Parent-Progeny Relationships and Implications for Stock-Recruitment Theory in Atlantic Cod.

EDWARD A. TRIPPEL

Fisheries and Oceans Canada, Biological Station, St. Andrews, New Brunswick, E5B 2L9, Canada (trippele@mar.df-rmpo.gc.ca)

SUMMARY: Fish recruitment models are being improved through our increased understanding of maternal and paternal traits that influence embryonic and larval fitness. New knowledge of the reproductive and developmental biology of Atlantic cod (Gadus morhua), a species exploited for centuries, has fueled further paradigm shifts in stock-recruitment theory that foster an ever increasing conservation perspective. Quantifying parental characteristics that affect future cohort strength requires refined data treatment that integrates annual variation in adult body metrics and demography that in turn influence egg and sperm quality and larval survivorship. Long-term research and stock assessment programs are recommended. These programs will lead to predictions of retrospective and future recruitment levels that are based to a greater degree on reproductive biology.

KEY WORDS: stock-recruitment, egg, spermatozoa, larval quality, survival, cohort

BACKGROUND

Fluctuations in fish recruitment have received considerable attention in the field of fishery science. Recruitment fluctuations strongly influence commercial catches and the economic prosperity associated with a fishery. These fluctuations are most commonly caused by losses incurred during larval stages. In order to give rise to strong year classes, optimal water temperature for larval growth, abundance of prey, and low predation pressure are required during early life. Given the high fecundity of teleost marine fish, the supply of spawned eggs is not perceived to be a serious limiting factor affecting cohort size. Also, due to their small diameter, variability in egg size and quality are often not considered to affect recruitment. As a result, reproductive traits are frequently downplayed as to their importance in influencing year class strength.

DECLINING FISHERY RESOURCES

This traditional view on stock-recruitment theory originated when stocks had moderately high status. Depleted populations are now widespread on a global scale. The desperate state of fish stocks is exemplified in the cod fisheries of the Northwest Atlantic. Northern cod is currently listed as a species of special concern by the Committee on Status of Endangered Wildlife in Canada (COSEWIC). When groundfish stocks were healthy, scientists and managers in eastern Canada did not perceive the reproductive base to have an impact on fish recruitment levels. As cod stocks declined in size in the late 1980s so did annual recruitment levels and the continued trend in the 1990s has left a sad state of affairs for Atlantic Canadians seeking a traditional living from the groundfish fishery. The use of spawning stock biomass (SSB) to represent reproductive potential was common. The ill fate of the cod fisheries of the Northwest Atlantic brought to the forefront our incomplete understanding of stock-recruitment mechanisms and the misuse of SSB. A variety of assumptions underly the practical application of SSB and these will be further discussed briefly under maternal and paternal factors.

The simultaneous downturn in stock size and recruitment also sparked considerable research activity in stock-recruitment theory. New scientific activity emerged which addressed how cod parental characteristics shape recruitment. Environmental factors remained an important component, though an exceptional amount of attention was directed at understanding maternal components of Atlantic cod reproductive biology, an effort shared by investigators concerned about Icelandic cod, Northeast Arctic cod, Baltic cod, and other cod stocks. As their understanding of Atlantic cod reproductive processes related to fish nutritional status and population demography improved, efforts were made to re-analyse stock-recruitment data using this newly found knowledge. It was learned that parental characteristics that correlated with successful reproduction reflected a healthy population and became fisheries management targets (e.g., high condition factor, repeat-spawners, adults of moderate to old age and large body size). Shifts in stock-recruitment theory that substantially broadened the SSB component were put forth which explained a greater amount of recruitment variation. New proxies that correlated with egg production but did not require the technical time invested in detailed fecundity analyses were sought. These efforts and more are being advanced and compiled as part of the Terms of
MATERNAL FACTORS

As early as the 1930's, Russian scientists recognized the important role that gamete quality played in reproductive success of marine and freshwater fishes (1,2), though this went largely unnoticed in North American and British advances of stock-recruitment theory (3,4). The practice of using SSB as a proxy of stock reproductive potential is associated with a number of assumptions. Factors of importance include: maturation, non-annual spawning, fecundity, egg size, egg quality (viability), spawning duration (number of batches), and environmental conditions. To improve on SSB estimates (particularly those based on age plus groups), a number of initiatives are required.

Fig. 1. Several factors affecting fertilization success of cod eggs. As a first step, maturity data need to be collected annually and research surveys should coincide with periods when macroscopic identification of maturity stage is feasible. As well, microscopic histological analyses may still be required as post spawning and early developing ovaries are often difficult to distinguish with the naked eye (5).

Fig. 2. Differences in cod larval morphology at hatch from initial (top) and terminal (bottom) egg batches of the same female.

PATERNAL FACTORS

There may be parallel problems in gamete quality of spermatozoa as observed in ova and the resulting zygote could fail entirely (i.e., synergistic effects). At first glance, energetic investment in tiny sperm cells (5 μm head size) is negligible compared to an egg (13 mm diameter). Few studies have focussed on male Atlantic cod reproduction (6,7) and the most relevant is related to sire condition and sperm potency. Sperm originating from cod of high condition fertilized more eggs than sperm originating from males of low condition when under in vivo sperm competition (8). Hence, fertilization success in the wild may deteriorate when fish are in poor nutritional condition. Sperm head size was not correlated with male body size or seasonality of spawning (9) (Fig. 3). Sperm swimming speed and sperm concentration were not correlated with male body length and reproductive experience (10).
MODEL APPLICATION

The Georges Bank cod stock is associated with an extensive population dynamics time series and this was used to incorporate a greater amount of reproductive data to stock-recruitment modelling. Data on Georges Bank were integrated with data from several other studies to replace the term SSB with a more refined estimate of reproductive potential (Fig. 4). It was shown that fisheries management biological reference points became altered with declines in age and size at sexual maturity and the increased proportion of virgin females in this stock. For Northeast Arctic cod, other avenues have been explored in relation to condition factor and total lipid energy reserves. The search continues to apply new findings on reproductive data to stock-recruitment theory and to extend these to fisheries management advice. Based on fish reproductive biology, long-term research on stock assessment programs are recommended that lead to improved predictions of retrospective and future recruitment levels.

REFERENCES


