Using Local Ecological Knowledge in Ecosystem Models

Cameron H. Ainsworth and Tony J. Pitcher
University of British Columbia, Fisheries Centre, Vancouver, British Columbia, Canada

Abstract
We aim to construct marine ecosystem models of the past for northern British Columbia as a component of a Back to the Future (BTF) project. In order to satisfy the immense data requirements of an Ecopath with Ecosim (EwE) model, it has been necessary to recruit unconventional sources of information. Local ecological knowledge (LEK) has been called upon to supplement scientific, archeological, and naturalist records, particularly when dealing with data-limited species. The BTF team interviewed forty-eight northern British Columbia community members in 2001-2002: mainly commercial, aboriginal, and recreational fishers. Our LEK database now contains detailed anecdotal information on fisheries and some 130 marine species. The changes in abundance perceived by fishers are of special importance as we try to gauge anthropogenic effects over time. Validation showed that LEK comments agree with formal stock assessments in only 37% of instances, although agreement improves with reported fishing experience. LEK seems best suited to detect long time-scale changes: LEK abundance trends correlate poorly with stock assessment in species that exhibit high inter-annual variability. Trends offered by respondents are more likely to contradict stock assessment if they were reporting a decrease in abundance. This indicates that respondents are more likely to err on the side of pessimism and/or stock assessment is more likely to err on the side of optimism. The use of LEK information to supplement standard data sources may become an important tool. Besides consolidating and preserving community perception, we may establish criteria by which we can assess the quality of scientific data, challenging it with an independent authority and identifying where fishers’ perceptions depart from the scientific understanding.
Introduction

The need for supplementary data

In modeling whole ecosystems, data deficiencies become apparent among species that hold no commercial appeal. Stock assessment records exist for only a small minority of species, so modelers must borrow parameters from other, often dissimilar systems, or rely on guesswork. Although Ecosim (Christensen and Pauly 1992, Walters et al. 1997) grants modelers some reprieve by automatically estimating biomasses of data-poor groups based on the availability of food and abundance of predators, there is a clear need to reduce uncertainty in our estimates by incorporating supplemental information. Local ecological knowledge (LEK) held by community members is one such resource.

LEK can be used to fine-tune static Ecosim models, to confirm dynamic Ecosim function, or to inform us how the ecosystem might have been structured decades ago, before time-series data began for most species. LEK therefore holds obvious application to the Back to the Future (BTF) technique (Pitcher et al. 2004), which seeks to quantify past changes in the ecosystem over time. The key step in adapting LEK to our modeling needs comes in producing a quantitative data series from qualitative accounts. This article will discuss how that was accomplished, how abundance information from interviews compares to values from stock assessment, and how we use LEK in ecosystem simulations of northern British Columbia. This work supports the historic models of Ainsworth et al. (2002) for use in ecosystem restoration policy evaluations (Ainsworth and Pitcher 2005).

Methods

Interviews

A team from the University of British Columbia Fisheries Centre interviewed forty-eight community members from the Prince Rupert region and Haida Gwaii, B.C. Interviewees represented a broad cross-section of commercial, recreational, and aboriginal fishers as well as processors and others who are familiar with the marine system of the study area: Hecate Strait, Dixon Entrance, and Queen Charlotte Sound (corresponding to Department of Fisheries and Oceans statistical areas 1-10 in northern British Columbia). As our aim was to improve the models, we did not select participants randomly, but sought the most knowledgeable contributors as recommended by partners and participants. Although we did not select interviewees based on years of fishing experience, or by the gear

1Dr. Tony Pitcher (P.I.), Dr. Ussif Rashid Sumaila, Dr. Sheila Heymans, Dr. Melanie Powers, Nigel Haggan, Russ Jones (Haida Fisheries Council), Eny Buchary, Cameron Ainsworth, Pablo Trujillo, Louisa Wood, Richard Stanford, Erin Foulkes, and Aftab Erfan.
type they operated, we did record that information and so could look for apparent biases in the information provided.

One-hundred-eighteen flashcards of marine mammals, birds, fish, and invertebrates were shown to each of the interviewees, who were asked whether the abundance of these creatures had increased, remained the same, or decreased during their career (i.e., from their first year of fishing to their last); see Ainsworth and Pitcher (2004) for a more complete description of the interview process. This method assumes that respondents made implicit allowance in their answers for any changes in catchability arising from new methods or fishing technology. Other information recorded included known aggregations of animals, seasonal movements, fisheries interactions, and population changes. These data, along with demographic specifics, were processed to ensure anonymity and entered into the BTF Historical and Interview Database (contact C. Ainsworth).

Creating a time-series of relative abundance

For each organism, an interviewee’s comment of increase, stable, or decrease was assigned as +1, 0, or −1 respectively. Every year that the respondent fished received one numerical “vote” for that organism. Summing votes from all respondents, the annual total was assumed to indicate the average perception for that year, where a positive value suggests the abundance had increased and a negative value suggests it had decreased. The resulting time-series indicated the perceived rate of change in abundance for that organism. The rate of change was converted into a running total—a time-series estimate of relative abundance.

Organisms were compiled into Ecopath functional groups (species aggregated according to trophic similarity) for comparison with the models (see Ainsworth et al. 2002 for a description of model groups). Some groups include several species, so we assumed that the abundance trend of the group most closely follows those species mentioned most often by respondents. For example, only eight comments concerning the functional group Odontocetaceae mentioned northern right whale dolphin, while 36 comments were made for orca. The abundance trend of Odontocetaceae therefore more closely reflects the trend for orca: it is a weighted average of the relative number of comments. Ideally, we would weigh the contribution of each species to the overall functional group abundance trend using some independent estimate of relative abundance. However, in the base Ecopath model, Ainsworth et al. (2002) has generally assigned important and commercial species (i.e., species for which abundance data are available), their own dedicated functional groups.

Weighting by expertise

The interviews captured a diverse sample of local knowledge. Many fisheries (and industries) were represented, and we expected each sector to carry its own special expertise in species of particular importance to
their specialization. We therefore applied weighting to the votes offered by each participant according to their expertise. “Expert” opinions were taken to be worth twice as much toward calculating the average (i.e., +2 and –2 for increasing and decreasing votes); “novice” opinions were taken to be worth half as much (i.e., +0.5 and –0.5). What constituted an “expert” or “novice” vote was determined under the following rules:

1. Fishers are expert in their target functional groups.
2. Group interviews are novice in all functional groups.
3. First Nation group interviews remain unchanged in First Nation specialties.
4. Non-fishers are novice in all functional groups.
5. Recreational fishers are novice on all functional groups except their specialty, in which they are expert.
6. Interviewee 20 was judged expert in all functional groups.
7. Interviewee 21 was judged expert in all rockfish functional groups.

Group interviews operated on consensus; their vote was reduced in importance to limit the effect of influence between respondents in our analysis. As most of our First Nation respondents participated in group interviews rather than individual interviews, we did not wish to limit their contribution to the study, especially with regard to traditionally harvested species. We assume that non-fishers and recreational fishers spend less time at sea than commercial harvesters, so we weighted their contribution by only half as much. In addition to years of fishing experience, interviewees 20 and 21 had formal ecological training.

A weighting scheme based on years of experience could be used alternatively, although some degree of ranking by gear specialization should still be included. Information from experienced fishers does actually influence the LEK abundance trend more than information from less experienced fishers under the current methodology, since their comments apply to more years in the analysis. Also, we felt that retired fishers could be inclined to answer differently from those who still rely on the resource for income.

Comparing LEK to stock assessment information

To determine how often comments agreed with stock assessment records, we compared the qualitative change in abundance offered by each interviewee with time series abundance data assembled from DFO stock assessment data (i.e., various Canadian Science Advisory Secretariat and Pacific Scientific Advice Review Committee reports). For the period in which a respondent fished, a simple program consults DFO records
to determine whether the recorded abundance of the subject functional group had increased, stayed the same, or decreased. It compares this result against the vote provided by the interviewee to determine agreement. This procedure was conducted for the eight functional groups that had continuous stock assessment information. Comments were used from only the fishers whose career spanned a period covered by stock assessment data.

For each comment made concerning a particular functional group, the span of the interviewee’s career at sea was divided into two halves. The average abundance of that functional group in the first and second halves of the fisher's career was determined from stock assessment records. If the average abundance was greater in the latter half than in the former, the functional group was said to have increased. If the fisher had indicated an increase in abundance, then their comment was considered “true” (indicating only agreement between data sets). Similarly, if the stock had declined according to stock assessment, then comments that indicated a decrease in abundance were considered “true.”

An arbitrary threshold was assigned so that if only slight increases or decreases in abundance had occurred during the fisher's career (according to stock assessment records), the functional group could be considered “stable,” and comments providing that response would be considered “true.” By decreasing the threshold required for a change in biomass to be considered significant, fewer comments indicating “stable” become true. The threshold was set as a fraction of the total amplitude of change in abundance witnessed for that group since time series stock assessment began (Table 1). It was found that when considering all functional groups together, a threshold of 15% change in absolute biomass yielded agreement equally often between increasing, stable, and decreasing votes ($\sigma^2 = 0.0018$). This assumes that fishers are equally likely to agree or not with stock assessment data, regardless of the direction of abundance change. That threshold was used for all calculations. For fishers whose careers were shorter than the 61 year maximum (the most experienced interviewee), the required threshold was decreased proportionately. For example, biomass would need to have only increased or decreased by approximately 7% of its maximum amplitude over the course of a 30-year career to be considered significant.

**Analysis of trend**

We compare the LEK relative abundance trend of commercial groups with stock assessment records. Time series are available for the following Ecopath functional groups: chinook, coho, transient salmon$^2$, flatfish, halibut, herring, lingcod, Pacific cod, sablefish, and seals/sea lions. In

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$^2$Transient salmon includes (adult) pink, sockeye, and chum salmon, which pass through the marine ecosystem but do not feed.
order to compare the LEK information with scientific data we converted the relative abundance time series suggested by the interviews into absolute abundance by assuming the same average and amplitude of change as in stock assessment data. The correlation of the LEK information to the assessment records was then measured using a non-parametric Spearman’s rank sum test for the weighted and unweighted interview information. We then divided the time series into two periods, before and after 1965, and repeated the correlation analysis.

**Challenging the model with LEK information**

The models were challenged with the LEK data to verify their structure and dynamic functioning. LEK information is used here in two ways to challenge the models: first, as a test of the relative (static) structure of the 1950 and 2000 Ecopath models, and second, as a test of the dynamic function of a 50-year Ecosim simulation.

**Static structure**

LEK information can serve as a check in a comparison between Ecopath time periods. Here we attempt to verify that the relative abundance has increased, remained the same, or decreased from the static 1950 and 2000 models in accordance with the fishers’ average perception. This process can validate the many data sources used. By weighing the credibility of our source against the magnitude of the disparity, a judgment can be reached whether to accept an alternate value (if one is available),

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**Table 1. Percentage of interviewee comments that agree with stock assessment records (N = 234).**

<table>
<thead>
<tr>
<th>Increase</th>
<th>Stable</th>
<th>Decrease</th>
<th>Total</th>
<th>Variance</th>
<th>Exact P</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>58.2%</td>
<td>0.0%</td>
<td>35.7%</td>
<td>33.8%</td>
<td>0.086</td>
</tr>
<tr>
<td>0.05</td>
<td>58.2%</td>
<td>21.8%</td>
<td>32.1%</td>
<td>37.2%</td>
<td>0.035</td>
</tr>
<tr>
<td>0.10</td>
<td>49.3%</td>
<td>30.9%</td>
<td>30.4%</td>
<td>35.9%</td>
<td>0.012</td>
</tr>
<tr>
<td>0.15</td>
<td>37.3%</td>
<td>38.2%</td>
<td>30.4%</td>
<td>34.2%</td>
<td>0.002</td>
</tr>
<tr>
<td>0.20</td>
<td>37.3%</td>
<td>40.0%</td>
<td>28.6%</td>
<td>33.8%</td>
<td>0.004</td>
</tr>
<tr>
<td>0.25</td>
<td>28.4%</td>
<td>41.8%</td>
<td>25.9%</td>
<td>30.3%</td>
<td>0.007</td>
</tr>
<tr>
<td>0.30</td>
<td>19.4%</td>
<td>56.4%</td>
<td>23.2%</td>
<td>29.9%</td>
<td>0.041</td>
</tr>
<tr>
<td>0.35</td>
<td>14.9%</td>
<td>65.5%</td>
<td>17.0%</td>
<td>27.8%</td>
<td>0.082</td>
</tr>
<tr>
<td>0.40</td>
<td>14.9%</td>
<td>72.7%</td>
<td>14.3%</td>
<td>28.2%</td>
<td>0.113</td>
</tr>
<tr>
<td>0.45</td>
<td>14.9%</td>
<td>78.2%</td>
<td>12.5%</td>
<td>28.6%</td>
<td>0.139</td>
</tr>
<tr>
<td>0.50</td>
<td>11.9%</td>
<td>80.0%</td>
<td>8.9%</td>
<td>26.5%</td>
<td>0.162</td>
</tr>
</tbody>
</table>

Shown on left is the fraction of the maximum amplitude of abundance change required for the change over the fisher’s career to be considered significant. In calculations, this threshold is proportionately reduced for fishers whose career is shorter than the maximum (61 years).
Table 2. Biomass estimates used in Ecopath models compared to LEK trend.

<table>
<thead>
<tr>
<th>Species</th>
<th>1950</th>
<th>2000</th>
<th>Change</th>
<th>LEK</th>
<th>Agree?</th>
<th>Data pedigreea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seals and sea lions</td>
<td>0.057</td>
<td>0.052</td>
<td>–0.005</td>
<td>+</td>
<td>n</td>
<td>6</td>
</tr>
<tr>
<td>Transient salmon</td>
<td>0.754</td>
<td>0.588</td>
<td>–0.166</td>
<td>+</td>
<td>n</td>
<td>5</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0.067</td>
<td>0.024</td>
<td>–0.043</td>
<td>+</td>
<td>n</td>
<td>6</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.026</td>
<td>0.018</td>
<td>–0.008</td>
<td>–</td>
<td>y</td>
<td>6</td>
</tr>
<tr>
<td>Dogfish</td>
<td>0.8</td>
<td>0.909</td>
<td>0.109</td>
<td>–</td>
<td>n</td>
<td>2</td>
</tr>
<tr>
<td>Forage fish</td>
<td>8.88</td>
<td>8.485</td>
<td>–0.395</td>
<td>–</td>
<td>y</td>
<td>1</td>
</tr>
<tr>
<td>Eulachon</td>
<td>1.758</td>
<td>1.661</td>
<td>–0.097</td>
<td>–</td>
<td>y</td>
<td>1</td>
</tr>
<tr>
<td>Herring</td>
<td>0.748</td>
<td>2.265</td>
<td>1.517</td>
<td>–</td>
<td>n</td>
<td>6</td>
</tr>
<tr>
<td>Piscivorous rockfish</td>
<td>0.416</td>
<td>0.654</td>
<td>0.238</td>
<td>–</td>
<td>n</td>
<td>1</td>
</tr>
<tr>
<td>Flatfish</td>
<td>0.221</td>
<td>0.392</td>
<td>0.171</td>
<td>–</td>
<td>n</td>
<td>5</td>
</tr>
<tr>
<td>Halibut</td>
<td>0.429</td>
<td>0.608</td>
<td>0.179</td>
<td>–</td>
<td>n</td>
<td>6</td>
</tr>
<tr>
<td>Pacific cod</td>
<td>0.086</td>
<td>0.163</td>
<td>0.077</td>
<td>–</td>
<td>n</td>
<td>4</td>
</tr>
<tr>
<td>Sablefish</td>
<td>0.602</td>
<td>0.301</td>
<td>–0.301</td>
<td>–</td>
<td>y</td>
<td>4</td>
</tr>
<tr>
<td>Lingcod</td>
<td>0.085</td>
<td>0.034</td>
<td>–0.051</td>
<td>–</td>
<td>y</td>
<td>2</td>
</tr>
<tr>
<td>Large crabs</td>
<td>0.31</td>
<td>0.46</td>
<td>0.15</td>
<td>–</td>
<td>n</td>
<td>2</td>
</tr>
<tr>
<td>Infaunal invertebrates</td>
<td>13.245</td>
<td>34.305</td>
<td>21.06</td>
<td>–</td>
<td>n</td>
<td>2</td>
</tr>
<tr>
<td>Epifaunal invertebrates</td>
<td>10.928</td>
<td>13.499</td>
<td>2.571</td>
<td>–</td>
<td>n</td>
<td>1</td>
</tr>
</tbody>
</table>

aData pedigree column indicates the quality of data. This scale measures from 1, the lowest quality (data point estimated by Ecopath) to 6 (high precision, sampling based measures).

or allow Ecopath to estimate that parameter. Table 2 compares model biomass parameters with the LEK trend, and includes Ecopath’s data ranking pedigree as a measure of data quality (Christensen et al. 2000). The pedigree describes the following ranking of data quality, where 1 indicates the lowest precision and 6 indicates the highest:

1. Estimated by Ecopath
2. From other model
3. “Guesstimate”
4. Approximate or indirect method
5. Sampling based, low precision
6. Sampling based, high precision

Ecopath’s pedigree considers any user input to be more reliable than an internally generated value. However, the six criteria listed above are only established by convention—if the user has reason to believe that
a value estimated by Ecopath is reliable, a higher data quality ranking can be entered manually. Similarly, if a “guesstimate” is made by expert opinion, it may warrant a better ranking than 3.

**Dynamic function**

LEK data is used to verify dynamic group interactions occurring in a 50-year harvest simulation from 1950 to present. Parameterizing the harvest simulation using real-world fishing effort, the dynamic model should recreate the patterns of abundance seen in stock assessment time series (the 1950 baseline static model is built on that information). For all functional groups, Ecosim’s predicted abundance trend is compared with the suggested biomass trend from the LEK interviews, and stock assessment information (commercial groups only). A Spearman’s rank correlation test determines whether abundance trends are in concordance with our two data sets.

**Results**

*Comparing LEK comments to stock assessment information*

Table 1 below records the fraction of instances where the interviewee comments agree with stock assessment records, varying the threshold of abundance change required to be considered significant. As that threshold is decreased, fewer “stable” comments become true.

Overall, agreement between data sets is poor, with a maximum of only 37% of comments concurring with stock assessment. This highest level of agreement occurs when the abundance change threshold is set to 5%. Votes that indicate increase, stable, and decrease are true most equally often when the threshold is set at 15% ($\sigma^2 = 0.002$). At most threshold levels, the “increase” votes show agreement with stock assessment more often than “decrease” votes. The discrepancy is significant ($\sigma = 0.05$) at all levels of threshold below 15%, according to Fisher’s exact test (Table 1).

Figure 1 shows the fraction of comments that agree with stock assessment records per functional group at a threshold level of 15%. Not shown, flatfish comments ($n = 16$) were never in agreement with stock assessment.

A binomial test shows that comments provided for three functional groups disagree with stock assessment more often than could be expected by chance at $\alpha = 0.05$. By experts, the interview trend for chinook contradicts stock assessment ($P = 0.004$); by non-experts, the interview trend for transient salmon and Pacific cod contradicts stock assessment ($P = 0.002$ and 0.011 respectively). Non-expert comments agree with stock assessment more often than expert comments for all groups except transient...
salmon, herring, and sablefish. Although non-experts are in agreement with stock assessment more often than experts, they are not as consistent across functional groups ($\sigma^2 = 0.010$ for experts, $0.046$ for non-experts). Still, there is little evidence to support the division between expert and non-expert (non-expert including both unchanged and novice votes).

Figure 2 tests whether experienced interviewees are in agreement with stock assessment more often than less experienced ones. There is a trend suggesting that agreement between data sets improves as fishers' experience increases. Fisher's exact test reveals that interviewees with 40 or more years of experience provide a significantly ($P = 0.045$) higher fraction of comments that agree with stock assessment (41%, $n = 74$) than less experienced ones (31%, $n = 148$).

**Analysis of trends**

Figure 3 presents the absolute abundance for eight functional groups estimated from the interview materials, and from DFO stock assessment information. Abundance trends determined with and without the data quality weighting scheme (reflecting fisher's expertise by gear type) are shown. Figure 4 summarizes correlation between weighted and unweighted data sets with stock assessment information.

There is a significant positive correlation between the interview trends and stock assessment for four groups, using the unweighted LEK trend, and only three groups using the trend weighted for data quality. In fact, there are significant negative correlations for several groups, indicating...
that the average fisher perception is in contradiction to the scientific data set. The abundance trend weighted by fisher’s expertise outperforms the unweighted trend only for chinook salmon.

With functional groups that display a large degree of inter-annual variability, we expect the correlation between interviewee and DFO data sets to suffer, since the abundance trend gleaned from the interview data is not suited to detect fine time scale changes in abundance. The LEK trend may be more suited to detect long-scale (e.g., decadal) changes. In fact, the best correlation occurs in lingcod and sablefish, two long-lived species whose abundances do not fluctuate greatly from year to year.

We tried dividing each data set into two series, before and after 1965. Since fewer interviewees could contribute to the early years of the analysis, we expected the LEK trend to match stock assessment information better, and more often (across functional groups) in the latter time series than in the former. However, not only did the LEK trend from the 1965-2001 data series achieve agreement with stock assessment information often than the 1933-1964 series, significant negative correlations were found for six functional groups, as opposed to three for the combined data set in Figure 4. This indicates that even when there was a maximum number of respondents contributing to the LEK trend, their perceptions of change in abundance still disagreed, and more frequently, with stock assessment information.
Figure 3. Weighted and unweighted LEK trends compared to stock assessment records. Solid line is stock assessment; large dots are unweighted LEK trend; small dots are weighted LEK trend. Absolute LEK trend is scaled using the same mean and amplitude as stock assessment.
Challenging the model with LEK information

Static structure
Table 2 shows the biomass estimates used in the 1950 and 2000 Ecopath models. The net change is compared to LEK results. The LEK column indicates the net change in fishers’ perception of abundance since 1950 according to the trends determined earlier. The data pedigree in the right column indicates the quality of data used in the 2000 model. Data quality in the 1950 model is generally poor for noncommercial groups as well. Not shown are the functional groups whose biomass remains constant between time periods.

For most functional groups, the LEK trend does not agree with the data used to construct the models. Fisher’s exact test shows that agreement between LEK and the models’ change in biomass is independent of the data pedigree ($P = 0.324$). Agreement between data sets is also independent from the direction of biomass change between periods, having increased or decreased from 1950 and 2000 ($P = 0.326$).

Dynamic function
A 50-year Ecosim simulation was run using the 1950 model as the starting point. Figure 5 shows how well LEK and stock assessment correlate with the Ecosim model’s predicted biomass trend using a non-parametric Spearman’s rank sums test. Dark bars indicate correlation with LEK information; light bars indicate correlation with stock assessment. Crossbars indicate the level of correlation needed for significance at $\alpha = 0.05$. 

Figure 4. Rank correlation of weighted and unweighted LEK abundance trend with stock assessment information. Dark bars are unweighted LEK; light bars are weighted LEK; crossbars indicate significance level at $\alpha = 0.05$. 

![Figure 4](image-url)
Validating LEK

In comparing the LEK trend with stock assessment, agreement is poor. The best correlation occurs in slow growing species, whose abundance does not fluctuate greatly from year to year. Agreement between data sets does improve with fishers’ experience. However, considering that LEK comments generally indicate a decrease in abundance for the majority of functional groups, regardless of fishing experience, it is likely that fishers’ perceptions come to resemble the scientific understanding only when considering the long-term trend. Presumably, a steady depletion (particularly among commercial species) becomes obvious over the course of several decades, where a short-term trend can be mired in fluctuations, and is open to some degree of interpretation. Interestingly, we found that interviewees were more likely to contradict stock assessment if they were reporting a decrease in abundance. This suggests that respondents are more likely to err on the side of pessimism and/or stock assessment is more likely to err on the side of optimism. We do not suggest that one data set is more accurate than the other, only that there is persistent bias in that direction. At any rate, discrepancies show where stock assessment records are in contradiction with fishers’ perceptions.

Figure 5. Correlation of LEK and stock assessment biomass trends to 50-year Ecosim model (beginning 1950). Dark bars show correlation with LEK; light bars show correlation with stock assessment; crossbars show significance at $\alpha = 0.05$. 

Discussion

Validating LEK
**Challenging the static Ecopath models**

We tested the relative biomass values used in the static 1950 and 2000 Ecopath models against the LEK trend. The LEK trend verifies the change in biomass for only five out of seventeen functional groups. Of those that disagree with LEK, we can remain confident in our data sources concerning well-studied groups such as seals and sea lions, transient salmon, coho, herring, flatfish, and halibut. However, the LEK trend also disagrees with data-poor groups like dogfish, piscivorous rockfish, large crabs, and infaunal/epifaunal invertebrates. In the absence of empirical data, LEK offers our only guide to the abundance change of poorly studied species. But through the rigor offered by the mass-balance modeling process, it is possible to test whether the perceived abundance change of these noncommercial groups is congruent, or at least possible, within the trophic constraints imposed by the well-understood ecosystem components.

**Testing dynamic Ecosim function**

We compared the LEK and stock assessment data sets with the output of a 50-year simulation. Nine functional groups show a significant negative correlation with the LEK trend: coho, sablefish, herring, infaunal/epifaunal invertebrates, inshore rockfish, skates, flatfish, and piscivorous rockfish. Of these, the commercial groups coho, sablefish, and herring are vindicated by a strong positive correlation with stock assessment data. Suspect groups are therefore flatfish, whose Ecosim trend is contradicted by both stock assessment and LEK trends, as well as infaunal/epifaunal invertebrates, inshore rockfish, skates, and piscivorous rockfish. Lingcod shows a negative correlation with stock assessment records despite endorsement by LEK information. Future work to improve the dynamic function of the models will begin with these problematic groups.

We could attempt to improve the fit of Ecosim to LEK information by making fine adjustments to predator-prey vulnerabilities, which govern the simulated trophic interactions (Walters and Kitchell 2001). Or, if after tuning the model the time series biomass trajectories cannot be made to agree with the LEK trend, we could employ a second, more desperate option. That is, to force the biomass trend of problem groups to agree with our inputted trend from LEK. Although this robs Ecosim of its predictive power, the method could be used to treat a small number of highly influential groups, so that their dependent predator/prey groups would behave appropriately.

**Future work**

As one reviewer pointed out, abundance trends suggested by local ecological knowledge may partly reflect changes in the spatial distribution of species—particularly if LEK is more spatially restricted than broad-scale survey data. However, there are enough site-specific references in the
interview materials that we could compare abundance trends with stock
assessment, by area, to estimate this potential bias.

As this article goes to press, a new method is under development that
would use this interview information, translated into a spatial context,
to validate the behavior of a spatially explicit Ecospace model (Walters
1998).

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The Scotian Shelf Experience with Emerging Bivalve Fisheries

Dale Roddick
Department of Fisheries and Oceans, Population Ecology Division, Dartmouth, Nova Scotia, Canada

Abstract
The development of commercial fisheries for offshore bivalves on Canada’s East Coast is reviewed. The arctic surfclam fishery and the ocean quahog population, for which there is currently no fishery but increasing interest, are examined. For the arctic surfclam fishery a government survey took place prior to the fishery in 1981-1982, and an industry-funded survey was conducted in 1996-1997. This fishery has extensive industry involvement in funding sampling and research programs which have increased understanding of the life history of the species involved and aided management of the resource. The crew on the vessels regularly sample the catch for length frequencies, conversion factors, and bycatch, and collect samples of whole clams for morphometric analysis and aging of shells at a Department of Fisheries and Oceans (DFO) laboratory.

DFO has data for the ocean quahog population from the 1981-1982 survey, and can make comparisons to other populations that have ongoing fisheries. Different methods of determining the sustainable yield for these data limited populations are discussed, yield estimates for the arctic surfclam fishery examined, and a yield estimate for a possible ocean quahog fishery defined.

Current management is based on setting long term allowable catch levels, as there are no annual surveys and little contrast in the data. With the movement toward ecosystem based management more information will be required on the effects of the fishery on other species.

Introduction
The Scotian Shelf of Nova Scotia is home to a number of large bivalves. Arctic surfclams, *Mactromeris polynyma*, support a commercial fishery that started in 1986, and there is growing interest in harvesting ocean quahogs, *Arctica islandica*, and northern propellerclams, *Cyrtodaria*
siliqua. On the adjacent Grand Bank the Greenland cockles, *Serripes groenlandicus*, are being harvested as a bycatch to the arctic surfclam fishery. These populations are on the offshore banks in waters between 50 and 100 m depth. For species such as Greenland cockles and northern propellerclams, little is known of their life history. For all of them the distance from shore and depths involved make sampling and surveys expensive and difficult. Arctic surfclams and ocean quahogs are long-lived species, 40 to 60 years for the arctic surfclams and over 100 for the ocean quahog. This means that sustainable exploitation rates have to be low, and there is likely to be little measurable population response to fishing.

The arctic surfclam fishery has evolved from the discovery of commercial concentrations on Banquereau Bank in the late 1980s, to a mature fishery with annual sales of $30-$50 million employing approximately 450 people. There are 3 large freezer-processor vessels in the fishery. These vessels use large hydraulic clam dredges that pump water down to the dredge to liquefy the sand at the front of the dredge so the clams can be separated out (Fig. 1). The fishing grounds are on Banquereau Bank on the Scotian Shelf, and Grand Bank off Newfoundland (Fig. 2). These are in different Department of Fisheries and Oceans (DFO) management regions, but the two banks are managed under a single management plan. In this paper I will concentrate on the fishery on the Scotian Shelf, but will include developments on Grand Bank as they influence management decisions.
The offshore clam fishery started when there was a directed effort to get industry involved as a partner rather than an adversary in fisheries management. It was also a time when reduced government budgets restricted DFO’s ability to fund research programs in support of emerging fisheries. This resulted in a high degree of industry involvement in research and management of this fishery, creating benefits and problems for government and industry.

There is no regular survey series for offshore clams, and there are no quantitative management targets for arctic surfclams. Targets have been constant harvest levels that have been based on empirical methods.

**History of the fishery**

The management of the fishery, developments occurring during each phase, and degree of industry involvement in research and management are discussed in relation to phases of the fishery (Table 1).

**Development phase**

In 1980 DFO initiated a fishery development plan to determine the resource potential of the ocean quahog (*Arctica islandica*) and other underutilized clam species on the Scotian Shelf (Fig. 2). During a series of offshore clam surveys from 1980 to 1982, commercial quantities of
Table 1. Chronology of the offshore clam fishery on the Scotian Shelf and Grand Bank.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Management program</th>
<th>Year</th>
<th>Management tools/changes</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development phase</td>
<td></td>
<td>1980</td>
<td></td>
<td>DFO developmental surveys on Scotian Shelf and Georges Bank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1983</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1986</td>
<td>Offshore Clam Advisory Committee (OCAC) established</td>
<td>3-month test fishery with 3 participants using chartered U.S. vessels</td>
</tr>
<tr>
<td>Exploratory phase</td>
<td>3 Year Fishery Program</td>
<td>1987</td>
<td>TAC, limited entry, EAs, logbooks</td>
<td>Commercial fishing starts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1988</td>
<td>OCAC requested to develop plan for Grand Bank</td>
<td>Requests for access to Grand Bank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1989</td>
<td>Surfclams added to Canadian Atlantic fishery regulations as limited entry fishery</td>
<td>2 Exploratory licenses and 2 permits issued for Grand Bank</td>
</tr>
<tr>
<td>Expansion and consolidation phase</td>
<td>1990-1994 Arctic Surf Clam Management Plan</td>
<td>1990</td>
<td></td>
<td>Quota shared equally between 4 EAs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1991</td>
<td></td>
<td>1 participant stops for financial reasons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1997</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1997</td>
<td>Offshore Clam Management Board established</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2002</td>
<td>Banquereau Bank quota reduced to 24,000 t</td>
<td></td>
</tr>
</tbody>
</table>

*EA = enterprise allocation.
arctic surfclams (*Mactromeris polynyma*) were found on Banquereau Bank (Rowell and Chaisson 1983, Chaisson and Rowell 1985). Areas with a large biomass of ocean quahogs were also found, but there was no commercial interest in this species.

In 1986 it was estimated that Banquereau Bank had a commercially exploitable arctic surfclam biomass of 561,000 t and maximum sustainable yield (MSY) of 16,821 t (Rowell and Amaratunga 1986). A three-month test fishery took place with three companies participating. Results from the test fishery increased the MSY estimate to 24,000 t (Amaratunga and Rowell 1986) based on the model $\text{MSY} = 0.5 M B_0$, ($B_0 =$ virgin biomass). They estimated natural mortality ($M$) with the equation $M = 3/T_{\text{max}}$ ($T_{\text{max}}$ defined as the age at which 95% of a cohort would be removed by natural mortality, equation derived from $0.05 = N_t/N_0 = e^{-M}$ with $t = T_{\text{max}}$). It was recognized that this approach makes some assumptions that compromise use of the model, especially that of equilibrium conditions within the population, and that it was based on limited data. Another approach used by Amaratunga and Rowell (1986) was to consider the biomass as a finite resource, without assumptions about natural mortality, growth, or recruitment. In this way an annual level of exploitation is established that would remove existing biomass over a defined period of time. This approach was taken to examine the time period available to gather the data needed to estimate sustainable catch levels, and not to manage arctic surfclams as a non-renewable resource. Assuming an initial biomass of 600,000 t, annual level of removals to have the resource last 10, 20, or 25 years were 60,000 t, 30,000 t, and 24,000 t respectively.

Industry involvement in management was through the Offshore Clam Advisory Committee (OCAC), established in November 1986 as an open and public forum to provide advice to the minister on all issues affecting the fishery. OCAC is responsible for development of management plans and considers fishery development, access, and allocation issues.

**Exploratory phase**

In 1987 a three-year offshore fishery program was developed with industry consensus. The fishery was to be reviewed after the 1989 fishing season. Total allowable catch (TAC) was based on biological advice from the development phase, and an economic break-even analysis on the resource required to make a vessel and processor viable. TACs were set at 30,000 t for Banquereau Bank and 15,000 t for the rest of the Scotian Shelf. TAC was broken down into enterprise allocations (EAs), shares of the TAC allocated to individual enterprises, in this case license holders. EAs are “quasi property rights” used to prevent overcapitalization in a race for a common property. Other requirements were that shore-based processing be located in the Cape Breton-Canso area of Nova Scotia, an economically depressed region, and all vessels were to be Canadian-owned and crewed.
within a set period of time. Details on the development of the fishery up to 1989 can be found in Roddick and Kenchington (1990).

During this time exploratory fishing on the Grand Bank discovered commercial concentrations of arctic surfclams. DFO received requests for licenses for this area, and in 1989 two exploratory licenses and two exploratory permits were issued for Grand Bank, with a “precautionary” TAC of 20,000. These were issued to the three current participants plus a fourth, Newfoundland-based company, and TAC for the Scotian Shelf outside of Banquereau Bank was increased to 20,000 t to include this new company. There was no scientific basis behind these TACs, as there was no biomass estimate for Grand Bank, and the developmental surveys of the Scotian Shelf in the 1980s had not found commercial concentrations outside Banquereau Bank.

By the end of the program an arctic surfclam fishery was considered viable, and in February 1989, arctic surfclams were added to the Atlantic Fishery Regulations as a limited entry fishery. Industry involvement at this phase was through OCAC and regulatory requirements, including logbooks and occasional observer coverage.

**Expansion and consolidation phase**

The 1990-1994 Arctic Surf Clam Management Plan covered the fishery on both Scotian Shelf and Grand Bank. TACs and EAs were initially the same, but when one company went out of business in 1992, allocations were revised, giving remaining participants equal access and allocations on all banks. Any changes in TAC would be equally split between license holders. Additional consolidation occurred when one of the licenses was bought out by an existing participant, leaving just two companies controlling three active licenses. Since early 1993 there have been three factory processors fishing year-round. The catch and value of the fishery can be seen in Table 2.

When the fishery started, the expected market was the U.S. Atlantic surf clam (*Spisula solidissima*) market. Due mainly to color differences, there was little demand in the U.S. market for arctic surfclams. A market was found in northern Japan, but this market was limited. In the early 1990s participants and government invested in a successful generic marketing effort to expand this market, but demand continued to limit landings.

Industry involvement during this period was still through OCAC and regulatory requirements, but industry was lobbying DFO to conduct surveys of Banquereau Bank and Grand Bank. DFO responded that it did not have the resources available to conduct offshore clam surveys.

**Mature fishery phase**

The 1995-1997 Offshore Clam Fishery Multi-Year Harvesting Plan contained several key points. TACs and EAs did not change. It contained
commitments by participants to fund a dockside monitoring program to check landed weights; to fund an economic study of the fishery by a reputable third party; and to cost-share scientific studies with DFO. The plan noted an absence of precise estimates of key parameters on which to base TACs, especially current biomass of arctic surfclams.

In 1995, facing decisions on investment in the fishery, the clam industry proposed supplying vessel time, crew, and funding over three years for stock assessment surveys, if DFO would design and carry out the assessment. Banquereau Bank was surveyed in 1996, with additional stations conducted in 1997. In addition to survey results, the assessment had information available from other studies. There was an independent economic analysis of the viability of the offshore clam fishery, which

Table 2. Landings and value for the arctic surfclam (Mactromeris polynyma) fishery.

<table>
<thead>
<tr>
<th>Year</th>
<th>Grand Bank</th>
<th>Banquereau</th>
<th>Total</th>
<th>Landed value</th>
<th>Export value</th>
<th>Cockles</th>
<th>Propeller-clams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>0</td>
<td>717</td>
<td>718</td>
<td>$71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>0</td>
<td>1,824</td>
<td>1,824</td>
<td>$2,724</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>402</td>
<td>7,666</td>
<td>8,068</td>
<td>$5,962</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>2,433</td>
<td>4,765</td>
<td>7,198</td>
<td>$8,160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>6,753</td>
<td>746</td>
<td>7,500</td>
<td>$8,607</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>11,154</td>
<td>0</td>
<td>11,154</td>
<td>$15,277</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>18,905</td>
<td>60</td>
<td>18,965</td>
<td>$25,034</td>
<td>$35,182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>15,881</td>
<td>4,590</td>
<td>20,471</td>
<td>$21,290</td>
<td>$39,448</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>14,108</td>
<td>10,427</td>
<td>24,535</td>
<td>$24,535</td>
<td>$51,374</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>6,458</td>
<td>18,745</td>
<td>25,203</td>
<td>$20,918</td>
<td>$34,991</td>
<td>96</td>
<td>153</td>
</tr>
<tr>
<td>1997</td>
<td>7,614</td>
<td>19,805</td>
<td>27,419</td>
<td>$24,202</td>
<td>$42,629</td>
<td>202</td>
<td>84</td>
</tr>
<tr>
<td>1998</td>
<td>963</td>
<td>24,695</td>
<td>25,658</td>
<td>$16,722</td>
<td>$33,514</td>
<td>36</td>
<td>63</td>
</tr>
<tr>
<td>1999</td>
<td>1,487</td>
<td>24,413</td>
<td>25,900</td>
<td>$23,783</td>
<td>$36,789</td>
<td>74</td>
<td>43</td>
</tr>
<tr>
<td>2000</td>
<td>3,775</td>
<td>19,989</td>
<td>23,764</td>
<td>$21,703</td>
<td>$31,699</td>
<td>57</td>
<td>33</td>
</tr>
<tr>
<td>2001</td>
<td>8,389</td>
<td>11,443</td>
<td>19,832</td>
<td>$17,538</td>
<td>$32,299</td>
<td>160</td>
<td>170</td>
</tr>
<tr>
<td>2002</td>
<td>6,901</td>
<td>12,492</td>
<td>19,403</td>
<td>$17,291</td>
<td>$46,665</td>
<td>757</td>
<td>437</td>
</tr>
<tr>
<td>2003</td>
<td>10,265</td>
<td>16,883</td>
<td>27,148</td>
<td>$24,193</td>
<td>$36,850</td>
<td>1,209</td>
<td>544</td>
</tr>
</tbody>
</table>

aFrom 1997 to present landed value is estimated; statistics branch no longer uses actual sales slips.
bStatistics Canada, International Trade Division, Domestic Exports of Selected Commodities, total for all provinces, arctic surfclams were first separated in 1992.
cPreliminary.
gave the economic breakeven density for the fishery as 0.09-0.1 kg per m² of arctic surfclams. A study looking at the impacts of clam dredging on the bottom (Gilkinson et al. 2003) had taken high resolution sidescan images of the bottom in an area recently fished (Fig. 3). This provided estimates of the percentage the bottom dredges had covered when the vessel moved on to a new area (Roddick and Smith 1999). Discussions of results with vessel captains as to how much additional effort they would put into these areas gave an estimate of 75% coverage of the bottom in high biomass areas.

The survey gave an estimate of 500,000 t of biomass of which 470,000 t was above commercial size (85 mm shell length). There was 344,000 t within areas with a density above 0.09 kg per m². Of this it was estimated that 75% or 258,000 t was harvestable, as the vessels could not economically cover more than 75% of the bottom area. This indicates that almost 50% of the survey biomass would not be caught. This may be considered a reserve spawning biomass, although the majority of this biomass is in low density areas where spawning success may be limited. The current TAC of 30,000 t was judged not to be sustainable as it resulted in a fishing mortality on the exploited biomass (344,000 t) exceeding $M$ (0.08). Setting $F = M$ is essentially fishing at MSY so it is usually recommended that $F$ should be set below $M$ (Quinn and Deriso 1999). The TAC was reduced to 24,000 t, which would result in an exploitation rate of $F = 0.9\ M$ on the exploited biomass and $F = 0.6\ M$ on the total biomass. For

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**Figure 3.** Tracing from sidescan image of clam dredge tracks from CFV Concordia on Banquereau Bank 1996. Dredge track width scaled to 12 feet wide (4 m). Box used for area analysis is 500 m × 125 m, percentage of ground covered within box is 67.42%.
comparison, the Pacific Fishery Management Council has used $F = 0.75 \, M$ for groundfish (PFMC 2001).

Industry began to look at other species they were catching as bycatch. The northern propellerclam (*Cyrtodaria siliqua*) was abundant on both banks, and the Greenland cockle (*Serripes groenlandicus*) on Grand Bank. Sales of these species in 1997-1998 were not followed by repeat orders and more marketing was undertaken to increase demand (Table 2). Ocean quahogs were not an abundant bycatch, but there was a large biomass on Sable Bank and southern Grand Bank. Industry made submissions to DFO for a directed ocean quahog fishery in these areas.

Following industry-funded surveys of Banquereau and Grand Bank, the clam industry entered into a series of joint project agreements (JPAs) with DFO to help fund research programs. Under these agreements the industry provides vessel time, manpower, and/or money depending on the requirements of the JPA. Part of the first JPAs signed for the arctic surf-clam fishery covered an onboard sampling program. Industry provides personnel onboard the vessel to carry out sampling programs. Various types of data were collected, one of the most important being length frequencies of the catch. Samples were taken from raw catch, retained catch, and discards. Logbooks and dockside monitoring of catch are mandatory for any license holder. Logbook data lacks accurate discard information because most of the separation of clams from the dredge contents is done mechanically and not observed by the crew. Discard rates are therefore estimated from the sampling data. Catch composition samples are periodically taken from the raw catch and all material is sorted and weighed. Accurate bycatch information will become more important as ecosystem approaches to fisheries management are implemented.

Samples are also run through the processing line to calculate conversion factors. Since all vessels involved in the fishery are freezerprocessors, catch data is recorded as processed weights, while TACs are round weights. Sampling personnel also collect samples of frozen whole clams which are sent to DFO for morphometric and age analysis. This data is used for growth studies and to estimate mortality rates. The length frequency data from these studies shown in Fig. 4 indicates a recruitment pulse, found on the eastern end of Banquereau Bank, but the rest of the population produces a single mode. The aging data, however, indicates that recruitment has not been constant. As well as the current pulse seen in the 5- to 10-year-old mode, there are at least two other modes in the age data, centered at approximately 19 and 33 years old. Since many assessment models assume constant recruitment, this would have to be taken into account.

Another JPA was signed in 1998 to help fund a multiyear program examining habitat impacts of clam dredges on Banquereau Bank (Gilkinson et al. 2003). It is providing valuable information on the impact of hydraulic clam dredging on the benthic community.
In addition to JPAs, industry involvement increased during this period with the establishment of the Offshore Clam Management Board (OCMB) in 1997. The OCMB consists of representatives from DFO and participants, and was established to oversee and direct the implementation of management plans. The management board is also responsible for recommending scientific research programs to be funded on a DFO-industry basis.

During this period there was further consolidation as the parent company of one participant bought out the clam operations of the other.

**Figure 4.** Aging and size frequency data for *Mactromeris polynyma* samples from Banquereau Bank. The growth model is a von Bertalanffy growth curve.
in 1998, so all existing participants are now controlled by one parent company, either directly or through subsidiary companies.

**Efficiency and species expansion phase**

The 1998-2002 Offshore Surf Clam Integrated Fishery Management Plan was extended for 2003. The fishery was still reporting landings below TAC due to market limitations. Participants invested in changes to vessels to improve efficiency of harvesting and processing operations to maximize return from their EAs. Tension compensating winches were installed on vessels to improve dredge efficiency during rough weather, and processing equipment was replaced and modified to increase product value and to produce different products from bycatch species. In 2003 an exploratory ocean quahog license for Sable Bank was issued, and a joint DFO-industry survey of the bank conducted. The newest integrated fishery management plan will run from 2004 to 2009 and incorporate the ocean quahog fishery.

**Discussion**

The offshore clam fishery has developed at a steady pace with few problems. The present exploitation rates appear to be sustainable, and the industry has shown its confidence in the future of the fishery with construction of a replacement vessel and a major refit of an existing vessel planned for 2004. It has stated that it will start fishing ocean quahogs in 2005. Part of this confidence may be based on knowledge that there is a large biomass of other species of bivalves on the banks. Information is collected on all clam species during surveys on the Scotian Shelf and Grand Bank, and samples of other species of clams are being collected from the bycatch in the arctic surfclam fishery for morphometrics and aging studies. For some species of interest such as northern propeller-clams, there is little information available in the literature. Preliminary age studies indicate that this species can live more than 70 years, putting their life span between arctic surfclams and ocean quahogs. Industry has encountered difficulties in marketing this species, due to its appearance when whole and the color of the flesh when processed. The Greenland cockle appears to be the fastest growing clam species of interest. It is another species of which there have been few studies. Greenland cockles have not been found in commercial quantities on the Scotian Shelf, but are an abundant bycatch on Grand Bank where their growth rate is faster than that of arctic surfclams. The data being collected will provide preliminary estimates of biomass, growth, and mortality rates. This will be available in the event directed fisheries are developed, and in preparation for the movement toward ecosystem approaches to management, which will require information on effects of the arctic surfclam fishery on other species.
There are problems in setting management targets when there are no regular surveys of the resource. MSY was used as the target reference point in the development phase of the fishery. When MSY is used as a reference point today, it is usually a limit that triggers actions aimed at reducing effort (Mace 2001). There is a variety of target reference points; a common one is a fishing mortality rate which takes a set fraction of the biomass. This can be based on empirical equations such as $F = xM$, as used for arctic surfclams after the 1996-1997 survey, or it can be set using a model such as yield-per-recruit (YPR). A YPR model can give two reference points, $F_{0.1}$ for the target mortality and $F_{\text{max}}$ for the upper limit. $F_{\text{max}}$ is the level of $F$ that results in the maximum yield-per-recruit; $F_{0.1}$ is the fishing mortality rate corresponding to 10% of the slope of the yield-per-recruit curve at the origin (Gulland and Boerema 1973). It is a more conservative level that is below $F_{\text{max}}$ with minimal loss in yield. Another approach is to set a target biomass. The fishery is managed to keep current biomass above a specified fraction of the unfished biomass. These approaches reduce growth overfishing, but do not prevent recruitment overfishing. This can create problems, especially when size of recruitment to the fishery is less than size of maturity. Approaches that set a target in terms of spawning stock biomass are an attempt to address this problem. One such approach is to calculate the spawning stock biomass per recruit (SSBR), and set a target to keep this at some fraction of the unfished state: $\text{SSBR}_{F}/\text{SSBR}_{F=0}$. Targets of 0.3 to 0.5 have been used for New England groundfish. A common lower limit used in this approach is 0.2 (Mace and Sissenwine 1993, Mace 1994, Quinn and Deriso 1999). All of these approaches will adjust allowable catch to match changes in biomass, which may increase yields over the long term. They require estimates of current biomass and are usually used in conjunction with a full age-structured model. This implies regular survey and catch sampling programs to collect required data.

A different approach is to set a maximum constant yield (MCY) (Annala 1993, Caddy 1998). The MCY is a yield that can be taken at an acceptable level of risk at all probable levels of the stock. Catches taken under this approach will be lower over the long term than those taken by the previously mentioned approaches, as the MCY method does not change catch levels to match changes in stock biomass. An MCY approach can be used in data limited situations, but perhaps even more important, it does not need regular estimates of population numbers or biomass to see where the fishery is in relation to its target. An MCY is often set with such empirical formulas as $2/3 \text{ MSY}$, $0.25 \text{ Mb}_{0}$, $0.5 F_{0.1} \text{ B}_{av}$ or $0.5 \text{ MB}_{av}$ where $\text{B}_{av}$ is average historical biomass (Annala 1993, Zhang 1999). There are factors that will increase or decrease these levels as well. If age of recruitment is above age of maturity, the population is better able to withstand higher fishing pressure (Clark 1991), and yield can rise with increasing age of first capture. Although the management agency does not have to
constantly check where the stock is in relation to the target, it must still monitor the stock, as any large changes in recruitment, growth rates, or other population parameters may produce biomass levels below that seen prior to setting the MCY and hence result in overfishing.

The MCY approach has been proposed for ocean quahogs on Canada’s East Coast. The largest problem in managing an ocean quahog fishery will be that it is a very long-lived and slow growing species. In the U.S. fishery, much of the catch consists of ocean quahogs between 70 and 100 years old, and the oldest age to date was over 225 years old (Ropes and Murawski 1983). This means that sustainable allowable catch must be a small fraction of biomass. For fisheries on long-lived species such as this, low exploitation rates mean that effects of fishing will not be discernable from natural variations in the population under study. Since most methods used in fishery models require variation in the data in order to fit parameter estimates, model-based methods will probably not be capable of providing precise estimates of all parameters.

In 2002 there was a survey of an inshore ocean quahog bed funded by the inshore clam fishery. Since it is unlikely that a regular survey series or catch sampling program will be established in support of this small inshore fishery, it will have to be managed as a data-poor fishery. An MCY approach was proposed to set an allowable catch. Data available included a biomass estimate from the survey, mortality rates for ocean quahogs from the literature, and some age and size of maturity data for the area from Rowell et al. (1990). Estimating $MCY = 0.25 MB_0$ provides a conservative catch level for this bed for start-up of the fishery. As the fishery develops, data for growth and mortality estimates specific to this area can be gathered and compared to those taken from the literature. Catch levels can be refined as more data becomes available, and a decision can then be made if it is worthwhile to move to more data intensive methods. A similar approach is envisioned for the start-up of an offshore ocean quahog fishery, but there is a higher probability that regular surveys and catch sampling will be established to allow for less conservative yield estimates.

A similar approach can be taken for the Greenland cockles and northern propellerclams. Their catches were recorded during clam surveys of Banquereau, Grand Bank, and Sable Bank, and aging of samples from commercial catches is supplying estimates of growth rates. There are no estimates of mortality rate in the literature, but preliminary estimates could be calculated using life history invariants, general relationships that exist between such life history traits as natural mortality, life span, and growth rate. Pauly (1980) has described an empirical relationship between $M$, the von Bertalanffy growth parameters, and mean annual water temperature. Froese and Binohlan (2000) have included such parameters as maximum length and length at maturity to derive their equations. These relationships are very general, but with the difficulties of deriv-
ing direct estimates of natural mortality they may be the best estimates available for a considerable period of time. The applicability of these relationships would have to be verified with bivalves, as most of the data used to derive them is from finfish.

Increasing interest in directed fisheries for bivalves on the Scotian Shelf at a time of decreasing DFO budgets means that initial management of these stocks will have to rely on methods that do not require many resources. As most developing fisheries take a few years for the landings to reach allowable catch levels, it is anticipated that by the time yields based on such methods as MCY have become restrictive, data required to move to models that are less conservative will be available. The risk is that if the fishery continues for this initial period without a problem, resources will not be put into gathering required data, and the assessment process will be no further ahead when landings reach the allowable catch.

Part of the decision on which approach to take will depend on the fishing industry. Does it feel that increased catches, made possible by methods that can react to changes in the population, are worth the additional costs they will have to bear to support the data requirements? Managers also may have to deal with a mixed species fishery if the arctic surfclam fishery expands into other species. Of the species presently being examined, Greenland cockles are faster growing than arctic surfclams, and northern propellerclams are slower. If commercial sizes are above size of maturity it is probable that sustainable exploitation rates will be related to growth rates. For a mixed species fishery, does this mean that exploitation rates should be set at a level to keep the slowest growing species at a sustainable biomass? With the movement toward ecosystem and precautionary approaches to fisheries management, decisions on such issues will have to be made even in the absence of multispecies fisheries.

Managers will also have to address the question of independence of management advice when it is increasingly based on data provided by the industry being managed. The JPA approach to research questions is increasing throughout DFO, and there are both benefits and problems with this type of arrangement. The benefit to DFO is that costs are being absorbed by industry, although it must still provide people and resources for analysis and assessment activities. For industry, costs are lower than for an independent sampling program, such as the observer program on the East Coast. Sampling is also more tailored to the fishery than it would be under the observer program, which, because it was designed to cover a variety of fisheries, is a “generic” program. Another advantage is that industry and personnel onboard vessels are more directly involved in the assessment process, provided they are given some feedback on results. The largest disadvantage is that data are not collected independently. Sampling data can be compared with survey and monitoring data for verification, but it can always be argued that fishery participants could
manipulate data to help pursue their own agenda. At present the arctic surfclam industry has little incentive to misreport. There is no reason to high grade or discard catch as the TAC is not limiting, and they have supported research on the habitat impacts of the fishing gear. This may not be true of all fisheries.

JPAs to date have covered regular sampling and research, a large research program on the habitat impacts of the clam dredges on Banquereau Bank (Gilkinson et al. 2003), a genetics study of the population structure of the arctic surfclam stocks on the East Coast, surveys of Banquereau Bank and Grand Bank, and a survey of the ocean quahog (*Arctica islandica*) stocks on Sable Bank. This is work that would not have been carried out without industry cooperation and funding; thus both DFO and industry are making decisions based on better information than they would have without these cooperative arrangements.

**Conclusions**

The offshore clam fisheries on the Scotian Shelf target long-lived, slow growing species. When this is combined with declining science budgets in DFO, management of this resource will depend on data limited methods or funding from participants to cover the cost of more data intensive methods. The level of industry cooperation and funding for research and stock assessments has been a positive influence on development and management of the resource. The research has provided information on the life history of both target and bycatch species, in some cases giving the first estimates of growth and mortality rates. Improved data and parameter estimates enhance the basis for advice, but raise questions on the independence of advice. Scientists and managers will have to be prepared to defend results based on data gathered by the industry that the data is being used to regulate.

At present the offshore clam fishery is healthy and appears to be sustainable. If it moves into new species and areas in the near future more research will be needed, and surveys should be conducted in advance of the fishery. As the fishery moves forward and management moves toward ecosystem-based approaches, there will be new questions on the optimal management strategy. More information will be required on the effect of the fishery on other components of the ecosystem, and how to balance the fishery components with broad system-wide ecosystem objectives.
References


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