Fish communities as ecosystem indicators for a changing system: the lower Fraser River.

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Introduction:
Acting to protect our environment depends on being able to separate out signals that indicate unwanted changes have occurred in contrast to changes that are “normal” variation. There are a number of ways scientists normally distinguish these two sources of variation, one is to have controls, which is easy when one has a well-designed experiment. Another is to have “reference” sites where the putative impact of interest is not present. A third way is to have a long-term data set for a system and observe deviation from the long-term patterns. Large ecosystems like the Fraser River present problems for any of these kind of approaches, since we don’t have “controls” and any rivers that might have served as a reference site for the Fraser River (Columbia River, or smaller rivers like the Skagit, Squamish, etc.) are either disturbed themselves or are clearly not comparable to the lower Fraser River. We also lack long-term data for most aspects of the river ecosystem.

There are a number of challenges in diagnosis of the condition and trend of the Fraser River ecosystem, including absence of long-term data for most variables, lack of reference sites, multiple sources of change, natural variation, and non-stationarity. Most fish data from the Fraser River are for anadromous species (salmon, eulachon) and there are surprisingly few data for resident fish species of the Fraser River, with the exception of some recent data for white sturgeon. The lack of reference sites is a severe challenge to ecosystem evaluation around the world. The changes in the Fraser River come from many sources, including chemicals (many of which we aren’t even aware), temperature changes, sediments, and species introductions. There are sources of variation driven by intrinsic and extrinsic forces, for instance the enormous numbers of pink salmon every other year. A critical assumption of most ecosystem studies (or any other system) is that the system is “stationary”, i.e., tending to some long-term, average condition. We may not have the long-term data, but most will acknowledge that the river has been changing ever since European settlement and there are underlying changes that cannot be ignored in developing a means of monitoring the ecosystem’s condition.

Some past approaches to assessment of the Fraser River ecosystem have included chemical monitoring (including using bioaccumulators). However, given the suite of chemicals present in the river it is not feasible to monitor them all, and some are only just starting to be tested for. Use of fish gross pathology was attempted, but this yielded no useful measure (diseased animals do not normally survive long anyway and samples would be biased). There were no associations between indices of fish pathology and water quality.

Why are biological indicators a useful approach to ecosystem monitoring? First, it is usually the biological species that are the valued properties of an ecosystem and we want to know what is happening to them. Second, organisms integrate aspects of their environment and thus are sensitive sentinels of ecosystem perturbations. Finally, subtle changes to the rates of survival, growth, and reproduction (often much more subtle than other measures) can be measured and used to predict future conditions. A predictive capability would be the *sine qua non* of a monitoring programme.

In 1996, Michael Healey and I published a paper that asked how we would know if we ever achieved the goal of a healthy Fraser River (Richardson & Healey 1996. J. Aq. Ecosystem Health 5:107-115.). In that paper we argued that in the absence of reference sites, a clear target of what the desired state should or could be, and the lack of long-term data from which to determine unwanted deviations, a new method would be required. This study will attempt to develop that method.

The goals of the current programme are to use communities of resident fish species as a means to detect and eventually diagnose, significant trends in the Fraser River ecosystem. Resident fish species, including juvenile salmonids and other species that spend some of their most sensitive stages in the river, can be sampled with simple methods to yield a number of variables capable of detecting and predicting change. These measures include community structure, demographic (age structure) characteristics, and knowledge of species' biology to assess ecosystem condition. The eventual goal is to develop an easily applied tool for monitoring. Another goal is to test an indicator species approach (sensu Dufresne and Legendre 1999) to determine which species might serve as indicators. Finally, we intend to determine if there are proxy variables that can be used in place of long-term fish assemblage data.

Background: Characterisation of the river community through space and time

There are surprisingly few long-term data for the physical environment and the biological community of the lower Fraser River. At the moment we do not have any time series of data that would address the question of how communities (or even populations other than harvested salmonids) of the Fraser River change through time. Before we can address any temporal trend in biotic communities, we need to understand the scale and kinds of variation in annual recruitment for the resident community. We have two years (1973 and 1994) of data for 14 sites (Northcote et al. 1976. Westwater Research Centre Tech. Rep.; Richardson et al. 2000. Env. Biol. Fishes 59:125-140), and several other years of data for three of those same sites (Brown et al. 1989, Richardson & Hinch - unpublished data). We have now sampled those three sites again in 2001. Having a continuous time series of data is critical to detection of trends based on short-term recruitment variation, which can be determined from demographic information from our sampling. The demographic information is useful if we can back calculate an age-specific survival rate for some of the species. Ideally this time series should be continuous over a decade or more, but useful information will be extracted from shorter intervals.

We sample three reaches of the river (each about 5 km long) for which there are the most data available (details in Brown et al. 1989). These three reaches are sampled twice a year for fish assemblages to coincide with previous sampling periods. These data will form part of a long-term time series from which to begin to evaluate the components of variation in the river ecosystem. The ongoing monitoring will be valuable in the short term to alert management agencies such as FREMP to changes that might indicate problems. Over the longer term, the time series will be used to refine our understanding of the system's dynamics and tools we develop to distinguish annual "noise" from signals of trends.

Previous work indicates that we know very little about where the resident fish assemblages in the lower river spawn and spend time as juveniles. Radio-telemetry of Starry flounders, an estuarine species, showed that adults and juveniles can move considerable distances up the river (Levings 2000). However, for the majority of species we do not know the spatial scales at which they operate, their use of habitats throughout their life history, and in particular how water quality may impact some of the critical habitats in their ontogeny, e.g. spawning and nursery areas. These uncertainties suggest we cannot confidently attribute any chemical load or pathology in an individual with a particular site. Study of the demography and recruitment dynamics of this species and others should yield important insights into the changes in the Fraser River on resident fish assemblages. For instance, we have demonstrated that the abundant Largescale sucker appears to have a preponderance of adults, indicative of impaired recruitment of this large omnivore (Richardson et al. 2000), also a pattern seen for white sturgeon.

2001 Results

In 2001 we sampled three sites within the Fraser River twice (spring and summer), two of those sites being in the estuary. These ‘sites’ are actually extended reaches of the river to characterise regions. Repeated sampling of each reach of the river yielded estimates of fish numbers and biomass. Estimates of numbers were generally similar between seasons and between reaches at about 0.5 fish for every m^2 of bottom, with the exception of the North Arm in spring, which had double that number. Biomass varied considerably amongst sites, but all sites had more than twice as much biomass in summer (August) than they did in spring (May). The large variation amongst samples within a site indicates that even more effort will be required to yield good estimates of densities. Composition showed some differences between past studies and 2001. Variation from year to year is expected to be large and until several consecutive years of data are available it will be premature to draw conclusions.

The three reaches of the Fraser River were each sampled during two sampling periods for 2001. Sample bouts were in late April to early May, and in August. At each reach an intensive series of beach seines were taken to characterise the reach, using a boat-set, 45.7 m seine net (150’) with fine mesh. A total of 7601 individuals of 26 different fish species were sampled and released during this past summer’s field work. The most abundant species were Peamouth chub, Starry flounder, Chum salmon (juveniles), and Chinook salmon (juveniles).

In terms of biomass, a total of 85.6 kg of fish were sampled in 2001 from the three sites and two bouts combined. Our sampling does not include adult salmonids returning to spawn as these are transient as far as the local Fraser River ecosystem is concerned. The three biggest contributors to the biomass of the fish communities are Largescale suckers (30.5% of the total), Peamouth chub (21%), Starry flounder (12.8%). These percentages of the community's biomass are concordant with those found in Richardson et al. (2000).

One of the goals of this year's sampling was to determine the intensity of sampling that is required to provide a robust estimate of the fish assemblages at each site (reach). In past sampling time limitations resulted in a maximum of about 4 beach seine samples per site and we have not performed a power analysis on those data. The seasonal sampling at those sites in the past helped reduce error associated with sampling bias. We will use the samples from this year to calculate the ideal number of samples to optimise the sampling programme. There is a tremendous amount of variation within a site and in some cases the coefficients of variation were in excess of 100%. More samples are necessary to adequately characterise each reach. These estimates will allow us to make more efficient use of our resources in future sampling.

The family-level composition of the fish communities from 1973, 1994, and 2001 for each site are shown in Figure 1. These are based on preliminary analysis of the 2001 data. There is considerable variation between years in terms of total numbers, total biomass, and composition. The relative numbers vary between sites and years, with 2001 appearing to have higher total densities of fish. There are shifts in composition between years that are very striking. For instance, suckers appear to be absent from the upstream site in 2001. These data will be checked again. This large amount of variation between years is exactly why this study needs to be continued. This variation may be differences in recruitment between years, timing of peak flows and how that affects distribution in the river, sampling at different stage heights of the river, etc. Without a long-term data series, it is impossible to separate out these separate factors. Whether changes through time reflect local conditions of flow and the past year or two, or some other habitat alteration (physical or chemical) will depend upon a rigorous analysis of time series data.

Discussion

The longer-term goal of the project is to develop a method for evaluating the "condition" of unique and changing systems. As discussed above there are no "replicates" one can realistically use for comparing large rivers (e.g. Fraser R., MacKenzie R., St. Lawrence R.) as each has unique features due to their geological setting, climates, post-glacial development of biological communities, etc. We know these systems are all changing through time and even if they were stationary, we lack detailed, historical baseline data and long time-series for comparisons. These limitations require a new approach to evaluation of large river systems.

The dynamics of this complex system will need to be evaluated through exploratory dynamic simulation models. These models would not be considered as a management tool, but as an experimental platform from which to generate scenarios for testing our ideas about indicator development. Data and relations among components obtained from previous studies of the Fraser River and other large rivers would be used to generate the modelling environment. The models could be validated with newer data collected as part of this project. One needs to avoid overparameterisation of predictive or descriptive models since multiple sources of variation are compounding and will make models useless. Modelling is the most appropriate method for investigating the properties of a large system, like the Fraser River, where it is impossible to conduct true experiments on any relevant scale.

Even with a detailed model, we need to consider how one measures statistical power when the system is non-stationary and unreplicated. This is not a trivial task. One will need to consider the possibility of finding proxy data that can adjust the fit of the model to data or vice versa. Proxy data can serve as covariables, to remove their effects on the components of interest, or as a way to estimate values for variables where such data are lacking (as a type of calibration).

Benthic organisms should probably also be included in this programme as well, but it is more expensive to carry out because of the labour requirements in the laboratory. Invertebrates add further to our understanding of changes in ecosystems and a great deal of effort has gone into biomonitoring studies, including in the Fraser River basin (Reynoldson et al. 2001. Can. J. Fish. Aquat. Sci. 58:1395). Other studies on benthos in the lower Fraser River (upstream of the FREMP area) could serve as background (references below).
The project is currently funded to continue for four years from 2001 to 2004, but a longer time series will be recommended, if this project yields useful methods and data.

Acknowledgements
We are grateful for the financial support of this project by the Fraser River Estuary Management Program and the Habitat Conservation Trust Fund (BC).

<u>Additional References for benthic macroinvertebrates of the lower Fraser River:</u>

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Figure 3: Biomass of groups of fish from the lower Fraser River as a percentage of the total biomass. Each circle is scaled to reflect the relative biomass of a particular site and year. Site numbers are keyed to Richardson et al (2000), with Site 1 - North Arm from MacDonald Slough to Mitchell Island, Site 4 is Main Arm from Canoe Pass to Annacis Island, and Site 13 is from the Agassiz Bridge to the upstream end of Herrling Island.