Two fishery scientists help explain allometric vs isometric scaling in fishery management

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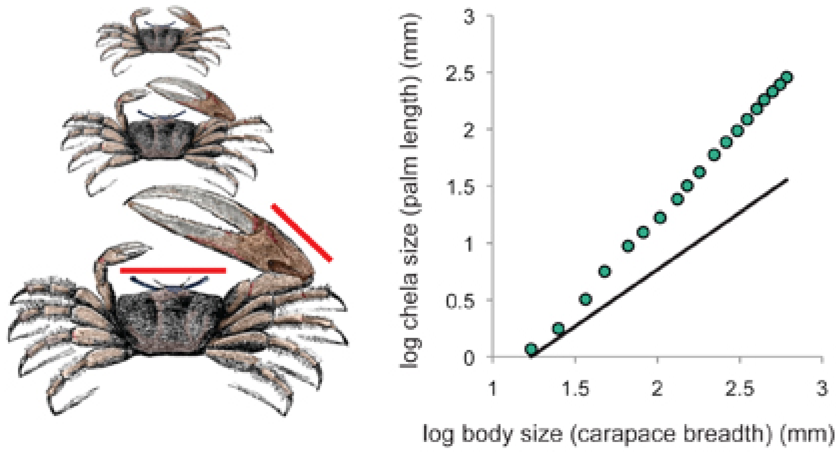
We had a few fishery scientists write to us about Barneche et al 2018, a recent paper that showed that big, old, fat, fertile, female, fish (BOFFFFs) produce significantly more, and much healthier, eggs than smaller females. For example, one 30kg cod mom has the same ***reproductive output***—or the amount of baby fish produced—as thirty-seven 2kg cod moms. The importance of BOFFFFs has been known for a long time, but the authors of the paper suggest that fishery management needs to better account for the importance of BOFFFFs in stock assessments and claims that overharvesting of BOFFFFs has created unknown and significant fish stock depletion.

The calculation of reproductive output as a function of size and age in the paper are sound, but the authors' fishery management conclusions are misguided. The reasons why the paper's conclusions are incorrect are complicated, but we weighed on the expertise of fishery scientists Ray Hilborn and Michael Sissenwine to help explain.

Concerning fishery management, the paper states that, when estimating the reproductive output of a fish population, allometric scaling models should be used instead of isometric scaling models. Isometric scaling assumes that female fish reproductive output increases proportionately with size increases, while allometric scaling assumes that female fish's reproductive output increases allometrically. Here is an example of allometric vs isometric scaling from a paper meant to explain the difference.



The allometric relationship between claw size and body size in growing male fiddler crab. The red lines show the measurements made on the crab. When the data are displayed on a scatter plot, the relationship between claw and body size is curve-linear, which becomes linear when plotted on a log-log scale and can therefore be described using a simple linear equation. The equation for the linear relationship indicates that its slope (which is the allometric coefficient α) is 1.57. Thus the relationship between claw and body size is allometric. The line illustrates the relationship if it were isometric and had a slope of 1.

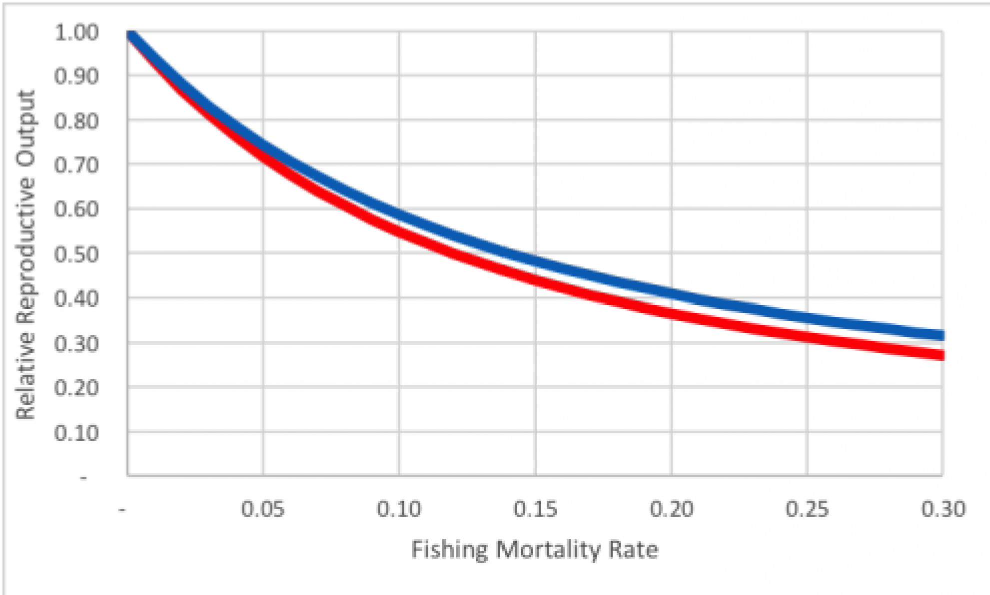
It has long been established that the reproductive output of female fish is not isometric, but indeed allometric. The authors of the paper wrongly assume that, since allometric scaling is not used in most fishery management, reproductive output has been significantly overestimated and fishery depletion is rampant. Depending on the stock being analyzed and the fishery science models used, sometimes allometric scaling is used, though most of the world's fisheries are managed using isometric scaling. However, fishery managers use a metric called ***F40%*** to monitor reproductive output—generally, allometric vs isometric assumptions matter very little with F40%.

Ray Hilborn explains:

Comment by Ray Hilborn

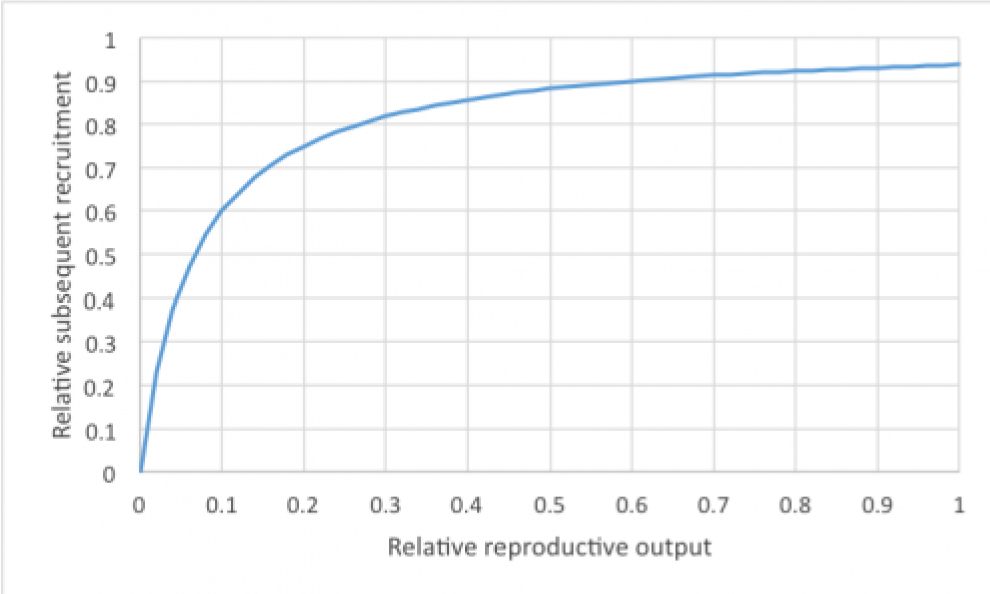
A common way of setting target harvest rates for fish populations is to use the relationship between female size and reproductive output to calculate what harvest rate would reduce total female output to 40% of what it would be in the absence of fishing. This is called F40% and is normally calculated by assuming reproductive output is proportional to body size (isometric), however, the difference between isometric and allometric assumptions are minor when using F40%.

To illustrate this, I graphed an isometric (blue) and allometric (red) population model with relative reproductive output on the y-axis.



If allometric (red) modeling is used, as the authors argue it should, then current F40% policies actually do lower the actual reproductive output, but slightly. If there is no fishing mortality, both the red and blue curves are at 100%; as you fish harder the relative reproductive output declines, but the two curves are not very different. At current F40% policy, the blue curve suggests a fishing mortality rate of almost exactly 20%. At this rate, the reproductive output of the red curve is 36%. The next step is determining what the difference between 40% and 36% reproductive output would have on the amount of fish for the following year.

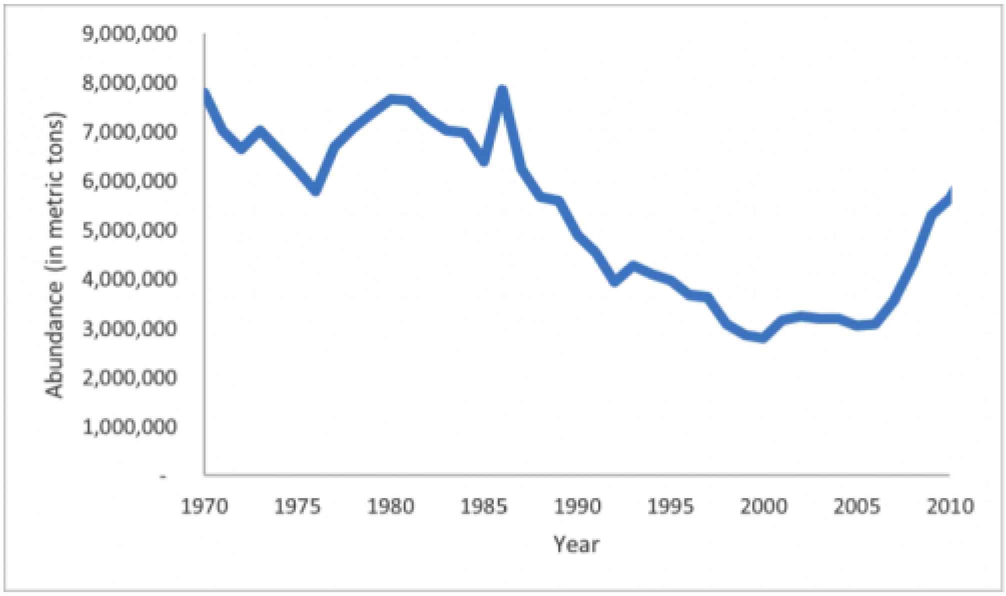
To understand this we need to look at the relationship between total reproductive output and subsequent recruitment to the population. This is not a linear relationship, almost all fishes show strong density dependence between reproductive output and actual recruitment of 1 year olds to the population. Meta-analysis suggests for Atlantic cod a relationship that looks like the figure below.



A 40% reproductive output results in an ~85% max recruitment, while a 36% reproductive output results in an ~83% max recruitment.

The difference in reproductive output as a function of body size that Barneche et al estimate has almost no impact on how we would manage fisheries. Using allometric scaling to estimate F40% instead of isometric might be a bit more precise (and in some cases it is used, e.g. West Coast groundfish), but there is no significant difference. Fishery management can improve dramatically in many other ways; rewriting decades of models would be a poor use of management resources.

My issue with Barneche et al. is that it suggests that the small differences they estimate are in some way responsible for the continued decline of fish stocks like Atlantic cod. This is wrong. In the places where fish stocks are actively managed, fish stocks are increasing, not declining. For instance the figure below shows the abundance of Atlantic cod globally. Cod were indeed overfished, but using traditional assumptions (i.e. isometric scaling) about reproductive output vs female size, stocks are recovering.



Atlantic cod abundance over time

Ray HIlborn

Ray Hilborn is a professor in the School of Fishery & Aquatic Sciences at the University of Washington

Comment by Michael Sissenwine

Egg size increasing with fish size (big old fish have bigger eggs) is well know and its implications were discussed and debated significantly about 15 years ago when I was with National Marine Fishery Service.

It is reasonable to expect that larger eggs are more viable, and therefore a population of large old fish (as occurs for an unfished population) produces more recruits per unit weight of spawning biomass than a fished population with smaller and younger fish (all other factors being equal). Existing population dynamics theory and models can easily account for this, but would require quantitative information on (a) the fish size-egg size relationship and (b) the survival ratio from egg to recruit as a function of egg size. Information on (a) could be collected, but (b) can only be estimated in the context of a spawner-recruit (S-R) function. These functions are notoriously difficult to fit because of noisy data. I doubt adding information about (a) would solve the problem, but Barneche et al would have been more impressive if it tried to do so.

Since noisy data often or usually precludes using stock specific S-R functions, the biological reference points that are commonly the basis of fishery management are based on proxies from so called “meta analyses” of data from hundreds of stocks. One of the most common proxies is F40% (the fishing mortality rate that reduces spawning biomass per recruit to 40% of the spawning biomass per recruit for an unfished population) as an overfishing threshold. The 40% value is supported by generic models, like Ray’s above, but the best reason for using F40% is that experience shows that most fisheries worldwide that are fished at or below F40% are probably “healthy” (putting aside views about forage stocks, which is another debate best left for another time!).

Michael Sissenwine

Michael Sissenwine was the Director of Scientific Programs & Chief Science Advisor at the National Marine Fisheries Service.

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