded by the stress of holding, to affect FCF. The haddock that died early did not appear to die from low condition (e.g., Dutil and Lambert 2000). To the contrary, it appears that haddock can handle lower levels of FCF (Figure 6). On the other hand, LSI was not related to treatment but was significantly lower in haddock that died prematurely in both treatment groups. This difference likely reflects starvation and lack of acclimation to the holding environment. Indeed, haddock that succumbed early were observed to cease feeding and these haddock were also afflicted with fin rot infections. Overall then, it is hypothesized that haddock in the laboratory experiment died mostly from infection and stress related causes (that led to starvation and low LSI; not expected to be a problem in natural settings), and that by the end of the experiment, tag implantation may have led to lower energetic fitness (i.e., lower FCF; could be a problem in natural settings).

This is the first study to examine the potential effects of intraperitoneal acoustic tag implantation on haddock survival and condition. Numerous acoustic tagging studies have been conducted on closely related Atlantic cod with great success (Cote et al. 1999, Robichaud and Rose 2001, Windle and Rose 2005). However, before applying the same protocols to haddock, which some considered to be less hardy and robust for tagging purposes than cod (CCCHFA, personal communication; also, tag return rates from a conventional tagging study on Georges Bank haddock are alarmingly low (1.7%; Brodziak et al. 2008) suggesting high tagging mortality), it was imperative to verify that haddock could withstand the surgery and the tags. Overall, haddock tolerated the experimental procedures quite well. They were responsive to clove oil anaesthesia, they survived both long-term laboratory and short-term field surgery trials at acceptable rates (it is argued that lab mortality was due mostly to infection), however, they exhibited decreased body condition (FCF) at the end of the six week laboratory trial. Based on these results, it was decided to continue with the longer term field study (tagging of 80 haddock and monitoring by an array of 18 receivers) for which this study was initiated, and where further information on haddock survival and behavior, following acoustic tagging, would become available (see Sherwood, unpublished).

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Table 1. Results of analysis of variance (ANOVA) for effects of treatment (surgery vs. control), survival, and their interaction on haddock FCF and LSI.

Effect	FCF		LSI	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Treatment (T)	10.415	0.007	0.047	0.831
Survival (S)	0.002	0.962	4.743	0.048
T×S	7.130	0.019	0.854	0.372
N	17		17	
R ²	0.57		0.17	



Figure 1. Surgery cradle.



Figure 2. Incision site on anaesthetized haddock.



Figure 3. Cage being deployed for field surgery trials.

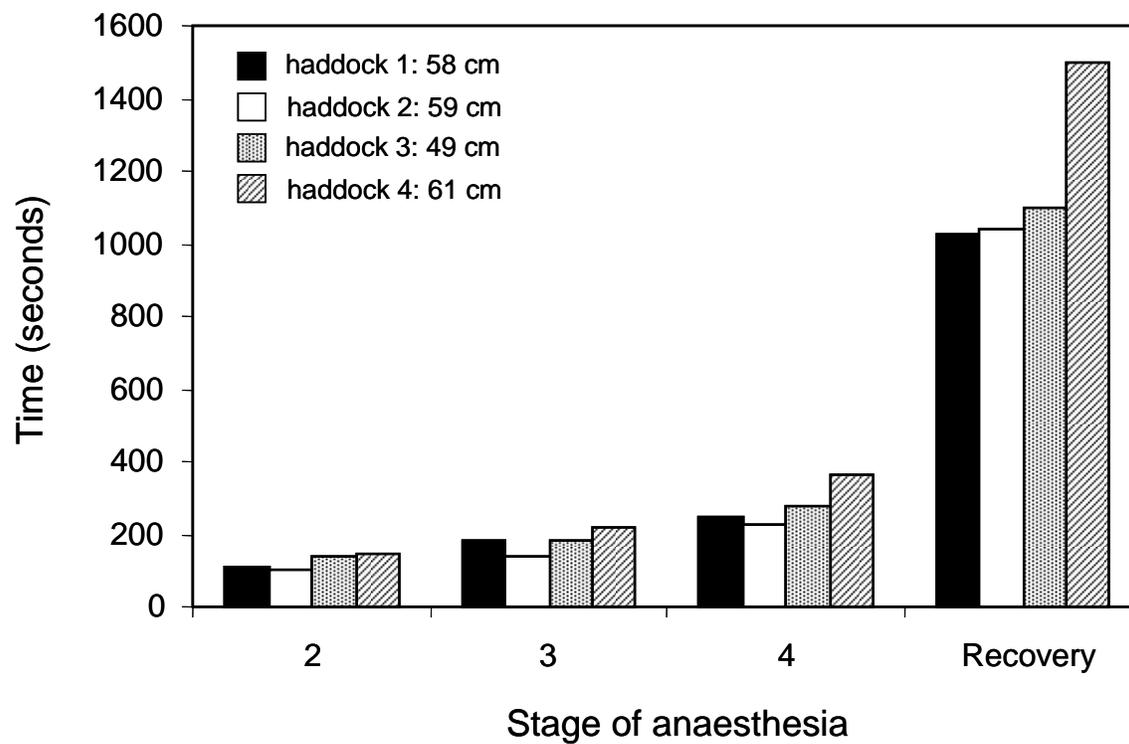


Figure 4. Time to 4 stages of anaesthesia (see methods) for 4 different haddock of varying sizes (lengths indicated in legend).

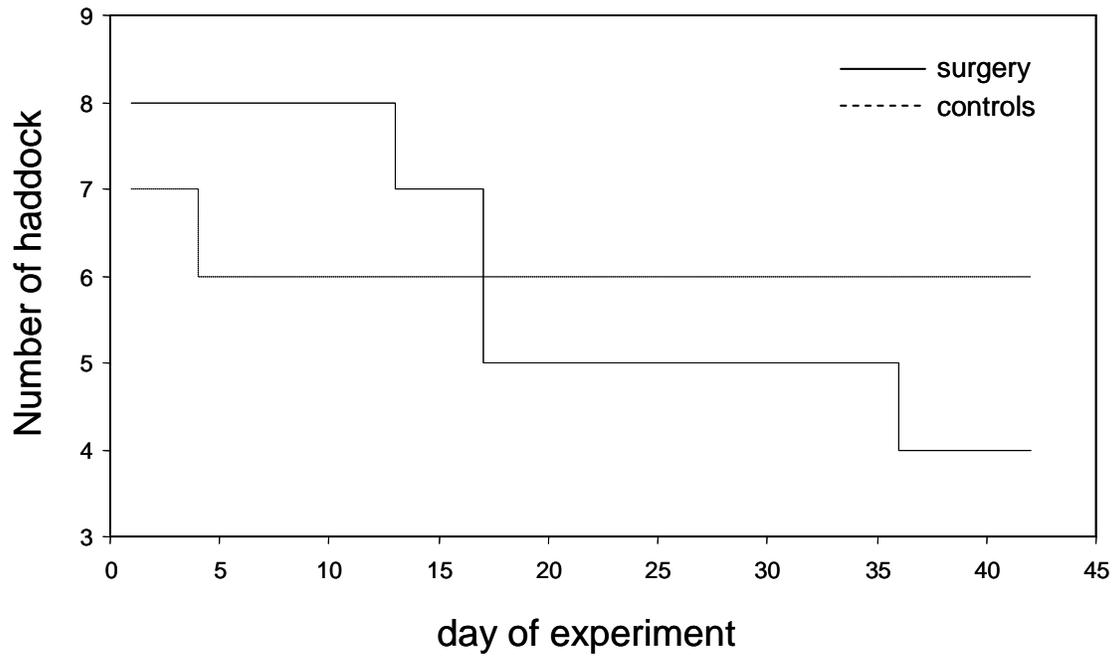


Figure 5. Number of surgery and control haddock remaining each day over the course of the 6 week experiment.

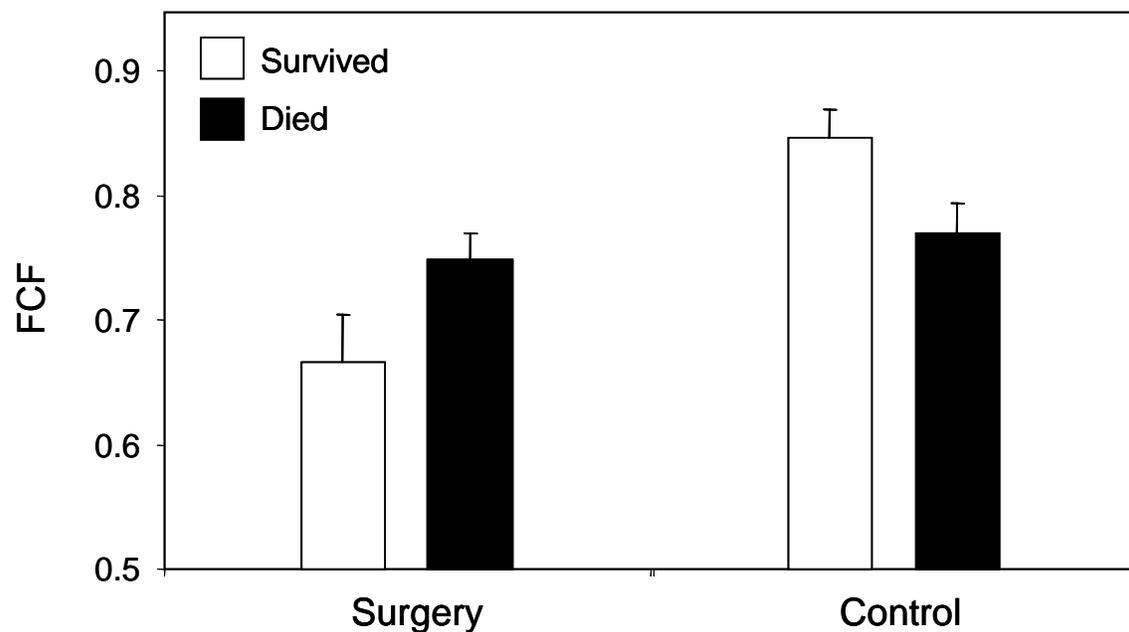


Figure 6. Fulton's condition factor (FCF) of haddock that underwent surgery versus control haddock, and by haddock that survived the duration of the experiment (6 weeks) and those that died prematurely (control haddock that died prematurely includes haddock that died during acclimation period). Error bars represent standard error.

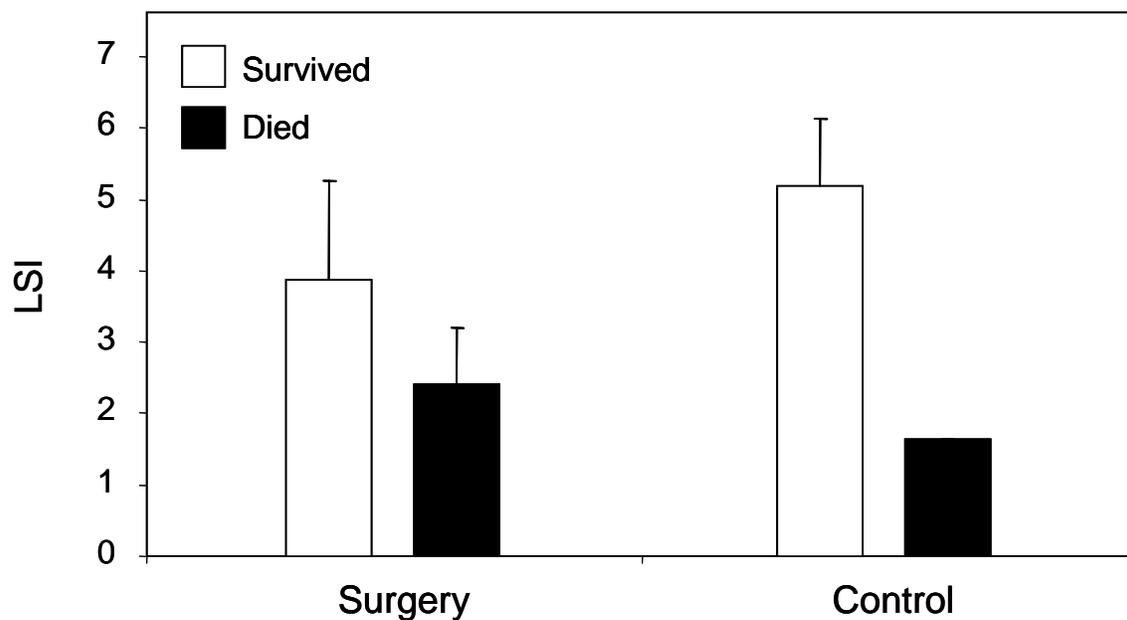


Figure 7. Liver somatic index (LSI) of haddock that underwent surgery versus control haddock, and by haddock that survived the duration of the experiment (6 weeks) and those that died prematurely (control haddock that died prematurely includes haddock that died during acclimation period). Error bars represent standard error.

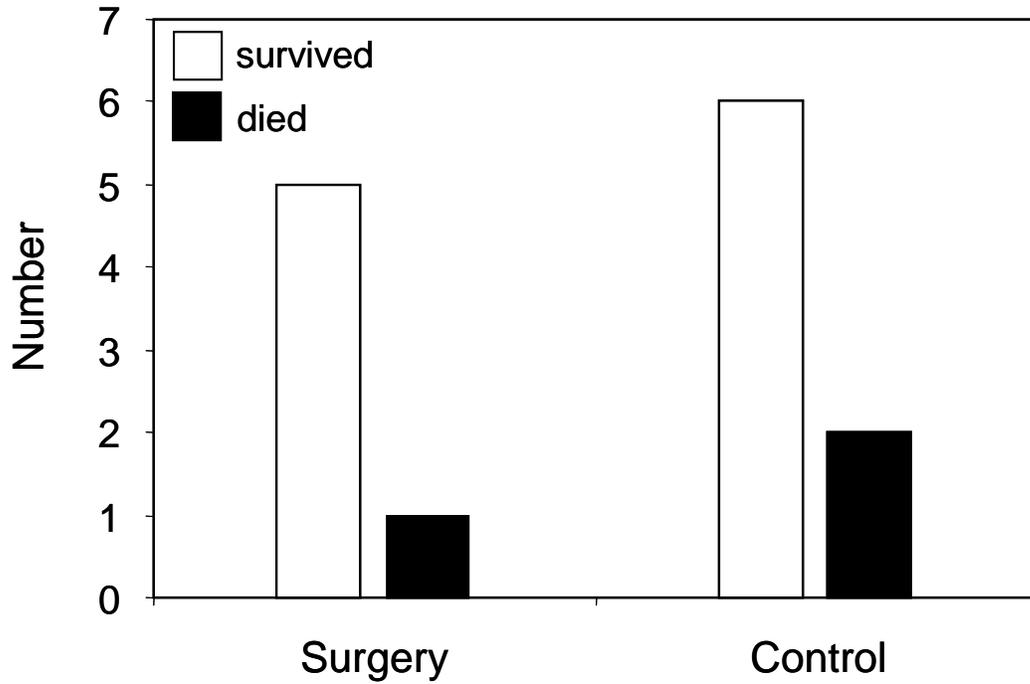


Figure 8. Number of haddock that survived field capture/surgery/release and capture/release (controls) versus the number that died. Note that release means being held for 3 days in cage on bottom at 90 m depth.

Monitoring haddock (*Melanogrammus aeglefinus*) residency and movement behavior in an extensive offshore closed area with a non-overlapping acoustic receiver array²

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² Note: This paper is in preparation and will be submitted to the NEC as a completed manuscript by Oct 31, 2009. The following is a brief summary of the results including all of the major figures that will be included in the final manuscript/report.

Executive Summary (interim)

According to the fishing community, Closed Area I (CAI) on Georges Bank is beneficial for haddock and may have been an important contributor to the recent recovery of New England haddock stocks. However, little fine-scale research has been conducted to determine if haddock are indeed making use of CAI as a refuge. To address questions related to movements and residency behavior of haddock in CAI, an array of 17 acoustic receivers (Vemco VR2W's arranged in a non-overlapping grid pattern) was deployed in the northwest portion of CAI at the end of July 2007 to monitor the movements and centers of aggregation of 80 haddock internally tagged with acoustic transmitters (Vemco VR16). Two months (August and September) of usable data for this entire array of receivers was downloaded before most of the array was lost (presumably) to a hurricane in early November 2007 (Hurricane Noel). Despite this loss, over 23,000 usable detections (representing 37 live fish and 144 discrete movements between receivers) were available from which numerous insights into the behavior of CAI haddock were made possible. Specifically, the data indicate a center of aggregation well away from the edge of the closed area in deeper waters (~ 80 fathom) and also reveal the existence of a movement “*highway*” which appears to end abruptly at the closed area boundary (an inference). In terms of basic haddock biology, movements on the order of 2-3 times laboratory-determined maximum sustainable swimming speeds (of 0.6 m/s) were found which are interpreted to represent tidal “*surfing*”. In fact the majority of movements, including the “*haddock highway*”, align well with the tidal ellipse for the area in a north – south direction. Finally, the array was able to uncover predominantly nocturnal movement behavior in haddock (i.e., haddock are more active at night than during the day) based on the number of arrivals and departures to and from the detection range of individual receivers during day and night.

The results of the full 2007 array (i.e., pre-hurricane Noel) were supported by data collected in late 2007 and up until September 2008. Three receivers survived Hurricane Noel and were downloaded in December 2007 (these were subsequently lost over the winter). An additional 2 receivers were recovered by fishermen and returned to GMRI in May and July of 2008. These 5 “bonus” receivers (relatively well spaced out in CAI) detected a total of 20 haddock over the course of 8 months, 8 of which had not been

previously detected by the full array of 17 receivers. The center of aggregation and movement patterns were very similar to those revealed in 2007 with the possible exception that haddock may have shifted slightly further west within the area in 2008. Finally, a mobile (boat-based) telemetry survey was conducted in August and September of 2008. A total of 11 individual haddock tags were detected, 3 of which were confirmed to be alive, 5 which were confirmed to be dead (on bottom) and 3 which were questionable. The advantage of the mobile survey was that data could be collected from outside of the area. Only 1 of the 11 detections was made outside of CAI suggesting that the haddock were much more likely to either reside or die in CAI. Overall the results of the full array (2007), the reduced array (2007/2008) and the mobile telemetry survey (2008) support the notion that haddock display residency behavior in CAI. An additional outcome of this study is the demonstration of the usefulness of non-overlapping grid arrays (a departure from the more popular line arrays) for studying residency behavior, movements and habitat associations in marine fish.

Figures (will be included in final report and manuscript)

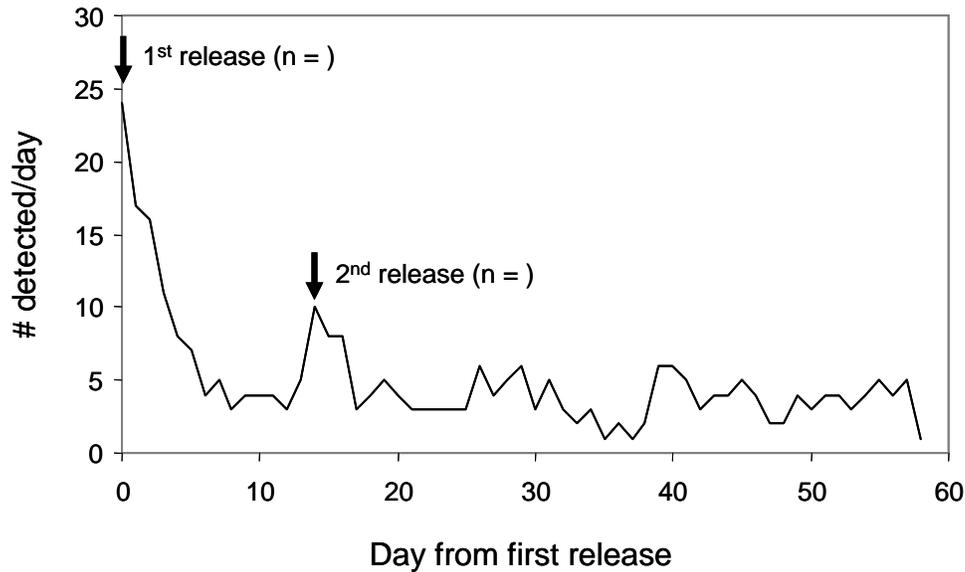


Figure 1. Number of haddock detected per day over the course of the first two months of the experiment (the time for which the full array was intact). An average of about 4 individual haddock were detected each day following release.

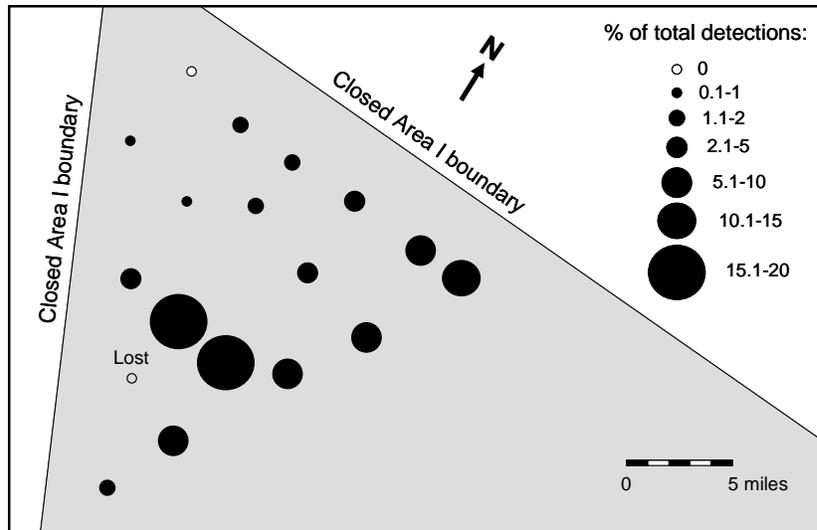


Figure 2. Detections by receiver (northwest corner of CAI) expressed as percentage of the total number of detections over the course of two months for which the full array was intact (total detections = 23,309). The majority of the detections were in the south portion of the array away from the closed area boundaries (2 receivers). There were also significantly more detections on the eastern half of the array compared to the western half suggesting again that haddock are not approaching the northwest boundaries of the closed area.

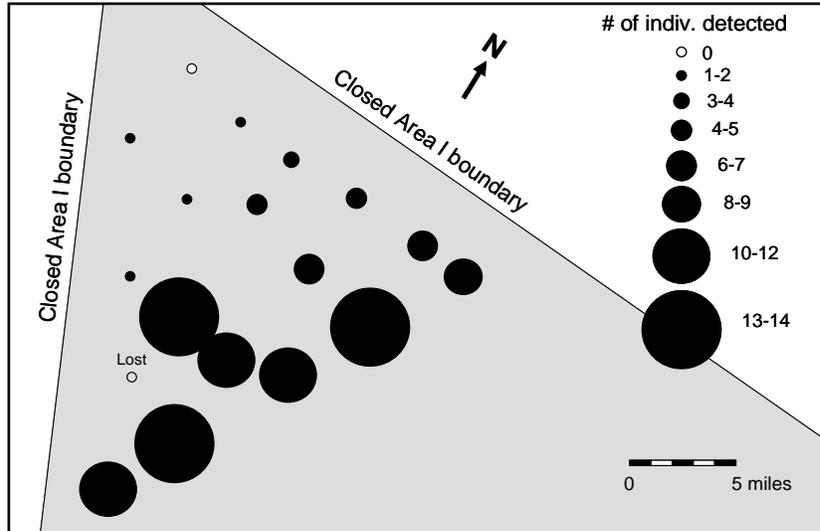


Figure 3. Detections by receiver expressed as number of individual haddock detected by each receiver in the array over the course of two months for which the full array was intact. The majority of haddock were detected on the southeast portion of the array well away from the northwest boundaries of the closed area. A total of 37 individual haddock (of the 80 released) were detected over these two months.

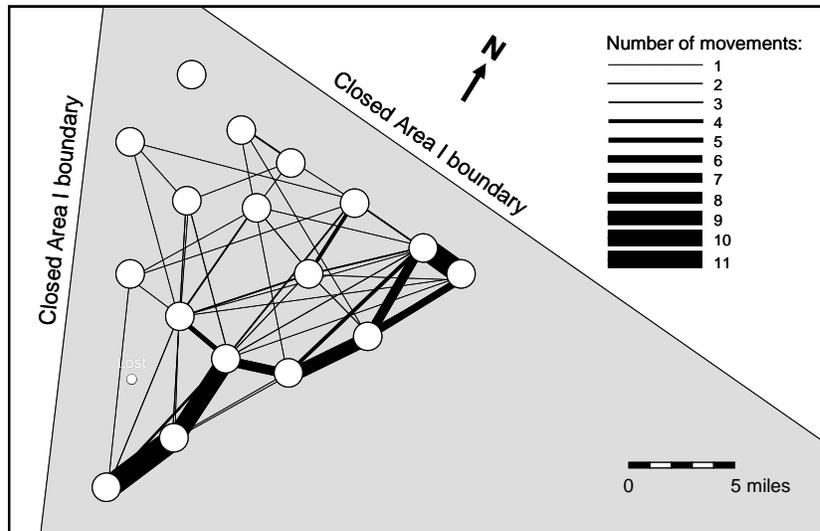


Figure 4. Number of discrete straight-line movements between receivers over the course of the two months for which the full array was intact (total number of movements = 144). The majority of movements were along the eastern edge of the array, near the center of the closed area in a north – south direction. [this corridor of movement will be dubbed a “haddock highway” in the full manuscript].

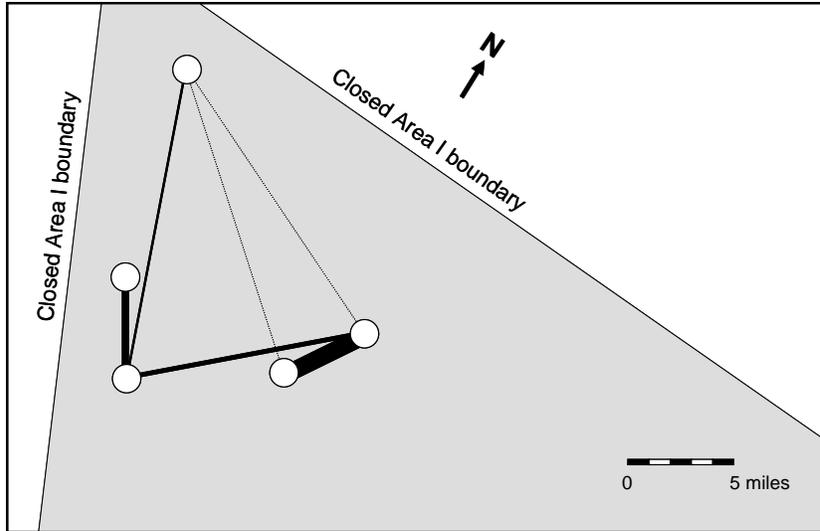


Figure 5. Number of discrete, straight-line movements between receivers over the course of the two extra months (Nov/Dec) for which 5 receivers remained in their original positions (total number of movements = 20). The majority of movements were again in the eastern side of the original array. 20 individual haddock were detected over this period of which 8 had not been detected in the prior 2 months (i.e., by the full array).

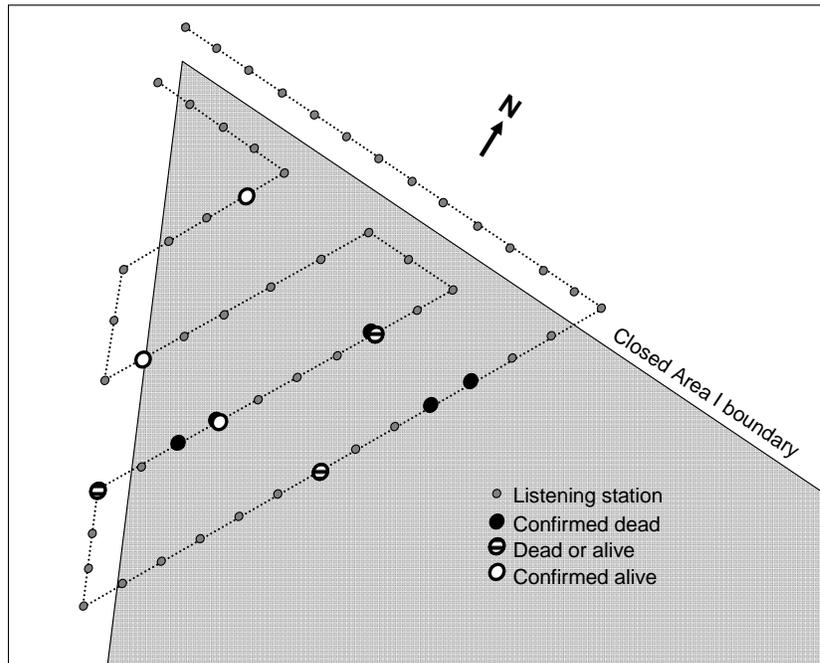


Figure 6. Results of mobile telemetry tracking (Aug/Sept 2008). Listening stations were visited briefly (~ 5 minutes) by boat over 7 different dates. A total of 11 haddock were located, 3 of which were confirmed alive, 5 of which were confirmed dead (always in the same place), and 3 of which were questionable. Only 1 of the 11 relocations was outside of the closed area (1 was on the edge).

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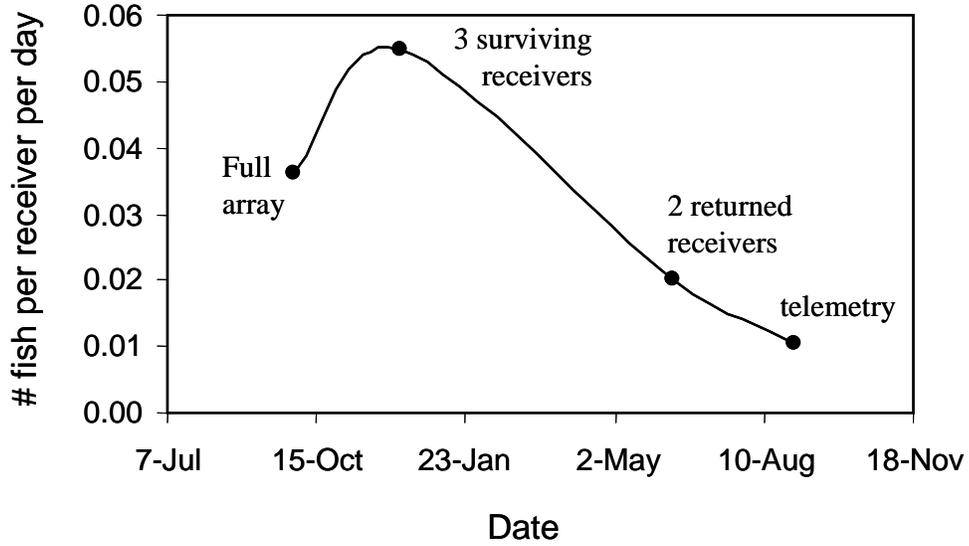


Figure 7. Attrition curve for the course of the experiment over which time data from different sources were available, but nonetheless converted to a common variable: number of haddock detected per day. The Curve indicates that haddock are highly resident to CAI for the first 5 months and detections fall off thereafter as a result of emmigration and/or mortality.

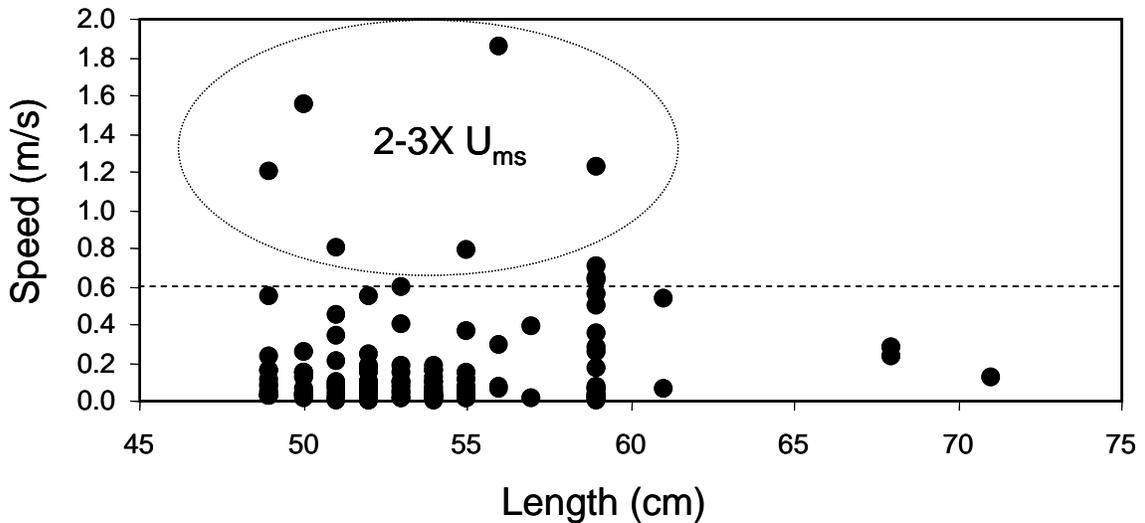


Figure 8. Swimming speed versus length for haddock detected within 24 hours on 2 adjacent receivers. Dashed line represents maximum sustainable swimming speed for haddock ($U_{ms} = 0.6$ m/s; Breen et al. ICES 2004). A number of haddock demonstrated swimming speeds in the range of 2-3 times U_{ms} .

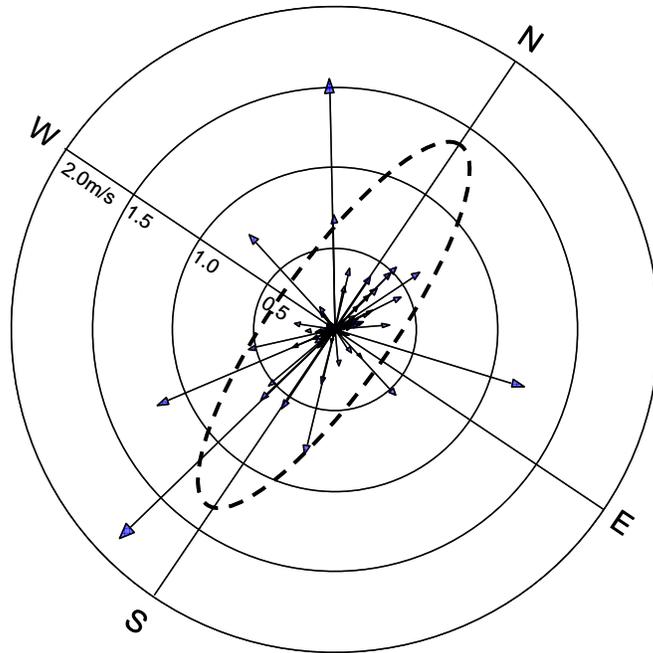


Figure 9. Vector diagram showing swimming speed and direction for haddock that moved between 2 adjacent receivers in the full array within 24 hours. Most movements are in the north south direction and tend to follow the tidal ellipse for the region (Chen lab).

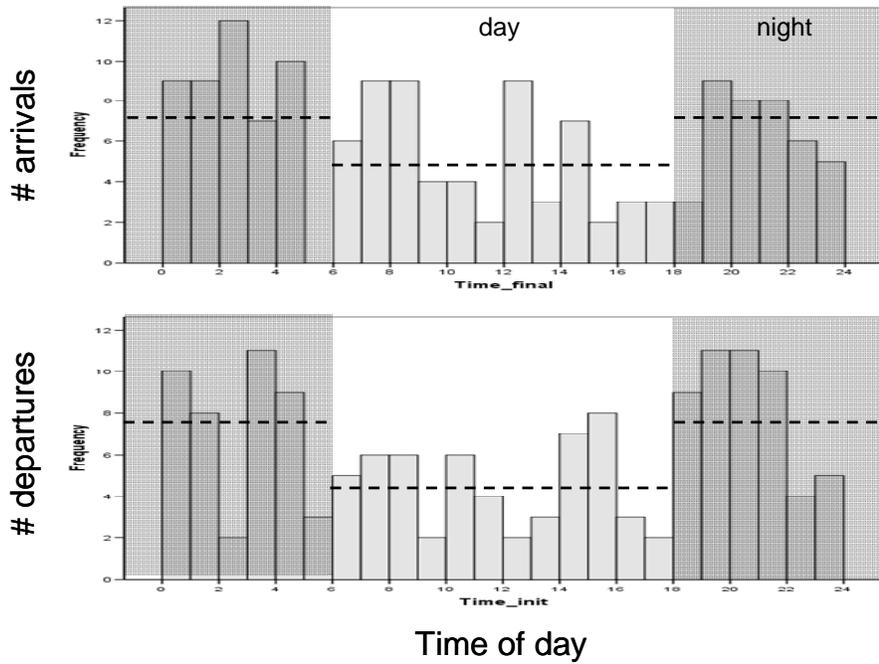


Figure 10. Number of arrivals and departures at receivers by time of day shows a pattern of nocturnal behavior.