9.8 Fishing policy search - background

A central aim of fisheries management is to regulate fishing mortality rates over time so as to achieve economic, social and ecological sustainability objectives. An important dynamic modelling and assessment objective is thus to provide insight about how high these mortality rates should be, and how they should be varied over time (at least during development or recovery from past overfishing). We cannot expect models to provide very precise estimates of optimum fishing mortality rates, but we should at least be able to define reasonable and prudent ranges for the rates.

Ecosim provides two ways to explore impacts of alternative fishing policies:

i. Fishing rates can be 'sketched' over time and results (catches, economic performance indicators, biomass changes) examined for each sketch. This is using Ecosim in a 'gaming' mode, where the aim is to encourage rapid exploration of options.
ii. Formal optimization methods can be used to search for fishing policies that would maximize a particular policy goal or 'objective function' for management.

These approaches can be used in combination, e.g. by doing a formal optimization search then 'reshaping' the fishing rate estimates from this search in order to meet other objectives besides those recognized during the search process.

The first of these approaches has been implemented in Ecosim since its first version, and has been widely applied for exploring ecosystem effects of changes in fishing effort (see Ecosim basics and the help topic for the Run Ecosim form). The second is 'open loop' policy exploration simulation that acknowledges that policy may be defined as an approach towards reaching a broadly defined goal, that fisheries policies are often implemented via TACs that are recalculated annually, and through regulation that affects fleet structure and deployment.

Two very different approaches can be taken to the identification of optimum levels of fishing efforts for multiple fleets that may each harvest multiple species from an ecosystem. The first or 'sole owner' approach is to identify a single, overall performance measure for combined value from all fishing operations, then vary the by-fleet efforts so as to try and maximize this performance measure. The sole owner approach has been used extensively in past Ecosim optimization exercises, using performance measures ranging from total profit from fishing (sum over fleets of incomes minus costs) to total employment (sum of catches times employment per catch) to risk-averse utility measures that favour a balanced 'investment portfolio' of fishing activities. A fundamental problem with this approach is the implicit assumption of value and cost pooling; supposedly 'optimum' solutions often involve operating one or more fleets at uneconomic levels, essentially using these fleets to cull some fish species so as to increase production from other, more valued species.

The second or 'multiple fishing rights' approach is to treat each fishing fleet (and perhaps non-consumptive stakeholder or user groups as well) as a separate economic industry with some legal right or entitlement to harvest, then seek a level for each fleet that optimizes a fleet-specific performance criterion such as total profits or growth until profitability (ratio of profits to income or cost) falls to a typical or reasonable level for economic industries in the economy as a whole.

See Implementing policy optimization in Ecosim for help with implementing these two approaches in Ecosim.

Policy objectives

Ecosim allows users to implement 'open loop' policy exploration simulations that acknowledges that policy may be defined as an approach towards reaching a broadly defined goal. The goal function for policy optimization is defined by the user in Ecosim, based on an evaluation of four weighted policy objectives:

i. Maximize fisheries rent;
ii. Maximize social benefits;
iii. Maximize mandated rebuilding of species;
iv. Maximize ecosystem structure or 'health'.

The first of these, maximizing profits, is based on calculating profits as the value of the catch (catch · price, by species) less the cost of fishing (fixed + variable costs). Giving a high weight to this objective often results in phasing out most fleets except the most profitable ones, and the wiping out of ecosystems groups competing with or preying on the more valuable target species.

The second objective, maximizing social benefits, is expressed through the employment supported by each fleet. The benefits are calculated as number of jobs relative to the catch value, and are fleet specific. Therefore social benefits are largely proportional to fishing effort. Optimizing efforts often leads to even more extreme (with regards to overfishing) fishing scenarios than optimizing for profit.

The third objective, maximization of mandated rebuilding of species (or guilds), is incorporated to capture that external pressure (or legal decisions) may force policy makers to concentrate on preserving or rebuilding the population of a given species in a given area. In Ecosim this corresponds to setting a threshold biomass (relative to the biomass in Ecopath) for the species or group, and optimizing towards the fleet effort structure that will most effectively ensure this objective. The implications of this are case-specific: we are finding that the optimization routine may rigorously hammer (through increased fishing) competitors and predators of the species in question; or at the other extreme that fisheries may be shut down without social or economic consideration (as is indeed often the case when legal considerations take over).

The last objective included, maximizing ecosystem structure (or 'health') is inspired by E.P. Odum's description of ecosystem 'maturity', wherein mature ecosystems are dominated by large, long-lived organisms, (see Christensen, 1995a). The default setting we have incorporated for ecosystem structure is therefore the group-specific biomass/production ratio as this measure is indicative of the longevity of the groups. The ecosystem structure optimization often implies reduction of fishing effort for all fleets except those targeting species with low weighting factors.

The fishing policy search routine estimates time series of relative fleet sizes that would maximize a multi-criterion objective function. In Ecosim, the relative fleet sizes are used to calculate relative fishing mortality rates by each fleet type, assuming the mix of fishing rates over biomass groups remains constant for each fleet type, (i.e., reducing a fleet type by some percentage results in the same percentage decrease in the fishing rates that it causes on all the groups that it catches). However, density-dependent catchability effects can be entered (using Ecosim's Group info form), and if so reductions in biomass for a group may result in fishing rate remaining high despite reductions in total effort by any/all fleets that harvest it. Despite this caveat, the basic philosophy in the fishing policy search is that future management will be based on control of relative fishing efforts by fleet type, rather than on multispecies quota systems. It is not yet clear that there is any way to implement multispecies quotas safely anyway, without either using some arbitrary conservative rule like closing the fleet when it reaches the quota for the first (weakest) species taken or else allowing wasteful discarding of species once their quotas are reached.

Optimization procedure

Invoking the search option causes Ecosim to use a nonlinear optimization procedure known as the Davidson-Fletcher-Powell (DFP) method to iteratively improve an objective function by changing relative fishing rates, where each colour-coded 'year/fleet block' defines one parameter to be varied by the procedure (e.g. setting four colour code blocks means a 4-parameter nonlinear search). DFP runs the Ecosim model repeatedly while varying these parameters; in the search output display, each simulation trial is labelled an 'eval' or function evaluation. So if you are running a large model for many years, where each simulation takes several seconds to do, the search may take quite a long time to do enough function evaluations to find a maximum for the objective function.

The parameter variation scheme used by DFP is known as a 'conjugate-gradient' method, which involves testing alternative parameter values so as to locally approximate the objective function as a quadratic function of the parameter values, and using this approximation to make parameter update steps. It is one of the more efficient algorithms for complex and highly nonlinear optimization problems like the one of finding a best fishing pattern over time for a nonlinear dynamic model.

The objective function can be thought of as a 'multi-criterion objective', represented as a weighted sum of three criterion components or indicators: economic, social, and ecological. Assigning alternative weights to these components is a way to see how they conflict or tradeoff with one another in terms of policy choice. For example, placing a high weight on the net economic value component (total fishing profits) typically causes the optimization to favour lower fleet sizes and severe simplification of the simulated ecosystem to maximize production of only those species that are most profitable to harvest. Placing a high weight on the employment (social) indicator typically results in favouring larger fleet sizes, and again often severe ecological simplification in order to maximize production for the fleet that employs the most people. The ecological criterion component is intended to balance these socioeconomic optimization effects: the ecological component is calculated as a sum of squared deviations of biomasses over time from biomasses that the user considers 'desirable' in terms of objectives like maintenance of biodiversity and insurance against ecological instability. The sum of squared deviations of biomasses from desirable values is treated as a negative value: larger sums of squares result in a decrease in the overall objective function value.

The search procedure results in what control systems analysts call an 'open loop policy', i.e. a prescription for what to do at different future times without reference to what the system actually ends up doing along the way to those times. It would obviously be very wrong to just apply an open loop policy blindly over time, each year committing a fishery to fishing rates calculated at some past time from only the data available as of that time. In practice, actual management needs to be implemented using 'feedback policies' where harvest goals are adjusted over time as new information becomes available and in response to unpredicted ecological changes due to environmental factors. But this need for feedback in application does not mean that open loop policy calculations are useless: rather, we see the open loop calculations as being done regularly over time as new information becomes available, to keep providing a general blueprint (or directional guidance) for where the system can/should be heading. Also, we can often gain valuable insight about the functional form of better feedback policies (how to relate harvest rates to changes in abundance as these changes occur) by examining how the open loop fishing rates vary with changes in abundance, especially when the open loop calculations are done with Ecosim 'time forcing' to represent possible changes in environmental conditions and productivity in the future. For an example of this approach to design of policies for dealing with decadal-scale variation in ocean productivity for single species management, see Walters and Parma (1996).