Sustainability & Age Structure in Marine Populations

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Why do age structure and sustainability matter?

A central goal of the Marine Life Protection Act is to "help ***sustain***, conserve, and protect marine life ***populations***, including those of economic value, and rebuild those that are depleted." We need to know the current sustainability of populations (i.e., whether they are declining), and how proposed reserves might change that. We need to maintain an age structure that ensures that populations remain sustainable.

What is a sustainable population?

A sustainable population is one that is able to replace itself with the next generation. In order to sustain marine life populations, we have to understand *how* they replace themselves. Unlike humans, fish do not dedicate time and energy to ensuring that each egg is protected and is able to mature into an adult. Most marine fish ensure their replacement by producing millions of eggs over their lifetime. Once mature, female fish can produce hundreds of thousands of eggs every year, resulting in hundreds of millions of eggs over their lifespan.

The number of eggs produced over the natural lifespan of a fish is called the Lifetime Egg Production (LEP). For the fish to replace itself, one of these millions of eggs must grow into a mature, reproductive fish. For humans we know that each couple needs to produce two offspring for the population to remain constant. However, the number of eggs that a fish must produce in its lifetime in order to replace itself is not as obvious. However, based on information from populations that have declined to low levels, scientists believe that if a fish is able to produce **35%-60%** of its natural LEP, then the population will be sustainable (i.e., remain roughly constant).

How does fishing affect age structure?

The age structure of a population is the number of individuals in each age bracket, and it is a key indicator of sustainability. It reflects how many fish are living long enough to reproduce.

The age structure of a population is affected by fishing. Because older fish have been exposed to fishing longer than younger fish, there are fewer of them. When we fish a population, we decrease the number of older, females available to produce young, thus reducing the LEP of the fish in the population (Fig. 1a, 1b).

Moreover, larger female fish produce more eggs than do smaller fish. For example, a 6-year-old black rockfish produces an average of just over 200,000 eggs per year, whereas a 12-year-old black rockfish produces nearly 10 times as many eggs (2 million). This contributes to the reduction of LEP by fishing.

The graph below (Fig. 2) shows how LEP declines as we increase the fishing mortality rate. Increasing fishing results in fewer older fish, which means that in their lifetime fish produce fewer eggs, and have a lower chance of replacing themselves.

Fish Lifecycle and Sustainability with Marine Reserves

When fish spawn, they release larvae or juveniles into the sea where they drift with the currents and are often subjected to high mortality. If they survive that stage, they may settle in an area that is suitable for them to feed and grow. A small fraction of these survive to become adults.

When there are marine reserves, and some areas are fished while some are not, the calculation of replacement becomes more complicated. Some larvae will be transported to reserves, so they will live longer and have a greater contribution to sustainability, while other larvae will be transported to fished areas where the average lifetime is shorter resulting in less egg production. Calculation of the effective LEP when there is this kind of variability involves consideration of replacement through all such possible pathways. It requires knowing larval dispersal, in addition to LEP at each location.

New Findings

Researchers have recently found that the larvae of young black rockfish do not survive starvation (which can occur in the ocean if suitable prey are not available when larvae are released) as well as larvae of old black rockfish. Therefore the number of offspring produced at each age is not as high as we thought (Fig. 1c). We need to allow more fish to grow older to bring the fraction of LEP up to a sustainable level (i.e., 35-60 percent)

What does this mean for marine protected area design?

To allow more fish to grow older, we need to reduce fishing mortality. We can do this either by (1) restricting fishing everywhere (as in Fig. 2) or by (2) setting aside part of the area as marine reserves. Marine protected areas that remove fishing pressure allow the fish in the reserves to grow older than those in the fished part of populations, hence reserves increase the effective LEP.

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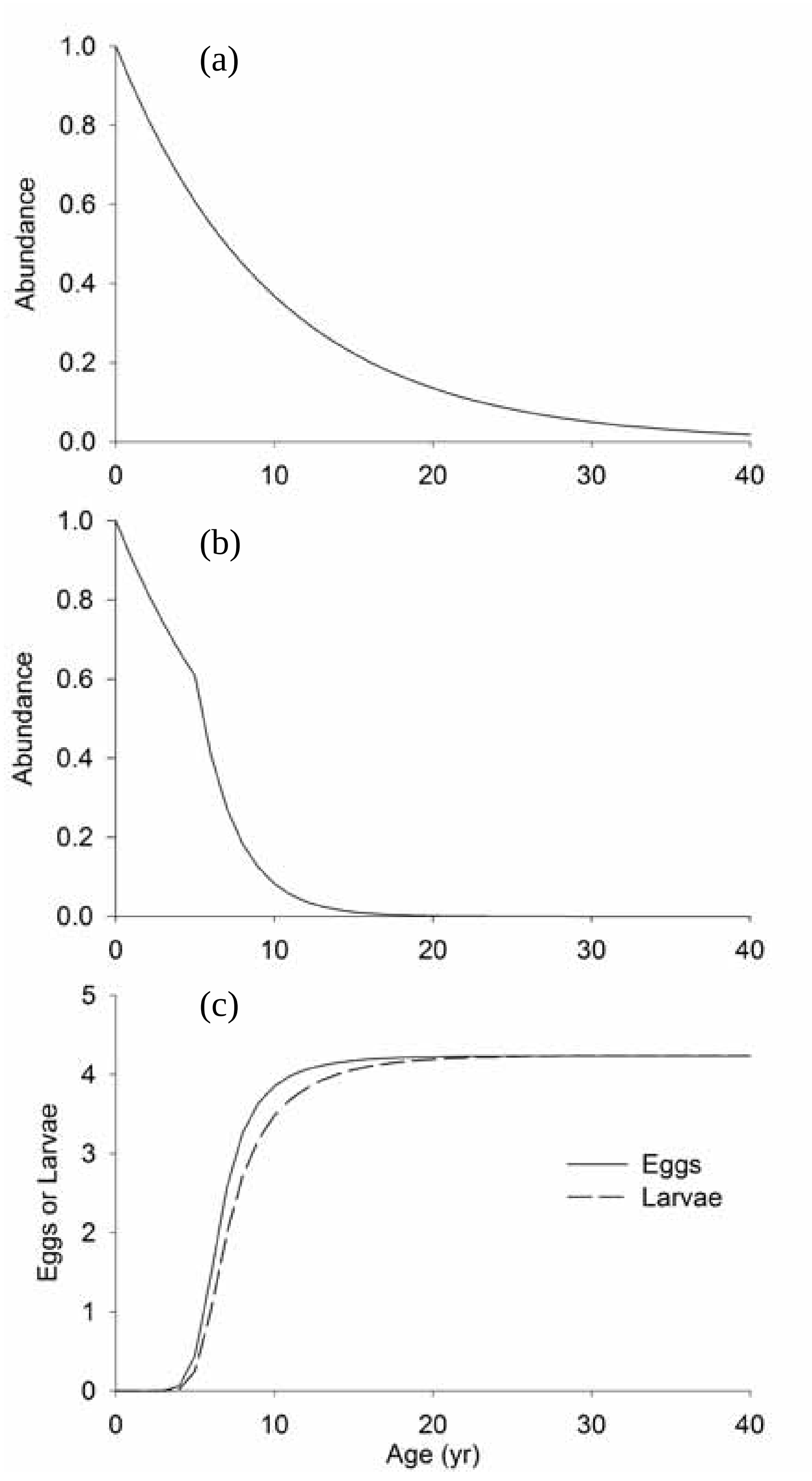

Figure 1. Typical age structures of a long-lived fish like rockfish in an unfished (a) and a fished (b) situation. The importance of living to each age is indicated by (c) which is the number of eggs produced at each age (solid line) and the number of larvae produced at each age (dashed line).

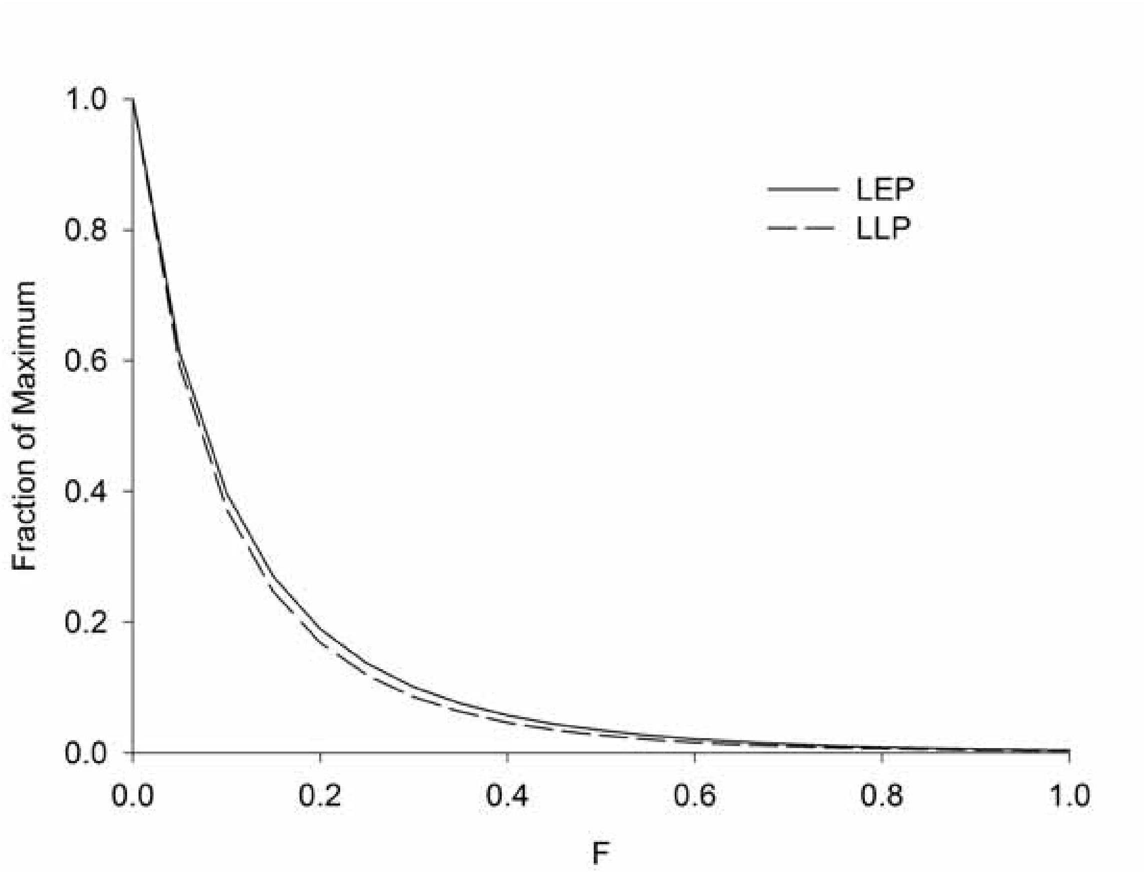

Figure 2. Fraction of lifetime egg production (LEP) for black rockfish as fishing increases. Also shown is the fraction of lifetime larval production, which includes the dependence of survival on female age. The dashed lines show the level of fishing necessary to maintain FLEP = 50%.