Science and Sustainable Fishery Management: The State of the Newfoundland Lobster Fishery

By

Jerry Ennis (Retired DFO Scientist)

Introduction

The fisheries management decision-making process in Newfoundland has always been a very difficult one and, despite good intentions on all sides in recent times to make it more cooperative, it continues to be highly adversarial. The opposing short-term economic interests of industry and long-term sustainability objective of resource management are always difficult and usually impossible to reconcile – decisions often leave sustainability compromised despite Canada's commitment to applying precautionary approach principles in fishery management. At the heart of the problem is the usual outright rejection by fishermen of scientific advice when it supports remedial management measures that mean short-term financial loss, which is most often the case. This is understandable, but it leads to ineffective discussion and consideration of scientific issues in the consultative part of the decision-making process and contributes to a general lack of understanding among fishermen of basic principles of fishery science applicable to the particular species.

Objective consideration of fishery science during formal consultations will always be compromised to some degree by overriding short-term economic issues. However, there has to be a serious attempt by fishermen to engage in reasoned debate of science issues if they are to achieve an understanding of the risks to long-term resource sustainability of current management practice – it surely wouldn't be a stretch to consider such to be an element of responsible fishing. Opportunities for discussion between fishery scientists and fishermen are very limited and totally inadequate for them to develop a proper understanding of each other's perspective on resource status and sustainability of the current fishery. The situation is unlikely to change appreciably unless both scientists and fishermen make a concerted effort to communicate more effectively. For scientists this should include preparing much more material intended for broad distribution among the fishing community and for harvesters an effort to access any available material and study it. This would go a long way towards providing a basis for real discussion of science issues during the infrequent opportunities that scientists and fishermen have to meet face to face.

My purpose here is to bring together in a single document material covering some of the basic principles of fishery science as they relate to the Newfoundland lobster fishery as well as various aspects of lobster population dynamics important to an objective consideration of the current management regime.

Components of the Lobster Fishery Management Regime

This account of lobster fishery management in Newfoundland provides background that will help to provide context for the more detailed biological considerations of the current management regime to follow.

Since a major task force review of the lobster fishery in Atlantic Canada, which reported in 1974, effort control, as opposed to catch control practiced in just about every other major fishery, has underpinned its management. The main component of effort control is restricted licencing. Introduced in the Newfoundland fishery in 1976, its main purpose was to eliminate so called moonlighters, those with some form of employment ashore and therefore less dependency on fishing, from participating, thereby making the fishery more economically viable for the bona fide fishermen who remain. Licencing policy in combination with licence buy out/early retirement programs of the 1990s reduced the number of licences in the Newfoundland lobster fishery by more than half from around 6000 in 1976 to less than 2900 in 2005. The vast majority of current licence holders have professional fish harvester status and in most areas around the island their licences have substantial monetary value. A qualified fish harvester wishing to enter the lobster fishery must arrange transfer of an existing licence to do so. Further significant reduction in the number of licences is unlikely without a new buy out program.

The second main component of effort control in the lobster fishery is trap limits. Prior to 1976, fishermen indicated on their licence applications for a given year the number of traps they intended to fish. The 1975 number was the individual trap limit applied to licence holders under the restricted licencing introduced in 1976 – the total allowed in the fishery that year was just over 740,000 traps. By the early 1990s, uniform trap limits (the same number for each licence holder) had been established for all Lobster Fishing Areas (LFAs) around the island – originally trap limits were set well above the average established in 1976 and this increased the total allowed or registered traps to almost 1.2 million. Through trap limit reductions in most LFAs as well as licence reductions during the 1990s, the number of registered traps finally dropped below the number in 1976 when trap limitation was introduced – the total is around 650,000 at the present time. In the absence of any effective means of enforcement, there was widespread disregard of trap limitation in the fishery even after uniform limits were established for each LFA. The use of tags to mark individual traps as legal, introduced in most areas during the 1990s, has provided an enforcement tool that appears to have curbed the use of excess traps and the established trap limit, which varies between LFAs and ranges from 100 to 425, is the number actually used in the fishery by the vast majority of licence holders.

Seasons too can be considered a component of overall effort control but have been in place for a very long time and were undoubtedly established based on practical as well as conservation considerations. While seasons restrict fishing to a relatively short period in spring-early summer, they have lead to an extremely intensive fishery that in productive areas harvests almost all the commercially legal lobsters available each year. Traditional season closing dates in the Newfoundland fishery varied from June 30 on the south coast to July 15 on the northeast coast and were clearly set to avoid fishing when summertime life-history activities (molting, mating, spawning and hatching) are underway in the population. Seasons were shortened somewhat in most LFAs during the 1990s supposedly to address conservation concerns, however, it had been common throughout the fishery for the bulk of the traps in use to be landed 2 or 3 weeks or even longer before the end of the season at any rate. In recent years, there has been increasing pressure from harvesters in some marginally productive fishing areas to delay season opening and extend the closing date to the end of July. Doing so would set a precedent that is clearly incompatible with prudent conservation practice.

The two main conservation measures that have been part of lobster fishery management from very early days are those protecting berried females and establishing a minimum legal size. Up until the early 1930s, the entire Newfoundland lobster catch was processed in many small canning operations all around the coast and early documentation indicates that enforcement of regulations was virtually non-existent. By the early 1950s, the transition to a live market industry was complete and this allowed for a far greater degree of enforcement. The U.S. was the only market for live lobsters from Newfoundland during this period and it essentially set the minimum legal size of 81 mm (3 3/16 in) carapace length (CL) based entirely on marketing considerations. It should be noted that conservation, strictly speaking, relates to the protection of a sufficiently large portion of population spawning potential to ensure that what is removed by the fishery and lost through natural mortality is replaced by new recruitment on an ongoing basis. In Newfoundland lobster populations a small proportion of females spawn for the first time at sizes below 81 mm CL – this makes the minimum legal size a critically important conservation measure because the level of exploitation once animals grow to legal size is very high. The 1.5 mm increase to the size limit implemented in 1998 will be covered in a later segment of this document.

A 1 ¾ inch spacing between the two lower laths has been required for traps used in the Newfoundland lobster fishery for a very long time. This provides a mechanism that provides undersize lobsters the opportunity to escape from traps before they are hauled thereby reducing injury and mortality due to handling in repeated catch and release over the fishing season. Its primary function therefore is to optimise utilization of recruitment due to become available to the fishery the following year. Nevertheless, it does have conservation implications in that egg loss from undersize berried females is much reduced and injury to or possibly even loss of non-berried undersize females, some of which would spawn later in summer, is reduced as well.

Biological Considerations of Fishery Management Objectives

Renewable marine resources are utilised by man primarily as a source of food. While there may be many extenuating considerations in that regard depending on the species being harvested, in general, the main objective of fishery management for a stock of any particular species consistent with its use as food is to allow for the highest annual catch without depleting the resource and compromising future catches. This is the objective that provides the basis for this consideration of lobster fishery management.

The basis for a sustainable yield fishery is the annual production (growth plus new recruitment) which occurs in the population (stock). In a virgin population the biomass is composed mainly of old, slow-growing individuals, annual production is low and basically just enough to replace or compensate for the loss from the population through natural mortality. A new fishery removes the accumulated biomass of old fish fairly rapidly and this triggers dramatic changes in the population. Increased availability of resources (food and space) leads to increased survival and faster growth of young fish along with a reduction in age (size) at maturity and increased fecundity. These dynamic responses to exploitation result in greatly increased annual production within the population. There is a limit of course to a population's capacity to compensate for increased removals and in most fisheries this limit is exceeded. Continued harvesting in excess of its capacity to produce inevitably results in decline of the population and greatly diminished annual production. We are generally faced with trying to manage a fishery at a low annual yield on a "sustainable" basis. Such a fishery is one that is inherently unstable (but not necessarily unsustainable) because the risk of recruitment failure is high and abundance fluctuates widely as dependence on one or two very strong year classes increases. The longer such a situation continues, the greater the likelihood of the kind of ecological shift, for instance, increased abundance of underutilised or non-commercial species that are prey for adults but predators on one or more of the early life-history stages, that would greatly impede population recovery if it were attempted.

Even in cases where the scientific basis for stock assessment has appeared to be reasonably sound, catch levels (TACs) at anything close to the estimated maximum sustainable yield (MSY) have usually resulted over time in major decline or even stock collapse. Even a more conservative harvesting strategy known as optimum sustainable yield (which considers increased earnings due to lower operating costs required to harvest the lower TAC – more or less equivalent to fishing at F0.1) has not provided a basis for managing fisheries sustainably. The reasons why attempts to manage fisheries have, for the most part, been so unsuccessful are not entirely clear and undoubtedly have been varied and complex. Actual removals from stocks far in excess of established TACs, invalid assumptions and other uncertainties included in even state-of-the-art scientific assessments, as well as the general inadequacy of single-species, stock-by-stock assessment and management are all likely contributing factors. What has become clear, though, is that ecological processes in the sea are far more sensitive than could have been imagined to the impacts of fishing activity and the high level of removals that have been and still can be generated by present day fisheries. The bottom line is that the effective sustainable yield from a fishery resource is far less than a MSY estimated by conventional stock assessment methods.

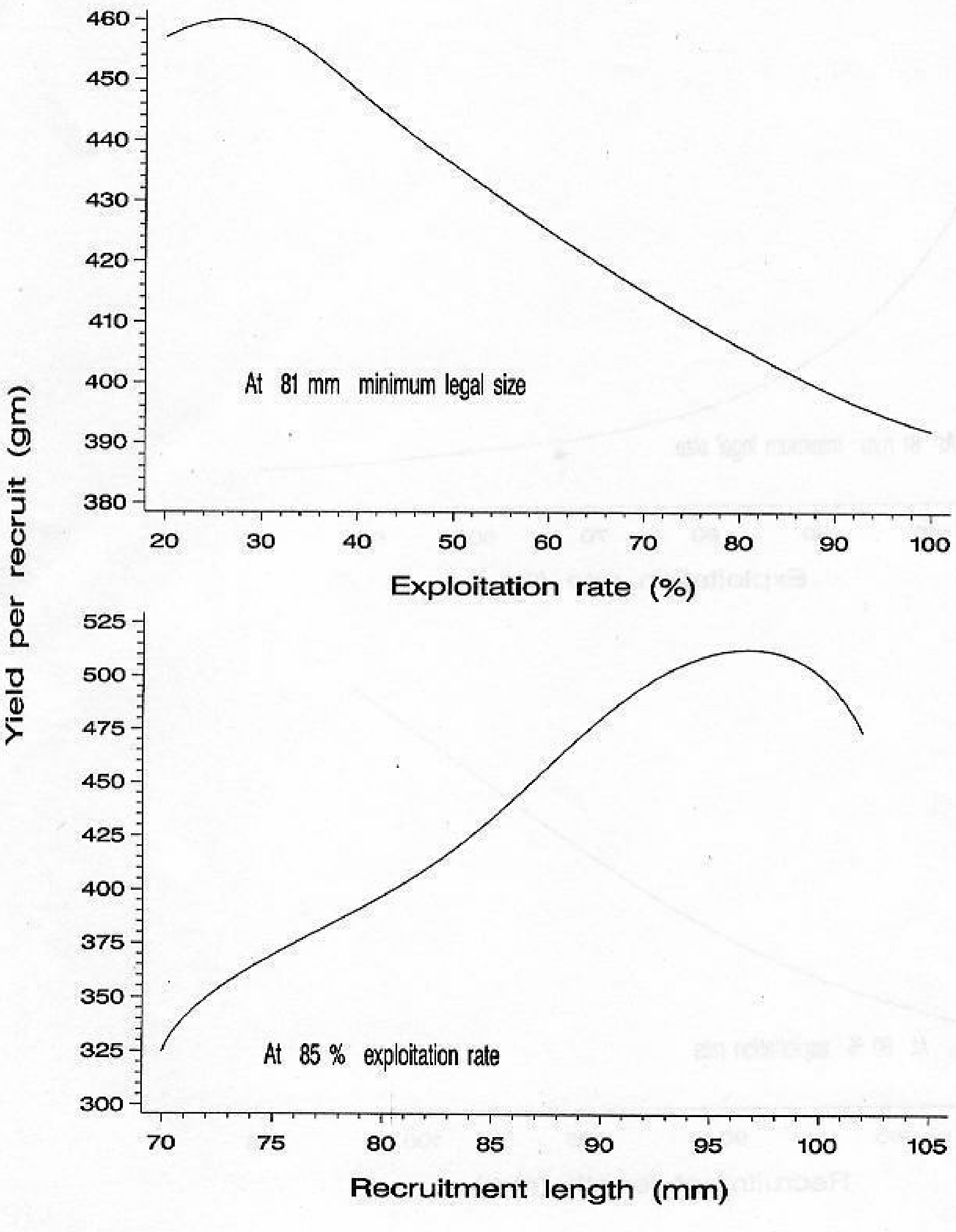
With the foregoing as backdrop, management of the Newfoundland lobster fishery for sustainable yield can be considered in some context. Management of fisheries on some sort of ecosystem basis is still very much a thing of the future. Nevertheless, of all the major commercial species exploited in Newfoundland waters, lobster is probably the one best suited to single-species assessment and management because of its shallow-water, near-shore distribution and limited overlap with other commercially important species.

As with any other species, there are two components to achieving the highest possible sustainable yield from the lobster resource. First there must be sufficient spawning biomass or annual egg production to ensure that recruitment to the fishery in subsequent years is as high as possible. Second, incoming, new recruitment to the fishery must be allowed to achieve a large enough measure of its growth potential to ensure that yield per recruit is as high as possible.

Yield per recruit will be considered first and to start it would be helpful to describe the growth of a single year class over its lifespan in the absence of a fishery. Any given year class starts off as a very large number of tiny individuals (larvae). While the natural mortality rate is very high, individuals surviving grow rapidly and the overall, total weight (biomass) of the year class increases fairly rapidly during the early years of life. This continues through juvenile stages as growth rate remains high and the natural mortality rate declines, but total weight of the year class will eventually peak or level off at a size (or age) that roughly corresponds to the size at which the majority of individuals have become sexually mature. Thereafter, as individual growth rate slows appreciably, weight loss due to natural mortality exceeds gain due to growth and total weight of the year class declines until it eventually dies out. In the context of a lobster fishery, achieving maximum yield from this year class will depend on the minimum legal size that is established and the rate of exploitation that will be applied to legal animals.

Generalized representation of the total weight of a year class of a species over its life span in a population.

If the rate of exploitation is very high, the appropriate minimum legal size would be that corresponding to the peak in the total weight of the year class. If the rate of exploitation is low, the appropriate minimum legal size would be a fair bit smaller to allow several fishing seasons to harvest new recruitment before it starts reaching the larger sizes at which total weight of the year class is in decline. In relation to this generalised model, yield per recruit analyses done for Newfoundland lobsters in the late 1970s demonstrated that the 81 mm CL size limit was too small for the 85-90% exploitation rate prevailing in the fishery. Very clearly, the management regime was resulting in what is known as growth overfishing and the results indicated that yield per recruit could be increased by around 30% with the right combination of minimum legal size and exploitation rate.



Yield per recruit analyses for the Arnold's Cove lobster population.

To achieve this extra yield, however, would require an increase in minimum legal size to around 95 mm CL or, alternatively, a smaller size-limit increase combined with a very substantial reduction in exploitation rate which could only be achieved by massive effort reduction. At the time, effort reduction was an established management strategy and there was overwhelming resistance from the harvesting sector of the industry to even very small increases in size limit spread over time that would have reduced the short term impact to negligible.

It was also during the 1970s, following a 20-25 year period of declining landings throughout the Canadian and U.S. lobster fisheries, that fishery scientists first raised the spectre of recruitment overfishing. It was apparent that size limits that were small in relation to size at maturity combined with high exploitation rates on legal animals were resulting in too little egg production in the overall population to sustain the high level of removals.

By the late 1970s - early 1980s it was apparent that the downward trend had bottomed out and a major recovery was underway. This new upward trend was as widespread as the preceding downward trend had been. It continued through the 1980s and in many areas landings reached unprecedented levels. Landings in the Newfoundland fishery peaked in 1992 at a level that was the highest recorded since 1905.

The reversal in trends was not only unexpected but, for the most part, inexplicable as well. The widespread nature of the recovery and the extent to which the trend in landings continued upward provide a strong indication that it was triggered and partly sustained by broadscale environmental and ecological conditions that were very favourable to lobster larval survival. This generated strong recruitment which increased population egg production at the higher level of abundance which in turn would have contributed to sustaining strong recruitment.

When the recruitment bubble burst, however, landings declines throughout Atlantic Canada were severe enough to trigger widespread concern which lead to a comprehensive review by the FRCC, its first ever of an invertebrate fishery. Its 1995 report renewed and greatly heightened concerns about recruitment overfishing throughout Atlantic Canada. It concluded that population egg production was being constrained at much too low a level by the combination of very high exploitation rates on legal lobsters and minimum legal sizes that were too small in relation to size at maturity. The FRCC recommended that management measures be implemented to increase egg production.

In the Newfoundland fishery it was clear that the overall level of exploitation on the lobster resource had increased to a very high level despite the substantial reduction in licences and trap limits that had been achieved under the licencing policy implemented in 1976. By the mid-1990s licences had acquired substantial monetary value and transfers to eligible fish harvesters was allowed. This virtually eliminated attrition and left buy-out by the federal government as the only effective way to achieve any further reduction in the number of licences.

It was recognized, however, that resource conservation needs would not be met by way of a reduced exploitation rate through ongoing effort reduction. Consequently, in 1998, as part of a long-term management plan (two multi-year plans that lasted through the 2005 season) a 1.5 mm increase in minimum legal size (to 82.5 mm CL) was imposed and the harvesting sector committed to the practice of v-notching berried females on an ongoing basis.

One can readily conclude from the foregoing that average annual yield from the lobster resource has been well below what would have been possible under much more moderate exploitation that would have allowed higher long-term, average recruitment as well as higher yield per recruit.

Egg Production in Newfoundland Lobster Populations

In Newfoundland populations, female lobsters start to lay eggs at sizes about 10-15 mm below minimum legal size and very occasionally at even smaller sizes. However, only very low percentages spawn at such small sizes, those that do usually molt and spawn in the same summer and, of course, they produce very small numbers of eggs. The percentage of females that will spawn in any given summer increases with increasing size and so does the number of eggs produced. The incidence of molting and spawning in the same summer drops to zero at sizes around the minimum legal which is also the size at which approximately 50% of the females will spawn for the first time. This means that the majority of females will not spawn until after they reach sizes larger than the legal size limit. These females have to molt (and mate) while still undersize and grow to commercial size in one summer but have to survive the spring fishery before actually getting a chance to spawn the following summer. The eggs are carried externally attached under the tail for about a year before they are fully developed and ready to hatch. Soon after hatching is completed, the female will molt and mate, beginning again the two-year reproductive cycle which is the norm beyond the initial spawning.

With exploitation rates in all productive fishing areas running in excess of 90%, the vast majority of female lobsters are taken by the fishery before getting a chance to spawn at all. As a result, the overall level of population egg production is a very low percentage of the potential, or what it could be if females were not exploited. In addition, over 80% of this very limited egg production is by undersize females almost all of which are spawning for the first time. Their eggs are of lower quality that result in larvae with a lesser chance of survival compared to eggs produced by large females spawning for the second or third time.

Egg per recruit models were developed in the 1980s as a basis for predicting the extent to which population egg production could be increased by small changes to the existing management regime. Results showed very clearly that egg production, just like yield per recruit, would be increased quite substantially by an increase in minimum legal size or a reduction in exploitation rate on the legal component of the population. Egg production per recruit (E/R) estimates provide an index of the relative level of egg production in a population under any particular management regime. More straightforwardly, E/R can be considered as an indication of the percentage of the females with ripening ovaries (i.e. getting ready to spawn) present in the population during spring that actually get a chance to spawn later in the summer. However, in terms of maintaining a high level of recruitment in a population, it is really the total number (in absolute terms) of eggs produced each year that is important and this depends on the overall level of population abundance as well as the percentage of females that get a chance to spawn. Total annual egg production could be high if abundance is very high even at a low E/R value but, if abundance is low a much higher E/R value will be needed to obtain the same high total annual egg production.

At the time that the FRCC was reviewing the Canadian lobster fishery, the fishery management system in the U.S. arbitrarily decided to define recruitment overfishing in lobsters as an E/R level that was 10% of what it would be in an unfished population. The FRCC asked Canadian lobster scientists to generate estimates to indicate where our fisheries were in relation to this 10% rule. Under the time constraints that were imposed, this could only be done by running existing E/R models at a 0% exploitation rate to estimate the E/R value in an unfished population. This was recognized by the scientists involved as a rather tenuous proposition, but, unfortunately, once estimates are generated they tend to get cast in stone for the sake of expediency.

The FRCC reported the relative E/R level for various lobster populations around Atlantic Canada, including Newfoundland, to be approximately 1-2% of what it would be in unfished populations. These were the very first estimates to indicate just how low egg production was in Canadian lobster populations generally, and, when compared with the American 10% E/R recruitment overfishing definition, suggested that the risk of recruitment failure under current management regimes was extremely high. The FRCC recommended that management measures be implemented as soon as possible to bring the E/R level up to 5%. Options suggested to achieve this target included size limit increase, the practice of v-notching, establishment of closed areas, and, of course, reduction in exploitation rate on the legal component of the population.

In ensuing consultations between DFO and stakeholders, elsewhere as well as in Newfoundland, there was strong resistance to implementation of measures that would be required to achieve the degree of egg production increase recommended by the FRCC (essentially a five-fold increase from 1% to 5% E/R). Eventually, DFO Regional Resource Management Branches throughout Atlantic Canada were directed by Ottawa HQ to develop four-year management plans for implementation in 1998 that would include measures to double the E/R level. Even this directive, much watered down from the FRCC recommendation, was strongly resisted throughout Atlantic Canada. There was a perceived inequity among lobstermen in some areas of Atlantic Canada regarding the relative impact of conservation measures required to achieve the E/R doubling objective that was associated with differences between areas in estimated E/R levels. This resulted in much confusion and controversy that fuelled the resistance. Nevertheless, two conservation measures were included in the management plan to achieve the E/R doubling objective in the Newfoundland fishery. A 1.5 mm increase in minimum legal size was imposed by DFO and representatives participating in the advisory/consultative process committed licence holders generally to the practice of v-notching at the rate of 25% annually.

Independent of the foregoing process and at the initiative of stakeholders, two small closed areas were established near the Eastport Peninsula in 1997 as part of a local lobster fishery co-management agreement between licence holders and DFO. Over the following several years, an additional seven closed areas were established by local stakeholders at five other locations around the island. Given the general resistance to implementation of conservation measures evident during development of the 1998 management plan, this was unexpected and represents an unprecedented development in terms of stakeholder stewardship initiative. The closed areas established to date, although a very small portion of the total lobster habitat around the island, collectively represent a meaningful contribution to conservation of the Newfoundland lobster resource.

Estimating Egg per Recruit for an Unfished Population

Egg per recruit models serve the purpose for which they were originally developed quite well. When run at the high exploitation rates that prevail in the fishery, there is limited opportunity for large error in estimating total egg production for an initial model population given that it disappears through removals in the fishery as well as through natural mortality in just a few annual cycles. On the other hand, when run at 0% exploitation rate to represent an unfished population, it takes many, many annual cycles before the initial model population disappears through natural mortality alone. In this unfished, model population, many lobsters reach very large sizes and the vast majority reach sizes at which life-history parameters and sequences (percent molting, molt increment, percent mature, alternate year molting/laying, fecundity, etc) are very lengthy extrapolations beyond the size range of the actual data originally used to develop the various biological relationships. All this leaves considerable opportunity for error in estimating total egg production for an unfished, model population and therefore much uncertainty in the reliability of the estimate of relative population E/R level (i.e. the E/R value for the current fishery expressed as a percentage of what the E/R value would be if the population were unfished).

For purposes of egg per recruit estimation, a model was developed specifically for Newfoundland lobsters. Results that are considered generally representative of Newfoundland populations were generated using a complete set of the necessary biological relationships which had been obtained from studies conducted at Arnold’s Cove, Placentia Bay. The egg per recruit level under the current management regime (defined at the time as 81 mm CL minimum legal size and 85% exploitation rate on legal lobsters) was estimated to be just under 1% of what it would be if the population were unfished.

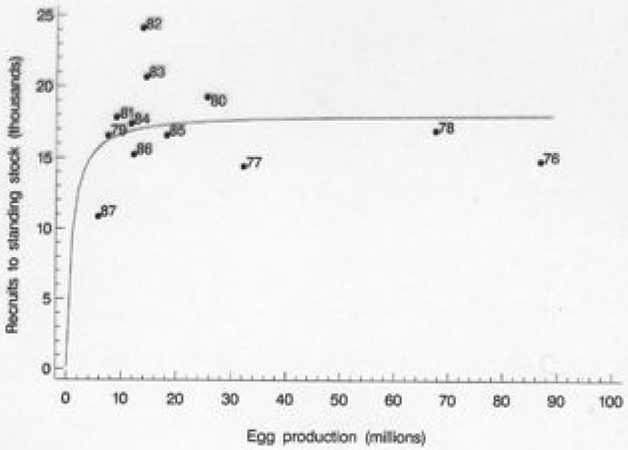
Subsequent to the FRCC review, the egg per recruit model was modified by incorporating life-history parameters for large lobsters based on data from the study of lobsters at the Shag Rocks, a small area in Long Harbour, Placentia Bay that had been closed to fishing for research purposes from 1976 to 1989. It was felt that these changes would enable the model to generate much more realistic estimates of egg production when run at 0% exploitation rate to represent an unfished population. This reduced the estimate of total egg production for the initial population (when the model was run at 0%) sufficiently to increase the estimated E/R level under current conditions from just under 1% to just over 4% of an unfished population. This meant that the management measures implemented in 1998 to achieve a doubling of the E/R level from 1% to 2% would have, in effect, increased it from 4% to 8%.

While this re-analysis probably provides a more realistic result, one must realize that any estimation for an unfished population is a very tenuous proposition that will include a great deal of uncertainty under the best of circumstances. This result indicates that the E/R level is probably not as drastically low as originally reported by the FRCC. Nevertheless, it is still pretty low. A completely reliable estimate of the E/R level under current conditions in the fishery (expressed as a percentage of what it would be in an unfished population) is not likely to be possible anytime soon. However, more important to the question of recruitment overfishing is the E/R level required to eliminate the risk of recruitment failure – a definitive estimate is just as unlikely.

Hopefully the foregoing will help to clarify egg per recruit analysis in general and eliminate some of the confusion that has plagued it since the concept was introduced to industry at large by the FRCC. In considerations of stock and recruitment that follow, I will focus more on population egg production in absolute terms and thereby try to discuss recruitment overfishing in a more straightforward manner.

The Relationship Between Egg Production and Recruitment in a Lobster Population

The best estimate of age at recruitment to the standing stock (i.e. the commercially legal component of the population) in Newfoundland lobster populations is 8-10 years. A long-term study of lobsters at Arnold’s Cove yielded a 21-year (1976-1996) series of annual estimates of population egg production and recruitment, and, using a 9-year lag (between hatching and subsequent recruitment), the relationship indicated is a curve with a very steep ascending limb that levels off near the low end of the egg production range and remains fairly flat-topped even at high egg production values. This suggests that only at the low end of the range would recruitment increase in relation to increasing egg production. There would appear to be some sort of control mechanism, probably related to habitat carrying capacity, tending to constrain recruitment at high levels of egg production.



Estimates of egg production for 1976 to 1987 and recruits to the standing stock (commercially legal portion of population) 9 years later for the Arnold's Cove lobster population fitted to the Beverton and Holt stock–recruitment model. Numbers adjacent to the data points indicate the yearclass.

There are some uncertainties that must be kept in mind, however, in any consideration of this relationship. Recruitment of a particular year class to the standing stock will most likely be spread over several adjacent years, rather than in a single year, because of variation in individual growth rate as well as differences between males and females. This will tend to obscure the relationship between egg production in one year and recruitment in a particular subsequent year. Also, processes and mechanisms which determine where larvae that originate in an area eventually settle are not completely understood and the extent to which recruitment to a localized population (i.e. postlarval settlement as distinct from recruitment to the standing stock) originates with egg production within that population is not known. More than likely, depending largely on spatial scale, the postlarvae that settle in an area originate from eggs produced within the area as well as from outside, and the mixture undoubtedly varies between areas as well as from year to year in any given area.

Just one other attempt has been made to determine the nature of the stock-recruitment relationship in a lobster population. One very similar to that described above was derived from data for a Southern Gulf of St. Lawrence population. A S-R relationship with a very steep ascending limb, like that indicated here for lobsters, suggests a species with a very high resilience to fishing , but also one in which the line, in terms of population egg production, between low and very high risk of recruitment failure (or recruitment overfishing) is very fine indeed. It should go without saying that defining this line with any degree of confidence is very difficult to do. Only one attempt to do so has been made for a lobster population and it was based on stock-recruit and egg per recruit estimates for lobsters at Arnold's Cove.

The approach is based on the concept that the recruits of one generation must, on average, produce enough eggs to replace their parental generation. Without getting into its very technical aspects, the analysis indicates that the so-called "threshold" for replacement is somewhere in the immediate vicinity of the level of egg production achieved under the current management regime. What this means essentially is that at the present size limit the lobster population can sustain exploitation rates on the legal component well in excess of 90% with relatively low risk of recruitment overfishing. This supports the notion that lobster populations have a built-in, very high resilience to fishing, but there are a fair number of considerations making it necessary to interpret this result with considerable caution.

Some of the uncertainties associated with determining a relationship between egg production and subsequent recruitment in lobsters have already been mentioned along with those associated with the egg per recruit model, especially its use to estimate egg production for an unfished population. An additional consideration is the fact that determination of the recruitment overfishing threshold referred to above would be affected by underestimation or overestimation of the egg production and recruitment values on which the stock-recruitment relationship is based. Also, the approach is most appropriately applied to a species with little resilience to fishing and to S-R data collected during a period when environmental/ecological conditions affecting survival are average. The Arnold's Cove S-R data were collected during a period of strong recruitment associated with very favourable conditions for survival, so, on both these counts, the analysis described here was less likely to detect recruitment overfishing.

Also, small pockets of mostly large lobsters occur in many areas around the island. In Newfoundland waters lobsters tend to be restricted to a narrow band of rocky-bottom habitat along the shore. Areas adjacent to exposed headlands are lightly exploited because of rough seas during much of the fishing season. Such areas yield small numbers of mostly large lobsters that are rarely seen in heavily exploited areas within the bays. Small pockets of large lobsters may also originate because some individuals have low vulnerability to capture in baited traps and avoid capture long enough to reach sizes at which entry to standard traps is restricted. Relatively small numbers of large lobsters may represent refugia that produce enough high-quality eggs to provide some of the resilience to fishing that lobsters exhibit and could confound analyses aimed at defining a recruitment overfishing threshold.

A cautionary interpretation of these analyses, therefore, would conclude that the current management regime results in a level of egg production very close to the recruitment overfishing threshold where the risk of recruitment failure during periods that conditions for larval/postlarval survival are unfavourable is very high.

I will now try to cast the above consideration of egg production and recruitment in terms of general precautionary approach principles of fisheries management. Simply put, the precautionary approach is all about managing a fishery to ensure that the spawning component of the stock is maintained at a level high enough to provide strong recruitment to sustain the fishery over the long term. It means, in effect, a fishing mortality rate or level of removals (i.e. yield) well below that associated with the MSY estimated in a traditional way. In the past, the typical fisheries management practice (i.e. non-precautionary approach) would have considered an estimated MSY to be the allowable catch. The much-lower-than-MSY catch level is referred to as optimum yield, and, beyond the cost-benefit considerations mentioned earlier on, under precautionary approach it is considered in a much broader sense to be the catch level providing the greatest benefit to the nation, particularly with respect to food production, but also taking into account recreational opportunities as well as protection of the marine ecosystem.

The precautionary approach defines three reference points in terms of spawning stock biomass (SSB). B(lim) is a very low or “limiting” level of SSB below which it should not be allowed to fall and at which the risk of stock collapse is extremely high – it can be considered the equivalent of the recruitment overfishing threshold described above. B(buf) is a level of SSB substantially higher than B(lim) which acts as a “buffer” against SSB falling to the B(lim) level. The greater the degree of uncertainty in estimating B(lim), the higher B(buf) should be. The precautionary approach requires that immediate management action be taken to ensure stock rebuilding if SSB has fallen to B(buf). B(tr) is the “target recovery” level to which SSB is to be rebuilt if it has been allowed to fall to a lower level. It is the SSB that would generate MSY and below which under precautionary approach management it would not have been allowed to fall in the first place. Strictly for the sake of putting all this in some context with respect to the E/R analyses considered earlier, lets just say that B(tr), for lobsters at least, represents something in the order of 20% of the SSB of an unfished population.

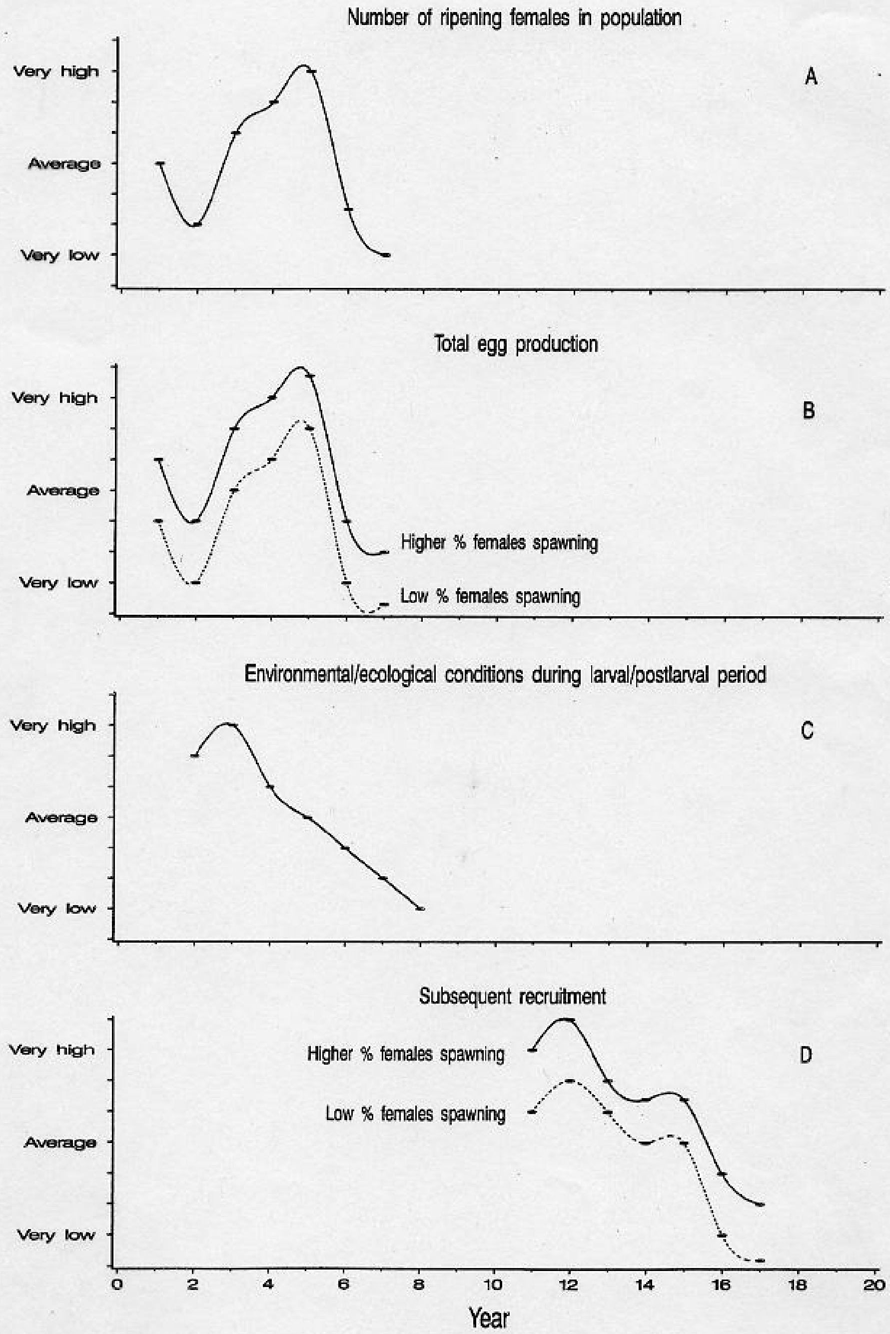
There is a degree of uncertainty in all aspects of fishery management, but fishery science is inexact to begin with and the subject of stock-recruitment and definition of recruitment overfishing by its very nature is fraught with uncertainty and imprecision in estimation. Nevertheless, the precautionary approach considers it unacceptable to use the lack of full scientific certainty as an excuse for inaction.

Therefore, a prudent, precautionary interpretation of the foregoing consideration of the stock-recruitment relationship and the recruitment overfishing question for lobsters would conclude that in Newfoundland populations generally the spawning stock biomass, at best, lies somewhere between B(lim) and B(buf). Therefore, management initiatives to increase egg production implemented in 1998 need to be expanded.

Environmental and Ecological Influences on Larval Survival

Over the past 50 years, major long-term trends in Newfoundland lobster landings have been part of widespread phenomena indicating a strong environmental-ecological influence on recruitment in lobster populations. This influence is most likely strongest on the larval-postlarval stages where it can be assumed to contribute in a significant way to determination of year-class strength. Annual variation in larval survival is linked to an interaction of various factors that make up what has to be an extremely complex process. In Newfoundland waters the lobster's planktonic phase may last for 6-10 weeks during July-September depending on temperature conditions in the surface and near-surface layers of the ocean. Higher temperature promotes rapid development and better survival overall and duration of the later stages is especially temperature dependent. But, rapid development is also very dependent on food supply – growth and survival of the early stages especially are critically dependent on an abundant supply of relatively small planktonic organisms. The plankton community as a whole undergoes dramatic changes in species composition and abundance over the spring-summer period and much of this is linked to timing and duration of the spring-early summer phytoplankton bloom. Conditions which are ideal for lobster larvae would also be very favourable for and very attractive to various species such as jellyfish and pelagic fishes that prey on the plankton community including lobster larvae. This brief sketch should serve to illustrate the potential for quite considerable annual variation in conditions affecting larval survival. The strength of a particular year class then, as well as the magnitude of eventual recruitment to the fishery, will be determined by the combination of total population egg production and the larval survival rate that year.

The accompanying very generalized series of figures will help to illustrate the importance of a reasonably high level of egg production in the face of ever changing environmental-ecological conditions in terms of maintaining future recruitment in a lobster population. Under any particular management regime, total population egg production will vary annually depending on the number of ripening females (panel A) which will vary with the strength of incoming new recruitment to the adult component of the population. The lower the exploitation rate the higher will be the percentage of ripening females that will survive the fishery in a given year and spawn later in summer. The higher the percentage of ripening females in the population that get a chance to spawn each year, the higher will be the total annual egg production (panel B). Superimposed on annual egg production are the annually varying environmental-ecological conditions that determine the larval survival rate (panel C). Depicted in panel D is the varying subsequent annual recruitment to the fishery to be expected under a management regime that allows a very low percentage of ripening females to spawn compared to one with a somewhat higher percentage. Over the long-term, future recruitment can be expected to be higher on average and declines resulting from periods of adverse environmental-ecological conditions can be expected to be less severe at a higher level of annual egg production.



An illustration of how population egg production and environmental/ecological conditions affecting survival combine to determine future recruitment. See text for explanation.

Larval Dispersal and Recruitment Processes

That closed areas lead to increased egg production in a local lobster population is clearly established, however, the spatial distribution of resulting recruitment benefit is unknown. Although some local groups have been willing to establish small closed areas in response to widespread concern over conservation of the lobster resource, the extent to which the benefit is localized has tended to be something of an “issue” during prior consultations that has persisted. In that regard, establishing a closed area is not much different, except for the spatial scale, from other voluntary conservation measures such as v-notching that might be practised locally, in contrast, for example, to a size limit increase which is imposed on all harvesters throughout the fishery.

This presents my perspective on the dispersal of lobster larvae from a localised source and the subsequent spatial distribution of postlarvae that successfully settle onto suitable habitat and recruit to the population. Considerations of the dispersal of the planktonic (larval) stages of marine benthic organisms, including lobsters, are generally based on the assumption they are simply passive drifters in currents at or near the ocean surface and, to simplify matters, it is the residual (mean speed and direction) surface circulation pattern that is used for the purpose. This represents an extreme oversimplification of what surely must be an incredibly complex process.

Superimposed on the general ocean current of a given area, such as the southward flowing Labrador Current off the northeast and east coasts, is a tidal cycle that is usually strong enough to reverse the direction of flow of the ocean current during one part of the cycle and double its velocity during the other. Superimposed on that twice–a–day variation is the waxing and waning of the strength of the tidal cycle associated with each lunar cycle and superimposed on all of this is a great deal of further variability associated with constant change in wind speed and direction. Coastal physiography and the adjacent bottom topography will further influence circulation in the immediate near–shore area from which lobster larvae originate.

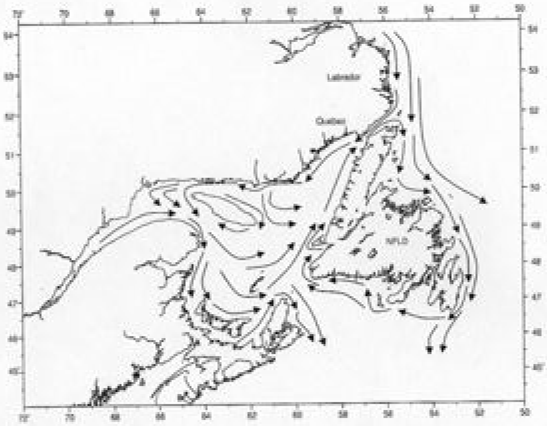
Lobster larvae possess a sufficiently sophisticated behavioral repertoire to indicate they cannot be considered simply as passive drifters in the surface current. In addition to a well developed swimming ability, which allows them to move vertically and horizontally, they possess a wide variety of behavioral responses to physical stimuli. In controlled laboratory experiments, larvae display a capacity to orient into and maintain position for varying periods in relatively slow-flowing water. They will move up or down in vertical temperature and salinity gradients to seek a preferred range. They respond to a change in hydrostatic pressure in a depth–regulatory fashion and the intensity of the response is modified with exposure and over the course of development. They are strongly attracted towards light but are repelled by very bright light and again the intensity of the response is modified as development proceeds. Field sampling has shown that larvae tend to concentrate within the upper 1–2 m of the water column during daytime, except during periods of bright sunshine which they avoid by moving downward. At night there is a fair degree of dispersal downward from the surface layer. In offshore areas larvae have been captured as deep as 30 m.

Given the extremely complicated and continuously changing speed and direction of surface currents in coastal areas, it seems quite possible that some portion of the larvae originating in a given area would be retained nearby over the 3-5 weeks required to reach the end of their larval development by this physical transport process alone. Small–scale vertical movements by larvae resulting from the behavioral responses to various stimuli would expose them to currents moving in different directions at different depths. This would likely serve to improve the chances of retention in the area of origin. Whether lobster larvae posses a behavioral capacity to actively avoid long–distance dispersal from their parental habitat is unknown. Nevertheless, the combination of normal larval activity and physical transport processes provide mechanisms whereby larval retention within the area of origin would be possible but certainly their dispersal could be slowed appreciably. The idea that larvae of many marine species play an active role in determining their dispersal is widely accepted these days.

During the molt at the end of the third larval stage, a remarkable metamorphosis occurs which transforms the larva into a miniature replica of a lobster called a postlarva that behaviorally is very competent. Settlement takes place during the postlarval stage, which could last another 3–5 weeks depending largely on temperature. Postlarvae swim with much greater agility, precision, and speed than do larvae. With their remarkable swimming ability and a capacity for directional orientation, postlarvae are capable of long-distance travel to locate suitable bottom on which to settle. In a Newfoundland context, suitable bottom essentially means nearshore, rocky–bottom habitat from which larvae originate. Successful settlement is achieved by a strong preference for substrate that provides good shelter for early benthic phase lobsters and an ability to settle very early in the postlarval stage if it is located quickly or to delay settlement significantly to increase the chance of finding suitable substrate before postlarvae will settle regardless. Whether the behavioral capabilities of postlarvae enable them to relocate their parental grounds or to simply locate the nearest suitable settling bottom is not known. Clearly though, successful settlement is not simply a matter of chance.

What is presented here represents a hypothetical, first attempt to depict the area over which lobster larvae originating in a small closed area in Newfoundland might be likely to disperse and then the area over which successful settlement by postlarvae might be likely to occur. This depiction is based on the contention that dispersal of larvae from a particular area is determined by processes associated with an interplay between the vagaries of surface and subsurface circulation through short–distance vertical movements. These processes generally slow dispersal out of an area and result in some degree of retention and possibly include as well transport out of (dispersal) and subsequently back into the area. Once the postlarval stage is reached, successful settlement is determined to a far lesser extent by the vagaries of circulation and to a considerable extent by behavioral processes which enable postlarvae to locate suitable settling habitat from a considerable distance.

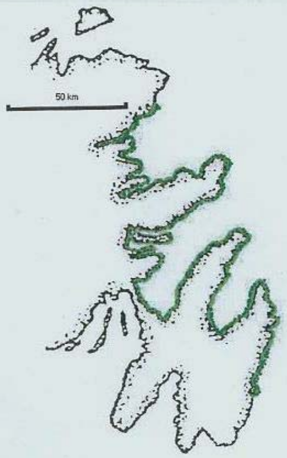
The following consideration of larval dispersal from a localized source and the area of subsequent settlement by the postlarval stage is based on the forgoing. The purpose is to provide context for the question of the extent of localized benefits from small lobster closed areas. Also, this is meant to be a starting point from which to develop a more scientifically rigorous evaluation of the question in relation to existing closed areas around Newfoundland.



Residual surface circulation around Newfoundland.

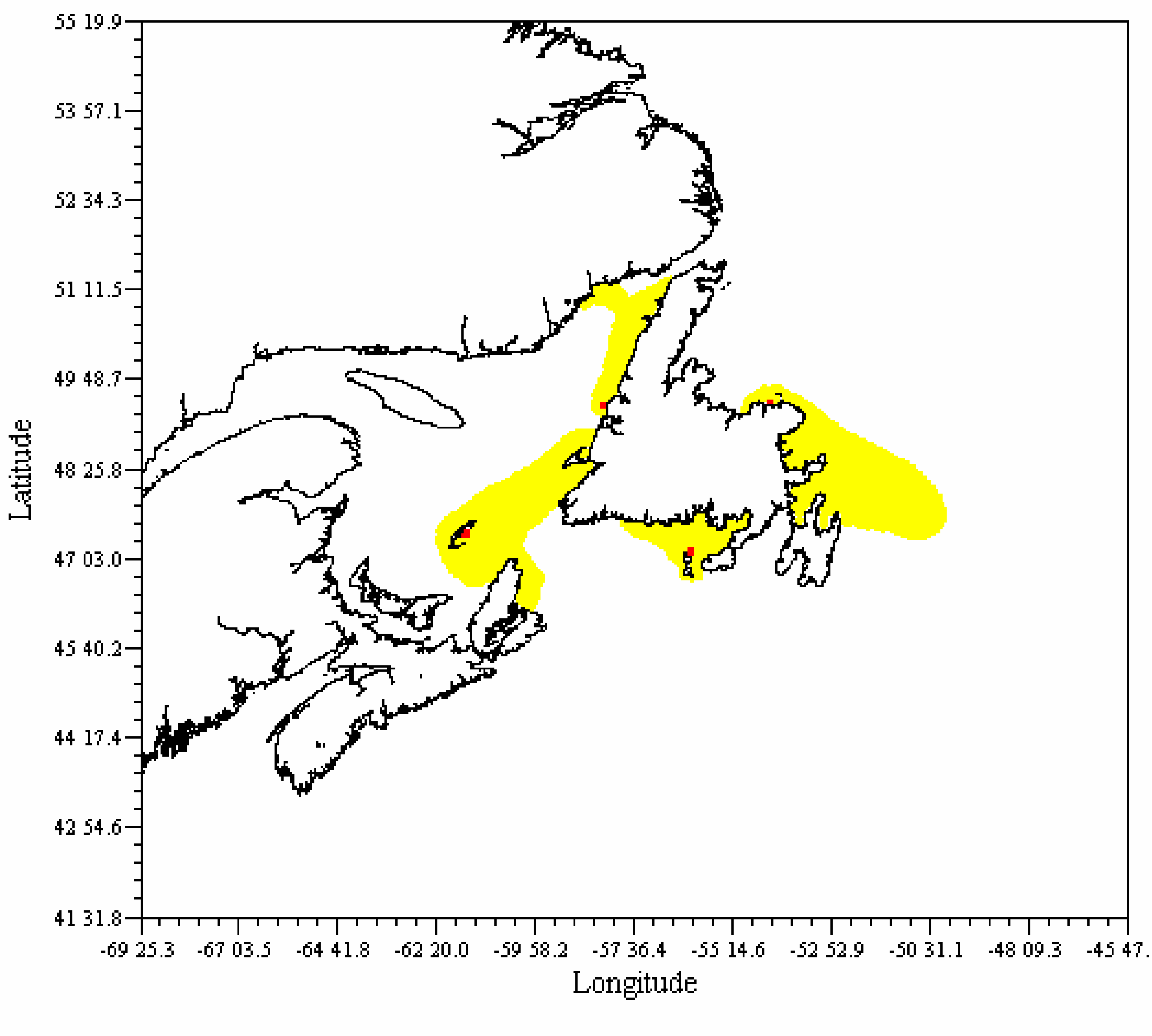
The residual surface circulation in coastal areas around Newfoundland is essentially clockwise. The flow along the NE coast would tend to disperse larvae originating in the closed areas near Eastport in Bonavista Bay generally out of the bay and to the south. The broad area over which they would be distributed by the time the end of stage III is reached probably includes a fair portion of Bonavista Bay, coastal areas southwards to somewhere along the Southern Shore of the Avalon Peninsula and extending offshore as much as 50 km. Successful settlement by postlarvae would occur all along the coast immediately adjacent to the area of dispersal. Apart from northward and southward extensions to the overall area, dispersal of larvae originating from the whole of Bonavista Bay, and subsequent settlement of postlarvae, probably would not be a great deal different from that depicted for the small closed areas near Eastport.

Likely distribution by end of stage III of lobster larvae originating in the Eastport closed areas (indicated by dot).



Likely distribution of settlement by postlarval lobsters (indicated by narrow strip adjacent to the coastline) subsequent to the dispersal depicted in adjacent figure of larvae originating in the Eastport closed areas.

The foregoing represents the broad spatial dimensions of dispersal and recruitment and no attempt is made to suggest how density might vary throughout the respective areas. Clearly though, it seems that a large portion of the recruitment benefit to be derived from establishing a small closed area will be well outside the area fished by the local group which did so – in itself a compelling argument for more doing likewise. The lobster fishery in any given area is dependent to some degree on recruitment that originates elsewhere and is therefore somewhat vulnerable to poor conservation practices in other, some fairly distant, areas. This suggests a very broad–scale inter–dependence for lobster recruitment and a need for good conservation to be practiced throughout the fishery.



Likely distribution by end of stage III of larvae produced in four widely separated local sites (indicated by dots) around Newfoundland.

An Evaluation of Recent Management and Conservation Initiatives

In addition to the size limit increase and commitment to the practice of v-notching, both of which are clearly conservation measures that would result in significant increase in egg production, some effort reductions (shortened seasons and reduced trap limits in particular) were included as a contribution to achieve conservation objectives in the multi-year management plan introduced in 1998. Even though it was clear that these effort reductions would not achieve a lowering of the exploitation rate, which is necessary for them to have conservation value, they were nevertheless given credit because it had been extremely difficult to gain acceptance by stakeholders of conservation measures otherwise sufficient to achieve the E/R doubling objective required of the management plan, at least on paper.

Harvesters have long had difficulty accepting the idea that effort reductions have no conservation value, unless they are sufficiently large to lower the exploitation rate. This is perhaps because they usually see a significant improvement in the quality of their fishing activity by way of higher catch rates (i.e. catch per trap haul) following any reduction in the number of licences in particular or reduction in trap limit. The fact of the matter is that the very substantial reductions in effort that have been achieved over time have actually lead to increased exploitation rates throughout the fishery. Despite a 30-year history of effort control in one form or another in the lobster fishery, exploitation rates on the legal component of the population exceed 95% in the more productive fishing areas.

Results from the long-term study of lobsters at Arnold’s Cove demonstrate that much more effort (in terms of total trap hauls for the season) is expended when abundance is high. Elimination of licences from the fishery is equivalent to increased abundance for those remaining in that they have access to a greater share of the available resource. Licence reduction has undoubtedly improved economic conditions for remaining licence holders compared to what they otherwise would have been. This provides greater incentive to haul all their traps daily, keep them freshly baited, and, through reduced competition for space on the fishing grounds, greater opportunity to move them around, all of which contribute to better quality fishing effort.

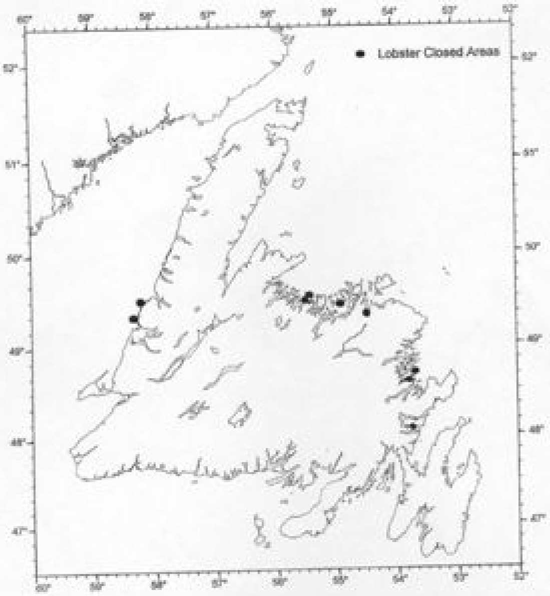
In the aftermath of the major downturn in the cod fishery around the island, the lobster fishery became far more important to inshore fishermen. In most areas, the limited cod and the crab fisheries are conducted on an IQ basis allowing lobster licence holders to extend fishing right up to the end of the season. Although seasons were shortened somewhat in most LFAs, it had been common in most for the bulk of the traps in use to be landed 2 or 3 weeks or longer before the end of the season – this was due to the degree of depletion of the supply of lobsters as well as to competitive pressure to move on to another fishery. In effect, in terms of actual fishing days, it is much more likely that seasons have been lengthened.

In consultations leading to the development of the multi-year management plan introduced in 1998, there was widespread, very strong resistance to the idea of a size-limit increase, despite the clear long-term benefits which were demonstrated. Nevertheless, DFO Regional Managers were obliged to impose a small increase (from 81 to 82.5 mm CL) in order to achieve the directed E/R doubling objective. Only harvesters fully understand their resistance to size-limit increase compared to generally more ready acceptance of other conservation measures. It is perhaps related to poaching and harvesters know better than anyone just how prevalent it is in their particular area. To a far greater extent than any other conservation measure, a size-limit increase makes additional resource available to poachers. A much reduced incidence of the largest of the undersize lobsters (i.e. 80-82 mm CL) is evident in much of the at-sea sampling of commercial catches conducted in very recent years. In the past, this was particularly noticeable only in certain locations where the exploitation rate had been quite high for a long time. In the same way that access to more of the resource stimulated effort on commercial lobsters, it is conceivable that effort directed at undersize lobsters has also increased. The actual level of harvesting of undersize lobsters must be a fair bit lower than for the commercial component which means that any increase at all in effort directed at the undersize component would result in a substantial increase in their removal from the population. Any increase in the rate of exploitation on legal lobsters as well as any increase in poaching on the undersize would significantly reduce the egg production benefits associated with the size-limit increase.

The voluntary marking by fishermen of berried females they catch, referred to as v-notching, was started as a lobster conservation measure in Newfoundland in the mid 1990s. The v-shaped notch cut in a segment of the tail fan remains visible through several molts and makes the lobster illegal for retention in the alternate years it is not berried. The practice had become fairly widespread in the fishery prior to its inclusion in the multi-year management plan. The plan committed harvesters to notch at least 25% of the berried females in the population each year from 1998 onwards and acceptance of this as a contribution to the conservation objective was conditional upon validation by way of broad-scale, at-sea sampling by fishery observers during the 2000 and 2001 fishing seasons. The plan made provision for a further size-limit increase if the validation process did not demonstrate that v-notching had been carried out to the extent required. However, following implementation of the size-limit increase in 1998, it became apparent that many who had been v-notching stopped doing so as a form of retaliation. At the time that the validation was supposed to have been done, it was generally considered to be a waste of time and money because it was widely recognized that v-notching had not been practiced throughout the fishery at anything close to the 25% rate. The validation was not done nor was the further size-limit increase implemented.

At-sea sampling of commercial catches has been conducted annually since 1998 around the Eastport Peninsula and at 12 other widely-separated locations around the island, mostly during one fishing season only, since 2000. Collectively, these locations represent a small fraction of the total Newfoundland fishery but this sampling provides the only basis for an overall impression of the extent of v-notching activity throughout the fishery. At three of the locations the incidence of v-notched lobsters was negligible, however, at the other 10 it ranged from moderate to very high. A very high incidence, which was observed at three locations, suggests a level of commitment to v-notching at or close to the 25% rate. Overall, this at-sea sampling indicates widespread involvement by harvesters in the practice of v-notching.

Between 1997 and 2004, nine closed areas were established in the interest of lobster resource conservation at six widely-separated locations around the island. In each case it was on the initiative of local licence holders acting independently of the formal management plan. This was completely unexpected and represents an unprecedented development in terms of stakeholder stewardship initiative.



Distribution of established lobster closed areas around Newfoundland.

A study focused on populations within the two closed areas that had been established at Eastport, along with comprehensive monitoring of the local fishery, was initiated in 1997. Estimates for 1999 indicated that the closed areas along with the v-notched component of the population produced nearly twice the number of eggs that was attributed to the size-limit increase implemented the year before. Whereas the eggs attributable to the size-limit increase were for the most part produced by females spawning for the first time, those from the closed areas and from v-notched lobsters were mostly produced by much larger animals that had spawned previously. Large female lobsters produce larger eggs with higher energy content than small females which represents a survival advantage for the larvae they produce. Large females also hatch their eggs earlier in summer and over a more protracted period ensuring that a large portion of their larvae can take advantage of rapidly increasing temperature and other conditions favouring their growth and survival. Large female lobsters, therefore, make a relatively much greater contribution to population recruitment than simply the larger number of eggs they produce.

Since 1998 there has been substantive progress with addressing resource conservation issues in the Newfoundland lobster fishery, but concerns have not been eliminated. Experience has demonstrated that harvesters tend to be much more receptive and relate more readily to measures such as v-notching and closed areas than to size-limit increase or the kind of massive effort reduction that would be necessary to lower the exploitation rate. To a far greater extent than any other in Newfoundland, the lobster fishery cannot be managed effectively without strong stakeholder support and particularly their acceptance of a stewardship role. It seems most likely that the cause of lobster conservation over the long term would be better served by promoting closed areas and v-notching and building gradually on what has been achieved with these conservation measures so far.

Future Prospects

The precautionary approach considers a stock to be in a state of collapse when the spawning biomass drops below the limiting level (Blim) and requires that the fishery be closed in order to start the re-building process. Difficulties with estimating Blim and actually determining whether a stock meets this collapsed definition have been considered earlier and it is very unlikely that a recommendation/decision to close a lobster fishery on that basis could be made in the foreseeable future. However, there is precedent in Newfoundland for lobster fishery closures based on pragmatic considerations. The whole fishery was closed for three years in the mid-1920s and the fishery in St. Mary's Bay was closed for three years as part of the multi-year management plan introduced in 1998. In each case, landings had declined to very low levels and continuing to fish was simply not practical. Although possibly not collapsed in a technical sense, drastic declines in landings mean severely depressed economic conditions under which the utility of continued fishing must be questionable. While short-term closures allow any incoming new recruitment to accumulate, they have no lasting conservation value unless the re-opened fishery is managed much more conservatively than before to allow re-building to continue. Eventually, it should be possible to fish somewhat less conservatively, but under no circumstances should the kind of high exploitation fishery that lead to the drastic decline in the first place be allowed to re-develop.

If a fishery were operating on an economic viability basis, it presumably would be closed long before a state of collapse was reached, regardless of confident estimation of the Blim reference point. It has become less and less likely over recent times, however, that pragmatic or economic viability considerations would kick in to close a lobster fishery. In the aftermath of cod fishery closures, even with the much smaller scaled re-opened fisheries in most areas, the lobster fishery took on a far greater importance to the overall inshore fishing sector than was previously the case. With the downturn in the crab fishery in recent years as well, the importance of the lobster fishery continues to grow. EI qualifying rules are such that in the face of diminishing opportunities in other key fisheries and the general lack of alternatives, harvesters will have little choice but to continue to fish lobsters with less and less consideration of economic viability. This is a clear example of social policy compromising effective fishery management.

Under precautionary approach principles, a sustainable fishery is one managed to ensure that spawning biomass is maintained at the target level in order to generate the highest possible recruitment on an ongoing basis. By this measure, management of the Newfoundland lobster fishery can only be described as unsustainable. Yet, the fishery has survived for well over a century on the strength of a high degree of resilience to fishing inherent in lobster populations. A number of times the fishery has undergone severe downturns from which it fortunately recovered, but at the time meant economic hardship for many. Under the kind of high exploitation management regime that prevails for lobsters, in which recruitment is limited by low egg production, extreme fluctuation in annual landings causing great instability in the fishery is to be expected. Part of what sustainable fishery management is about is minimizing downturns and maintaining a greater degree of stability. The effect of environmental/ecological variability on recruitment will cause landings fluctuations no matter what level of egg production can be achieved, but in a fishery managed on a sustainability basis fluctuations will be moderated and instability much less severe.

There can be little doubt, even in the minds of those most sceptical of the work of fishery scientists, that the Newfoundland lobster fishery could be managed to achieve a much higher level of production from the resource over the long term. To do so will require an ongoing commitment to lowering the overall level of exploitation by way of building on the conservation initiatives of recent years. However, a critically important component of lobster conservation in Newfoundland is the adoption by local stakeholder groups of an active stewardship role.