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Temperature-corrected abundance index of sub-legal lobsters in LFA 33 – 1999-2000 to 2008-2009

Indice d’abondance corrigé en fonction de la température et concernant les homards qui n’ont pas encore la taille réglementaire dans la ZPH 33 – de 1999-2000 à 2008-2009

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ABSTRACT

Abundance indices, temperature-catchability relationships, spatial abundance variation, and low-effort sampling schemes are of interest in the management of several crustacean fisheries. A low-effort sampling scheme and a mathematical model that simultaneously produces an estimate of the temperature-catchability relationship, a temperature-corrected catch-per-unit-effort (CPUE) based abundance index (TCAI), and a spatial abundance index for a non-exploited class of a population of crustaceans are presented. The sampling scheme is based on standardized traps monitored continuously through the fishery and water temperature recorders retrieved at the end of each season. The TCAI is obtained from a probabilistic model of the catch from a single sampling event as a function of the number of crustaceans available at the sampling location, the current temperature, and the catchability-temperature relationship. The parameters of the model, including the TCAI, are estimated by maximum likelihood and standard errors are obtained using Wald's method. Model diagnostic procedures are proposed. The model is applied to data from Nova Scotia (Canada) Lobster Fishing Area (LFA) management zone LFA 33. In LFA 33, there is a strong association between catchability and water temperature, suggesting that the TCAI improves on CPUE. The TCAI indicates that the abundance of prerecruit lobsters in LFA 33 increased substantially (approximately 1.9 fold) from 1999 to 2009.

RÉSUMÉ

Les indices d'abondance, les liens entre la température et le potentiel de capture, la variation spatiale de l'abondance et les plans d'échantillonnage à faible effort sont importants pour la gestion de plusieurs pêches de crustacés. Un plan d'échantillonnage à faible effort et un modèle mathématique qui produit simultanément une estimation du lien entre la température et le potentiel de capture, un indice d'abondance basé sur la capture par unité d'effort (CPUE) corrigé en fonction de la température et un indice d'abondance spatial pour une catégorie non exploitée d'une population de crustacés, sont présentés. Le plan d'échantillonnage est basé sur des casiers normalisés surveillés en continu par l'entremise de la pêche et d'enregistreurs de température de l'eau retirés à la fin de chaque saison. L'indice d'abondance corrigé en fonction de la température est obtenu à partir d'un modèle probabiliste de la prise à chaque échantillonnage comme fonction du nombre de crustacés disponibles au site d'échantillonnage, de la température courante, et du lien entre le potentiel de capture et la température. Les paramètres du modèle, y compris l'indice d'abondance corrigé en fonction de la température, sont estimés par la méthode du maximum de vraisemblance et les erreurs types sont obtenues par la méthode de Wald. Des procédures de diagnostic du modèle sont proposées. Le modèle est appliqué aux données de la zone de pêche du homard ZPH 33 en Nouvelle-Écosse (Canada). Dans la ZPH 33, il existe un lien étroit entre le potentiel de capture et la température de l'eau, ce qui laisse supposer que l'indice d'abondance corrigé en fonction de la température est plus fiable que la capture par unité d'effort (CPUE). L'indice d'abondance corrigé en fonction de la température indique que l'abondance de prérecrues dans la ZPH 33 a augmenté considérablement (par un facteur de 1,9 approximativement) de 1999 à 2009.

INTRODUCTION

Catch-per-unit-effort (CPUE) is often used as an abundance index in crustacean stock assessments (Quinn and Deriso 1999). However, the impact of temperature on catchability can have a confounding effect on CPUE-based stock assessment when there is a change in water temperature. For example, the CPUE may change when water temperature changes, even if the abundance is constant, a situation that will lead to the false conclusion that abundance has changed. In this Research Document, a method of sampling concurrently with the fishery and a mathematical model that yields a temperature-corrected CPUE-based abundance index (TCAI) for a target non-legal length class of lobsters are presented. The methodology yields other information useful to fishery managers and biologists, and it can be applied to other crustacean fisheries.

Researchers have suspected or proven that temperature affects the activity level (which affects catchability) or the catchability of crustaceans (e.g. McLeese and Wilder 1958, Skinner and Hill 1986, Miller and Mohn 1993, Ziegler et al. 2003, Koeller 1999, Drinkwater et al. 2006) and fish (e.g. Campana and Joyce 2004, Goodyear 2003, Swain et al. 2000).

The TCAI is derived from catches in sets of standardized traps soaked for a standardized period or, more generally, from catches from a standardized effort, and water temperatures recorded continuously at each trap set location.

Because the TCAI uses the temperature observed during each soak period, it corrects not only for changes in average annual temperatures but also for the more subtle impact of changes in temperature patterns. For example, the temperature correction may not have the same effect in a season beginning with higher-than-normal temperatures and ending with lower-than-normal temperatures as in a season with the inverse pattern, even if both seasons had the same overall average temperature. Similarly, a higher-than- average water temperature observed during a period of high fishing effort will produce a larger correction to the abundance index than the same temperature observed during a period of low fishing effort.

The sampling method offers some practical benefits. Cost limits the feasibility of government surveys, making low-effort sampling schemes important to fishery managers. Incorporating fishers in the management of their fishery, including sampling, has also become imperative. As a consequence, new sampling methods and mathematical models are required to maintain the scientific integrity of the stock assessment. For example, using standardized traps reduces or avoids the confounding effect of fishers or of changes in fishing technology on the abundance index.

The mathematical model provides information on several subjects related to the stocks and the fisheries. The temperature-catchability relationship has mostly been estimated from laboratory experiments, and it is not known if these estimates are representative of the *in situ* relationship. The proposed methodology yields an estimate from *in situ* data. Local populations can constitute independent units important for genetic diversity. Changes in spatial distribution can be early indicators of changes in the overall population. Under some conditions, this model can yield a spatial abundance index.

The methodology can only be applied to non-exploited segments of the stock. During the fishery, the abundance of exploited animals declines because of removals. Hence, obtaining an abundance index for these animals during fisheries would require a model that takes into account the on-going catches. Comparatively, annual natural mortality rates of the non-legal animals are much lower than fishing mortality rates. Thomas (1973) indicates that estimates of 0.08 are appropriate. Exploitation rates of lobster vary from 40% to 80% in the areas discussed (Fogarty 1995). Therefore, the abundance of non-legal animals can be considered approximately constant within a fishing season, and obtaining a non-legal abundance index can be considerably simpler.

The non-exploited segments are relevant to management, and they become crucial when measures are taken to increase numbers of recruits or spawners. Sub-legal abundance can be an indicator of future commercial-size abundance.

The main model assumptions are the following: a class of non-exploited animals in a crustacean population for which a single abundance index is suitable is considered. Such a population will usually be defined by an ecological or administrative area where all the population is subject to the same natural and man-made conditions. It is assumed that, within each fishing season, the target class is locally closed in the sense that migration, moulting into or out of the class, and mortality are negligible at each sampling location. Given that catchability can be affected by moulting (Ziegler et al. 2003, Tremblay and Eagles 1997), the non-moulting assumption is necessary. It is also assumed that the same temperature-catchability relationship for the target class applies within each fishing season, across the fishing seasons, and across locations.

The abundance indices are parameters of a mathematical model that describes the probability distribution of the number of animals caught at each location and sampling event as a function of their number within the maximum area of attraction of the set of traps and the temperature. The mathematical model is fitted by maximum likelihood, yielding estimates of the standard errors of the parameters. Therefore, information is provided on sampling error for the TCAI, as well as for other parameters of interest (e.g. catchability-temperature relationship, spatial abundance index).

The model was developed and is presented using data from the Canadian Atlantic coast lobster (*Homarus americanus*) fishery, where CPUE is currently the main abundance index (Tremblay et al. 2012). The TCAI is computed for Nova Scotia (Canada) Lobster Fishing Area (LFA) 33 for seasons 1999-2000 to 2008-2009 for the sub-legal 76-80.9 mm lobster size class. LFA 33 covers the portion of the south-east coast of the province of Nova Scotia extending approximately from Halifax to the southern tip of the province.

METHODS

MATHEMATICAL MODEL

Consider an administrative or ecological lobster fishing area of interest containing lobsters in a target sub-legal length class for which a single abundance index is suitable. Consider $\boldsymbol{l+1}$ seasons $s=s_0,...,s_l$. Using the first season as the base season, a single abundance index I_s, can be defined, where $I_0=\mathbf{1}$. The abundance index I_s is the main object of this document.

Consider m sampling locations $L=L_1, \dots L_m$ such that, at each location, the stock can be considered locally closed within each season, as defined in the introduction.

A sampling event consists of fishing a fixed set of standardized traps at a single sampling location L for a fixed soak time. This set of traps and this soak time define a unit of effort.

Since the stock is locally closed, $n(L,s)$ can be defined to be the number of lobsters in the target length class within the maximum area of attraction of the set of traps at location L during season s. Using the abundance index, we can write $n(L,s) = n(L,s_0)\ I_s$. Across areas where the attraction areas of the sets of traps can be considered similar (e.g. similar bottom type, bathymetry, currents, etc.), the parameters $n(L,s_0)$ can be viewed as a spatial abundance index.

Define catchability classically (Quinn and Deriso 1999) as the probability p that a given individual is caught by a unit of effort.

Let T_0 be the lowest temperature at which lobster catchability starts to significantly increase as a function of temperature and let T_1 be the highest temperature at which the fishery occurs. Let $p_{linear}(T)$ be the probability that a lobster is caught at temperature T. Laboratory experiments (McLeese and Wilder 1958) suggest that catchability p of non-moulting lobsters depends linearly on temperature T in the temperature range relevant to the fisheries, i.e. $T_0<T<T_1$. Therefore, the catchability-temperature relationship can be expressed as follows:

$$p_{linear}(T;T_0,a)=0 \text{ for } T<T_0 \text{ and } p_{linear}(T;T_0,a) = a(T-T_0) \text{ for } T_0\leq T < T_1 \qquad (1)$$

where the slope a describes the linear temperature effect.

A differentiable function is preferable to a piecewise linear function for mathematical reasons. Therefore, the following function will be used to describe the relationship between catchability and temperature:

$$p(T;T_0,a) = k/[((T-T_0)^2+2k/a)^{1/2}-(T-T_0)] \text{ for } T<T_1 \qquad (2)$$

where k is an arbitrary constant (k=0.02 is used) that determines how far $p(T;T_0,a)$ is to $p_{linear}(T;T_0,a)$ (Figure 1).

Consider a sampling event at location L, during season s and with water temperature T. Then, the number X of lobsters caught is a binomial random variable with parameters $n(L,s) = n(L,s_0)I_s$ and $p(T;T_0,a)$, i.e $X \sim B(n(L,s_0)I_s,p(T;T_0,a))$. The parameters to be estimated are T_0 and a, $n(L,s_0)$ for all locations $L= L_1, \ldots, L_m$, and I_s for seasons $s=s_1,...,s_l$.

Since typical values of $p(T;T_0,a))$ are small and typical values of $n(L,s_0)I_s$ are relatively large, the binomial distribution can be replace by the Poisson distribution $P(n(L,s_0)I_s p(T;T_0,a))$ for computational purposes.

MODEL FITTING

The parameters can be estimated using standard statistical methods. In this document, the maximum likelihood and the Wald estimator of the standard error are used. Other methods producing estimates with confidence intervals, including bootstrapping, can also be used.

Let $b(x,n,p) = \binom{n}{x} p^x (1-p)^{n-x}$ for $0\leq x\leq n$ be the probability density function of the binomial random variable B(n,p). Consider observations (x_i,T_i,s_i,L_i) each consisting of a catch number, a temperature, a season, and a location. Then the likelihood function is:

$$L(I_{s_1},...,I_{s_m},n(L_1,s_0),...,n(L_1,s_0),T_0,a) \;=\; \Pi_i \; b(x_i,n(L_i,s_0)I_{s_i},\; p(T;T_0,a)).$$

Missing observations at a location (even missing seasons) are acceptable.

Maximization was performed using R 2.1x (Free Software Foundation 2012) optimization facilities.

MODEL DIAGNOSTICS

For each sampling event, the model gives the expected catch *n(L,s)p(T;T₀,a)* and the variance of the catch *n(L,s) p(T;T₀,a) (1- p(T;T₀,a))*. For an observed catch ***x***, the Pearson residual is $(x - n(L,s)\, p(T;T_0,a))/[n(L,s)\, p(T;T_0,a)\, (1- p(T;T_0,a))]^{1/2}$.

We examine graphically the Pearson residual by location and season and also by longitude over all seasons. Notice that, since the marginal distribution is binomial, some positive skewness is expected.

For each sampling event, we compute the quotient of the observed catch ***x*** by the estimated number of lobsters ***n(L,s)*** at the event location ***L*** and during the event season, thus obtaining a semi-empirical catchability value. By applying a loess smoothing to the plot of these values against the temperature, we obtain a semi-empirical catchability-temperature relationship to which the model functional relationship can be compared.

Statistical due diligence suggests that one also applies the usual diagnostic methods, such as examining any dependency of the residuals on longitude or latitude and comparing early and late season residuals.

CATCH PER UNIT OF EFFORT (CPUE) AND DATA FROM LFA 33

It is natural to compare the TCAI to the non-temperature-corrected CPUE currently used as an abundance index. It is computed as the quotient of total season catch over total season effort.

In this research document, the data from LFA 33 for seasons 1999-2000 to 2008-2009 are analyzed. The LFA 33 fishing season is from the last Monday in November to May 31st. The minimum legal carapace length (CL) is 82.5 mm. There are 723 fishing licences with 250 traps per licence. Average landings have been around 2,000 metric tons per season.

The TCAI is applied to the 76 to 80.9 mm carapace length lobster class. This class was sub-legal for seasons 1999-2000 to 2008-2009 as required for the model.

MONITORING PROGRAM

Fishermen in the Fishermen and Scientists Research Society (FSRS) began to collect data in 1999 from sets of standardized monitoring traps located in 8 LFAs (Tremblay et al. 2009). These data have also been used for an exploitation rate indicator (Claytor and Allard 2003).

The monitoring program used standardized 101.6 cm by 53.3 cm by 35.6 cm traps with a 2.5 cm mesh and a 12.7 cm entrance. To prevent small lobsters from leaving, the traps did not have escape vents. In comparison, commercial traps were of variable designs, usually larger and with mesh sizes ranging from 3.81 to 5.08 cm and an escape vent (Miller 1995). Participants placed the monitoring traps within their fishing ground where they expected to catch juvenile lobster. A sampling location was defined as a circle with a 1 km radius within which a set of traps was located across seasons. As a consequence, moving a set of traps more than 2 km between seasons would always lead to the creation of a new location. There were 3 monitoring traps at each location. The vessel fishing a given location can change over time.

Trap monitoring occurred on a daily basis unless weather or other factors prevented it. In order to satisfy the assumption that the effort is constant, only catches from one-soak day trips were retained. For each monitoring trap, on each fishing day, fishers recorded the number of lobsters caught, their sex and length class.

A Vemco 8-bit Minilog automated temperature recorder was placed on one monitoring trap at each location and recorded temperature at 30 minute intervals with an accuracy of ± 0.2 C. Average daily temperatures based on recordings from midnight to midnight were computed after the recorders were retrieved at the end of each season.

Overall, 245 locations within LFA 33 were reported. Locations with observations from 5 or less soak days within a single season were removed from the database. Very few locations showed data for the complete time sequence: The number of monitoring locations within LFA 33 ranged from 31 in 1999-2000 to 59 in year 2005-2006.

RESULTS

CATCHABILITY-TEMPERATURE RELATIONSHIP

The parameters of the temperature-catchability function are estimated to be T0 = 0.36 and a = 0.0025 ºC-1 (using k = 0.02). The temperature-catchability function is illustrated in Figure 2.

DIAGNOSTICS

The semi-empirical catchability is obtained by smoothing the quotient of the catches by the estimated number of lobsters 76-80.9 mm CL in the area of attraction of each set of traps.

The estimated temperature-catchability relationship shows slightly higher catchability than the semi-empirical catchability (Figure 2). However, because the estimate of the temperature-catchability relationship and the estimate of the number of lobsters in the area of attraction of each set of traps are correlated, the result may indicate that there is either a positive bias in the catchability estimate or a positive bias in the number of lobsters estimate. In either case, the bias would be relatively small.

Figures 3a to 3j show the Pearson residuals for the catch by location and by season. Because the marginal distribution is binomial, the residuals are positively skewed.

Figure 4 show the Pearson residuals for the catch versus the longitude. The loess smoothing shows an extremely small pattern from west to east.

ABUNDANCE INDEX

Estimates of the most important parameter, the TCAI, are shown in Table 1 and illustrated in Figure 5. The number of lobsters in the 76 to 80.9 mm CL class appears to have nearly doubled between 1999-2000 and 2008-2009.

SPATIAL ABUNDANCE INDEX

The initial numbers of target lobsters at each location, $n(L,s_0)$, are illustrated in Figure 6. These numbers, which can be viewed as a spatial abundance index, varied from single digit values to levels around 250, with an average of 87 lobsters and a median of 78 lobsters.

DISCUSSION

The semi-empirical relationship between catchability and temperature (Figure 2) indicates catchability increases with temperature. The model diagnostics indicate that the model fit is acceptable.

The annual index increased substantially from the 2000-2001 season to the 2008-2009 season (Table 1, Figure 5). The modeled CPUE of sub-legals (uncorrected for temperature) also increased, but to a lesser extent (Tremblay et al. 2012). Accounting for temperature differences can make a substantial difference in the perception of abundance trends. Based on the TCAI, the abundance of prerecruit lobsters almost doubled from 1999 to 2009.

The spatial abundance index (Figure 6) is reliable only for locations with a relatively large number of observations. Nevertheless, higher abundance is mostly found in the southwestern end of the LFA, consistent with higher landings and catch rates in this portion of the LFA (Tremblay et al. 2012).

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Table 1. Temperature corrected abundance index (TCAI) and catch-per-unit-effort (CPUE) for LFA 33.

Period	TCAI	Standard Error	CPUE
1999/2000	1.00	0.00	1.00
2000/2001	1.19	0.06	1.05
2001/2002	1.22	0.06	1.34
2002/2003	1.15	0.05	1.01
2003/2004	1.53	0.07	1.33
2004/2005	1.22	0.06	1.12
2005/2006	1.49	0.07	1.25
2006/2007	1.59	0.07	1.44
2007/2008	1.76	0.08	1.34
2008/2009	1.92	0.09	1.48

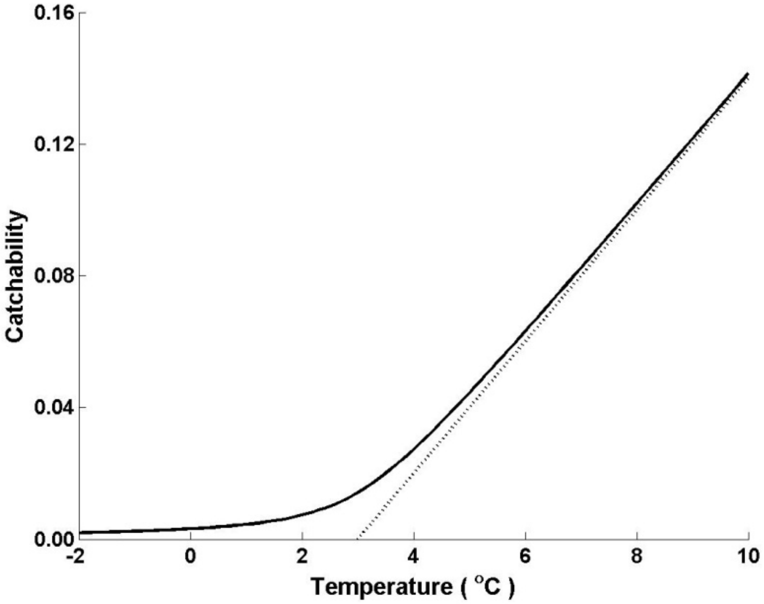

Figure 1. Example of smooth and piecewise-linear catchability-temperature relationships: $p_{T_0,a}(T)$ *for* T_0 *= 3 ºC, a = 0.02 ºC*$^{-1}$ *and k=0.02.*

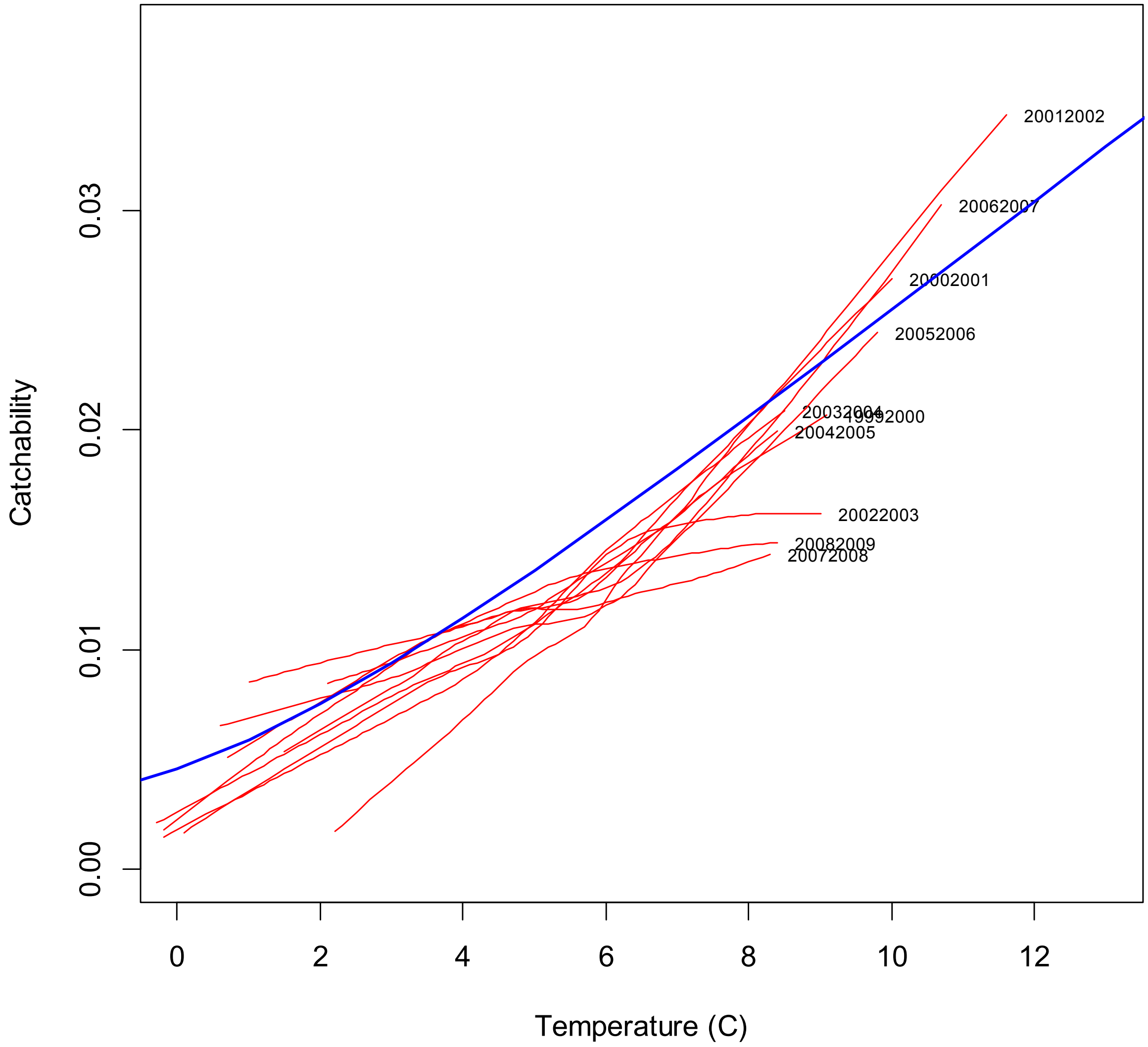

Figure 2. Estimated catchability function (blue) and smoothed semi-empirical catchability, by seasons. The semi-empirical catchability is obtained by smoothing the quotient of the catches by the estimated number of lobsters 76-80 mm carapace length (CL) in the area of attraction of each set of traps.

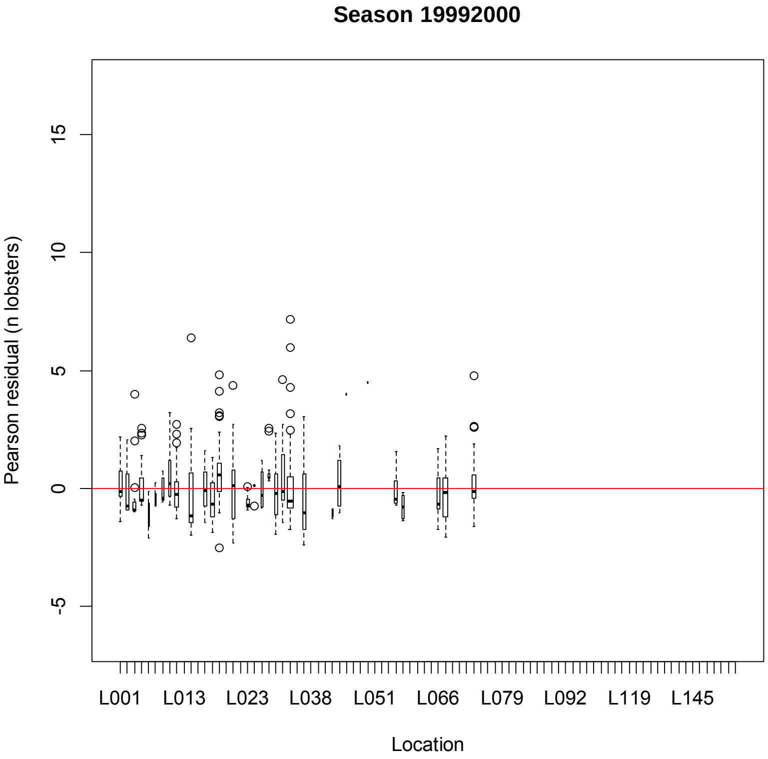

Figure 3a. Box-and-whisker plot of model residuals by vessel and season = 1999-2000.

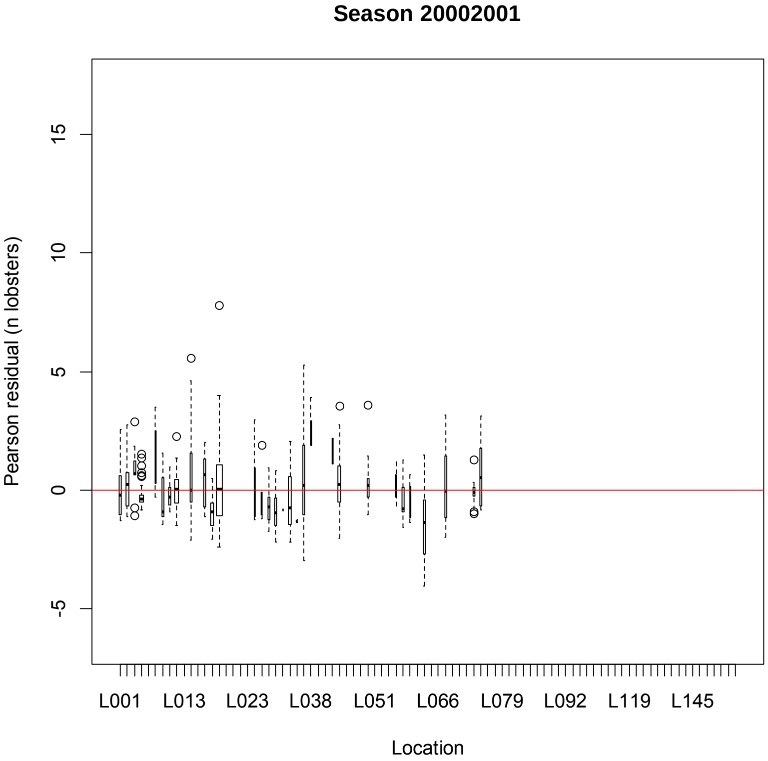

Figure 3b. Box-and-whisker plot of model residuals by vessel and season = 2000-2001.

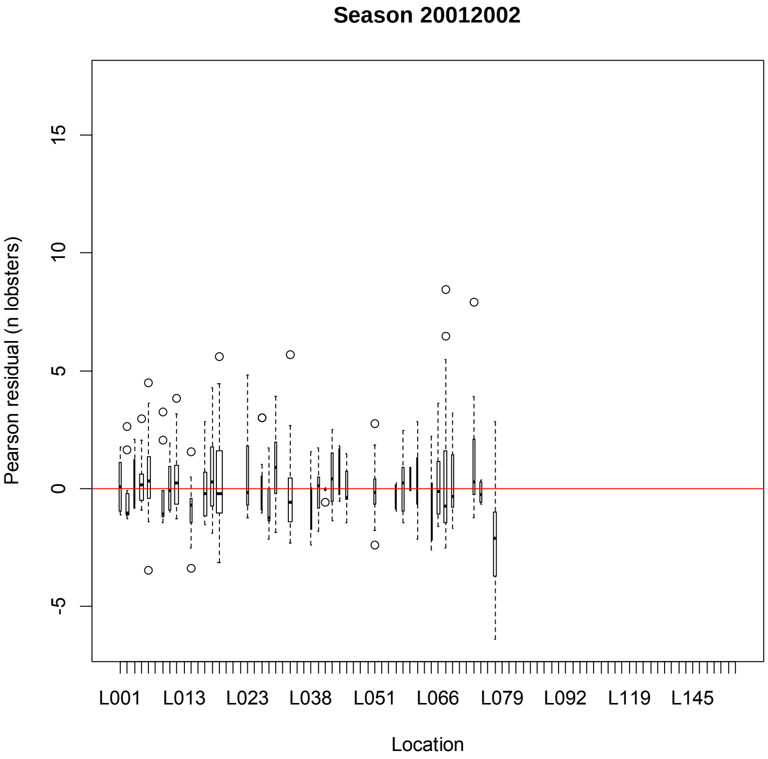

Figure 3c. Box-and-whisker plot of model residuals by vessel and season = 2001-2002.

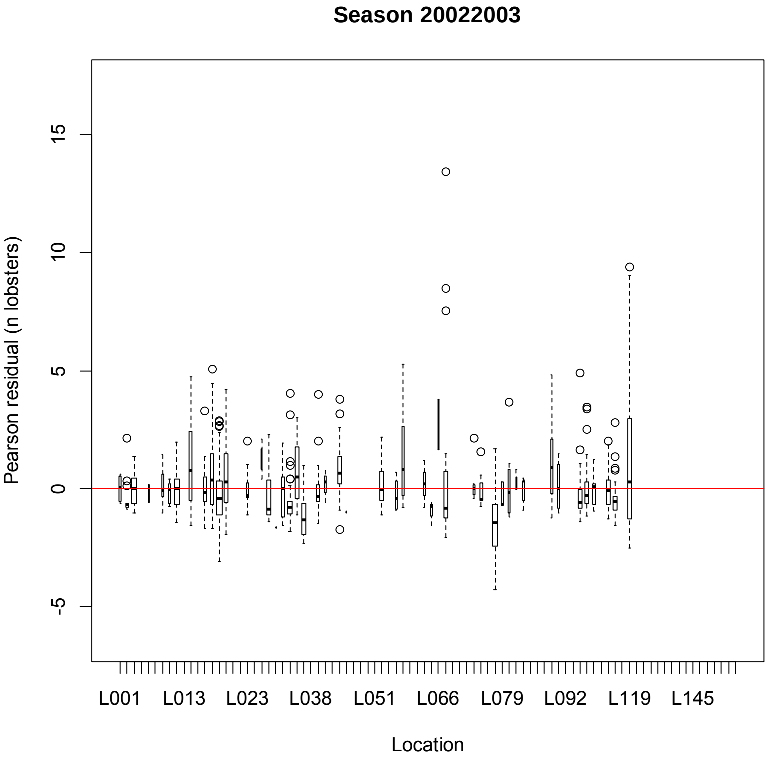

Figure 3d. Box-and-whisker plot of model residuals by vessel and season = 2002-2003.

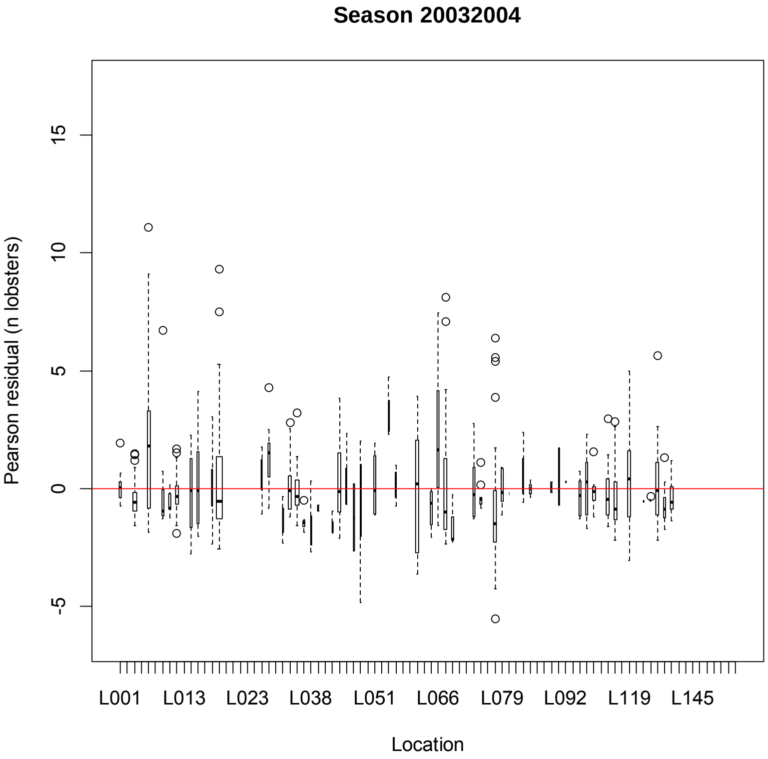

Figure 3e. Box-and-whisker plot of model residuals by vessel and season = 2003-2004.

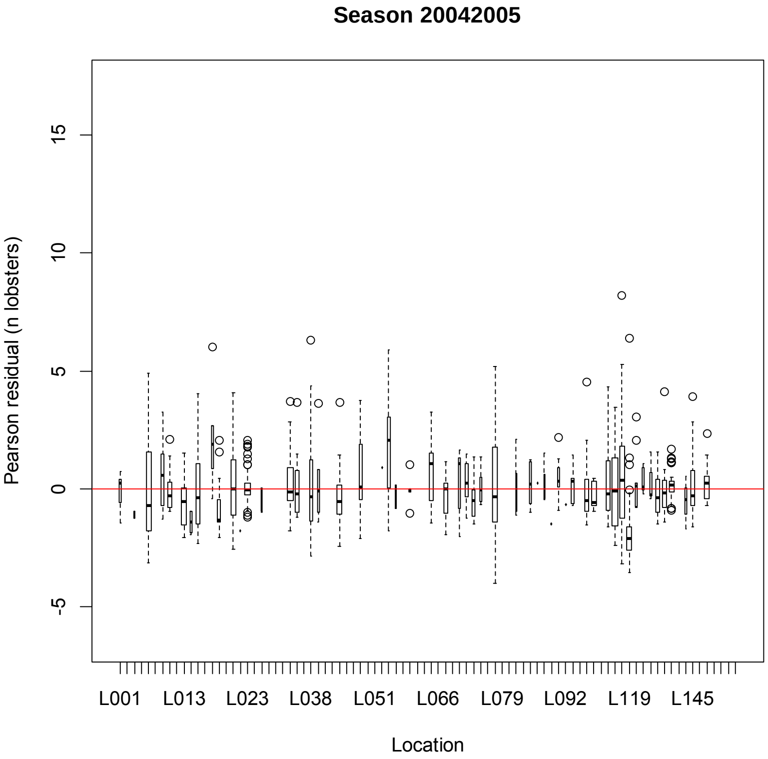

Figure 3f. Box-and-whisker plot of model residuals by vessel and season = 2004-2005.

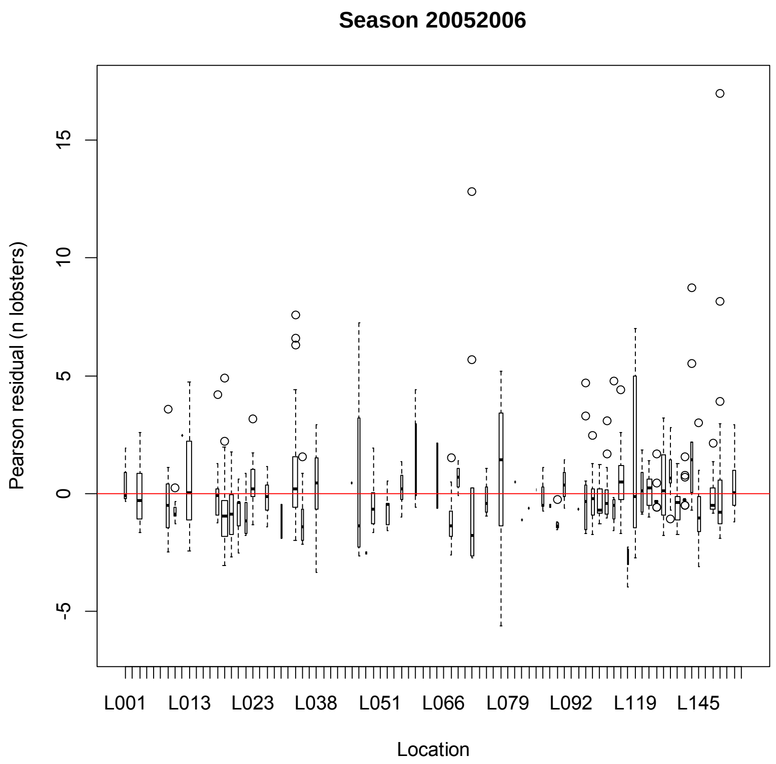

Figure 3g. Box-and-whisker plot of model residuals by vessel and season = 2005-2006.

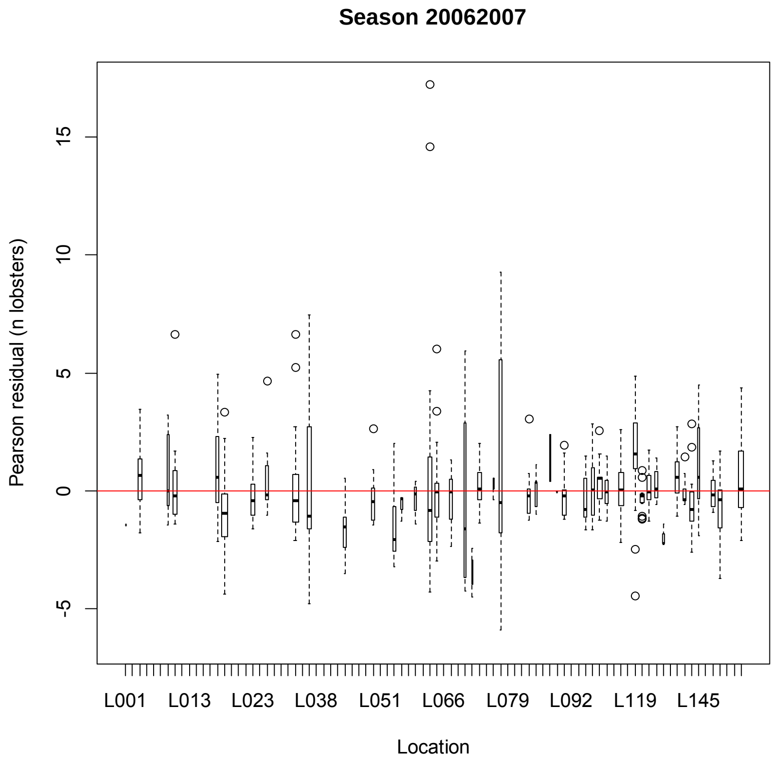

Figure 3h. Box-and-whisker plot of model residuals by vessel and season = 2006-2007.

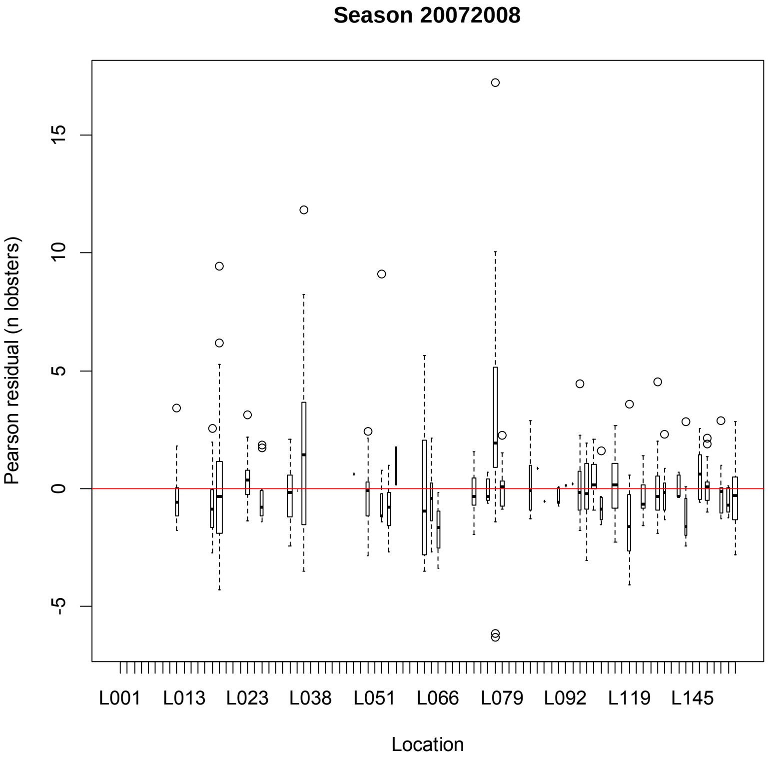

Figure 3i. Box-and-whisker plot of model residuals by vessel and season = 2007-2008.

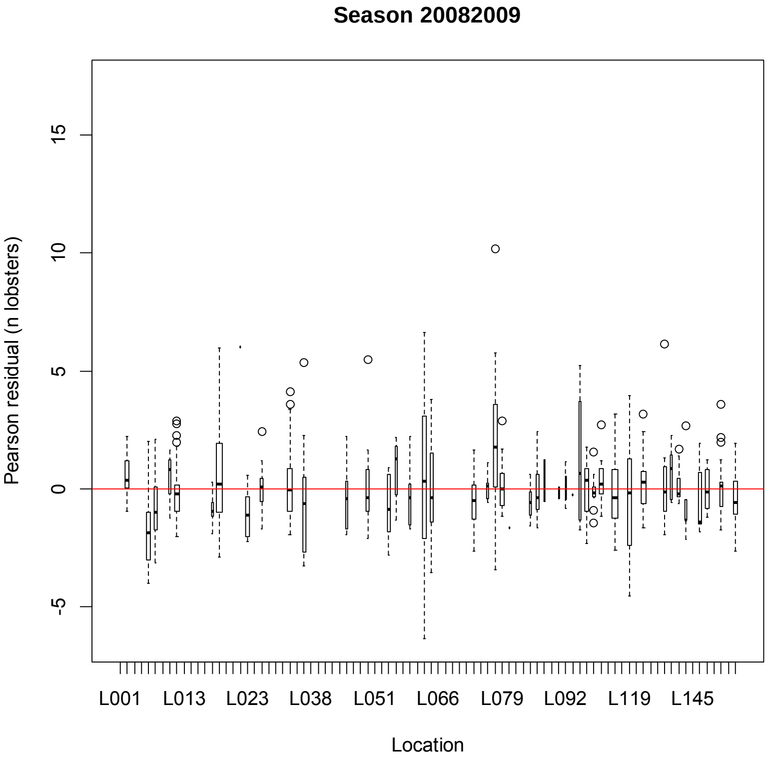

Figure 3j. Box-and-whisker plot of model residuals by vessel and season = 2008-2009.

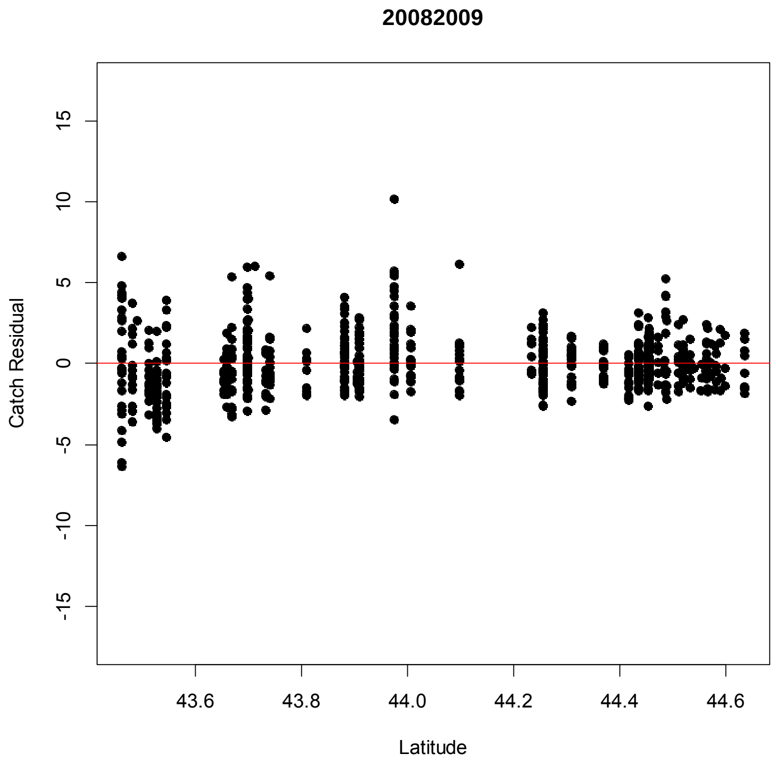

Figure 4. Pearson residuals versus latitude.

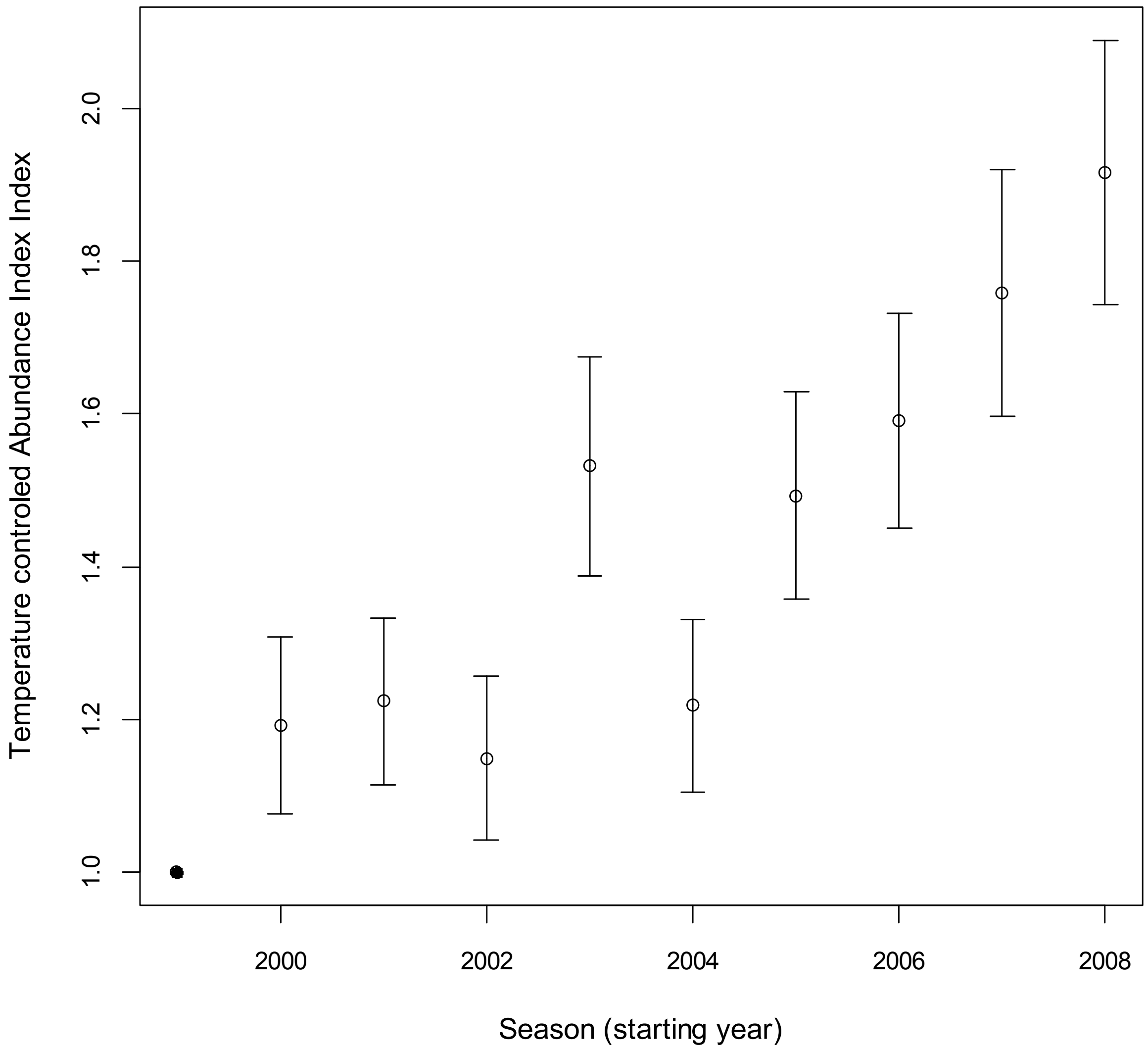

Figure 5. Temperature-corrected abundance index for 76-80.9 mm CL lobsters (1999-2000 =1) and 95% confidence interval.

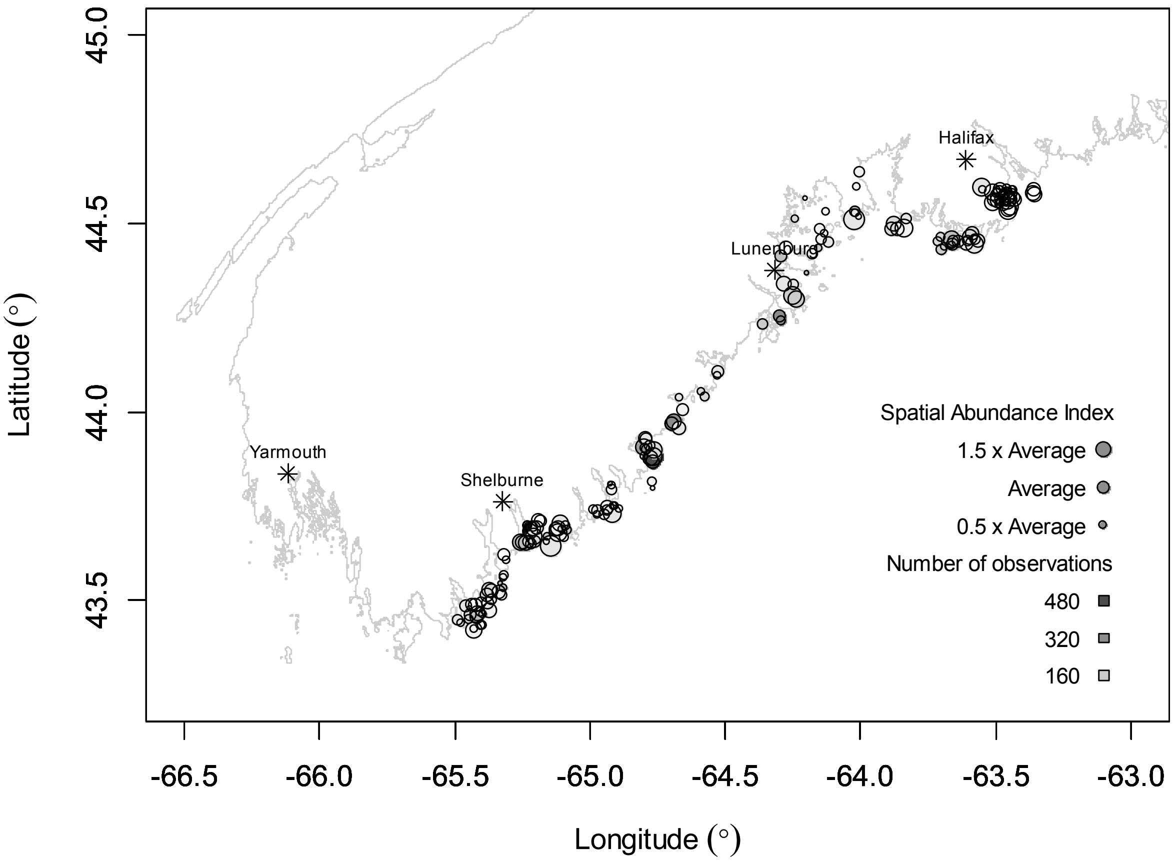

Figure 6. Spatial abundance index. Circle areas are scaled to the estimated number of lobsters 76-80.9 mm CL in the area of attraction of each set of traps. Circle shade indicates the number of observations (soak days) at the location across all seasons.