Use of Landings Data and Production Models (and Global Reef Production Values) as Ecosystem Caps

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SEDAR 103: US Caribbean Application of Alternate Assessment Methods

Summary
The use of landings data and biomass data for production models can provide historical statistics (time series, central tendency, stability, variance, etc.) of landings and estimates of yield; these can also be calculated from production models. This can directly set MMSY and aggregate MSY, largely for use as ecosystem caps. They do not require copious information as might be implied. Instead, two of these methods depend on simple production model fits. All methods remain quite viable and relatively robust, particularly in data limited situations. These methods obviously depend on the veracity/robustness of biomass (or fisheries independent survey data) for MS production models, and often need some information by species whereas the aggregate production model does not need species data or information. At the simplest, historical estimates of landings can provide a basis for known landings levels, particularly if they have been consistent and non-directional over long periods of time. However, the veracity or robustness of landings data might affect this method. Finally, via proxy from other ecosystem regions, one can use estimates of reef production globally to provide a gauge of how productive Caribbean reef fish communities could be on a per unit area basis, scaled to the size of a particular island ecosystem.

I. Introduction

The concept of ecosystem caps is legal, allowable, and advisable to do now. It affords the opportunity for potential deregulation of copious single stock-oriented status determination criteria (SDCs) or biological reference points (BRPs). Ecosystem caps provide SDC coverage and a backstopping for all species, many of which are never assessed individually or as part of a complex. Furthermore, ecosystem caps provide an overall sense of the capacity, and hence limits, of any ecosystem, as tied to regional primary productivity. The limits can set expectations for regional fisheries economics, and can provide a 'trade-space' for regional fisheries priorities.

The benefits of ecosystem caps are numerous. When implemented, this approach has categorically resulted in improved regional fisheries economics. It also affords opportunities for some fisheries flexibilities, thereby reducing discarding. Ecosystem caps also facilitate the development and monitoring of key fisheries performance measures.

Using common and widely available information, landings data, production models, and global context can help establish how fish can be caught in an entire ecosystem and whether those limits are being met (or exceeded).

II. Method Description

Adapted from Link et al. (in press)

Landings and Catch

Data Sources

The most basic approach for estimating the maximum sustainable level of harvest for an ecosystem is to use the average historical catch of all species from an area, assuming that in a well-managed and stable fishery, the resource is being harvested at its maximum sustainable yield. Optimally, the level of total catch can be obtained from records of commercial and recreational landings and discards (target and non-target species caught but not retained). For this study, we used, as much as possible, publicly available data that can be reasonably accessed. Fisheries landings can be obtained from the NOAA Fisheries One Stop Shop (FOSS; https://www.fisheries.noaa.gov/foss/). The commercial landings data in FOSS are from 1950 - present, and recreational landings data are available from ~1981 to present. However, Caribbean landings were calculated by summing the U.S. Territorial landings for Puerto Rico and U.S. Virgin Islands available in FOSS. The data only include commercial landings from 2009 - 2021. Limited recreational data are in FOSS, particularly for the Caribbean. More so, no recreational data are typically included these broad approaches, but they can be included if available. No data are available in FOSS for discards. These are readily aggregated across all landed taxa. If there are locally sourced data, they can be easily used to calculate sustainable harvest levels on a per island basis.

Calculating Ecosystem Caps from Landings

From the catch and landings datasets, the arithmetic mean and median were calculated using all values available across the extent of the time series. To reduce the influence of the mismatch between major changes in management and policies (e.g. establishment of the U.S. EEZ in 1983 and subsequent exclusion of foreign fishing fleets), and to favor recent environmental conditions and management policies we also calculated an arithmetic mean for the most recent 10 years of each data set. One could envision multiple, statistical treatments of these data (e.g. 3, 5 or 10 year moving averages and then mean or median values thereof, more sophistical ARIMA modeling thereof [but see Tipping Point Analysis below], etc.), but for an initial suite of landings estimates we provide the mean, median, and most recent 10 year mean of landings. One could also envision various estimation approaches to calculate bycatch and discards, and though in particular a simple scalar of some fixed percentage of landings was explored in some of our preliminary works, it essentially just modified the mean and median values and we did not think it provided additional information beyond the range already noted here and by the methods described below.

Environmental Tipping Point Analyses

Ecosystem-level reference points can also be identified via changepoints or segments in the mean or variance of ecosystem indicator timeseries. Here, we explore statistical properties of aggregate fisheries landings to see if changepoints could identify dramatic changes, either as decreases or as increases, which could inform a change in the system carrying capacity and thereby indicate possible ecosystem caps.

Within the R statistical software framework, EnvCpt is a package that explores a series of 11 models and selects the model that provides the best fit to represent the time series (Killick et al 2025). Constant mean (Mean), a constant mean with first-order autocorrelation (Mean + AR(1)), a linear trend (Trend), a linear trend with first-order autocorrelation (Trend + AR(1)), multiple changepoints in the mean (Mean cpt), multiple changepoints in the mean and first-order autocorrelation (Mean cpt + AR(1)), a trend with multiple changepoints in the regression parameters (Trend cpt), a trend with multiple changepoints in the regression parameters and first-order autocorrelation (Trend cpt + AR(1)), a linear trend with second-order autocorrelation (Trend + AR(2)), multiple changepoints in the mean and second-order autocorrelation (Mean cpt + AR(2)), and a trend with multiple changepoints in the regression parameters and second-order autocorrelation (Trend cpt + AR(2)). Maximum likelihood estimation is used to fit each model. Changepoints vary from 1 to the maximum number of changepoints given the timeseries segment length (default segment length = 5). Model selection uses AIC, which penalizes model likelihood by the number of parameters for each model (Akaike 1974).

For each region or island, we can select the model with the lowest AIC and extract changepoint indices, thereby identifying the value of landings associated with the changepoint.

Aggregate (Surplus) Production Models

Given a timeseries of landings and biomass data (or even simulated measures of these values), annual surplus production (ASP) can be calculated for each species, species group, or entire suite of fisheries as:

$$ASP_t = B_t - B_{t-1} + C_t \qquad [2]$$

where B is biomass, C is catch, and t is year (see Mueter and Megrey 2006). Such Schaefer surplus production models can then be fit to *ASP* versus B model outputs, or if necessary, ASP can be averaged over a set of years. The results from modeling provides estimates of maximum surplus production, interpreted as maximum sustainable yield (MSY), and these can be estimated for individual species or species groups, which can then be summed across species or species groups to estimate multispecies maximum sustainable yield (MMSY). Or they can be estimated in aggregate for all (most) harvested taxa for MMSY. Either way such MMSY can be considered an ecosystem-level catch limit or cap, even if only partially covering the suite of harvested LMRs.

Global estimates of reef fish production

Most fisheries tend to support landings of ~1-5 t km-2 yr-1 (Bundy et al. 2012, etc.). Reef fisheries have a smaller area, but on a per unit area basis have supported fisheries at something closer to ~15-20 t km-2 yr-1 (Zamborain-Mason et al. 2025, etc.). A lot of these methods use simple Aggregate or MS production models to come up with said estimates. One approach would be to glean from the literature (there is a reasonable set of information on this topic) and set a limit/cap based on an amalgamated global standard. For example, estimates from Gomis et al. (2025) have values ranging from 0.53 to 5.25 t km-2 yr-1, whereas Douglas et al. (2001) range from 0.36 to 49.5 t km-2 yr-1. The reviews by Zamborain-Maison et al. 2025, Link 2026, and associated works contains a suite of such estimates that have ranges of production on the same order, so one can reasonably expect an ecosystem cap from global reef averages, or more specifically the average from similar reefs as to the Caribbean, to be of the same order of magnitude (Table 1). A range of estimates from these landings, production model, and other approaches (see related SEDAR WPs) are provided here (Fig. 1).

A. Data Input

- Catch (landings)
- Biomass over time for surplus production models
- Fishing effort

B. Analyses/Data Outputs

- Historical statistics (time series, central tendency, stability, variance, etc.) of Landings
- Environmental Tipping Point Analysis
- Estimates of Yield from Production models
- Global estimates from reef fisheries in the literature

C. Implications for Management

- Ecosystem caps can be developed from these methods
- These ecosystem caps or limits can set limits for MMSY and aggregate MSY
- These can serve as an ecosystem level reference point (Morrison et al. 2024).

D. Caveats

- veracity/robustness of landings data; which is universally true of any methods applied in this region.
- does not need copious information as might be implied
- some of the approaches noted herein depends on simple production model fits, but those are downplayed in SSSA due lack of age/size structure
- depends on veracity/robustness of biomass (or fisheries independent survey data)
- MS production model needs some info by spp
- aggregate production model does not need spp data/info

- Ecosystem caps do not prevent overfishing of particular species, especially if they are targeted at a higher rate of exploitation, but they do cover species that typically do not have any BRP

III. Applications of the Method

- Landings data are used as data inputs globally in nearly every stock and MS assessment
- Landings data have been used to set BRPs in data limited situations around the world and the US. Even in FMCouncils with copious data, when there are challenging model diagnostics it is not uncommon for ACLs to have been set to the past 5 years of landings if they are stable
- Ecosystem caps are already used in Alaskan regions
- Ecosystem caps are used internationally to establish total fishing limits in countries in SE Asia
- National working group estimating caps is ongoing in parallel
- Landings and production model approaches are well known, well-vetted, and largely depend upon confidence of the input data.

IV. Discussion

Ecosystem caps are estimates that attempt to relate the removal of all harvested stocks (or at least most of them) to the underlying production capacity of a given ecosystem. The thinking from hierarchy theory is that though important and problematic, it is one thing if lower level (e.g., a couple of populations) components are perturbed, but if the entire system (large aggregate groups or the entire ecosystem) is perturbed there are much bigger concerns and issues occurring which cannot be rectified by resolving issues at lower levels in the hierarchy. Ecosystem caps have a solid theoretical backing, particularly via the principle of carrying capacity for an entire suite of species, and can provide a strategic backstop by reverting to the first principles of said carrying capacity (Link, 2018; Morrison et al., 2024). By utilizing ELRPs, managers can evaluate harvestable biomass to account for larger system dynamics. This range of methods serve as ecosystem-level reference points that act as a reality check on the sustainability of total removals. While single-species approaches remain valuable for a limited sub-set of specific allocations, these broader ecosystem-level caps offer a relatively inexpensive and robust safeguard, ensuring that the cumulative pressure of all fisheries does not exceed the fundamental energetic limits of the marine environment (Link, 2018; Morrison et al. 2024). The ecosystem cap estimates also have utility for management as indicators of system-level trends, the likelihood of ecosystem overfishing, and as context for discussing tradeoffs of various management approaches and decisions.

Legal & Mandate considerations- such ecosystem level reference points like ecosystem caps are legal, allowable, and advisable to do now. They afford the opportunity for potential deregulation of copious single stock oriented SDCs or BRPs. They provide SDC coverage and a backstopping for all spp, many of which we may never assess individually or as part of a complex, but we can do so as an “uber” complex, including EC spp. The utility of such ecosystem limits are that they give an overall sense of the capacity, and hence limits, of an ecosystem, as tied to regional (primary) productivity. They can set expectations for regional fisheries economics– potential. They can and have provided a “trade-space” for regional fisheries priorities.   The benefits of these approaches are that when implemented, they have categorically resulted in improved regional fisheries economics (c.f. Link 2018 for more details). They afford opportunities for some fisheries flexibilities, thereby reducing discards and they facilitate development and monitoring of key fisheries performance measures.

The specific methods noted herein are simple, robust, well-known, well-tested, and rely on rather basic input data. The application we recommend is calculation of some of these as a back-stop, per island, as the data are readily available and the computational/analytical costs are minimal. These can then delineate whether an Island ecosystem is experiencing excessive ecosystem overfishing, or is close to its production potential, and then be used to ensure that there are SDCs and BRPs for all/most taxa without having to worry about conducted detailed analyses for every taxa in these ecosystems. In conjunction with other approaches, these simple landings or production-based methods provide a limit to fishing in each island ecosystem and can provide the basis for further evaluations of higher priority species.

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VI. Tables and Figures

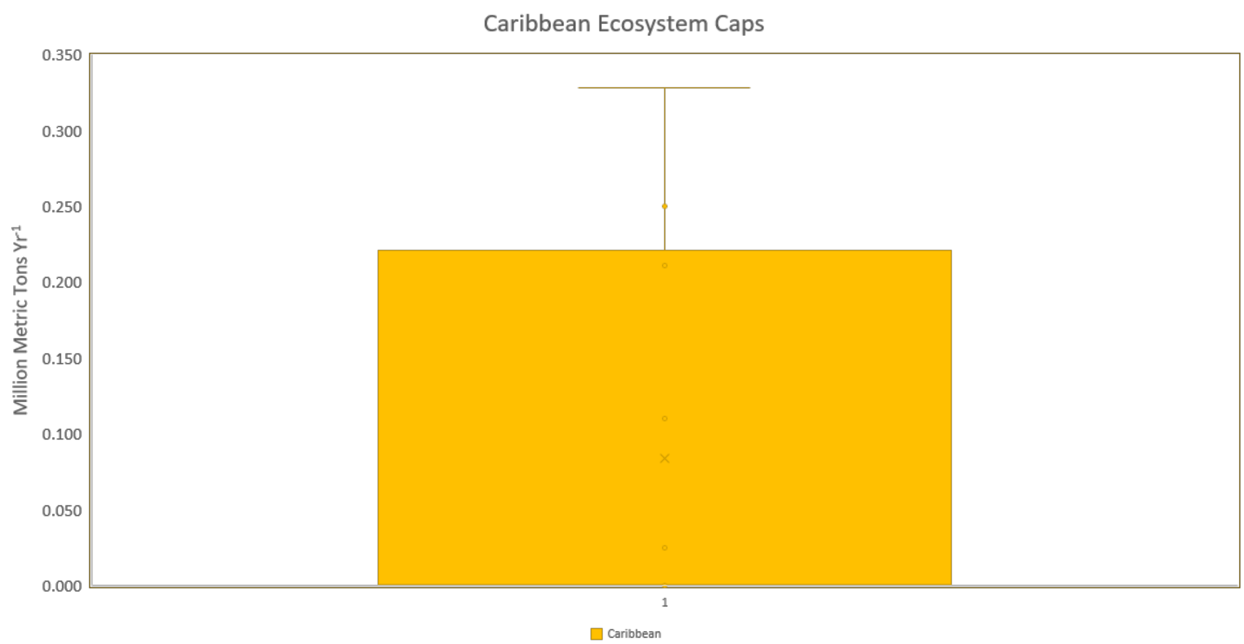

Figure 1. Most of these ecosystem cap estimates from the Caribbean are either trophic index-based, trophic declination-based, or statistical landings-based, the latter of which are primarily noted herein. The median value is 0.07 million metric tons yr^{-1} for all U.S. Islands.

Table 1. MMSY estimates from surplus production models for global coral reef sites. Adapted from Zamborain-Mason et al. (2025).

	Gompertz-Fox	*Graham-Schaefer*	*P-T 3*	*P-T 4*
MMSY for average environmental conditions and non-atolls ($t/km^2/y$)	5.8	5.5	5.7	5.5
Range of site-specific MMSY ($t/km^2/y$)	[2.5 – 20.6]	[2.4 - 19.8]	[2.4 – 21.8]	[2.3 - 26.1]
B_{MMSY} for average environmental conditions and non-atolls (t/km^2)	42.5	56.9	65.4	70.9
Range of site-specific B_{MMSY} (t/km^2)	[18.0 – 151.0]	[23.8 – 200.8]	[27.3 – 234.6]	[28.2 – 294.8]