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**Harvest rates and movements of cod (*Gadus morhua*) in NAFO Divs. 3KL from tagging and acoustic telemetry**

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## Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## ABSTRACT

Results from analyses of recaptures of cod tagged and released in the Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 3KL during 2004-12 are reported along with updated analyses of acoustic telemetry data from cod released offshore during March 2008. During 2004-11, approximately 25,000 tagged cod have been released and approximately 1,370 recaptured. Mean annual exploitation rates (percent harvested) are estimated for cod released in various regions (unit areas); the methods incorporate estimates of initial tagging mortality, tag loss (from double tagging) and reporting rate (from high-reward tags) and a range of assumed values for the instantaneous rate of natural mortality ( $M$ ). Annual tag reporting rates were also estimated; the time-series average was 70% and estimate for 2012 was 65%. Separate reporting rates were also estimated for recreational and commercial fishers and these indicated a lower reporting rate for recreational fishers (49% in 2012), compared to commercial fishers (71%). Recreational fisher tag returns amounted to 73% of commercial fisher tag returns suggesting that landings during recreational fishery, though not directly measured, are a substantial fraction of total removals. Average annual exploitation rates (percent harvested) for 2010-12 estimated from tagging were low in all regions (range 2-6%). These results indicate that fishing is a small component of total mortality rates ( $Z=0.46$  or 37% mortality per year during 2010-12) estimated from cohort analyses of Fisheries and Oceans Canada (DFO) autumn trawl survey data. However, overall productivity of the stock is low and management actions should focus on promoting further increases in spawning biomass and subsequent recruitment as the stock is currently (2012) at 15% of the limit reference point. Cod released offshore in Div. 3K during March 2008 with implanted acoustic transmitters migrated inshore during summer and were detected widely throughout the inshore of 3KL during summer and fall 2008-10; these cod disappeared during intervening winters and presumably migrated back offshore, indicating that the traditional seasonal migration pattern observed prior to the moratorium was taking place. Migratory offshore cod first arrived inshore in late June and through July, approximately 3-4 weeks later than in those tagged offshore in the 1980s.

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**Taux de récolte et déplacements de la morue (*Gadus morhua*) dans la division 3KL de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) provenant du marquage et de la télémétrie acoustique**

**RÉSUMÉ**

Les résultats des analyses de recaptures des morues marquées et remises à l'eau dans la division 3KL de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) au cours de la période s'étendant de 2004 à 2012 font l'objet d'un rapport comptant aussi les analyses mises à jour des données de télémétrie acoustique liées à la remise à l'eau de morues au large au cours du mois de mars 2008. Au cours de la période s'étendant de 2004 à 2011, environ 25 000 morues marquées ont été remises à l'eau et environ 1 370 morues ont été recapturées. Les taux d'exploitation annuels moyens (pourcentage d'exploitation) sont évalués pour la morue remise à l'eau dans différentes régions (sous-zones). Parmi les méthodes d'évaluation, on retrouve les estimations liées à la mortalité suivant le marquage initial, la perte d'étiquettes (à partir du marquage double), le taux de signalement (à partir des étiquettes accordant de grosses récompenses) et la gamme de valeurs présumées pour le taux instantané de mortalité naturelle. Le taux de signalement annuel des étiquettes a également été évalué. La moyenne de la série chronologique était de 70 % et l'estimation pour 2012 était de 65 %. Des taux de signalement distincts ont également été évalués pour les pêcheurs commerciaux et sportifs et ces taux ont révélé un taux de signalement inférieur pour les pêcheurs sportifs (49 % en 2012), comparativement aux pêcheurs commerciaux (71 %). Le pourcentage de retours d'étiquettes de pêcheurs sportifs correspondait à 73 % des retours d'étiquettes de pêcheurs commerciaux, ce qui laisse entendre que les débarquements au cours de la pêche récréative, même si ces derniers ne sont pas directement évalués, représentent une partie significative du total des prélèvements. Les taux d'exploitation annuels moyens (pourcentage d'exploitation) pour la période s'étendant de 2010 à 2012 qui sont évalués à partir du marquage étaient faibles dans toutes les régions (entre 2 % et 6 %). Ces résultats laissent entendre que la pêche représente une petite partie des évaluations des taux de mortalité totaux ( $Z = 0,46$  ou mortalité annuelle de 37 % au cours de la période s'étendant de 2010 à 2012) à partir des analyses par cohorte découlant des données d'automne de relevé au chalut de Pêches et Océans Canada. Cependant, la productivité globale du stock est faible et les mesures de gestion doivent se concentrer sur la promotion de la croissance de la biomasse des reproducteurs et du recrutement à venir, puisqu'à l'heure actuelle (2012), le stock est fixé à 15 % du point de référence limite. Les morues remises à l'eau au large dans la division 3K au cours du mois de mars 2008 implantées d'émetteurs acoustiques ont migré dans les eaux côtières au cours de l'été et ont été repérées à grande échelle dans les côtes de la division 3KL au cours de l'été et de l'automne de la période s'étendant de 2008 à 2010. Ce groupe de morue a disparu au cours des hivers dans les intervalles et il a probablement migré au large des côtes, ce qui laisse entendre que la tendance de migration saisonnière habituelle dénotée avant le moratoire était en cours. Les morues du large migratrices sont arrivées dans les eaux côtières à la fin du mois de juin et au cours du mois de juillet, soit environ trois ou quatre semaines plus tard que celles qui ont été marquées au large dans les années 1980.

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## INTRODUCTION

An ongoing mark-recapture study of Atlantic cod (*Gadus morhua*) in NAFO Divs. 2J3KL initiated in 1997 was continued in 2012. Although the offshore portion of the stock area has remained under moratorium since 1992, directed fishing for northern cod has taken place in the inshore (i.e. within 12 nautical miles (NM) of the coast) during much of the post-moratorium period, most notably during 1998-2002 and from 2006 onwards. These inshore fisheries have provided the opportunity to use tag return information to determine exploitation rates and investigate cod movement patterns and stock structure during the post-moratorium period.

Recent assessments of northern cod have mainly been based on a cohort analysis of the autumn research vessel (RV) trawl survey data, because reliable catch information from this stock are not available for use in traditional stock assessment models such as virtual population analysis (VPA). The cohort analysis (DFO 2011; Cadigan 2013) provides relative estimates of stock size and absolute estimates of total mortality rates ( $Z$ ). Analysis of mark-recapture data provides a means of estimating the proportion of total  $Z$  that can be attributed to fishing. Data from tagged cod released during 2004-11 and recaptured during 2004-12 were used in the current analysis.

Acoustic telemetry has proven to be a useful method for investigating cod movement patterns (Comeau et al. 2002; Windle and Rose 2005; Zimmerman et al. 2013) and was used in the present study in conjunction with conventional tagging to provide additional information about offshore cod movement patterns (Bratney et al. 2008; 2011). A network of acoustic receivers deployed around the northeast coast of Newfoundland throughout the year was used to provide fishery-independent information about migration patterns of offshore cod. Preliminary results from the acoustic telemetry study on offshore cod reported by Bratney et al. (2011) are updated herein. Movement patterns based on recaptures of cod tagged inshore during the post-moratorium period are described in previous documents (Bratney and Healey 2003, 2007).

## MATERIALS AND METHODS

Tagging procedures are described in detail elsewhere (Bratney and Cadigan 2004; Cadigan and Bratney 2004, 2006). Briefly, cod for tagging were captured with various gears, measured (nearest cm) and tagged with one Floy t-bar anchor tag inserted at the base of the first dorsal fin, and released. Experienced technicians conducted the tagging. Only cod  $\geq 45$  cm fork length (FL) were tagged as smaller cod are not generally captured in fisheries. Double tagging was conducted during 1997-2004 to investigate and quantify tag loss rates, and results from those studies are used to account for tag loss over time (see below). Tags were uniquely numbered and bore a return address as well as the value of the reward; a high-reward tagging program was used to estimate tag reporting rates. The tagging program was advertised extensively among those participating in the fishery (commercial and recreational fishers, and plant workers).

Cod have been tagged and released at multiple sites in the inshore, and a single site in the offshore (Table 1, Fig. 1) Most of the cod for inshore tagging were captured with baited hand-lines or cod-pots; offshore cod were captured with an otter trawl on CCGS Teleost during a joint tagging/hydro-acoustic survey.

Reported landings of cod from 2J+3KL during the period 2006-12 were extracted from the DFO Newfoundland and Labrador (NL) Region Statistics Branch catch database and are summarized to aid in the interpretation of tag returns. These do not include landings from the recreational fishery, or estimates of unreported commercial landings.

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## ESTIMATION OF EXPLOITATION RATES

The methods used to estimate exploitation rates from tagging are described in a previous document (Bratley and Healey 2003). In this analysis, the fraction of available tagged cod that were harvested annually from each tagging experiment (i.e. from each batch of cod tagged in a specific area at a specific time) was estimated, irrespective of where recaptures came from. Results were grouped by unit area (of release) and for many areas there were multiple annual estimates of exploitation rate, each based on separate tagging experiments. A mean annual estimate was also computed for each unit area, with the number of cod tagged in each experiment used to weight the values from individual experiments within a unit area. No attempt was made to estimate population size in this analysis, because some harvesting occurs in areas different from where fish were tagged and this makes it difficult to convert local catches to local population biomass. Various factors that could influence the availability of tagged cod to the fishery were accounted for, as described below.

### Tagging mortality

To determine the level of tagging-induced mortality (the fraction of tagged cod that die due to the stress of capture, handling, and release) various methods were used, such as retaining tagged cod in submersible enclosures and comparing recapture rates of cod tagged with various gears (Bratley and Cadigan 2004), and more recently releasing batches of cod with surgically implanted acoustic transmitters and monitoring survival using moored acoustic receiver arrays (Bratley et al. 2008). Estimates of exploitation rate can be negatively biased if substantial fractions of tagged cod die immediately after release due to the stress of capture and tagging. Results from the aforementioned studies were used to estimate a value for tag-induced mortality for each tagging experiment (Table 1) based on capture gear, capture depth, and time of year. Bratley and Cadigan (2004) found that tagging mortality was low (0.03) during spring (April-May) and higher (0.22) during late summer and fall (August-November) for cod caught with hand-line and otter trawl in shallow water, based on cage retention experiments. Acoustic telemetry also confirmed the high survival rates of cod caught for tagging in shallow water during early spring when no thermocline was present. Bratley et al. (2008) found > 96% survival (N=166) for cod tagged with external t-bar tags and implanted with acoustic transmitters. Therefore, seasonal estimates of tag-induced mortality were used in the current analysis based on the month of release, capture gear, and capture depth. A value of 0.03 was used for tagged cod captured with hand-line or cod pot at depths < 90 m and released during November-December and January-June, and a value of 0.22 was for those released during July-October. For cod captured using otter trawls in deep water ( $\geq 200$  m) information from acoustic telemetry indicated that mortality was higher, and a value of 0.44 was used for tag-induced mortality for all experiments where cod were caught with otter trawls in deep water (Bratley et al. 2008).

### Tag loss

Tag loss rates were estimated from a double-tagging study (see Cadigan and Bratley 2004, 2006), which showed that tag loss mostly occurred in the first 3-4 months after release with only minimal losses thereafter. The model proposed by Kirkwood (1981) was used to estimate tag loss:

$$\phi_t = ((\beta_0 / (\beta_0 + \beta_{1t})) \beta_0 ; \beta_0, \beta_1 > 0$$

where  $\phi_t$  is the cumulative probability that a tag is retained on a fish after time  $t$  since release. Cadigan and Bratley (2006) show that for cod tagged with Floy t-bar anchor tags as in the present study this model is more suitable than the proportional tag loss model proposed by Barrowman and Myers (1996). For each recapture year, a time at liberty was computed, which

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in the first year corresponds to the number of weeks between the median date of release of tagged fish and the median recapture date of tagged individuals in the year of release. For subsequent years, time at liberty was calculated by incrementing the number of weeks between the annual median dates of recapture. In this study the estimates of the two parameters for the tag loss model ( $\beta_0$  and  $\beta_1$ , above) were updated using methods described in Cadigan and Bratley (2006). The values were  $\beta_0 = 0.0739$  and  $\beta_1 = 0.0443$ . The proportion of initial number of tags applied that were retained at the median date of recapture for each recapture year was computed and used in the estimation of annual exploitation rates. No further results from the analysis of tag loss rates are reported herein; the model has shown that cod typically lose about 22% of their single tags in the first year, but subsequent losses are much lower (< 5% per year, see Fig. 4. in Cadigan and Bratley 2006).

### **Reporting rate**

Estimates of the fraction of tags returned by those participating in the fishery are also required to infer exploitation rates. It is well known that not all tags are reported and failure to account for non-returns would result in negative bias in the estimates of exploitation rates. A high-reward tagging study was used to encourage return of tags and to estimate the fraction of tagged cod captured and returned by those participating in the fishery. The reward for returning a standard (yellow) tag was \$10 CAD and for returning a high-reward (pink) tag the reward was \$100 CAD. Details of earlier methods of analyzing this type of data have been described previously (Cadigan and Bratley, 2004; 2006). However, the time-series of tag reporting rate data now extends over a period of 16 years (1997-2012) and encompasses four regions around insular Newfoundland. A new approach that utilizes a mixed-effects logistic regression model (LRM) was used to estimate annual reporting rates for each region (for details see Cadigan and Bratley 2008). In this analysis annual reporting rates for each region are decomposed into a main effect and a random year effect; essentially the year-region interactions in the LRM are treated as random effects. Tagging data from 1997 to 2012 from the four regions grouped as in Cadigan and Bratley (2008) were used in this analysis, although only the annual estimates for the inshore of 3KL are reported here. Reporting rates were also estimated separately for commercial and recreational fisheries.

### **Natural mortality rate**

Similar to previous assessments the instantaneous rate of M was assumed to be 0.4 per year for cod tagged in 3K and 0.2 per year for those tagged in 3L in the base analysis of exploitation rates. Analysis of autumn survey data has shown the most of the expansion of age structure and increases in biomass in Northern cod during 2005-09 have taken place in 3L therefore a reasonable starting point is that assumed values for natural mortality rates are higher in the northern portion of the stock area. Estimates of exploitation rate were also computed for a range of fixed values of M (i.e. 0.4 and 0.5 in all areas). Cohort analysis (DFO 2011; Cadigan 2013) of age-disaggregated DFO autumn trawl survey data was used to estimate total instantaneous mortality rates (Z) for ages 5-11. The value of Z averaged 0.46 per year (=37% mortality per year) during 2010-12 and this value was used as a basis for the range of values assumed for M in the estimation of exploitation rates in the recent period.

### **Growth and fishery selectivity**

The minimum size of tagged cod at release was 45 cm FL (~ age 4), but typically a broad size range of cod are tagged and released in each tagging experiment. The post-moratorium inshore fishery in 2J3KL is mostly pursued using 5.5" mesh gillnets which show a domed selectivity pattern, and previous analysis showed that gillnets catch relatively few cod < 50 cm FL or > 85 cm FL (Myers and Hoenig 1997; Bratley and Healey 2007); consequently, estimates of exploitation rates are likely to vary with the length composition of tagged cod. To reduce the



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influence of differences in the length composition, exploitation rates were computed for each tagging experiment based on cod tagged within this restricted size range. An additional complication is that tagged cod grow after release and gradually move through the selectivity pattern of the fishery as they increase in length and age. To minimize the influence of growth, only recaptures within two years after the release date were used. When computing exploitation rates recapture data from the year of release were avoided if the release date was within 6 weeks of the opening of the fishery; this was to allow tagged cod to disperse from the tagging sites and to recover from the stress of capture which could influence catchability. The numbers recaptured within the first six weeks after releases tended to be small, i.e. there was no high capture rate soon after release.

## **ACOUSTIC TELEMETRY**

### **Acoustic transmitters**

A subset of the cod captured and tagged with Floy- t-bar tags offshore in 3K during March (Table 1, experiment 2008-001) were also released with implanted acoustic transmitters. A total of 146 cod were released with individually coded acoustic transmitters (Vemco Division of Amirix Systems Inc., Shad Bay, NS, Canada). Two types of transmitters were used (both 69kHz frequency) ; Model V13-1H, 13 mm×45 mm, mass 6 g,  $120 \pm 60$  s ping rate in cod < 60 cm FL, and model V16-5H transmitters (16 mm×93 mm, mass 16 g,  $120 \pm 60$  s ping rate). Of these, 72 cod were released with V13 transmitters and 74 with V16 transmitters. The mean lengths of cod acoustically tagged with V13 transmitters ranged from 53 cm to 57 cm per set; the mean lengths are therefore comparable to those of cod tagged with Floy tags alone. Cod with larger V16 transmitters were on average approximately 10 cm larger and mean lengths ranged from 63 cm to 69 cm per set. Transmitters were surgically implanted into the body cavity of cod through a small (2.5 cm) incision in the posterior abdominal wall. The incision was subsequently closed with two independent sutures using a standard procedure approved by the local committee of the Canadian Council for Animal Care. Surgery took < 2 minutes. Transmitter weight relative to fish weight was < 1.4% for cod with a V13 and < 0.8% for cod with a V16. Cod were held for 30-60 min post-surgery and then released close to the capture site. Transmitter function prior to release was confirmed using a receiver (VR100 or VR2/W) held in the holding tank during recovery. Expected battery life for V13 transmitters was 360 days; for V16 transmitters it was 900 days.

### **Acoustic receivers**

An extensive series of bottom-moored acoustic monitoring receivers (Vemco VR2 or VR2w) has been deployed in coastal waters off the north-east coast of Newfoundland continuously since 2006 to monitor the movements of coastal cod and other species with implanted transmitters (Bratley et al. 2008). These arrays were used herein to investigate movements of offshore cod within the near-shore region that is open to fishing on a seasonal basis. Mooring apparatus and method of retrieval of receivers are described in Bratley et al. (2008). During the study, 29 monitoring arrays each comprising 1-9 receivers equipped with long-life (i.e. ~ 14 month) batteries were deployed at a total of 86 stations throughout the near-shore waters off the northeast coast of Newfoundland. Most receivers were initially deployed in 2005 or 2006, i.e. well in advance of release of acoustically tagged offshore cod. For the current study the monitoring period extended from release of the first batch of acoustically tagged offshore cod on 3 March 2008 until 30 October 2010 (2.6 years), i.e. about four weeks after the estimated expiry date of V16 transmitter batteries. There were some changes in receiver coverage during the study; five new arrays were introduced in early summer 2008 (arrays 4, 5, 23, 25, 29) and four were discontinued part-way through the study in August 2008 (array 2) and November 2008 (arrays 9-11). Some receivers were lost (8 receivers, 6 of which were replaced), or were not

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retrieved prior to battery depletion (e.g. receivers closest to shore in array 13), or more rarely malfunctioned (2) during the 31 month monitoring period. Given the harsh environmental conditions, wide range of depths, and exposed location of many monitoring stations, the percentage of time receivers were operational at each station was generally high (i.e. 76% of the receivers were operational for > 90% of their deployment period).

### **Range testing procedures**

The detection range of transmitters was determined by carrying out an extensive series of range tests. Transmitters were moored 5 m off bottom at fixed distances from receivers in our array at the mouth of Newman sound for several months and the percentage of detections over time under various weather and water temperature conditions determined. Based on these results it was concluded that our transmitters would have a high (> 50%) detection probability to a radius of 800 m and a spacing of 1600 m or less between adjacent receivers within an array was used.

## **RESULTS**

### **TAGGING DATA**

Since 2004 the number of cod tagged per year has ranged from 932 to 6,628 (Tables 1 and 2). Tagging was usually conducted at multiple sites in the inshore (Fig. 1). Offshore tagging was conducted in 2007 (expt. 2007-001, Table 1) and 2008 (expt. 2008-001) in 3K; this is the first time that offshore northern cod have been tagged since the moratorium, but results from expt. 2007-001 were not used in further analyses due to high tagging mortality presumably due to extreme depth (> 400 m) of capture and associated stress of bringing them to the surface for tagging. Cod tagged in 2012 were often released after the fishery and these are therefore not considered further in analyses of exploitation rates presented herein, but those released in 2012 before the fishery and recaptured in 2012 were used in the estimation of 2012 reporting rates (see below). Mean sizes (FL in cm) of cod tagged in each experiment have mostly ranged from the mid-50s cm to upper 60s cm. Cod tagged in Smith Sound have often been of larger average size with several means > 70 cm. However, in the past five years (2008-12) the availability of cod for tagging in Smith Sound has diminished, as fewer cod are overwintering in this inshore area. Most of the tagging in recent years has been conducted during summer and late fall when migratory offshore cod would be inshore. The general perception over the past five years is that fewer cod are overwintering inshore and that most of the cod being tagged are migratory cod from the offshore that are tagged during their summer feeding migration to the inshore.

The total number of reported recaptures has varied during 2004-12 (Table 3). Recaptures were fewer during 2004 and 2005 when the directed fishery for cod was closed and recaptures came only from smaller catches attributed to by-catch and sentinel fisheries. There are also fewer recaptures (< 110) in the two most recent years (2010 and 2011), partly because fewer cod were tagged compared to the 2006-09 period; however, there were several thousand tagged cod available for recapture throughout the study period.

### **COD LANDINGS**

During 2006 to 2012 a small-scale directed fishery for cod in the inshore (stewardship fishery) has been permitted. There is no TAC, but fishers have been permitted a fixed annual allowance per license holder of amounts ranging from 2,500 lb to 3,750 lb. Limits on season dates, amount of gear, and size of vessel have also been imposed. Reported landings of cod from the inshore of 2J3KL have ranged from 2,400 t in 2006 to about 3,300 t in 2008 and 2012 (Table 4). These estimates do not include recreational fishery catches, and analysis of tagging results from recent assessments (see below) suggests that recreational landings could be substantial

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(i.e. > 50% of annual stewardship fishery removals)(DFO 2012). Consequently, total landings are uncertain, but could be in the range 3,500 to 5,000 t. The offshore portion of the stock area remains closed to directed fishing for cod and reported by-catch from the offshore has been small relative to the inshore.

The stewardship fishery is not competitive; consequently, landings trends across the inshore area largely reflect the distribution of effort, i.e. the number of active license holders per unit area (see Fig. 1 for unit area boundaries). There were approximately 1,800 active license holders in 2012 and this number has been diminishing in recent years by approximately 5-10% per year. The largest number of active license holders (~ 500 in 2012) reside in 3Ki (eastern Notre Dame Bay and the Fogo-Twillingate area) and this area accounts for approximately 24-28% of the annual landings, followed by 3Kh, 3La and 3Lb (western Notre Dame Bay, Bonavista Bay and Trinity Bay) each with about ~ 280 fishers and 10%-21% of landings. Fishing effort in 2J (Southern Labrador), 3Ka (the northern Peninsula), 3Kd (White Bay), and 3Lq (St. Mary's Bay) is lower (23-150 active licenses) and collectively accounts for only about 8% of the reported landings. There have been no major changes in the pattern of landings (Fig. 2), but there was a slight increase in proportion of total landings in 3Ka, 3Kd, and 3Kh during 2012, and a corresponding drop in 3La, 3Lb, and 3Lf, suggesting an increase in availability of cod in these more northerly inshore areas of 3K during 2012.

The stewardship and recreational fisheries are open for an approximately 3-5 week period during the summer months (July-September), but specific opening dates have varied widely between years and in some years among different areas. In 2012, the stewardship fishery in most areas was open for 3 weeks starting in mid-to late August depending on area. The recreational fishery in most areas was open during 21 July-12 August, and from 22-30 September.

Most of the tagging results reported here are based on tagging conducted in areas 3Ki, 3La, 3Lb, 3Lf and 3Lj (see Fig. 1) where most (~ 70%) of the inshore fishery landings occur and hence most of the exploitation takes place. Other areas are remote, difficult to access, and have fewer fishers and landings.

## **TAG REPORTING RATES**

Estimates of annual tag reporting rates from the mixed effects LRM ranged from 0.63 to 0.86 during 1997-2012 (Table 5; Fig. 3). The 2012 estimate was 0.65. Although the number of tags available to estimate reporting rates has declined in recent years this has not resulted in an appreciable increase in the size of the confidence intervals. The intervals tend to be marginally higher in 2004 and 2005 when the directed fishery was closed and this resulted in fewer tag returns (Table 3). Cadigan and Bratney (2008) note that the mixed effects model standard errors are complicated to interpret and they do not necessarily decrease the way one normally expects as sample size increases. A useful area for future research would be to explore the statistical properties of the mixed model estimators in more detail.

The reporting rates were also computed separately for recreational and commercial fishers (Fig. 4). There was no recreational fishery in 2004-05 and only a small by-catch fishery resulting in few tag returns and wide confidence intervals for the reporting rate estimates for commercial fishers in those years. In 2012 the results were similar to the recent past (i.e. 2006-11), and the rate was lower for recreational fishers (49%) compared to commercial fishers (71%). When raw tag recapture numbers from these fishers were adjusted by the corresponding reporting rates, overall 42% of the total tags received in 2012 came from recreational fishers and 58% from commercial fishers, i.e. recreational fisher tag returns corresponded to 73% of commercial fisher tag returns. This result suggests that landings during recreational fishery, though not directly

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measured, are a substantial fraction of total removals. Similar findings were reported for the recreational fishery in recent years (DFO 2012).

## **EXPLOITATION RATES**

The annual estimates of exploitation rate for each region are summarized in Table 6. All of the estimates are <8%, except for the Twillingate-Fogo-Notre Dame Bay area during 2006 (19%). Otherwise, there are no major differences between regions. In most regions the estimates tend to decline slightly over time and are lowest in 2012. Annual catches have been broadly similar over the seven year time period, suggesting that the exploitable biomass available to the inshore fishery is increasing.

Exploitation rates computed with higher assumed values for  $M$  (i.e. constant  $M$  of 0.4 or 0.5) had little impact on the overall results. Higher assumed values for  $M$  increased the estimates slightly because fewer tagged fish are available for recapture. For example, the values for exploitation rate by unit area in 2012 reported in Table 6 ranged from 1.8% to 3.6% and increased to 2.1% to 4.5% at an assumed value for  $M$  of 0.4 for all areas. At an assumed value of  $M=0.5$  exploitation rates increased to 2.4% to 5.4%. In all analyses, the fraction of available tagged cod captured in the fishery was small and overall the results indicate the fishing was a small proportion of the overall rate of total mortality ( $Z=0.46$  or 37% per year) estimated from the cohort analysis.

Estimates of exploitation rates for cod tagged offshore in 3K but recaptured inshore during 2008-10 were similar to those for cod tagged inshore. The recaptures from offshore-tagged cod were widely distributed throughout the inshore, from the tip of the northern Peninsula (3Ka) southward to the eastern Avalon (3Lj), indicating that offshore tagged cod dispersed widely throughout the inshore of 3KL during 2008-10 (Fig. 5).

Brattey and Healey (2007) discuss in more detail many of the difficulties in estimating exploitation rates when the fishery is size selective and tagged cod increase in size (age) with time at liberty but diminish in numbers available due to cumulative effects of natural mortality, tag loss, and fishing.

## **ACOUSTIC TELEMETRY**

From the cod released offshore in 2008, 21 (29%) with V13 transmitters and 17 (23%) with V16 transmitters were subsequently detected inshore. The smaller cod (< 60 cm) released with V13s in March 2008 were detected only in the summer and autumn of 2008 as the batteries in these transmitters expired before the summer of 2009. Among the cod with V16s, eleven were detected inshore in 2008, fourteen in 2009, ten in 2010, and six of these were detected in all three years. In addition, four acoustically tagged cod (3 with V13s, one with V16) were recaptured inshore in the 2008 fishery, two of which had not been detected at the time of capture. Thus, a total of 40 (27%) of the initial 146 acoustically tagged cod released in 2008 were subsequently known to have survived and migrated inshore. Most of the receiver arrays (87%) detected at least one offshore cod during 2008-10 (Fig. 6). Acoustically tagged cod were detected widely across the northeast coast of Newfoundland, from array # 2 at Twillingate in 3K southward to array # 30 at Cape Broyle on the eastern Avalon in 3L (Fig. 6). The numbers detected annually at each array were variable (i.e. 1-10, Fig. 6), but there was a tendency for larger numbers of acoustically-tagged cod ( $\geq 3$ ) to be detected on arrays located off the headlands (i.e. array #s 6, 14-15, 27) and smaller numbers (< 3) on arrays located at the mouth of inlets located inside major bays (i.e. array #s 8-13, 17-22).

To determine when offshore cod arrived inshore during 2008 and 2009, the cumulative dates of first inshore detection of each acoustically tagged cod were plotted (Fig. 7). The overall timing

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was similar in both years; the first cod were detected on inshore receivers during early July (2008) or late June (2009) and detections extended throughout the summer and autumn mainly to mid-October in both years, except for a single fish on 31 December 2008. There was no significant correlation ( $P > 0.25$ ) between the date of first inshore detection and the length of the cod at tagging (range 50-69 cm) for the 2008 detections; the available size range was too narrow in 2009 to correlate size with inshore arrival dates.

Inshore arrival dates of migratory offshore cod from the present study were also compared with data from the pre-moratorium period. The historical information available for comparison is limited as there is only one tagging experiment conducted in the same offshore area at the same time of year (i.e. March, experiment 1980-002, Taggart et al. 1995). The cumulative dates of inshore recaptures from this experiment were compared with the cumulative dates of inshore detections during 2008 and 2009 (Fig. 7). In 1980, the first inshore recaptures of offshore-tagged cod were taken in mid-May, and approximately 30% of all the recaptures were taken by the beginning of July. Although recaptures (but not detections) are strongly influenced by the timing of fishing effort, the comparison nonetheless shows that migratory offshore cod arrived inshore 3-4 weeks later in 2008 and 2009 than in 1980.

Inshore detections and inshore recaptures of acoustically-tagged and conventionally-tagged cod showed the same distinct seasonal pattern in the three years of the study (Fig. 8). The acoustically tagged cod were detected inshore throughout the summer until late autumn (mostly July to October), but disappeared from approximately January to June each year (Fig. 8, top panel). Results from the 2008 releases indicate maximum numbers of offshore cod were detected inshore in September in both 2008 and 2009, and July in 2010. Predictably, the timing of recaptures of conventionally-tagged cod coincided with the inshore commercial and recreational cod fisheries, which were restricted to a few weeks in late summer and early autumn. Some tagged cod are also recaptured in the Sentinel survey during June-November. The numbers of tagged cod reported as recaptured per month ranged from 1 to 21 and these were taken during July to November (2008), July to October (2009), and August-September (2010), with peak returns mostly in September (Fig. 8, lower panel).

## **MOVEMENTS OF COD**

Movement patterns based on recaptures of cod tagged inshore were generally similar to those reported from previous post-moratorium tagging experiments, with most of the recaptures coming from within the same general area (bay) where tagging took place, or the adjacent area with considerable movement of cod between Trinity, Bonavista Bay, and to a lesser extent Notre Dame Bay (Figs. 9-11). Recaptures of tagged cod released in Trinity Bay and Bonavista Bay tend to show more dispersal during the more recent period (2010-12) with less concentration of recaptures around the Bonavista Peninsula compared to the 2007-09 period; this difference may be reflecting tagging of a higher proportion of migratory cod from offshore in the past three years, rather than overwintering cod from Smith Sound that tended to disperse mainly around the Bonavista Peninsula. Cod tagged within Notre Dame Bay tended to be recaptured in subsequent years within Notre Dame Bay itself and showed less dispersal to other regions compared with cod tagged further south.

Conventional tagging provides information about the locations of recaptured cod during the fishing season, whereas acoustic telemetry can monitor movements throughout the year and provide multiple measures of the location of individual cod each time they pass within range of a receiver. Acoustically tagged offshore cod showed various movement patterns. Approximately half of the acoustically tagged cod were detected at a single acoustic array, suggesting that many offshore cod did not migrate extensively along the coast upon arrival inshore. However, the remainder showed multiple detections at successive arrays, often being detected initially off

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headlands (Cape Bonavista [array #13], or Grates Cove [#24]/Baccalieu Tickle [#26]) then passing successive arrays towards the bottom of major bays. Detection sequences such as Cape Bonavista (#13), Melrose (#14), Bonaventure Head (#15) were often observed as cod migrated into the western side of Trinity Bay. Alternatively, some arrived at Grates Cove (#24), then Hants Harbour (#23) and Bellevue (#22) as they migrated into the eastern side of Trinity Bay. Others showed detection sequences of Cape Bonavista (#13), Tickle Cove (#12), Newman Sound (#8) as they migrated into Bonavista Bay. A few individuals migrated extensively along the coast past successive arrays (i.e. ID9952 Grates Cove Pt (#24), Baccalieu Tickle (#25), Cape St Francis (#27), Petty Harbour (#28), Cape Broyle (#29) then northward at the same arrays in reverse sequence. There was no clear pattern of movement either northward or southward after arriving at the coast. Summer movement directions were generally shoreward and autumn movements tended to be outwards towards headlands. Migratory offshore cod were not detected inshore during winter (approximately December to May).

Thirteen acoustically tagged cod with V16s were detected inshore in two or more summer-autumn periods during 2008-10 (i.e. ID#s 9906, 9908, 9909, 9910, 9915, 9916, 9925, 9947, 9952, 9954, 9963, 9969, 9975) providing information about whether individual cod visited the same inshore regions in successive years. There was no consistent pattern; some cod visited the same general inshore area in consecutive summers, i.e. Northwestern Trinity Bay (#9947, 9954, 9947), Fogo (#9909), or Baccalieu Tickle (#9915). Others were detected in Bonavista Bay in one summer and Trinity Bay in subsequent summer(s) or vice versa (#9916, 9954, 9963, 9969). Cod #9910 was unusual and was detected at Lumsden in 2008, Bonavista Bay in 2009 and Trinity Bay in 2010. The general diversity of movement patterns is consistent with the notion that most cod foraged widely in search of prey, with no fine-scale fidelity to a particular inshore area; however, at a broader spatial scale many did return to an area of coastline spanning approximately 1.5 degrees of latitude.

## DISCUSSION

Exploitation rates of offshore Northern cod by inshore fisheries during 2008-10 were generally less than 6% and similar values were obtained for cod tagged inshore throughout 2006-12. The inshore estimates were based on multiple tagging experiments conducted widely throughout the coastal zone in shallower water where initial tagging mortality is much lower and less uncertain (Bratley and Cadigan 2004; Bratley et al. 2011). Collectively, the tagging and acoustic telemetry data from inshore and offshore cod have provided several estimates of exploitation rates for different components of the overall Northern cod population. As Bacheler et al. (2009) have pointed out, the combined use of tag return and telemetry techniques provides a useful alternative for estimating exploitation rates from the traditional stock assessment approach that relies on survey data and fisheries landings. This is particularly true for Northern cod where recent estimates of total landings are uncertain and the proportion of the stock that resides outside surveyed areas (i.e. inshore) varies over time.

Cohort analysis of DFO autumn trawl data indicates the instantaneous rate of Z is still high for Northern cod, with Z averaging 0.46 (=37% mortality per year) during 2010-12 for cod aged 5-11 (DFO 2013). The results from this study indicate that fishing accounts for a small fraction of total mortality during this period, i.e. approximately 3-6% of total mortality can be attributed to fishing. Fishing is not having a major impact on stock dynamics, but overall productivity of the stock has been low, due to a combination of a high level of total mortality and weak recruitment (DFO 2013). The stock has shown some growth, mostly during 2004-08, but the trajectory of the stock for the 2009-12 period is less clear, and the estimate of 2012 spawning stock biomass (SSB) is 85% below the LRP. At current levels of SSB the stock is still considered to have suffered serious harm and the ability to produce good recruitment remains seriously impaired.

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When the stock is at such a low level management actions should focus on promoting further increases in SSB and subsequent recruitment until the stock is more resilient to the effects of fishing. Shelton et al. (2006) cautioned that fishing under low productivity conditions can further delay recovery of cod stocks. A specific time frame for recovery is required to more fully evaluate the impacts of current fisheries on Northern cod recovery.

Results from this study demonstrate that many cod from an offshore over-wintering aggregation migrated inshore to coastal areas and were vulnerable to capture by inshore fisheries. Both conventional tag returns and detections of acoustically tagged cod indicated that offshore cod were widely dispersed in the inshore; however, acoustic telemetry provided additional fishery-independent information about when and where cod were available to the inshore fishery, whereas conventional tagging only yielded information during the short fishing season. Acoustic receivers operated throughout the year and indicated that offshore cod migrated inshore and were vulnerable to capture mostly through July-November, but disappeared from the inshore during winter and early spring (January-mid-June) and presumably migrated back to offshore overwintering grounds. The combined results from tagging and telemetry indicate, therefore, that the traditional migratory pattern of Northern cod, i.e. overwintering offshore along the shelf edge and migrating inshore during summer, was taking place during 2008-10.

This study found a notably later timing of inshore arrival for offshore cod during 2008 and 2009 compared with the pre-moratorium period. For Northern cod, a shoreward seasonal migration of offshore cod prior to the moratorium was associated with the inshore migration of large schools of spawning capelin, *Mallotus villosus*, which are important prey (Templeman 1979). Capelin biomass collapsed in the early 1990s, the inshore migration of cod observed herein coincides with a slight improvement in capelin biomass during 2007-09 (DFO 2010). In addition, after capelin collapsed the spawning times of the much reduced capelin stock were about four weeks later than observed prior to 1991 (Carscadden et al. 2002). Later inshore arrival times of cod are therefore consistent with the changes observed for capelin.

Initial tagging mortality is difficult to quantify, particularly among offshore cod as these were captured in extremely deep (> 300 m) water using otter trawls. Estimates of the survival rate of cod caught using otter trawls have been variable (Hysten 1958; Lear and Rice 1987; Bratney and Cadigan 2004). Relatively low tag returns from cod tagged offshore in deep water is a common feature of many cod tagging experiments (Wise 1963; Taggart et al. 1995; Fowler and Stobo 1999). For most studies it has been difficult to determine whether the low returns were due to low exploitation rates, or because most cod died soon after release and were unavailable for subsequent recapture. Failure to account for initial tagging mortality can result in under-estimates of exploitation rates. Releasing acoustically tagged fish along with conventionally tagged ones can be useful for estimating initial tagging mortality, as subsequent detections of acoustically tagged fish give at least a minimum estimate of the fraction that survived. When feasible it would be prudent if future researchers released some acoustically tagged fish along with each batch of conventionally tagged ones to provide information on initial tagging mortality.

A high level of initial tagging mortality is costly, both financially and in terms of loss of information; however, tagging cod that reside in deep water can be important, particularly when they account for a large proportion of the total population. Other methods could be explored to reduce mortality of fish captured for tagging in deep water. A potentially useful method that has been used successfully in the near-shore region at shallower depths (< 60 m) is to capture cod using baited cod-pots (Pol et al. 2010; Safer 2010) that can be hauled to the surface slowly. The cod suffer less baro-trauma, and are not subjected to trauma that can occur in the cod-end of a conventional otter trawl. An alternative that to our knowledge has not been used for capturing cod for tagging would be to use the "live fish trawl sampler" (Holst and McDonald 2000) which

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consists of a stainless steel or aluminum box attached to the cod end of the trawl that remains filled with water when the catch is hauled on board the vessel; the box reduces crushing, abrasion, and turbulence and exposure of fish to air. These boxes were recently tested within our region and preliminary indications are that they show considerable promise for capture and tagging of cod, turbot (*Reinhardtius hippoglossoides*), and other species that inhabit deep waters (Brian Healey, DFO Science NL Region, pers. comm).

In conclusion, using a combination of conventional tagging and acoustic telemetry this study shows that a substantial portion of cod tagged offshore migrated to the inshore in summer and fall during 2008-10. These migratory cod dispersed widely across the coastal region, rendering them vulnerable to inshore fisheries for several months, mainly during July-November. Exploitation rates (percent harvested) estimated from tagging are generally low, but overall the stock is not productive and still suffers from high total mortality rates and low recruitment. Acoustic telemetry is shown to be particularly useful for investigating the timing of migration and the results show that cod arrived inshore later in 2008 and 2009 compared to the early 1980s when the offshore stock was much more abundant. Tagging cod following capture in extremely deep water can result in high mortality, but combining tagging with acoustic telemetry can be useful for putting reasonable upper limits on the level of initial tagging mortality. This study also offers some practical suggestions for field methods that future researchers could use to reduce this mortality. If fishing on Northern cod continues and catch information remain uncertain, continued tagging studies combined with acoustic telemetry, particularly in offshore areas, would provide a useful method of estimating exploitation rates (fishing mortality) and for evaluating the impacts of fishing on stock dynamics.

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Table 1 Details of cod tagging experiments conducted in NAFO Divs. 2J3KL from 2004-12. (LA=Labrador, BB=Bonavista Bay, TB=Trinity Bay, CB=Conception Bay, EA= eastern Avalon; OT=otter trawl, HL=hand line, CP=cod pot).

Expt.	Unit	Release date				Depth	Mean	Total	Nos.
number	area	First	Last	Tagging site	Gear	(m)	length (cm)	tagged	50-85 cm FL
2004-001	3LB	1-Dec-04	2-Dec-04	SMITH SOUND	HL	20-30	61.4	932	879
2005-001	3LB	3-May-05	19-May-05	SMITH SOUND TB	HL	15-22	71.6	667	539
2005-002	3KI	28-Jun-05	29-Jun-05	TOO GOOD ARM	HL	25	54.3	190	151
2005-003	3LB	16-Nov-05	16-Nov-05	SMITH SOUND TB	HL	20-37	66.0	110	106
2005-008	3LA	1-Dec-05	1-Dec-05	NEWMAN SOUND BB	HL	31-46	57.6	8	8
2005-009	3LB	13-Dec-05	13-Dec-05	SMITH SOUND TB	HL	73	66.5	51	40
2006-001	3LB	26-Apr-06	29-Apr-06	SMITH SOUND TB	HL	9-50	75.5	376	266
2006-002	3LB	30-Apr-06	30-Apr-06	NORTHWEST ARM TB	HL	17	56.6	9	7
2006-003	3LB	29-Apr-06	1-May-06	SMITH SOUND TB	OT	191-209	92.3	105	18
2006-004	3LB	9-May-06	25-May-06	SMITH SOUND TB	HL	8-18	84.5	390	174
2006-005	3LA	4-Jun-06	10-Jun-06	BONAVISTA BB	HL	14-33	74.9	1345	1075
2006-006	3KI	15-Jun-06	23-Jun-06	TOO GOOD ARM	HL	31	56.4	488	367
2006-007	3KI	27-Jun-06	8-Jul-06	TWILLINGATE	HL	25-45	55.8	1282	888
2006-008	3KI	5-Jul-06	7-Jul-06	FOGO	HL	20-28	53.7	941	569
2006-009	3LB	8-Nov-06	16-Nov-06	SMITH SOUND TB	HL	46-60	69.1	472	447
2006-010	3LB	16-Nov-06	22-Nov-06	SMITH SOUND TB	CP	31-46	68.2	264	244
2006-011	3LB	25-Nov-06	30-Nov-06	SMITH SOUND TB	CP	33-41	67.6	319	297
2006-012	3LB	26-Nov-06	30-Nov-06	SMITH SOUND TB	HL	35-51	72.3	637	561
2007-001	3KG	17-Mar-07	19-Mar-07	OFFSHORE 3K	OT	406-416	53.8	1127	871
2007-002	3LB	6-May-07	7-May-07	SMITH SOUND TB	OT	190-225	78.7	110	73
2007-003	3LB	30-May-07	31-May-07	SMITH SOUND TB	HL	15	75.6	272	202
2007-006	3KI	3-Jul-07	6-Jul-07	TOO GOOD ARM	HL	13-24	55.0	505	403
2007-009	3LJ	18-Jul-07	20-Jul-07	PETTY HARBOUR EA	HL	29-31	60.3	553	523
2007-012	3LA	26-Jun-07	26-Jun-07	DEER HARBOUR BB	HL	15	59.4	54	50
2007-015	3LA	7-Dec-07	8-Dec-07	BONAVISTA BAY	HL	45-76	59.5	137	105
2007-016	3LB	16-Nov-07	26-Nov-07	SMITH SOUND TB	CP	22-46	70.1	977	862
2007-017	3LB	16-Nov-07	26-Nov-07	SMITH SOUND TB	HL	27-49	71.0	57	50

Table 1 Cont'd.

Expt.	Unit	Release date				Depth	Mean	Total	Nos.
number	area	First	Last	Tagging site	Gear	(m)	length (cm)	tagged	50-85 cm FL
2008-001	3KG	3-Mar-08	6-Mar-08	OFFSHORE 3K	OT	314-375	56.1	2268	1758
2008-002	3LB	9-May-08	22-Jul-08	SMITH SOUND TB	OT	8-30	86.7	112	49
2008-003	3LA	19-Jun-08	5-Jul-08	BONAVISTA BB	HL	19-31	73.8	611	512
2008-004	3LB	29-Jun-08	29-Jun-08	SMITH SOUND TB	OT	241	83.6	5	3
2008-005	3LB	1-Jul-08	1-Jul-08	SMITH SOUND TB	OT	25-25	61.5	15	14
2008-007	3KI	3-Jul-08	18-Jul-08	TOO GOOD ARM	HL	31-32	62.0	539	490
2008-008	3KI	23-Jul-08	25-Jul-08	FOGO NORTH	HL	7-25	61.6	325	307
2008-009	3LJ	21-Aug-08	4-Sep-08	PETTY HARBOUR EA	HL	25	62.6	454	414
2008-010	3KI	21-Aug-08	21-Aug-08	TWILLINGATE	HL	33	62.6	200	184
2008-011	3LB	7-Oct-08	16-Oct-08	SMITH SOUND TB	CP	43-54	64.2	373	355
2008-012	3LB	10-Nov-08	12-Nov-08	SMITH SOUND TB	CP	43-63	62.5	425	401
2008-013	3LB	10-Nov-08	11-Nov-08	SMITH SOUND TB	HL	40-55	64.3	115	105
2009-005	2JM	22-Jul-09	22-Jul-09	S'THN LABRADOR	HL	35	48.0	2	0
2009-004	3LA	10-Jul-09	10-Jul-09	BONAVISTA BB	HL	22-26	70.4	595	517
2009-001	3LB	19-Mar-09	30-Mar-09	SMITH SOUND TB	CP	194-198	63.9	59	53
2009-002	3LB	5-May-09	4-Jun-09	SMITH SOUND TB	HL	14-62	65.9	1168	1138
2009-006	3LJ	2-Sep-09	2-Sep-09	PETTY HARBOUR EA	HL	31	63.5	236	216
2009-007	3LB	4-Nov-09	4-Nov-09	SMITH SOUND TB	HL	32	62.9	20	19
2009-008	3LB	4-Nov-09	20-Nov-09	SMITH SOUND TB	CP	36-100	73.9	463	406
2009-009	3LB	4-Nov-09	20-Nov-09	SMITH SOUND TB	HL	53-57	73.9	124	110
2009-010	3LB	9-Nov-09	14-Nov-09	SMITH SOUND TB	HL	44-57	71.6	529	485
2009-011	3LB	15-Nov-09	15-Nov-09	NORTHWEST ARM TB	HL	45	63.6	7	5
2009-012	3LA	24-Nov-09	24-Nov-09	SOUTHERN BB	OT	76	52.6	42	26
2010-002	3LA	5-Jul-10	7-Jul-10	BONAVISTA BB	HL	18-27	61.4	271	220
2010-003	3LB	24-Aug-10	25-Aug-10	HEARTS CONTENT TB	HL	24-53	55.9	204	151
2010-004	3LJ	26-Aug-10	26-Aug-10	PETTY HARBOUR EA	HL	24	61.9	59	49
2010-005	3KI	9-Sep-10	9-Sep-10	TWILLINGATE	HL	40	59.8	22	19
2010-006	3LF	7-Oct-10	7-Oct-10	CARBONEAR CB	HL	42	51.9	10	7
2010-007	3KI	13-Oct-10	13-Oct-10	SELDOM FOGO	CP	32	59.3	231	189
2010-008	3LB	23-Oct-10	26-Oct-10	TRINITY BAY WEST	HL	35-45	59.7	189	160

Table 1 Cont'd.

Expt. number	Unit area	Release date		Tagging site	Gear	Depth (m)	Mean length (cm)	Total tagged	Nos. tagged 50-85 cm FL
		First	Last						
2010-009	3LB	12-Nov-10	8-Dec-10	SMITH SOUND TB	CP	34	69.9	617	536
2010-010	3LF	27-Oct-10	27-Oct-10	BACCALIEU CB	HL	35	59.3	133	117
2010-011	3LB	29-Nov-10	29-Nov-10	SMITH SOUND TB	HL	53	62.2	60	55
2010-012	3LA	9-Dec-10	9-Dec-10	NEWMAN SOUND TB	HL	54	55.4	14	6
2010-013	3KH	15-Dec-10	16-Dec-10	TRITON NDB	HL	7	51.0	235	133
2011-003	3LJ	9-Aug-11	22-Aug-11	BAY BULLS EA	HL	35-36	58.2	114	85
2011-004	3LA	14-Sep-11	14-Sep-11	NEWMAN SOUND TB	HL	27	66.0	112	104
2011-005	3LF	19-Oct-11	19-Oct-11	OCHRE PIT COVE CB	HL	68	62.3	133	105
2011-006	3LB	20-Oct-11	22-Oct-11	BAY DE VERDE TB	HL	30-68	58.5	536	374
2011-007	3LA	23-Oct-11	25-Oct-11	CAPE BONAVISTA BB	HL	53-58	58.7	546	417
2011-008	3LA	25-Oct-11	25-Oct-11	SWALE ISLAND BB	HL	65	54.4	27	15
2011-009	3LB	3-Nov-11	1-Dec-11	SMITH SOUND TB	HL	18	59.4	262	248
2011-010	3LB	3-Nov-11	1-Dec-11	SMITH SOUND TB	CP	37-53	61.1	282	248
2012-003	3KI	4-Jul-12	5-Jul-12	TWILLINGATE	HL	27-30	58.1	271	228
2012-006	2JM	6-Sep-12	9-Sep-12	MURRAY'S HBR. LA	HL	20-43	53.7	328	223
2012-007	3LA	15-Oct-12	16-Oct-12	NEWMAN SOUND BB	HL	36-60	52.4	44	22
2012-008	3LF	20-Oct-12	20-Oct-12	COLLINS LEDGE TB	HL	63	59.2	290	245
2012-009	3LB	21-Oct-12	21-Oct-12	OLD PERLICAN TB	HL	40-55	51.9	40	24
2012-010	3LA	22-Oct-12	24-Oct-12	BONAVISTA BB	OT	73-115	56.7	505	400
2012-011	3LB	26-Oct-12	28-Oct-12	NORTHWEST ARM TB	HL	29-55	50.6	123	63
2012-012	3LB	27-Nov-12	27-Nov-12	SMITH SOUND TB	HL	49	60.6	52	52

Table 2 Number of cod tagged and released in NAFO Divs. 2J3KL during 2004-11 with low reward and high reward tags.

Release Year	Reward		Total
	Low	High	
2004	828	95	923
2005	885	141	1026
2006	5205	1423	6628
2007	2848	944	3792
2008	4211	1231	5442
2009	2549	696	3245
2010	1487	558	2045
2011	1605	407	2012
Totals	19618	5495	25113

Table 3 Numbers of low reward and high reward tags returned to DFO during 2004-12 from cod recaptured in NAFO Divs. 2J3KL.

Recapture year	Reward		Total
	Low (\$10)	High (\$100)	
2004	55	11	66
2005	68	11	79
2006	200	94	294
2007	120	60	180
2008	155	76	231
2009	127	73	200
2010	91	37	128
2011	77	32	109
2012	48	33	81

Table 4 Distribution of cod landings by unit area (upper panel in tonnes (t), lower panel annual percents) in the inshore from north (2J) to south (3Lq) in NAFO Divs. 2J3KL during 2006-12. Reported offshore by-catch by non-Canadian fleets (3L) was < 30 t during 2006-09, 61 t in 2010, and 292 t in 2011 (2012 value not available). Values exclude recreational fisheries.

<b>Tonnes</b>											
<b>Year</b>	<b>2J</b>	<b>3Ka</b>	<b>3Kd</b>	<b>3Kh</b>	<b>3Ki</b>	<b>3La</b>	<b>3Lb</b>	<b>3Lf</b>	<b>3Lj</b>	<b>3Lq</b>	<b>Totals</b>
2006	48	32	68	286	573	410	478	260	221	47	2,424
2007	65	34	94	304	601	454	464	274	227	44	2,562
2008	71	52	152	427	885	548	530	349	248	45	3,306
2009	56	28	90	269	795	608	584	416	223	8	3,078
2010	59	34	84	313	742	605	508	339	194	8	2,885
2011	47	16	108	396	856	582	516	338	244	26	3,129
2012	71	49	198	535	889	518	472	318	216	28	3,293

<b>Annual Percent</b>										
<b>Year</b>	<b>2J</b>	<b>3Ka</b>	<b>3Kd</b>	<b>3Kh</b>	<b>3Ki</b>	<b>3La</b>	<b>3Lb</b>	<b>3Lf</b>	<b>3Lj</b>	<b>3Lq</b>
2006	2.0	1.3	2.8	11.8	23.6	16.9	19.7	10.7	9.1	1.9
2007	2.6	1.3	3.7	11.9	23.5	17.7	18.1	10.7	8.9	1.7
2008	2.1	1.6	4.6	12.9	26.8	16.6	16.0	10.5	7.5	1.3
2009	1.8	0.9	2.9	8.8	25.8	19.8	19.0	13.5	7.3	0.2
2010	2.0	1.2	2.9	10.8	25.7	21.0	17.6	11.8	6.7	0.3
2011	1.5	0.5	3.5	12.7	27.4	18.6	16.5	10.8	7.8	0.8
2012	2.2	1.5	6.0	16.2	27.0	15.7	14.3	9.6	6.5	0.8

*Table 5 Annual estimates of the single cod tag reporting rates for all fishers and commercial versus recreational fishers in the inshore of NAFO Divs. 3KL from the mixed effects LRM. There were no estimates of recreational reporting rate for 1997, 2004, and 2005.*

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
<b>All Fishers</b>	0.71	0.69	0.78	0.71	0.86	0.72	0.73	0.69	0.69	0.63	0.65	0.65	0.63	0.71	0.71	0.65
<b>Commercial</b>	0.76	0.75	0.75	0.80	0.77	0.74	0.76	0.85	0.80	0.78	0.72	0.77	0.75	0.74	0.74	0.71
<b>Recreational</b>	-	0.54	0.52	0.53	0.51	0.47	0.52	-	-	0.49	0.51	0.51	0.52	0.53	0.52	0.49



Table 6 Annual exploitation rates (% harvested) during 2006-12 based on analysis of cod tagging data. See text for details.

Region	Mean annual % harvested						
	2006	2007	2008	2009	2010	2011	2012
Twillingate/Fogo/ Notre Dame Bay (3Kh/i)	19.2	6.3	4.5	3.9	3.3	3.3	2.7
Bonavista Bay (3La)	4.8	5.4	2.7	3.9	2.4	2.1	1.8
Trinity Bay (3Lb)	8.1	6.3	5.7	5.4	3.9	2.7	3.6
Conception Bay (3Lf)	-	-	-	-	-	0.0	2.4
eastern Avalon (3Lj)	-	7.2	7.1	7.5	5.4	6.0	2.1
Offshore 3K	-	-	5.4	2.4	3.9	-	-

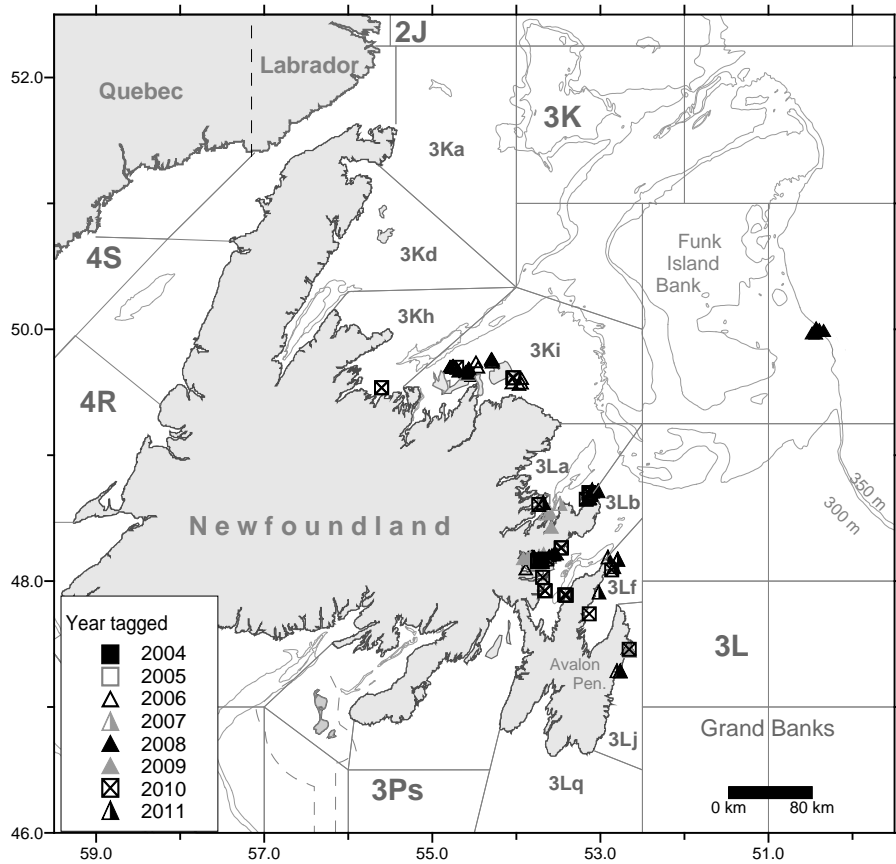


Figure 1 Locations where cod were tagged and released off eastern Newfoundland (NAFO Divs. 3KL) during 2004-11. Boundaries of statistical unit areas and the 300 m and 350 m depth contours are shown (grey lines) along with the French economic zone around St. Pierre and Miquelon (dashed line).

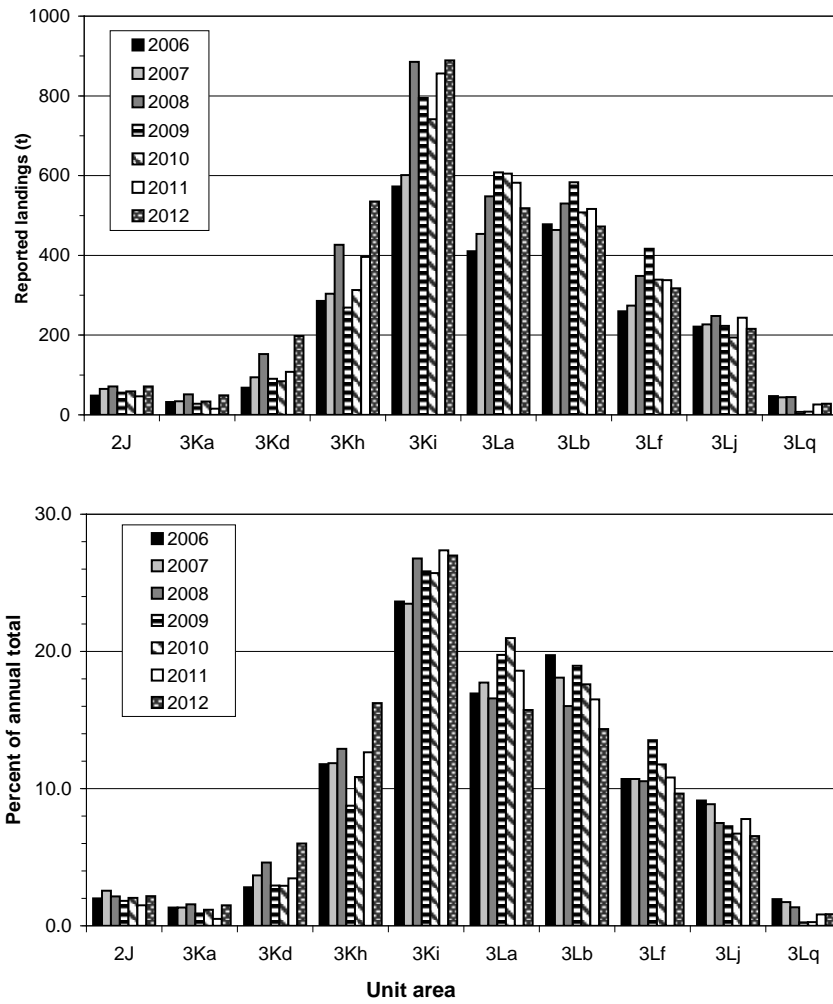


Figure 2 Reported inshore landings of cod by unit area (upper panel in tonnes (t), lower panel in annual percents) from north (2J) to south (3Lq) in NAFO Divs. 2J3KL during 2006-12. Reported offshore by-catch by non-Canadian fleets (in 3L) was < 30 t during 2006-09, 292 t in 2011 (2012 value not available). Values exclude recreational fisheries.

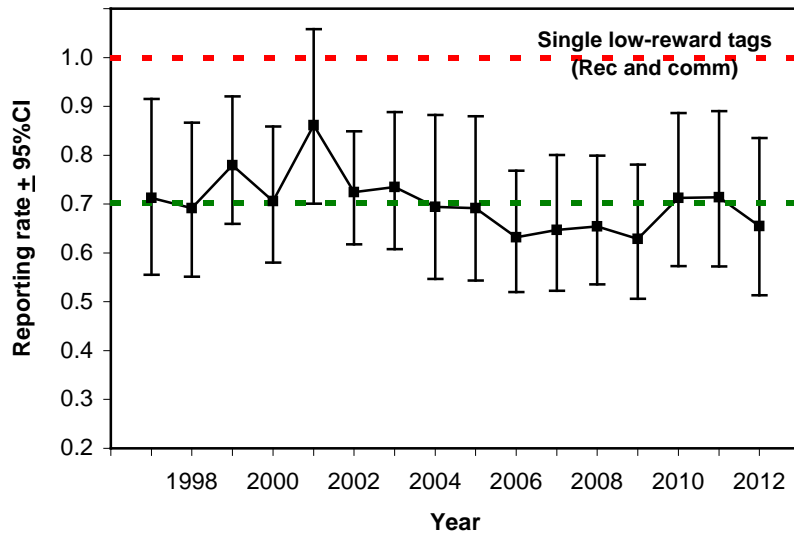


Figure 3 Estimates of single low-reward tag reporting rates (recreational and commercial fishers combined) from the mixed effects logistic regression model, with 95% confidence intervals. The red dashed horizontal line at 1.0 is shown for reference and the average of the series (0.70) is shown as a green dashed line.

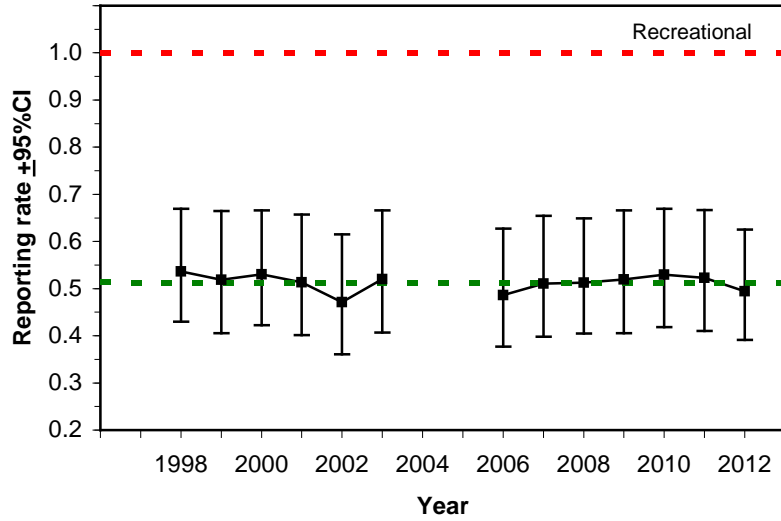
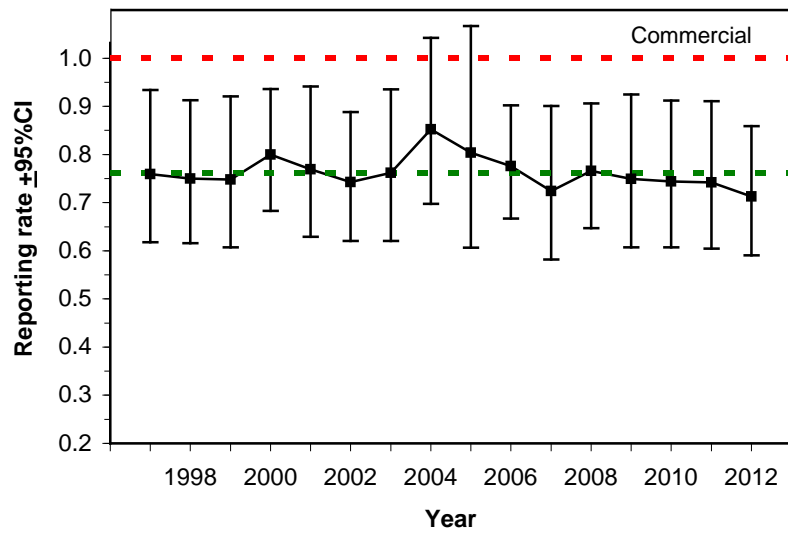


Figure 4 Estimates of single low-reward tag reporting rates for commercial and recreational fishers from the mixed effects logistic regression model, with 95% confidence intervals. The red dashed horizontal line at 1.0 is shown for reference and the average of the series (0.70) is shown as a green dashed line.

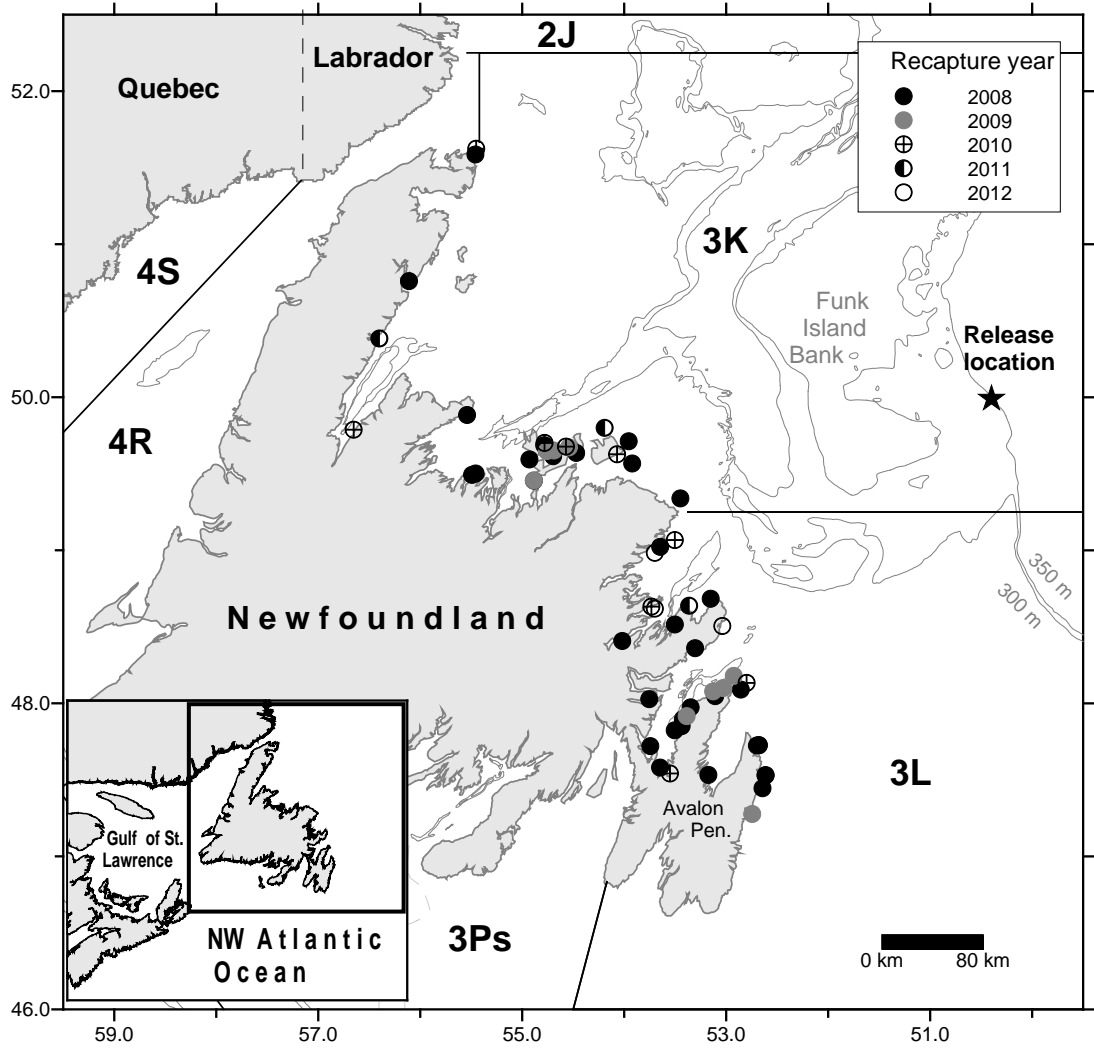


Figure 5 Release and recapture locations of cod tagged and released offshore on the shelf break in NAFO Div. 3K during March 2008.

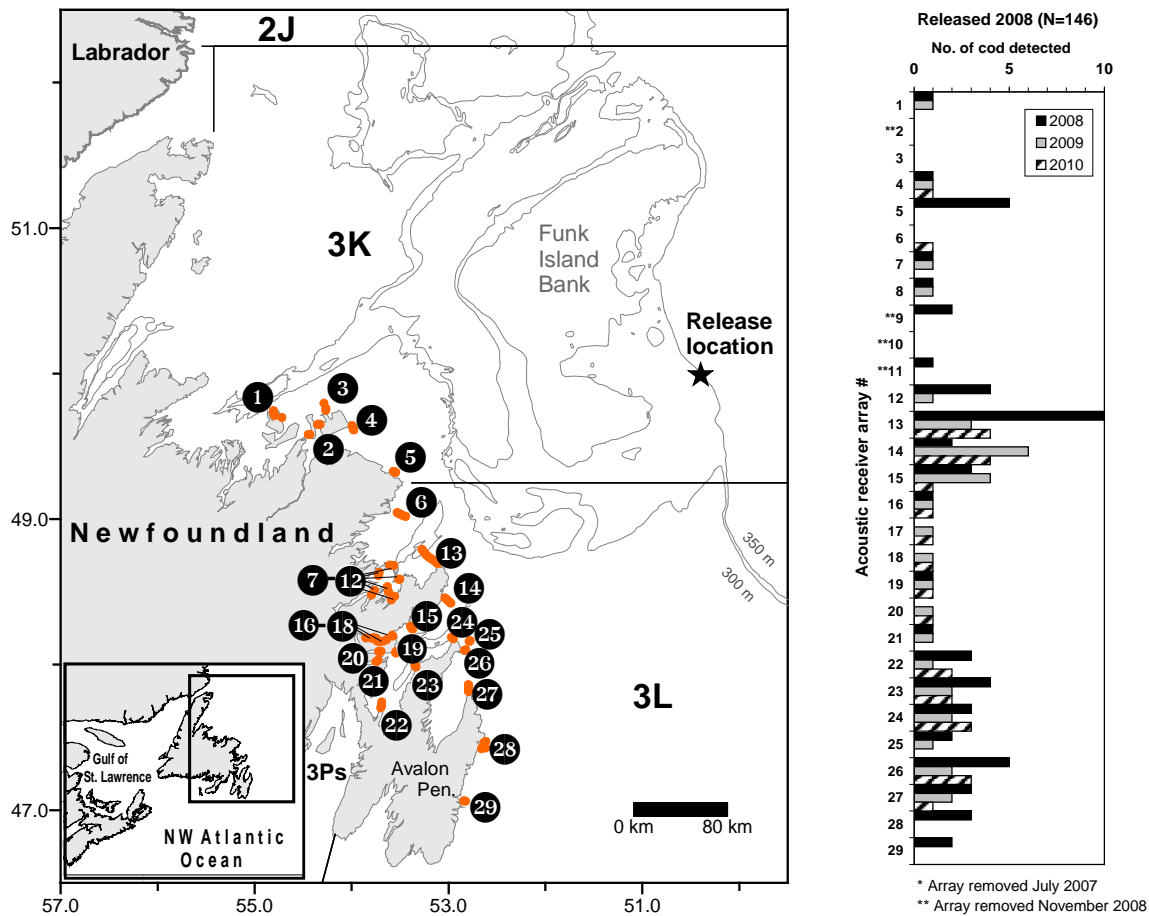


Figure 6 Eastern Newfoundland and the adjacent continental shelf showing release sites of acoustically tagged offshore cod (star) and locations of moored acoustic receiver arrays (red dots) numbered clockwise around the coastline (left panel). Numbers (annual totals) of acoustically-tagged offshore cod detected on each numbered inshore array during 2008-10 (right panel). Numbered array locations are: 1. Twillingate; 2. Change Islands; 3. Fogo; 4. Seldom; 5. Lumsden; 6. Greenspond; 7. Little Denier Isl.; 8. Newman Sound; 9. Chandler Reach; 10. Southern Bay; 11. Sweet Bay; 12. Tickle Cove; 13. Cape Bonavista; 14. Melrose; 15. Bonaventure Head; 16. Outer Smith Sound; 17. Middle Smith Sound; 18. Inner Smith Sound; 19. East Random Head; 20. Northwest Arm; 21. Southwest Arm; 22. Bellevue; 23. Hant's Harbour; 24. Grates Cove Pt.; 25. East Baccaieu Isl.; 26. Baccaieu Tickle; 27. Cape St. Francis; 28. Petty Harbour; 29. Cape Broyle.

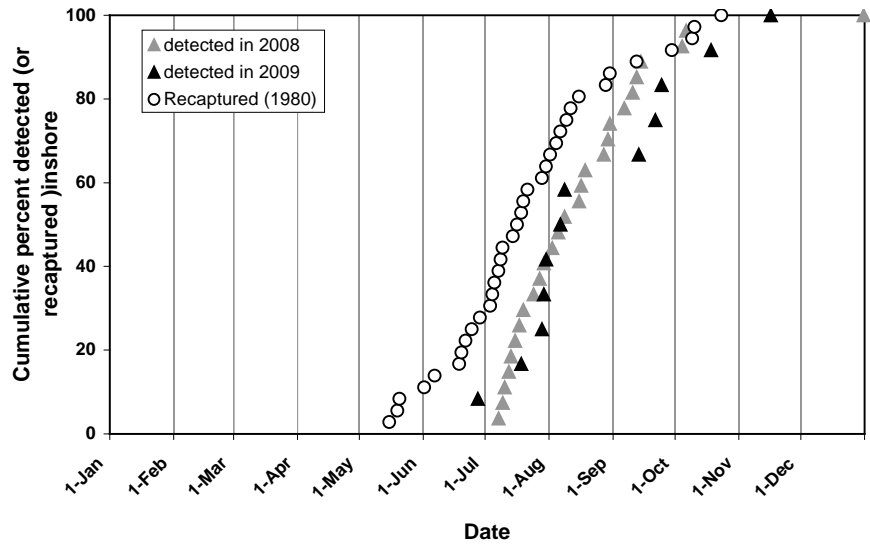


Figure 7 Cumulative dates of first inshore detection of acoustically tagged offshore cod on inshore receiver arrays in 2008 (grey triangles) and 2009 (black triangles). The cod were released approximately 208 km offshore on 3 March 2008. Vertical dashed lines indicate the first day of each month. Cumulative dates of inshore recapture for cod tagged and released in the same offshore area in a previous tagging experiment (March 1980, open circles) described in Taggart et al. (1995) are shown for comparison.



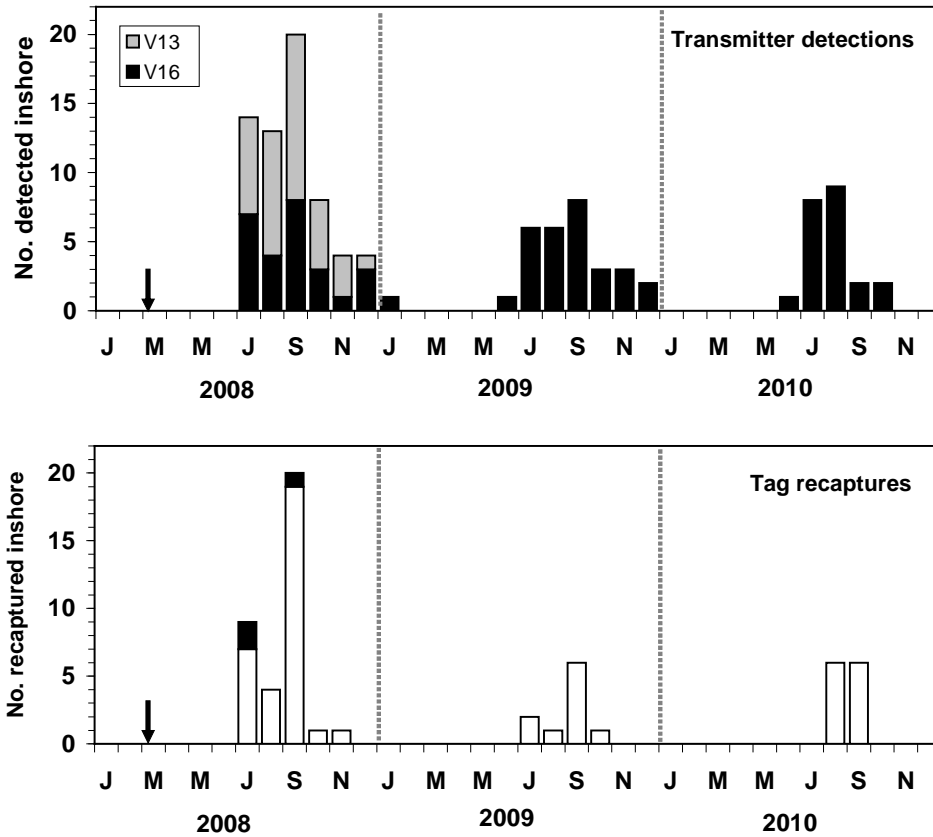


Figure 8 Seasonal trends in the numbers (monthly totals) of offshore cod detected on inshore receiver arrays moored off the east coast of Newfoundland (upper panel), or recaptured during inshore fisheries (lower panel) during 2008-10. The cod were initially captured and released with surgically implanted acoustic transmitters (V13 or V16) and/or external Floy tags off the continental slope edge in NAFO Div. 3K (see Fig. 5) in March 2008 (vertical arrows in upper and lower panels).

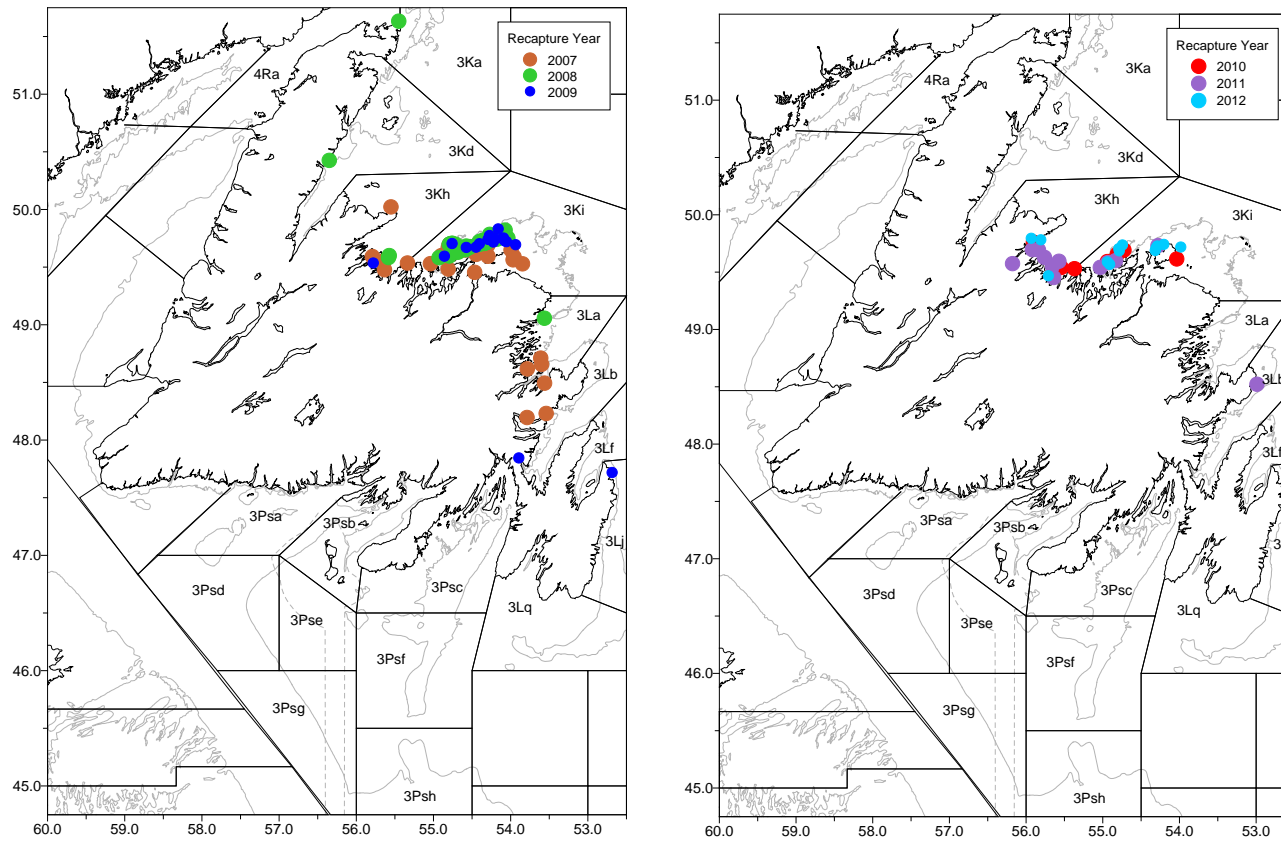


Figure 9 Reported recapture positions for cod tagged in 3K and recaptured during 2007-09 (left panel) and 2010-12 (right panel).

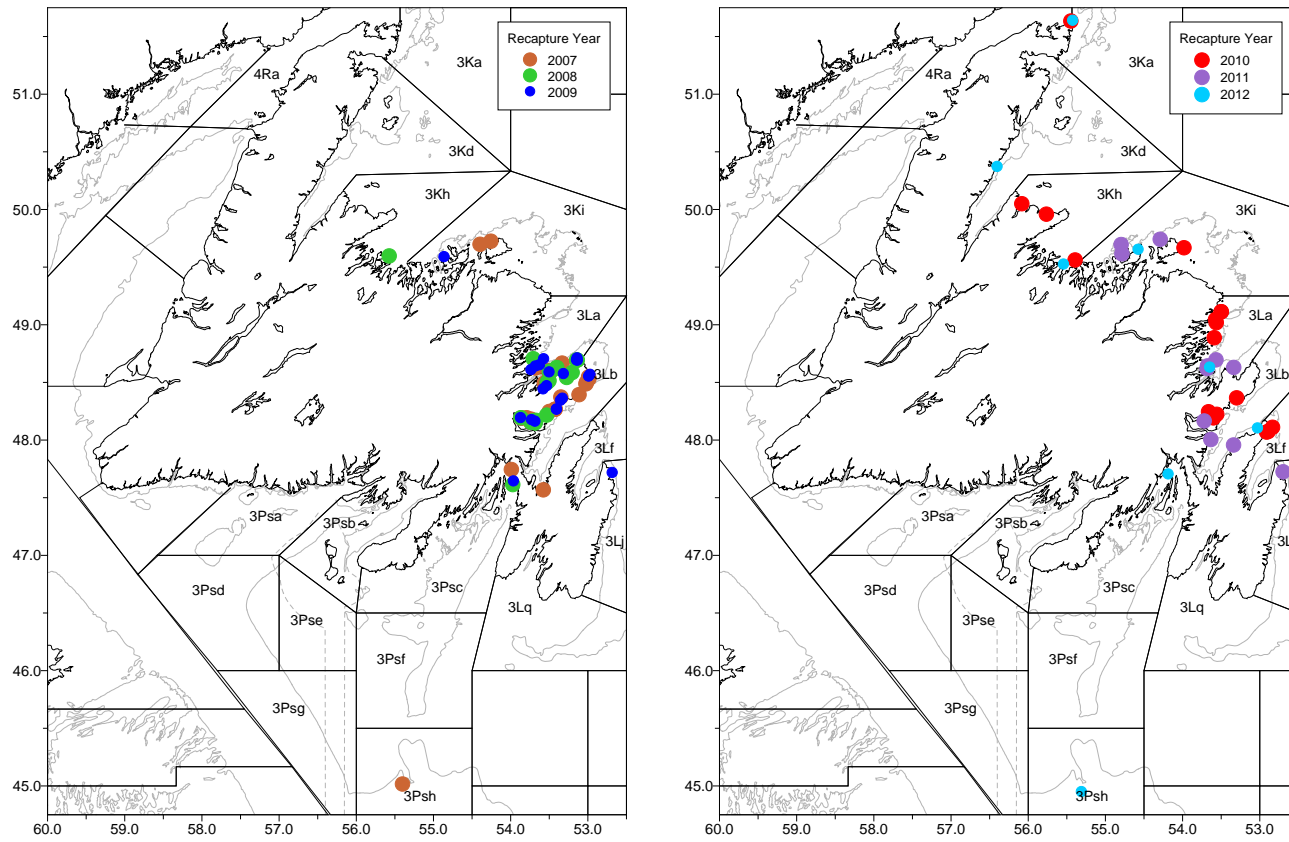


Figure 10 Reported recapture positions for cod tagged in 3La (Bonavista Bay) and recaptured during 2007-09 (left panel) and 2010-12 (right panel).

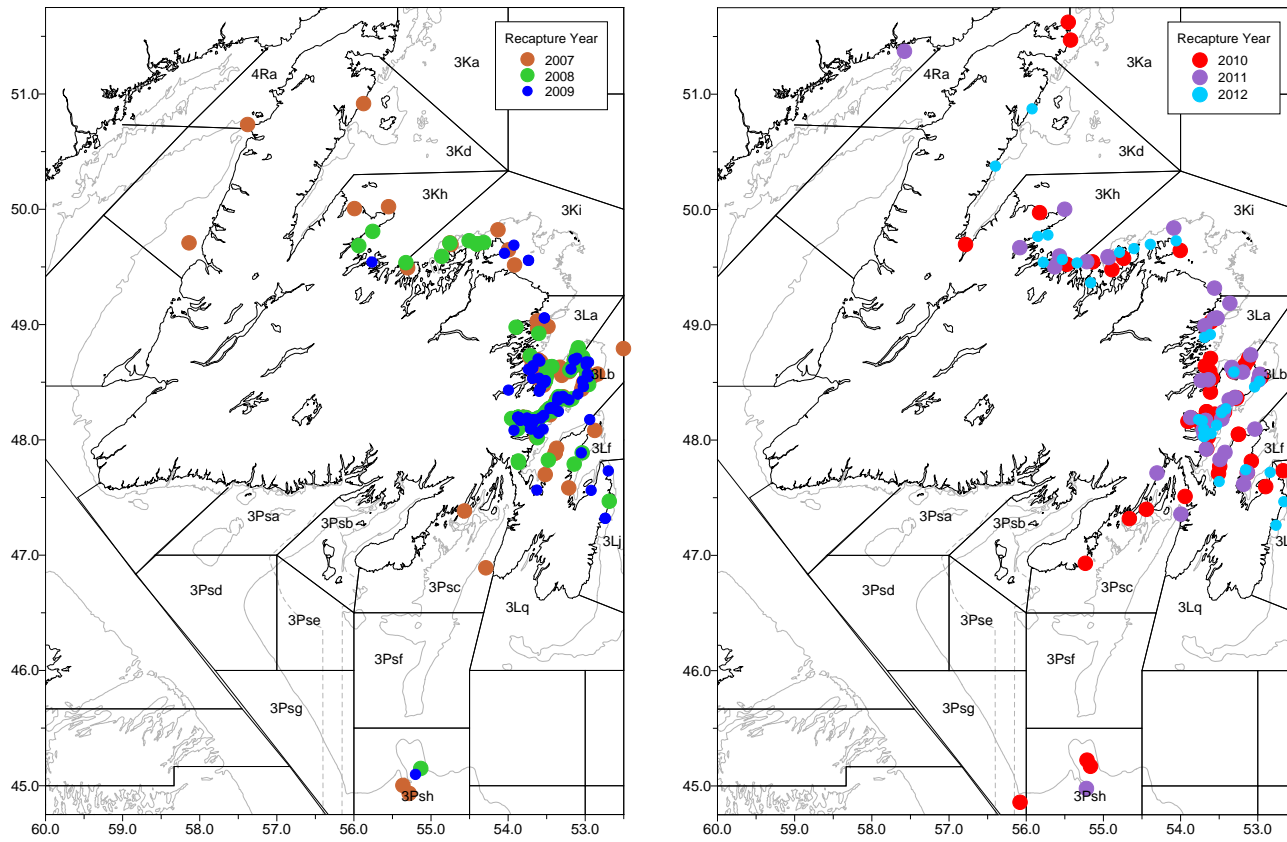


Figure 11 Reported recapture positions for cod tagged in 3Lb (Trinity Bay) and recaptured during 2007-09 (left panel) and 2010-12 (right panel).