Fisheries and Oceans Canada | Pêches et Océans Canada

Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

National Capital Region

Canadian Science Advisory Secretariat
Science Advisory Report 2016/053

SCIENCE ADVICE ON REGIONAL PRODUCTIVITY BENCHMARKS

Figure 1. Department of Fisheries and Oceans' (DFO) six administrative regions.

Context:

The Fisheries Act was amended in 2012 to include new provisions for fisheries protection which came into force in 2013. The amended Act focuses on managing threats to the sustainability and ongoing productivity of commercial, recreational or Aboriginal fisheries and contains a prohibition against causing serious harm to fish that are part of or support a commercial, recreational or Aboriginal fishery (CRA). Serious harm to fish is defined in the Act as the death of fish, the permanent alteration to, or destruction of, fish habitat. When proponents are unable to completely avoid or mitigate serious harm to fish*, their projects will normally require authorization under Subsection 35(2) of the* Fisheries Act *in order for the project to proceed without contravening the* Act.

Although productivity is not part of determining whether serious harm to fish has occurred, Fisheries Protection Program (FPP) considers fisheries productivity, among other factors, when considering whether an authorization is appropriate and when determining offset conditions that will be attached to such authorisation (section 6, 6.1 in the Fisheries Act)[1].

The FPP aims to support its project review and decision-making processes with the development of quantitative metrics that can be coupled with decision criteria to assist FPP staff when determining whether to authorize serious harm to fish.

[1] More information on the Fisheries Protection provisions of the *Fisheries Act* can be found in the Fisheries Protection Policy Statement.

Consistency in decision-making by the FPP would be aided by the development of a methodology that can accommodate a diverse range of project impacts, including fish mortality and the destruction of fish habitat. Previous advice has been provided on using the concepts of "Equivalent Adults", area per recruit, and production foregone in regulatory decision-making framework. This advice was largely conceptual and at coarse scale (lakes versus rivers) across Canada, noting that further regional and habitat stratifications may provide more precise estimates.

Fisheries and Oceans Canada (DFO) Ecosystems Management is requesting advice from DFO Science to understand how fisheries productivity varies regionally across Canada, in support of implementation of the fisheries protection provisions. The regional productivity benchmarks are anticipated to be used in the following ways:

- *To refine the estimates of equivalent adults and area per individual for informing decisions about whether an authorization is required.*
- *To provide estimates of regional productivity that can be used for understanding baselines for the purposes of impact assessment in the absence of site-specific data for small-medium impact projects.*
- *To provide estimates of regional productivity that can be used to reasonably estimate targets of potential gains in productivity expected from offsetting.*

This Science Advisory Report is from the September 29-October 1, 2015 meeting to provide Science Advice on Regional Productivity Benchmarks. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule *as they become available.*

SUMMARY

- In general, the development of regional community and population productivity benchmarks was considered appropriate and feasible.
- Benchmarks can be used for establishing baseline values of productivity for the purposes of impact assessment, and to estimate potential gains in productivity expected from offsetting to establish equivalency relative to the impact (especially for small to medium sized projects), including establishing offset ratios.
- The benchmark approach can provide a reference condition when site-specific data are available (e.g., degree of anomaly from the reference).
- In data deficient areas, transferrable landscape fish-production relationships could be used to inform benchmarks for the FPP assessment process.
- Ecoregions (25 000 to 500 000 km^2) appeared to work relatively well as a broad scale stratification but smaller scales may be useful for predictions. Clear examples in the literature exist as to how to achieve an appropriate scale relevant to the FPP and these consider information on drivers of production (e.g., nutrients, climate, etc.). Benchmarks may need to be established at multiple scales where feasible.
- Actual productivity may differ from expected/predicted productivity based on benchmarks thus several critical things to consider when developing and/or using regional benchmarks include: life history (what life stage was measured), environmental forcers (e.g., climate), human impacts, types of habitat used to establish the benchmark, species included in the productivity metrics, methods used to sample (i.e., capturing biomass for system or only a portion of the system), status of the resource, etc.
- Data and analyses presented at the meeting provided evidence of biologically significant differences in productivity of wadeable flowing riverine habitat among studies/regions in Canada.

INTRODUCTION

Regional productivity benchmarks can be drawn from a framework consisting of two nested hierarchies of productivity indicators and spatial scales (Figure 2). The productivity indicators may range from total primary productivity at the ecosystem scale, to the summed productivity of all fish species, down to the productivity of an individual CRA fishery species, in any target region. Sampling methods and survey designs for measuring productivity are also scale dependent, ranging from very small points or patches where individual fish are encountered, through several trophic levels or species assemblages to large ecosystems such as watersheds or lakes. Datasets used to develop benchmarks are unlikely to be available at similar spatial and ecosystem scales of productivity across all regions and, due to combinations of sample and geographic scale limitations, are unlikely to include all life stage and habitat diversity. Direct estimates of productivity are unlikely to be available for many ecosystem components in the framework; hence, a range of surrogate metrics for productivity may need to be considered including biomass or numbers per unit area, catch per unit effort, weighted suitable area, water quality indicators, ecosystem morphometry, climate norms, etc. As such, additional effort will be needed to demonstrate the relationships between productivity itself and the proxy metrics for productivity at various ecosystem scales.

Given the diversity of climates, habitats, and ecosystems across Canada’s aquatic environments and the varying levels of information available regional specific productivity benchmarks can be expected. For example, benchmarks for inland lakes might be established from studies of individual lakes of differing ecosystem complexity using, differing sampling methods such as shallow littoral electrofishing transects with measured catch efficiency versus combinations of gillnet or trawl sampling over a wide range of depth to determine species and size composition with hydro-acoustic surveys to lake-wide estimates of primary production and trophic transfer efficiency, or long-term records sustained fishery harvests. For rivers, benchmarks might be established for the Maritime provinces Atlantic salmon watersheds based on estimates of standing biomass of a single species from multiple wadeable electrofishing sites to estimates of potential total returns of adults from the sea, or estimates of allochthonous carbon inputs to all streams derived from remote-sensed estimates of terrestrial primary production.

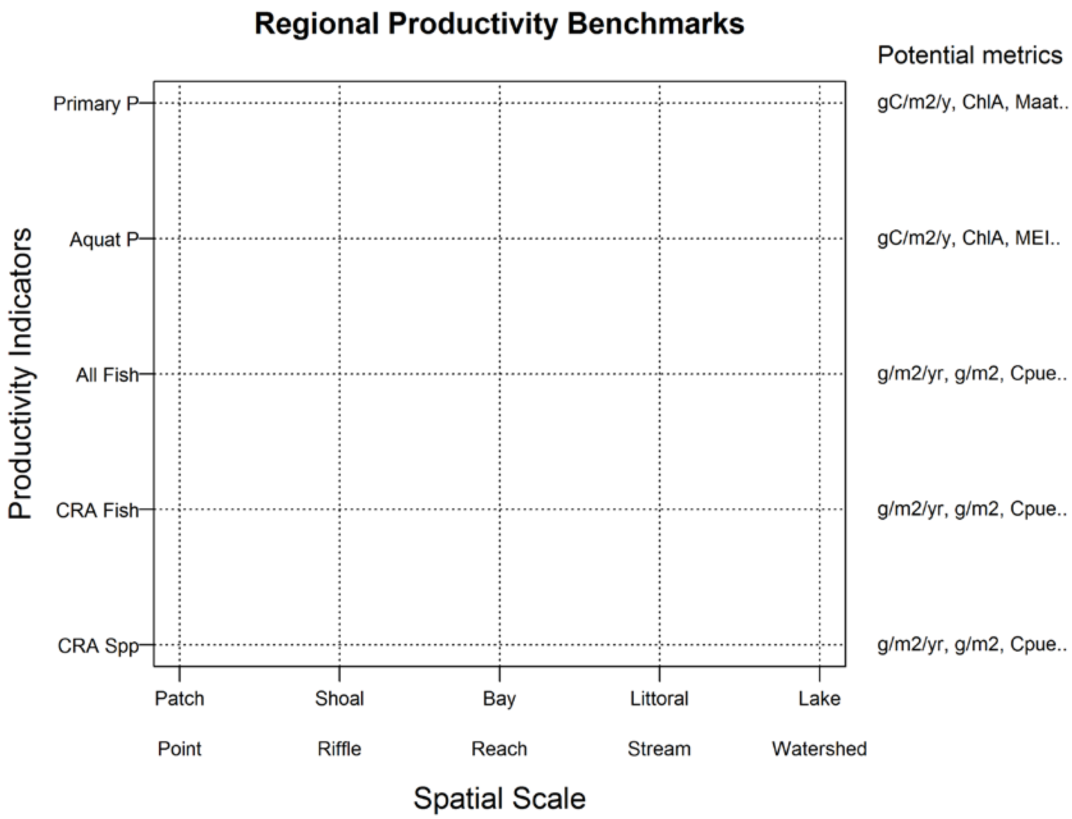

Figure 2. Conceptual model showing the interaction of spatial scales and productivity indicators (from single CRA species to total primary production) that could be used to develop regional benchmarks. The labels on the right vertical axis illustrate potential units that may be used (e.g., Chlorophyll A concentration; morphoaedaphic index (MEI); yield as catch per unit effort (Cpue); productivity as $g/m^2/y$ or, biomass as g/m^2, etc.). The examples from this science review of freshwater productivity benchmarks were mostly in the lower portion (from individual CRA spp. to all CRA fish with respect the productivity indicators and from point to watershed with respect to spatial scale).

ANALYSIS

Usage

Regional benchmarks of productivity have been referred to and defined in previous advice:

Regional benchmarks of productivity are indicators of carrying capacity for a particular region, using metrics (e.g., Chlorophyll a concentration, fish biomass or density) that are based on empirical data from reference sites within the region (DFO 2014).

Carrying Capacity is central to this definition and it has been previously defined in this context as the maximum abundance which any given habitat can support. The product of the amount of habitat and the carrying capacity, expressed as density, usually determines the maximum size of a population. Given these definitions regional benchmarks of productivity would be a useful addition to the ‘toolbox’ when trying to assess any potential changes in fisheries productivity that may result from a work, undertaking or activity (i.e. project) that is being reviewed by the Fisheries Protection Program.

Benchmarks may be used in a variety of ways during the FPP assessment process, including to provide a preliminary assessment of the relative importance of a given habitat in the project planning phase, or to formally evaluate the proposed project's potential impacts to fisheries productivity. Likewise once a productivity assessment has been made, benchmarks may also help inform equivalency analyses that may be required to offset lost productivity (DFO 2012). Additionally benchmarks may also inform other assessment methods such as 'production foregone' and/or 'adult equivalency' which are further discussed in DFO (2015).

A number of metrics may be used to quantify productivity. For example, density, biomass or some other productivity index that has been shown to be related to carrying capacity could be a potential benchmark metric. Therefore when using benchmarks in the FPP process it is important that the assessment information used by the assessor be compatible with the methods and metrics used to establish the benchmark. This requires that the procedures used to define the benchmark be completely documented and replicable and that data used, including those provided by the proponent, include details of data collection and analysis methods.

Regional benchmarks of productivity are proposed as indicators of carrying capacity. As such knowledge of the relative health of the ecosystem being sampled and any resultant effects on fish abundance are important considerations when developing benchmarks. Carrying capacity can only be defined in cases where habitat is limiting abundance for the life stage being sampled or where abundance is not being affected by other life stages not living in the sampled habitat. For many species, this information may not be readily available and auxiliary information such as expert opinion will be required to ascertain the status of the resource relative to its maximum production potential. In a similar context, fish community data from habitats or systems in which anthropogenic stressors, including cumulative stressors, have reduced the carrying capacity of the habitat to a measurable extent below what would be expected for habitats of similar characteristics without the stressors would not appropriate for development of productivity benchmarks. Therefore if the resource has been depleted due to non-habitat related reasons and/or the habitat itself has been degraded caution should be used when using a benchmark approach as it may not be valid for use in FPP assessment processes.

Regional benchmarks of productivity may be particularly important for assessments under data-deficient situations but they should not be used in isolation when other data sources exist. Where acceptable site-specific quantitative fish data and/or species/community specific models exist they should be used in combination with a regional benchmark. The utilization of a variety of methods would be expected to reduce the uncertainty within the FPP process. Since benchmarks can be used in a variety of ways and at different times within the FPP process and there is a need for complete documentation it is important that the overall framework of an individual benchmark be consistent and robust. For this reason individual benchmarks should be peer reviewed before being used in the FPP process.

Stratification

There is a large body of evidence indicating that climatic, physiographic, and other abiotic and biotic factors are key ecological processes that determine regional levels of fish productivity. However, the magnitude of the relationship between one particular variable and fisheries productivity is highly dependent on the spatial scale of the study area. At large scales the influence of climate is often apparent and affects fish growth rates, population turnover periods and standing stocks of fish biomass. However, at finer spatial scales, the relative difference in productivity between a habitat with low quality features and one with abundant high quality features could easily eclipse the relative differences in climate driven productivity, even across a continental scale. When aquatic ecosystems are classified, the explanatory physio-climatic and biotic variables are rarely shared among spatial scales. Therefore, we conclude that physio-climatic relationships with productivity could be highly informative at broad spatial scales and provide predictive models to set regional benchmarks. However, at finer scales, local benchmarks would be more accurate if the relationships were based on local fish habitat features as well as fish communities. In addition to considerations of the spatial scale of the explanatory variables, it is important to take note of the spatial scale of study that is relevant to the benchmark CRA fishery. In some cases, the productivity of the fishery may rely most on the health of the entire stock, which could span many different ecosystems depending on connectivity of the watershed and the species migratory ability. In others, populations, or even sub-populations may be separated enough from the overall stock that local factors influence their productivity the most.

A variety of schemes for the stratification of physio-climatic and biotic mechanisms at different spatial scales can be found in the scientific literature, for both aquatic and terrestrial systems (see de Kerckhove et al. unpublished manuscript[2]). One of the most common is the Ecoregion Classification System which categorizes aquatic and terrestrial surface areas into about seven stratifications (see Table 1). There is no consensus on whether terrestrial classification systems adequately represent aquatic systems, but this is mostly because it depends on the research question being examined. It has been demonstrated many times that fisheries productivity will align with changes in Ecoregions due to changes in nutrient levels across geological formations and climatic clines; however, there is less support that fish species richness, or even individual species distributions are stratified across similar criteria. Nested stratifications in which the boundaries of finer scale regions fit completely within the coarser scaled boundaries are the most commonly used in the scientific literature; however, place-independent considerations (i.e., dependent on an environmental variable rather than geographic proximity) are also important in defining the appropriate stratification dimension for benchmarks because of important and overriding local factors (e.g., variations in nutrient levels, anthropogenic stressors, stream order, etc.). These place-independent considerations lead to discernable patterns in species richness and fish productivity in which the headwaters of different watersheds are often more similar to each other than their main river habitats.

Finally, productivity metrics will differ most between coastal and inland aquatic environments, and so benchmark stratification will likely follow coastal watershed boundaries. In coastal areas, large fisheries yields may be derived from production of anadromous species whose life stages may not be available to be sampled in standard wadeable flowing riverine habitat. This could also be the case in inland areas where fish species may only be present for intermittent periods of their life history, or specific life stages only migrate through an area. Estimates of productivity will be most complete for species that are resident for their entire life cycle in the area under assessment.

Table 1. Eco-classification systems used by the World Wildlife Fund in Canada (see de Kerckhove et al. unpublished manuscript[2] for details).

Terrestrial

Eco-classification	Area	Map Scale	Canada
Continental Ecozones	500,000 - 50,000,000 km^2	World Map	1
Ecozone	150,000 - 2,000,000 km^2	1:7,500,000	15

[2] de Kerckhove, D.T., J. A. Freedman, K. L. Wilson, M . V. Hoyer, C. Chu and C. K. Minns. (2016). Choosing Spatial Units for Landscape-Based Management of the Fisheries Protection Program. DFO Can. Sci. Advis. Sec. Working Paper

Eco-classification	Area	Map Scale	Canada
Ecoprovinces	50,000 - 500,000 km^2	1:2,000,000	53
Ecoregions	25,000 - 500,000 km^2	1:500,000	194
Biogeoclimatic	25 - 2,500 km^2	1:100,000	N/A
Ecodistricts, Land Resources Areas	5 - 50 km^2	1:20,000	1021
Land Unit	0.5 - 5 km^2	1:20,000	N/A

Aquatic

Eco-classification	Area	Map Scale	Canada
Marine Ecozones	25,000 - 2,000,000 km^2	1:7,500,000	5
Freshwater Ecozones	250,000 - 1,000,000 km^2	1:7,500,000	18

Examples Presented at the Meeting

Fisheries productivity was examined using data collected via electrofishing in wadeable flowing water habitat from the east coast of Canada, Ontario, Alberta, and British Columbia. Standing stock biomass of dominant salmonid species and of the fish community were estimated and used as metrics of carrying capacity. Habitat productivity indices were also calculated from these data (see Randall et al. unpublished manuscript[3] for details).

Electrofishing data from Newfoundland, the Maritime Provinces, Ontario and British Columbia were presented to show regional differences in fish productivity. Regions were defined as Salmon Fishing Areas (Atlantic Provinces) or Fisheries Management Zones (Ontario). The electrofishing data were collected by different agencies for various reasons: to determine stock status (mostly salmonids), to investigate fish habitat associations, or to investigate status and life history characteristics of species at risk. Despite being targeted for specific species, all catches of cohabiting species (i.e., the total fish community) were also recorded. Most of the electrofishing data were quantitative, such that numbers and biomass densities of fishes could be estimated (number of fish m^{-2} and g m^{-2}). The data sets varied in duration and extent from 'snapshots' (<5 yrs and few sites) to time series (> 10 yrs and spatially extensive). For each site, a Habitat Productivity Index (HPI) was also estimated. HPI was calculated as the product of the biomass density for the site and the production/biomass ratio (P/B), where P/B was estimated from average fish weight at the site and literature-based allometry relationship of P/B with body size.

Two methods for estimating biomass were used: average biomass density for the survey area (site), and biomass density adjusted to a constant fish weight. Both methods were comparable. Density-body size relationships were variable among regions. Limitations and constraints of the data sets for estimating regional productivity included: uncertainty of carrying capacity and fish population status, habitat stressors and the possible influence of non-random survey designs.

Average mean productivity was estimated to be highest in monitored riverine systems in southern Ontario which also had the highest species richness, followed by the Maritime provinces and British Columbia, and lowest in Newfoundland river systems (productivity was also low in north-central Ontario (Magpie and Batchawana), but catch efficiency and habitat coverage was unknown for this area.). In all areas, there was large variation in estimated productivity values (Figure 3).

[3] Randall, R.G., M.J. Bradford, D.T. de Kerckhove and A. Van Der Lee. 2016. Determining regional benchmarks of fish productivity using existing electrofishing data from rivers: proof of concept. DFO Can. Sci. Advis. Sec. Working Paper.

Average biomass densities among regions were significantly and positively related to air temperature, for both the fish community biomass and for the biomass of individual salmonid species. These results were preliminary. Other environmental cofactors that could potentially affect productivity have not yet been investigated.

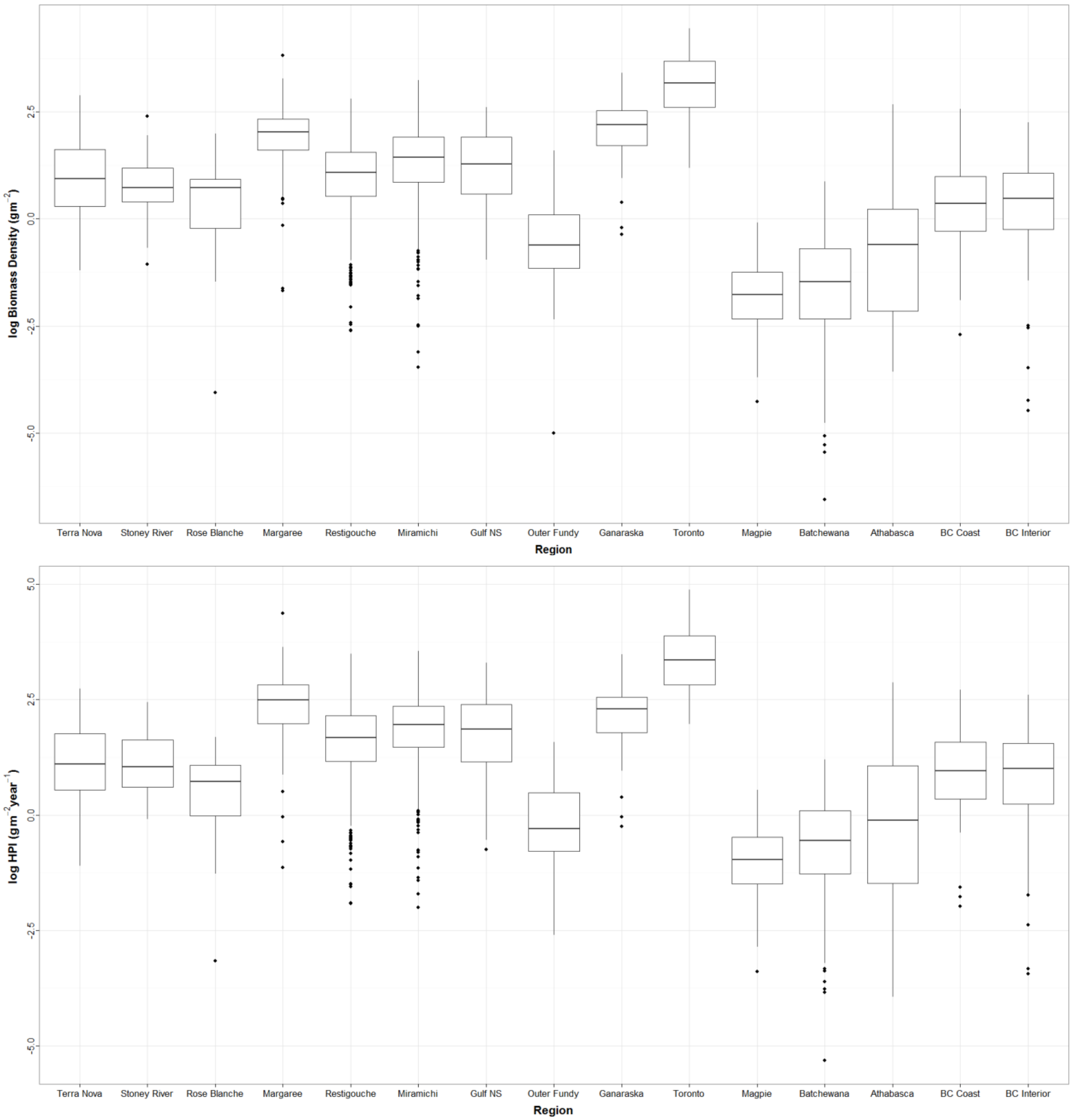

Figure 3. Region-specific benchmarks of fish productivity. Average fish biomass density (g m^{-2}; upper panel) and the Habitat Productivity Index (g m^{-2} y^{-1}; lower panel) are shown in box and whisker plots as metrics of productivity. All values are provisional, and are shown as proof of concept for using existing electrofishing data for assessing fish productivity in the different regions. Biomass density was likely at or close to ecosystem capacity for some regions, but electrofishing catch efficiency was not known or was assumed for others.

Sources of Uncertainty

The variation observed in the estimates of productivity from wadeable streams that were evaluated at this meeting was large within and among monitored sites. High variance can be attributed to a number of factors acting at local scales including characteristics of the habitats sampled, nutrient levels, temperature, species diversity and distribution, sampling bias, model uncertainty and other undefined factors.

Given this variation, risk management considerations would be appropriate when using the benchmark approach. Therefore instead of using a measurement of central tendency (i.e. mean or median) to compare a site to a regional benchmark it may be better to use the cumulative distribution of estimated productivities for a given area. For example, choosing a percentile higher than the median as the benchmark value would ensure a lower probability of underestimating the productivity of sampled sites. The actual choice of an appropriate risk level is a management decision that can be informed by science.

Contemporary data (within the past two decades) were used in the analysis of the riverine productivity benchmarks. Over the past two decades, there have been important and sustained directional changes in some important drivers of productivity, for example warming temperatures associated with climate change, increases in nutrients from non-point sources in regions with agriculture. These non-stationarity considerations should be recognized when choosing the data to be used in the development of regional benchmarks of productivity. In addition, the timeframe over which the benchmark values could be appropriately applied in FPP assessments needs to be evaluated in the future, therefore periodic reviews of benchmark values would be appropriate.

The regional benchmarks of productivity that were reviewed used standing stock biomass as the main metric of productivity. Caution with this or similar metrics of productivity should be exercised when the life history of the species includes significant migrations of life stages that result in production being accrued in very different habitats than those being sampled for the benchmark (e.g., anadromous species, or potadromous species moving between lakes and tributaries). While the benchmark approach may still be useful to FPP in these situations, it may underestimate the habitat’s importance for individual species. An analytical method that could potentially resolve this issue (i.e. ‘production potential’ which includes production from all life history stages even when they are outside the studied habitat area) was discussed at the meeting but its usefulness largely remained unresolved and should be the subject of future work.

CONCLUSIONS AND ADVICE

The feasibility of developing regional community and population productivity benchmarks was evaluated through an analysis of standing stock biomass estimated from habitats of wadeable streams in five southern areas of Canada. In general, the development of regional community and population productivity benchmarks was considered appropriate and feasible. Benchmarks may be used in a variety of ways during the FPP assessment process including evaluating the potential impacts to fisheries productivity of a proposed project and informing any equivalency analysis that may be required to ensure any lost productivity is counterbalanced by the offsetting plan. Regional benchmarks of productivity may be particularly important for assessments under data-deficient situations but they should not be used in isolation when other data sources exist.

There is a large body of evidence indicating that climatic, physiographic, and other abiotic and biotic factors are key ecological mechanisms that determine regional levels of fish productivity. Therefore some level of spatial stratification is important for the use of regional benchmarks.

Ecoregions (25 000 to 500 000 km^2) appeared to work relatively well as a broad scale stratification but smaller scales may be more predictive. Examples of how to achieve an appropriate scale relevant to the FPP exist in the scientific literature (see de Kerckhove et al. unpublished manuscript[2]).

Actual productivity may differ from productivity derived from benchmarks. Several factors may need to be considered when developing and using regional benchmarks. These include: life history (what life stage was measured), environmental forcing variables (e.g., climate, flow), human impacts, types of habitat used to establish the benchmark, species included in the productivity metrics, methods used to sample, and the status of the resource. Given this potential for variation, risk management considerations would be appropriate when using the benchmark approach.

OTHER CONSIDERATIONS

The benchmarks of freshwater productivity examined in this peer review process were specific to wadeable flowing water habitats for the most part. Benchmarks of production from other habitats were not examined in detail. Data from other habitat types (e.g., lakes) most likely exist, and the inclusion of these data could result in a broader spatial coverage across the country. Even with these additions, however, it was recognized that many habitats (e.g., large rivers) and species many not have the information required to create a benchmark at this time. A gap analysis within the hierarchical nested framework described above would be useful to prioritize the next steps with respect to benchmark creation.

There are also several next steps that could be explored to improve the overall confidence of the benchmark approach for use in FPP processes. Further validation of the approach could be provided by comparing benchmarks with empirical pre- and post-monitoring data and/or quantitative fisheries data or models in areas where both exist. Likewise as more benchmarks are developed, the sources of variability (e.g., metrics used, sampling methods, regional stratification etc.) within in each benchmark will become better understood. This information would help to ensure benchmarks are consistently applied and could possibly lead to recommendations on data requirements and stratifications needed to establish consistently valid benchmarks.

While it was acknowledged that other databases probably exist that could lead to productivity benchmarks in other habitats, it was also recognized that a large number of monitoring programs could also supply data for benchmark creation. These programs may be designed to monitor target species or to evaluate environmental effects at the community/ecosystem level, but if they could be modified to include some basic information on abundance, size and biomass of the entire fish community the potential source data for benchmark creation would be substantially increased.

SOURCES OF INFORMATION

This Science Advisory Report is from the September 29 to October 1, 2015 national peer review on Science Advice on Regional Productivity Benchmarks. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 2015. Science Guidance for Fisheries Protection Policy: Advice on Equivalent Adult Calculation. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/011.

DFO. 2014. A science-based framework for assessing changes in productivity, within the context of the amended *Fisheries Act.* DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/071.

DFO. 2012. Assessing the Effectiveness of Fish Habitat Compensation Activities in Canada: Monitoring Design and Metrics. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/060.

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