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Determining regional benchmarks of fish productivity using existing electrofishing data from rivers: proof of concept

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March 2017

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Electrofishing data from streams and rivers in Newfoundland, the Maritime Provinces, Ontario, Alberta and British Columbia showed regional differences in fish productivity. The existing electrofishing data were originally collected by different agencies for various reasons, including the determination of stock status of harvested species, the investigation of fish habitat associations, and the investigation of the status and life history characteristics of Endangered fish species. Despite being targeted for specific species, electrofishing catches of all cohabiting species at the sites were recorded, providing estimates of total density (fish m^{-2}) and biomass (g m^{-2}) of the fish community. The datasets varied in duration and spatial extent from 'snapshots' (< 5 years and a small number of sites) to time series (> 10 years and spatially extensive). For each site, a Habitat Productivity Index (HPI) was also estimated as an index of production.

The average fish biomass density and HPI varied among the regions from about 2.5 to 22 g m^{-2}, and were roughly similar to literature values from a small subset for these areas. The regional averages however are tentative, and require further confirmation. The lowest biomass and HPI estimates were from insular Newfoundland, where water fertility and species richness (SR) were low. In contrast, fish biomass and HPI values in the relatively warm fluvial waters of southern Ontario (Toronto region) were high. Average biomass densities among regions were significantly and positively related to average long-term air temperature, for both the fish community biomass and for the biomass of individual species of Salmonidae. The salmonid biomass-temperature relationship was likely not linear (i.e., dome-shaped). Body size-density relationships were variable among the data sets, but generally showed an inverse relationship between body size and density consistent with the science literature. Together, fish density, body size and temperature were key metrics of region-dependent fish productivity.

Estimates of region-dependent fish productivity were proof of concept and demonstrated the feasibility of using existing electrofishing data to determine spatial differences in productivity in the rivers and streams of Canada. Also, differences in productivity are likely predictable from readily-available landscape drivers such as air temperature and location. Existing fishing areas or zones are a possible spatial unit for aggregating the data. Limitations of using existing electrofishing data included uncertainty of fish capture probability and unknown status of resident and migratory species in terms of carrying capacity.

Déterminer les points de référence régionaux pour la productivité du poisson au moyen de données existantes sur la pêche à l'électricité dans les rivières : validation de principe

RÉSUMÉ

Les données tirées de la pêche à l'électricité dans des cours d'eau et des rivières de Terre-Neuve-et-Labrador, des provinces maritimes, de l'Ontario, de l'Alberta et de la Colombie-Britannique ont révélé des différences régionales sur le plan de la productivité du poisson. Les données existantes sur la pêche à l'électricité ont été recueillies à l'origine par différents organismes pour diverses raisons, notamment pour déterminer l'état du stock des espèces récoltées, pour enquêter sur les associations d'habitats du poisson et pour enquêter sur l'état et les caractéristiques du cycle vital d'espèces de poisson en voie de disparition. Malgré le fait qu'elles visaient toutes des espèces particulières, les prises à l'électricité de toutes les espèces cohabitant dans les sites ont été enregistrées, ce qui a permis de fournir des estimations de la densité totale (poissons en m^{-2}) et de la biomasse (g m^{-2}) de la communauté de poissons. La durée et l'étendue spatiale des ensembles de données ont varié; soit des « aperçus » (< 5 ans et petit nombre de sites), soit des séries chronologiques (> 10 ans et vastes étendues). Pour chaque site, un indice de productivité de l'habitat (IPH) a également été estimé, à titre d'indice de production.

La densité moyenne de la biomasse de poissons et l'IPH ont varié d'une région à l'autre, de 2,5 à 22 g m^{-2}, et étaient passablement semblables aux valeurs documentées pour un petit sous-ensemble dans ces mêmes régions. Les moyennes régionales sont cependant provisoires et nécessitent une confirmation plus poussée. Les plus faibles estimations de la biomasse et de l'IPH ont été observées dans la région de l'île de Terre-Neuve où la fertilité des eaux et la richesse en espèces étaient faibles. En revanche, les valeurs de la biomasse de poissons et de l'IPH observées dans les eaux fluviales relativement chaudes du sud de l'Ontario (région de Toronto) étaient élevées. Les densités moyennes de la biomasse parmi les régions étaient considérablement et positivement liées à la température moyenne de l'air à long terme, qu'il s'agisse de la biomasse de la communauté de poissons ou de celle de chaque espèce de salmonidé. La relation entre la biomasse des salmonidés et la température n'était probablement pas linéaire (c.-à-d. en forme de dôme). Les relations entre la taille du poisson et la densité variaient d'un ensemble de données à l'autre; par contre, en général, on a observé une relation taille-densité inverse, ce qui cadre avec la littérature scientifique. Ensemble, la densité du poisson, la taille du poisson et la température ont servi de paramètres principaux pour déterminer la productivité du poisson en fonction de la région.

Les estimations de la productivité du poisson en fonction de la région ont servi de validation de principe et ont permis de démontrer la faisabilité d'utiliser les données existantes sur la pêche à l'électricité pour cerner les différences spatiales en matière de productivité dans les rivières et les cours d'eau du Canada. De plus, il est probable que les différences de productivité puissent être prédites au moyen des caractéristiques du paysage toujours disponibles, comme la température de l'air et l'emplacement. Les zones ou secteurs de pêche existants pourraient possiblement servir d'unité spatiale pour délimiter les données. Les obstacles à l'utilisation des données existantes sur la pêche à l'électricité comprennent l'incertitude liée à la probabilité de capture de poissons et l'état inconnu des espèces résidentes et migratoires au chapitre de la capacité de charge.

INTRODUCTION

The DFO Ecosystems Management sector requested advice from DFO Science to understand how fisheries productivity varies regionally across Canada, in support of implementation of the Fisheries Protection Provisions of the *Fisheries Act* (2012). The identification of regional productivity benchmarks is anticipated to be used in a number of ways, including providing the information needed to inform offsetting programs, providing baselines for impact assessments in the absence of or to complement site-specific data, and refining on a regional basis the estimates of equivalent adults, a metric of productivity that converts the loss of juvenile fish or habitat to the loss of adult fish (DFO 2015). In addition, regional benchmarks may assist in assessing changes to watershed productivity from accumulated effects (Rice et al. 2015).

Text from the Terms of Reference for this project (DFO 2016), synthesized and condensed here, provides additional context for this study. Amendments to the *Fisheries Act* (2012) came into force during 2013. The amended Act focuses on the sustainability and ongoing productivity of commercial, recreational or Aboriginal (CRA) fisheries and contains a prohibition against causing serious harm to fish that are part of or support a CRA fishery. Serious harm to fish is defined in the Act as the death of fish, or 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 to proceed without contravening the Act.

Benchmarks of region-specific productivity were originally examined and proposed as a method for determining ‘no net loss’ of the productive capacity of freshwater fish habitat for compensation projects (Randall et al. 2014). For this more recent report, to update and reflect the 2013 amendments to the *Fisheries Act,* the terms fisheries productivity and offsetting are used, rather than the former terms of productive capacity and habitat compensation, respectively. The focus of the new amendments is on the ongoing productivity of CRA fisheries rather than habitat productive capacity. Assessment of productivity on a regional basis rather than at individual sites is consistent with area-based and ecosystem approaches that integrate productivity, biodiversity and habitat (Gavaris 2009). Region is defined broadly and generically as a geographic area with similar fish assemblages, climate and water nutrients (e.g., watershed or adjacent watersheds, coastal management areas). In freshwater, regional landscape drivers of productivity, such as waterbody surface area, air and water temperature, nutrients, primary productivity and habitat structure, have been shown to be key determinants of fish production (e.g., Bradford et al. 1997; Coté et al. 2011; Jonsson et al. 2011; Kim and Lapointe 2011, McGarvey and Johnson 2011; McGarvey et al. 2010; Poff and Huryn 1998).

For this study, total fish biomass density for all cohabiting species or for individual target species are the key metrics of productivity. Regional averages of fish biomass density are determined empirically using field survey data. The assumption is that the sum of biomass of all cohabiting species in the survey areas within a region is a first-order estimate of current habitat capacity. The rationale (Randall and Minns 2000; Randall et al. 2014) is that although the abundance of an individual population may be reduced at the time of survey because of a factor unrelated to habitat, it is more likely that the summed wet biomass of the fish community will approach and reflect habitat (= ecosystem) capacity, if sufficient data are used for the assessment. This is consistent with using biomass density body-size spectra with different elevations to reflect ecosystem productivity (Boudreau and Dickie 1992). Data requirements and adjustments for the confounding influence of non-habitat factors (fishing exploitation, adult fish sea survival of anadromous species) on fish biomass are discussed later. Fish biomass for populations or communities is proposed as a useful standard metric for measuring habitat value quantitatively and consistently across multiple regions of Canada. Fish biomass (and calculated or inferred production) can also be used to measure the ecological consequences of development projects (biomass loss, production forgone *sensu* Rago 1984).

Conceptually, the regional benchmarks in this paper reflect the elevation of the upper productivity threshold in the productivity-state framework (see P1 of Figure 1 in Rice et al. 2015). For the upper threshold, capacity is defined as carrying capacity for individual populations (CRA fishes) and as ecosystem capacity for the fish community.

Biologists and managers recognize that CRA fishes, their habitat and factors affecting their productivity differ among the regions of Canada, and also that potential impacts are project and context specific. Quantification of regional productivity for informing offset programs at watershed or coastal management zone scales is the primary application for regional benchmarks. Additionally, the results may be useful for measuring relative habitat value, for identifying region-specific equivalent adults (DFO 2015), and for identifying Ecologically Significant Areas in freshwater (DFO 2014).

Specific objectives of this ‘proof of concept’ study were to:

1) determine if survey area and abundance are related, and if it is feasible to quantify regional differences in average community biomass of fishes with existing electrofishing data;
2) determine if fish density-body size relationships differ among regions;
3) assess if the current biomass of populations and communities reflect the carrying capacity (of the habitat) and are influenced by temperature, consistent with the Metabolic Theory of Ecology;
4) evaluate the proof of concept and the potential utility of regional benchmarks as a frame of reference for offsetting programs.

For this study, region is defined as Salmon Fishing Areas (Figure 1) (or Salmon Management Areas) or Fishery Management Zones (Figure 2). The four objectives are complementary and interrelated. Objectives 1 and 2 describe two different methods of estimating ecosystem capacity and should be similar, objective 3 is fundamental for consistently applying the regional benchmarks in offsetting programs and objective 4 assesses feasibility of using existing data and electrofishing-based regional benchmarks as a tool for managers, and is prerequisite to extrapolating the results to areas where benchmark data are not available.

The focus of this study was on river shorelines and streams that were sampled with electrofishing equipment due to the availability of data, but we expect that the findings will inform similar efforts for lentic habitats, and nearshore marine areas.

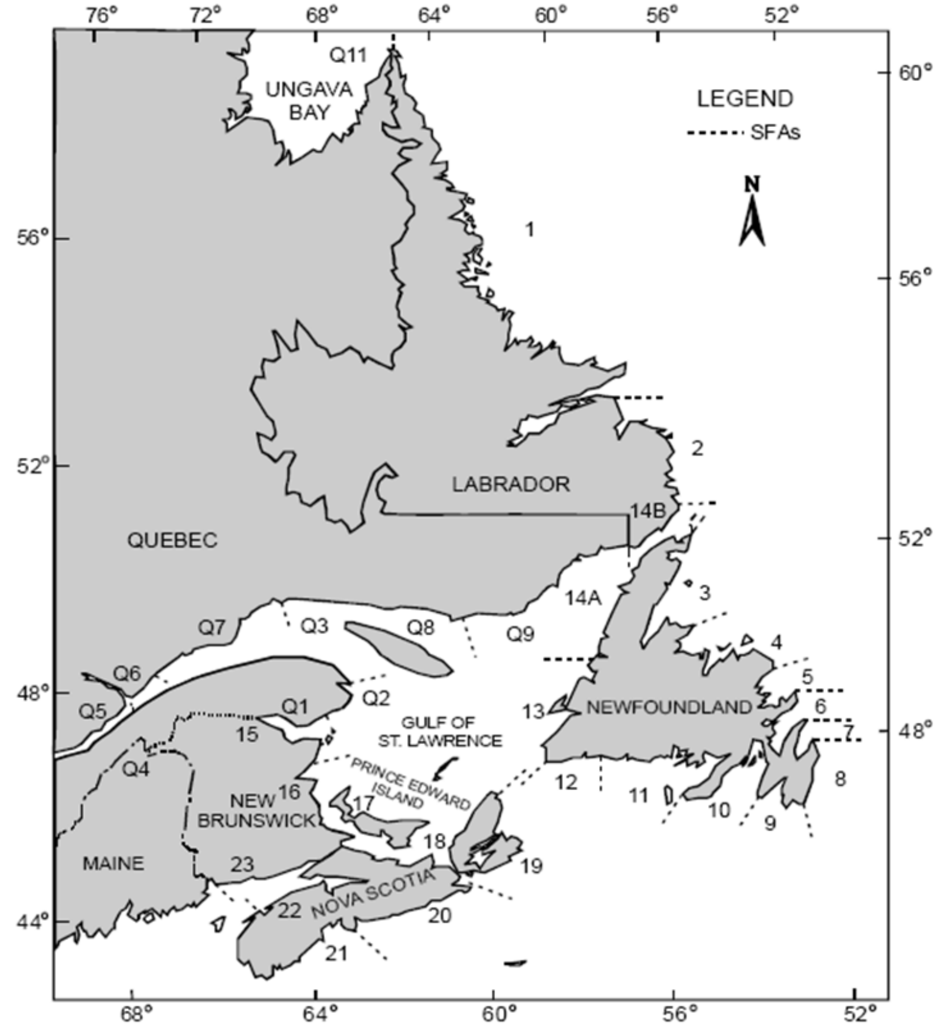
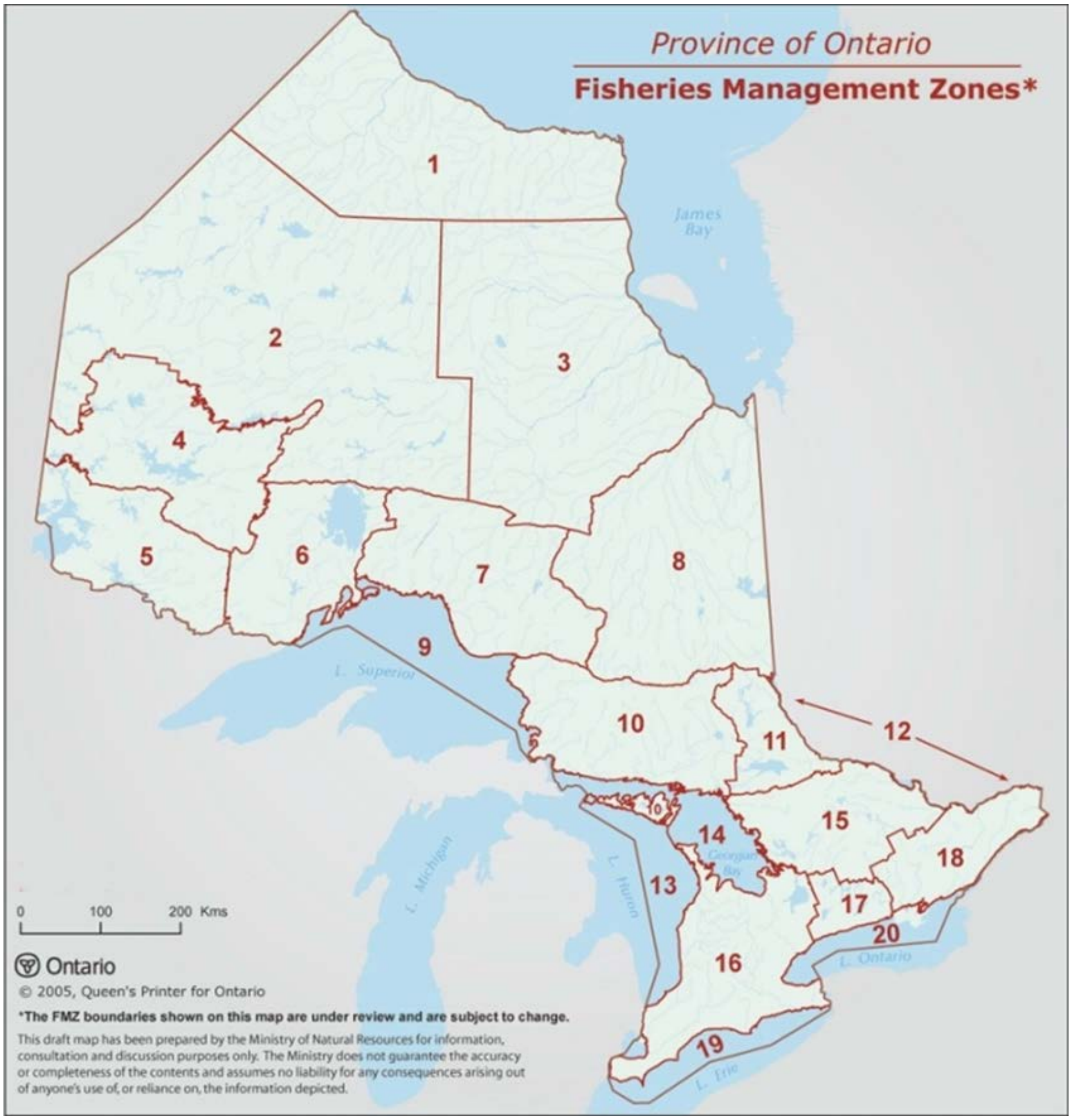


Figure 1. Map of eastern Canada showing the location of Salmon Fishing Areas (from O'Connell et al. 1997).



***The FMZ boundaries shown on this map are under review and are subject to change.**

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Figure 2. Ontario Fisheries Management Zones

METHODS

Methods for addressing each of the four objectives are described separately.

OBJECTIVE 1: SURVEY AREA METHOD TO MEASURE CAPACITY

Survey area-fish catch relationships were analyzed using regression models. Response variables were fish catch (number), fish biomass (individual species or community g) and a calculated Habitat Production Index (HPI; Randall and Minns 2000). HPI was calculated as $\sum B_i (P/B)_i$, where B_i is the total biomass of species *i* (g) and P/B_i is the ratio of production over biomass for species *i*. The species P/B ratio (1/y) was calculated as $P/B = 2.64W^{-0.35}$ (Randall and Minns 2000), where W was the average weight (g) of each species captured at each site (Randall and Minns 2002). Total numbers and biomass, and then biomass density (B), as functions of survey area were investigated. The abundance of salmonid species has been related to stream width and area using linear models in other studies (Bradford et al. 1997; Coté

2007; Coté et al. 2011; Randall 2015). Coefficients were determined to be significant at $\alpha \leq 0.05$. The fish response variable and survey area were natural (*ln)* transformed to normalize their distributions. Mean fish biomass densities (g m^{-2}) were calculated as geometric means (GM) with 95% confidence limits (CL). Analyses were conducted using SAS (2012) and R (R core team 2015) software.

Statistical models were fit (for both objectives 1 and 2) as ordinary least squares (OLS) linear regressions and, when multiple sampling of the same location occurred, the use of mixed models with sampling location (sites within a river) as a random-effect was investigated. Mixed models are useful when fitting relationships to grouped data. In this case, the possibility of a grouping effect due to annual sampling of the same location within a river was investigated. This would account for a site effect where there is a consistent difference between sampling locations due to some unmeasured characteristic. A mixed model was favored over an OLS regression only if inclusion of a random effect resulted in a change in the fixed-effects parameter estimates or level of significance.

OBJECTIVE 2: DENSITY-BODY SIZE MEASURE OF CAPACITY

Density-body size relationships for fishes (and animals in general) are described by the allometric relationship (e.g., Peters 1983):

$D = aW^{-b}$ D is density (number per unit area) and W is body mass (g)

Also referred to in the literature as the self-thinning relationship, the scaling coefficient (intercept) *a* is a function of resource availability (Kerr and Dickie 2001; Brown et al. 2004; for salmonids, see Grant and Kramer 1990, and Keeley and Grant 1995). The density-body mass relationship is a model for ecosystem carrying capacity (Brown et al. 2004). Evidence that populations are often resource-limited is provided by empirical density fish-size relationships and energetic equivalence (Peters 1983; Allen et al. 2002; Brown and West 2004; Brown et al. 2004). Fish abundance is negatively correlated with average fish size (Peters 1983; Randall et al. 1995), while individual metabolic rate (biomass production per individual) increases with size (Peters 1983). The finding of inverse but equal magnitude between the metabolic and density-size exponents indicates that energy flux of a population per unit area is invariant with respect to body size (Brown et al. 2004), and that there is a metabolic constraint on animal abundance. The energetic equivalence implies that populations are resource-limited.

For each empirical data set from the different regions, density-body mass regressions were calculated for dominant Salmonidae species and for the whole fish community. Regression slopes were compared among regions (also see objective 3). For the density-body size method, region elevation (B), standardized to a body weight of 10 g, was interpreted as the measure of habitat carrying capacity (g m^{-2}).

Habitat capacities estimated by biomass density–area (objective 1) and by density-body-size relationships (objective 2) were tested for statistical (OLS) correlation.

OBJECTIVE 3: CARRYING CAPACITY AND METABOLIC THEORY OF ECOLOGY

The Metabolic Theory of Ecology (MTE; Brown et al. 2004) links the metabolic rate of individual organisms to the ecology of populations, communities and ecosystems. MTE predicts how metabolic rate varies with body size and temperature, and controls ecological processes at many levels including population carrying capacity. Brown et al. (2004) described ecosystem carrying capacity in terms of numeric density and biomass density in two related equations:

Number per unit area: $K \propto [R]M^{-3/4}e^{E/kT}$ *K* is equilibrium number of individuals, R is the limiting resource, *M* is body mass and E/kT is Boltzmann factor

Biomass per unit area: $W \propto [R]M^{1/4}e^{E/kT}$ W is equilibrium biomass

The limiting resource R has direct linear effects on both K and W.

The underlying assumptions, mechanisms and complexity of MTE are still being investigated and tested by ecologists (White et al. 2007), but for this paper we assume that the fish density-body size empirical relationships, and the factors affecting limiting resources, are sound and predictable at a broad scale for fishes and can be used to reliably inform regional productivity. Biomass density, body size and ambient temperature are the key variables.

Note that for this paper W from the Brown et al. (2004) biomass equation is analogous to the symbol B used above (objective 1 – total biomass density), except that B in this study may be below capacity for some of the regions. We are assuming that the regional benchmarks as measured by average community biomass is a function of R (the limiting resource). Also, the exponents are empirically determined from the region data sets, and are not assumed to follow the -¾ and ¼ scaling rule.

Average B of all cohabiting species was estimated (as $g{\cdot}m^{-2}$), and as noted in the introduction, was assumed to be a measure of habitat carrying capacity (W in the above biomass equation). We use the electrofishing data from the different regions to test if fish density and biomass scale with body mass and temperature consistently with MTE. Specifically, we test if the density-fish mass slope was different from – ¾ (above density equation) or from unity as was found by Grant and Kramer (1990), Randall et al. (1995), and Bradford (pers. comm.; DFO 2015). Density-fish mass slopes were investigated for dominant individual salmonid species (i.e., biomass dominant, > 50% of total biomass), and for community assemblages, separately. Also, we tested if average community biomass density and production among regions, as inferred by the HPI index, was a function of temperature, in a predictable manner (similar to the observations of Downing and Plante (1993)). Temperature for each region was obtained from station data (city or community) in the vicinity from Environment Canada (Canadian Climate Normals). For each station, average air temperature was obtained for the long term normal (1981–2010) and for the actual time period of electrofishing survey (if available).

For each regional dataset, a tentative determination of whether or not B approximated carrying capacity (W) was;

1) derived from scientific literature and/or the expert opinion of scientists from the region (location of source data);
2) assumed, or;
3) unknown but likely below carrying capacity (reasons given). For this study, carrying capacity was defined as the maximum population or community biomass that could reasonably be expected in recent years (at the time of survey) and assumes the habitat was accessible and naturally recruited with fishes. Carrying capacity was not scientifically evaluated at or for this meeting; the tentative status of the populations was given to show the potential value of the benchmarks.

OBJECTIVE 4: PROOF OF CONCEPT

Proof of concept is defined as ‘evidence, typically derived from an experiment or pilot project, which demonstrates that a design concept, business proposal, etc. is feasible’ (Oxford University Press 2015). In this case, the design concept is region-specific benchmarks of productivity derived from the empirical field survey data from streams and rivers. Evidence to demonstrate feasibility of measuring region-specific productivity is provided in objectives 1–3. Evidence that these benchmarks can potentially be used as predictive tools (by managers) for offsetting programs is considered in the Discussion.

RESULTS

SYNOPSES OF INDIVIDUAL REGION DATA SETS

In this section, information is provided for each dataset used in the analysis on geographic location, number of years and sites surveyed, survey area and methods, air temperature, fish species, population and community area-abundance and density-body size relationships, biomass density and status of biomass with respect to carrying capacity (if available). For the long term datasets (> 10 years), mean annual discharge rate (m^3 sec^{-1}) and the average air temperature (°C, nearest community) were also provided.

Terra Nova River (Region SFA 5) – Newfoundland and Labrador

Within Terra Nova National Park, 29 sites were sampled from 18 brooks (Terra Nova River, tributaries and adjacent rivers) in 2002, 2003 and 2005 to measure salmonid population performance (density, biomass and estimated production) in relation to habitat (Coté 2007). Additional surveys were conducted in 2006 to 2010 (Coté pers. comm.), to provide a total of 88 site samples. Mean annual air temperature at Port Blandford (1981 to 2010) was 5.0 °C (Table 1). Water conductivity was < 100.0 µS cm^{-1}, total phosphorus concentration was 0.6 mg P m^{-3}, and alkalinity was < 15 mg l^{-1} Coté (2007).

At each site, 50 m sections of stream habitat were blocked with barrier nets, and catch-depletion surveys were conducted. The average survey area was 180.7 m^2 (range: 52–647). SR was low (as is the case in all insular Newfoundland streams), averaging 2.01 species (range: 1–5) per site. Brook Trout (Latin names of fishes mentioned in the text are given in Appendix 2) and Atlantic Salmon were the dominant species, together comprising > 90% of the total in terms of both abundance and biomass (Figure 3). Brook Trout, both resident and anadromous populations, was the dominant species at the sites comprising about 69% of the biomass, and anadromous Atlantic Salmon juveniles comprised about 23% of the fish biomass. Other cohabiting species were American Eel, Threespine Stickleback and Ninespine Stickleback. Coté (2007) also reported the occurrence of Arctic Char and Rainbow Smelt.

Species richness (SR) and total biomass density were significantly related (OLG regression, P = 0.011), as was richness and survey area (P < 0.001). Density and biomass density, both for all species and for brook trout alone, decreased significantly with survey area (Figure 3). Negative density-stream width relationships for salmonids (both species combined) were previously documented and quantified by Coté (2007).

The density of all species and the density of brook trout alone decreased with body size, with slopes of -0.48 (P = 0.02) and -0.39 (P = 0.05), respectively. Neither were significantly different from -0.75 (Figure 3).

Average (GM) biomass density was 2.48 g m^{-2} (CL: 2.03–3.02) for the community and 1.65 g m^{-2} (CL: 1.29–2.10) for Brook Trout alone (Figure 3). Average community fish body size was 9.6 g.

Because these biomass density estimates were from Terra Nova National Park, fish biomass was assumed to be at or close to ecosystem carrying capacity.

Table 1. Comparison of the benchmark average biomass density (Salmonidae species and total community, g m^{-2}), average body size (g), species richness (average number site^{-1}) and air temperature (°C) at the different regions and sub-regions in Canada. For some regions, ecosystem capacity was assumed (see text).

Region	Sub-region	Years	Salmonid Biomass (g m^2)	Community Biomass (g m^2)	Community Biomass for 10 g fish	Species Richness	Body Size (g; GM)	Air Temperature[1]	City	Assumed Capacity
SFA 5	Terra Nova	2002–2010	1.65	2.48	2.50	2.0	9.6	5.0(6.6)	Port Blandford (TNNP)	Yes
SFA 9	Stoney Brook	2001–2003	0.81	1.93		3.3	5.2	5.0(5.1)	St. John’s	Unknown
SFA 12	Rose Blanche	2000–2002	0.41	1.36		2.5	12.4	4.6(5.2)	Port aux Basques (Isle aux Morts)	Unknown
SFA 15	Kedgwick	1993–2013	1.57	2.97	1.86	3.3		3.4(3.8)	CharloA	Yes
	Little Main R	1993–2013	1.81	3.28	2.56	3.0		3.4(3.8)	CharloA	Yes
	Main Restigouche	1993–2013	1.50	2.50	1.36	2.8		3.4(3.6)	CharloA	Yes
	Upsalquitch	1993–2013	1.66	2.63	2.23	3.1		2.0(2.2)	Upsalquitch Lake	Yes
	Matapedia	1993–2013	1.45	2.31	2.08	2.9		3.4(3.8)	CharloA	Yes
	Patapedia	1993–2013	1.26	2.26	1.20	2.7		3.4(3.8)	CharloA	Yes
SFA 16	NW	1994–2013	3.29	3.95		2.6	3.6	4.9(5.1)	MiramichiA	Yes
	LSW	1994–2013	1.92	2.91		2.8	4.0	4.9(5.1)	MiramichiA	Yes
	Renous	1994–2013	2.54	2.96	6.90	3.3	3.1	4.9(5.1)	MiramichiA	Yes
	SW	1994–2013	3.36	4.26		2.8	3.1	5.0(5.2)	Doaktown	Yes
	Catamaran	2002–2004	0.7	1.9				5.0(4.8)	Doaktown	Unknown
SFA 18	Margaree	1993–2013	5.47	6.80	7.20	2.1	4.8	6.1(6.4)	Margaree Forks	Yes
	West River, Antigonish	2006–2013	2.69	3.12	3.29	2.2	3.9	6.7(NA)	Pugwash	Yes
	East River, Pictou	2006–2013	1.96	2.17	2.16	1.8	3.3	6.7(NA)	Pugwash	Yes
	River Philip	2006–2013	4.52	5.12	4.04	2.6	3.6	6.7(NA)	Pugwash	Yes
SFA 23	Above Mactaquac	2009						3.7(NA)	Juniper	Unknown
	Below Mactaquac	2009						5.6(NA)	Fredericton	Unknown
	Outer Fundy	2009						5.2(NA)	Pennfield	Unknown
	Saint John all[3]	2009	0.09	0.54		4.9	3.8	5.6(NA)	Fredericton	Unknown
	Inner Fundy[2]	2000–2003		9.6				7.1(7.7)	Kentville	Unknown
Q2	St. Jean	1988–1992						3.1(2.6)	Gaspe	
Q7	Trinite	1984–1992						1.7(1.3)	Baie-Comeau	
Q10	Bec-Scie	1985–1994						1.0(0.5)	Sept Iles	
ON Fishing Zones 16/17	Ganaraska	2002–2004	2.77	8.21		7.5		8.1(8.2)	Oshawa	Yes
	Toronto	2005–2006		21.93	24.79	10.1	7.7	8.2(9.4)	Toronto	Yes
ON Fishing Zone 10	Magpie[4]	2002–2013	.	1.15		7.0	1.7	2.1(2.9)	Wawa	Unknown
	Batchawana[4]	2002–2013		0.85		8.0	1.3	4.7(5.1)	Sault Ste Marie	Yes
Alberta	Athabasca			0.45			3.0	1.0(0.0)	Fort McMurray	Unknown
British Columbia	Interior			1.14			3.6	9.3(NA)	Kamloops	Unknown
	Coastal			1.42			3.5	10.4(NA)	Vancouver	Unknown

[1] Canadian Climate Normals. Long term (1981–2010) average and at the time of electrofishing survey, if available (in parenthesis). NA is not available.

[2] reference values unadjusted for catch efficiency (from Randall et. al. 2014)

[3] not adjusted for catch efficiency

[4] assuming 0.2 catch efficiency

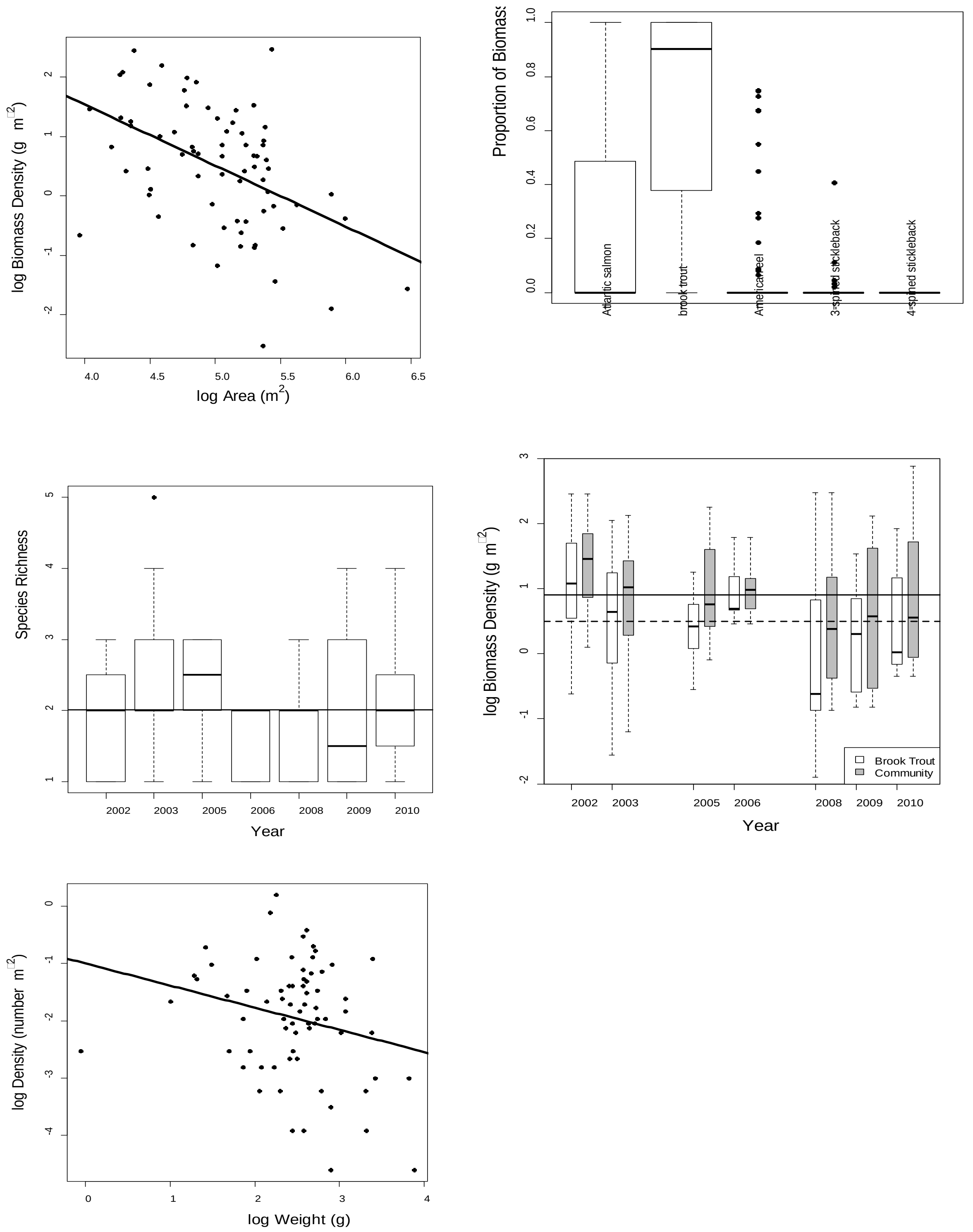

Figure 3. Terra Nova benchmark data (Region SFA 5): A) Relationship between site survey area (log m^2) and biomass density (log g m^{-2}); B) Proportional biomass by species; C) Average species richness by year; D) Biomass density by year for brook trout and community; E) Relationship between average body size of brook trout (g) and density (number m^{-2}) at the survey sites. Log values are base e.

Stoney River (Region SFA 9) – Newfoundland and Labrador

A small dataset of fish biomass estimates (n = 21) was available from Stoney Brook in southeast Newfoundland (Clarke, pers. comm.). Densities were estimated by catch depletion. Data were collected from seven sites in 2001 to 2003 to study fish movements and behaviour (Enders et al. 2007; Robertson et al. 2003). The survey sites averaged 205.3 m^2 (range: 102–345) in area. Atlantic Salmon, Brown Trout and American Eel comprised most of the total biomass; Brook Trout, Rainbown Smelt and Threespine Stickleback were also captured but in lower abundance (Figure 4). The average proportional biomass of Atlantic Salmon was about 42%. SR was low, averaging 3.3 species per site.

Biomass density of Atlantic Salmon decreased weakly with survey area (slope -1.206, $P< 0.05$, $R^2 = 0.25$), but the sample size was low. The relationship between community density and area was not significant. The negative relationships between density and body size were not significant for either Atlantic Salmon or the total fish community. Average community fish size was 5.2 g.

Average (GM) biomass density of salmon and the total fish community was 0.81 g m^{-2} (CL: 0.58–1.13) and 1.93 g m^{-2} (CL: 1.35–2.77), respectively (Figure 4).

These field estimates were short term, and whether or not the average fish biomass at Stoney Brook was at near carrying capacity was unknown.

Rose Blanche (Region SFA 12) – Newfoundland and Labrador

A small dataset of fish biomass estimates (n = 30 site samples) was also available from Rose Blanche in southwest Newfoundland (Scruton et al. 2005; K. Clarke, pers. comm.). Data were collected from seven sites in 2000 to 2002 to study habitat compensation to ameliorate impacts of hydroelectric development (Scruton et al. 2005). The sites averaged 205.3 m^2 in area (range 102–345 m^2). Densities were estimated by catch depletion. Brook Trout and Atlantic Salmon comprised the most biomass, with Brook Trout being dominant. American Eel were also captured (Figure 5). The average proportional biomass of Brook Trout and Atlantic Salmon varied among the three years of monitoring (Figure 5). SR was low, averaging 2.5 species per site.

Densities of Brook Trout and Atlantic Salmon were not significantly related to survey area. The relationship between community density and area was also not significant. The negative relationships between density and body size were not significant for either Atlantic Salmon or the fish community. Average community fish size was 12.4 g.

Average biomass density of salmon and the total fish community was 0.41 g m^{-2} (CL: 0.25–0.68) and 1.36 g m^{-2} (CL: 0.90–2.06), respectively.

Whether or not average biomass density reflected carrying capacity was unknown. Habitat in the compensation channel was enhanced, and trout biomass continued to increase each year during the three years of monitoring (Scruton et al. 2005) indicating site biomass density was dynamic and not yet at an asymptote. The enhanced physical habitat in the compensation channel was used preferentially by Brook Trout.

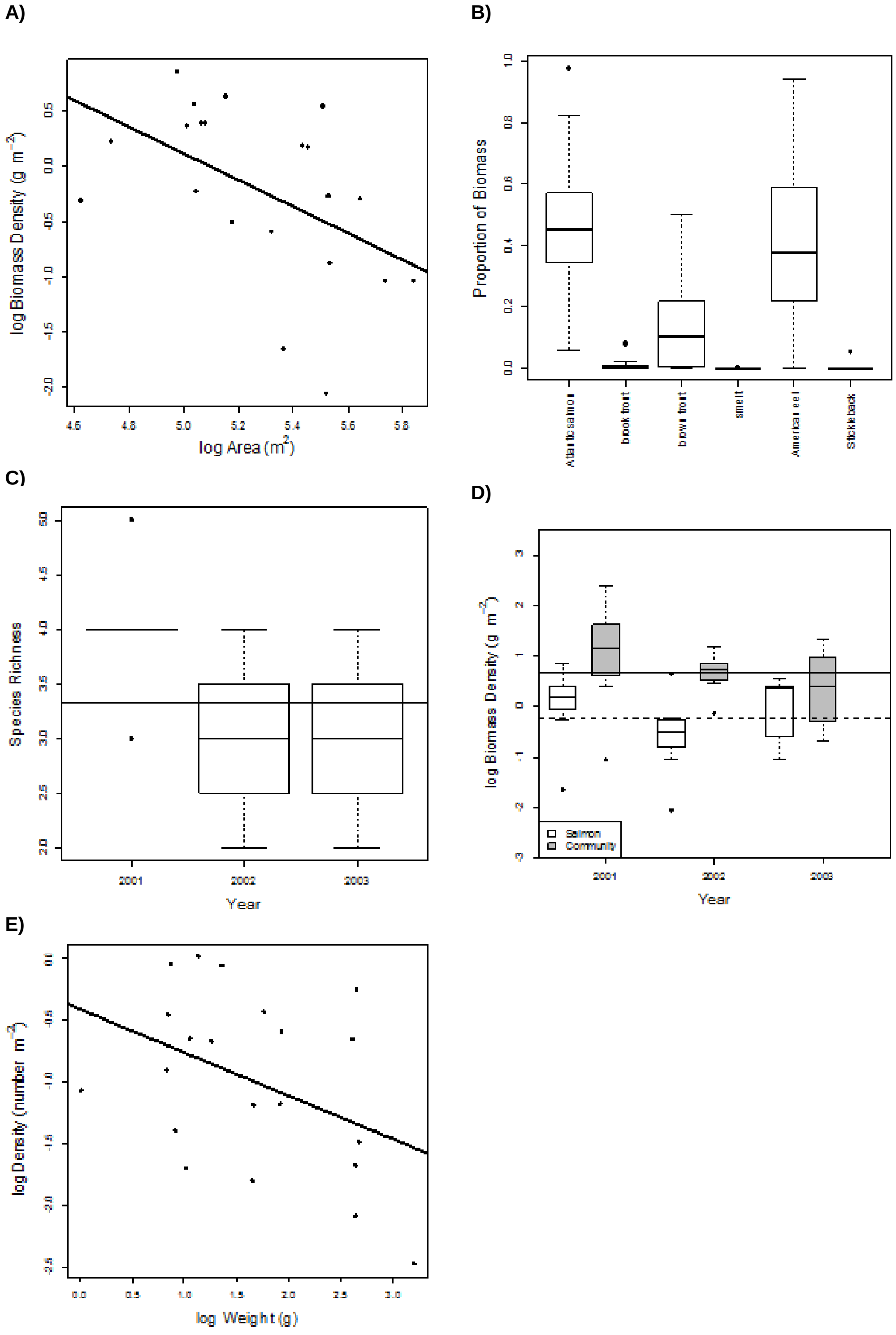

Figure 4. Stoney River benchmark data (Region SFA 9): A) Relationship between site survey area (log m^2) and biomass density (log g m^{-2}); B) Proportional biomass by species; C) Average species richness by year; D) Biomass density by year for Atlantic Salmon and community; E) Correlation between average body size of Atlantic Salmon (g) and density (number m^{-2}) at the survey sites. Log values are base e.

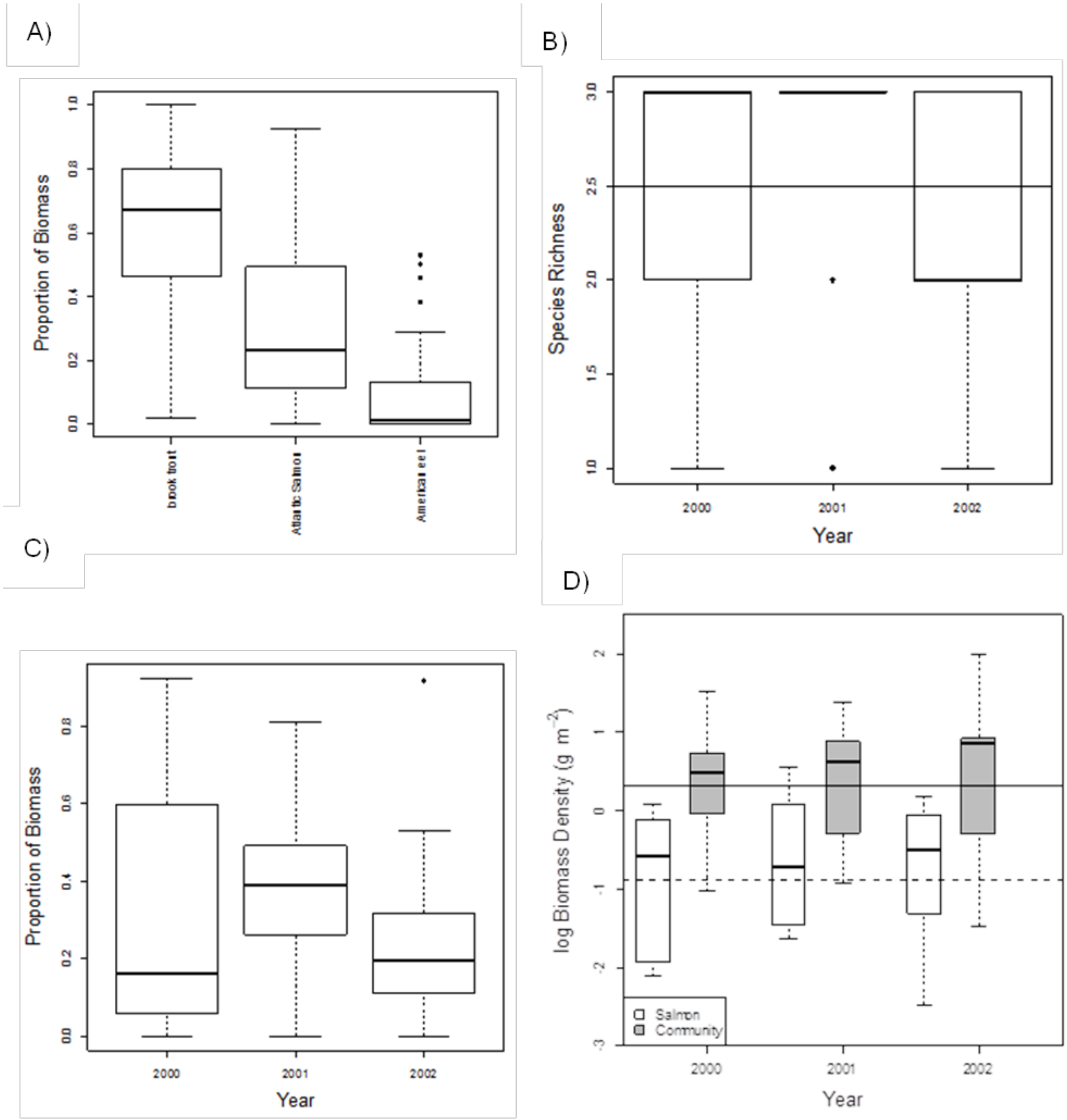

Figure 5. Rose Blanche benchmark data (Region SFA 18): A) Proportional biomass by species; B) Average species richness by year; C) Proportion of biomass of Atlantic Salmon; D) Biomass density by year of Atlantic Salmon and community. Log values are base e.

Margaree River (Region SFA 18) – Cape Breton, Nova Scotia

Margaree River has an average annual discharge rate of 18.7 m^{-3} sec^{-2} (Water Survey of Canada (WSC) station 01FB003), a drainage area of 1,100.0 km^{2}, and is divided into two main tributaries, Northeast Margaree and Southwest Margaree. Total fluvial area, suitable habitat for juvenile salmon rearing, was estimated to be about 2.8 million m^{2} (Breau et al. 2009). Mean annual air temperature at Margaree Forks (1981 to 2010) was 6.1 °C (Table 1). Habitat-related threats were considered to have a low effect on salmon populations (< 5% of salmon affected;

interpreted as the fraction of the population exposed), with the exception of habitat fragmentation (non-compliant culverts) which were judged to have a medium effect (5–30%) (Breau et al. 2009).

Quantitative river electrofishing data have been collected from the Margaree since 1957 (Breau et al. 2009). For this report, data for the period 1993 to 2013 were used. The river surveys were conducted on an annual basis at fixed sites to monitor the population status of Atlantic Salmon. Juvenile salmon was the most abundant species captured at the sites and the variability in total community biomass among and within sites was therefore determined by the abundance of salmon. Conservation requirements for Atlantic Salmon in the Margaree River have been met or exceeded in most years since 1985 (Breau et al. 2009; DFO 2012). Analysis of stock and recruitment data, using a Beverton-Holt model, indicated that the Margaree River has a relatively high habitat carrying capacity, measured in terms of parr density, compared to other Maritime rivers (Gibson 2006).

Despite the reasonably high levels of escapement in all years, salmon juvenile abundance has been lower in the recent time period (2009 to 2013) than previously (1991–2008), possibly at least in part due to a 100 year flood event in 2010 (Breau 2013).

The number of survey sites in the Margaree River each year ranged between 3 and 42; more extensive surveys were done in 2002. The total number of surveys from 1991 to 2013 was 209, and the survey areas averaged 165.07 m^2 (range 24.4–506.8). For all sites combined, there was a significant positive correlation between the area surveyed and total fish catch in numbers and biomass. The slopes of these regressions were greater than unity, indicating fish density (number and biomass) increased slightly but significantly with survey area (Figure 6). In general although significant, the relationships were weak ($R^2 < 0.10$), and therefore standardization for survey area would have little effect.

Total estimated fish density was positively related to SR. Among sites and years, minimum SR was 1, the maximum was 5, and the average was 2.1 species of fishes per site. In addition to native juvenile Atlantic Salmon, hatchery salmon, Brook Trout, Brown Trout, White Sucker, Threespine Stickleback, Sea Lamprey and Alewife were sometimes captured at the sites, but at low frequency and abundance. During monitoring for salmon smolts from 2004 to 2009, Breau et al. (2010) reported 15 freshwater species of fishes in total in the Margaree River. Juvenile Atlantic Salmon were ubiquitous in the electrofishing catches and, as noted above, were the most abundant fish species at the Margaree survey sites, averaging > 80% of the total fish community biomass, with little variation among the years (Figure 6).

Juvenile Atlantic Salmon (pre-smolt) in the Margaree River are largely comprised of three age groups: age 0 fry, and age 1 and age 2 parr. Margaree salmon become smolts predominantly at ages 2 and 3, and occasionally at ages 4 and 5 (1–9%; Breau et al. 2009). Hence, a small proportion of parr are ages 3 and 4. Salmon were not aged, but catches were reported as two size groups, fry and parr, that could be distinguished by length-frequency distributions.

Average fish body size (geometric mean; GM) at the sites was 4.87 g for salmon and 4.78 g for the fish community. Salmon density decreased with body size ($R^2 = 0.36$; *ln*(density) = 1.723 - 1.024 *ln* (weight); P<0.0001) (Figure 6). The slope of -1.02 was significantly lower than -0.75 but not -1.0. There was no relationship between density and body size for the other species, but as noted previously the occurrence and density of cohabiting species was low. The body size-density slope for all species -0.84 and was not significantly different from -0.75 or -1.00.Biomass of all species at sites could be predicted from catch in numbers of non-salmon fishes ($R^2 = 0.75$, P< 0.0001; *ln*(biomass) = 2.824 + 0.7586 *ln*(catch); Figure 4.). This regression was used to estimate biomass at sites if catch in numbers only was available (primarily 1995–2001).

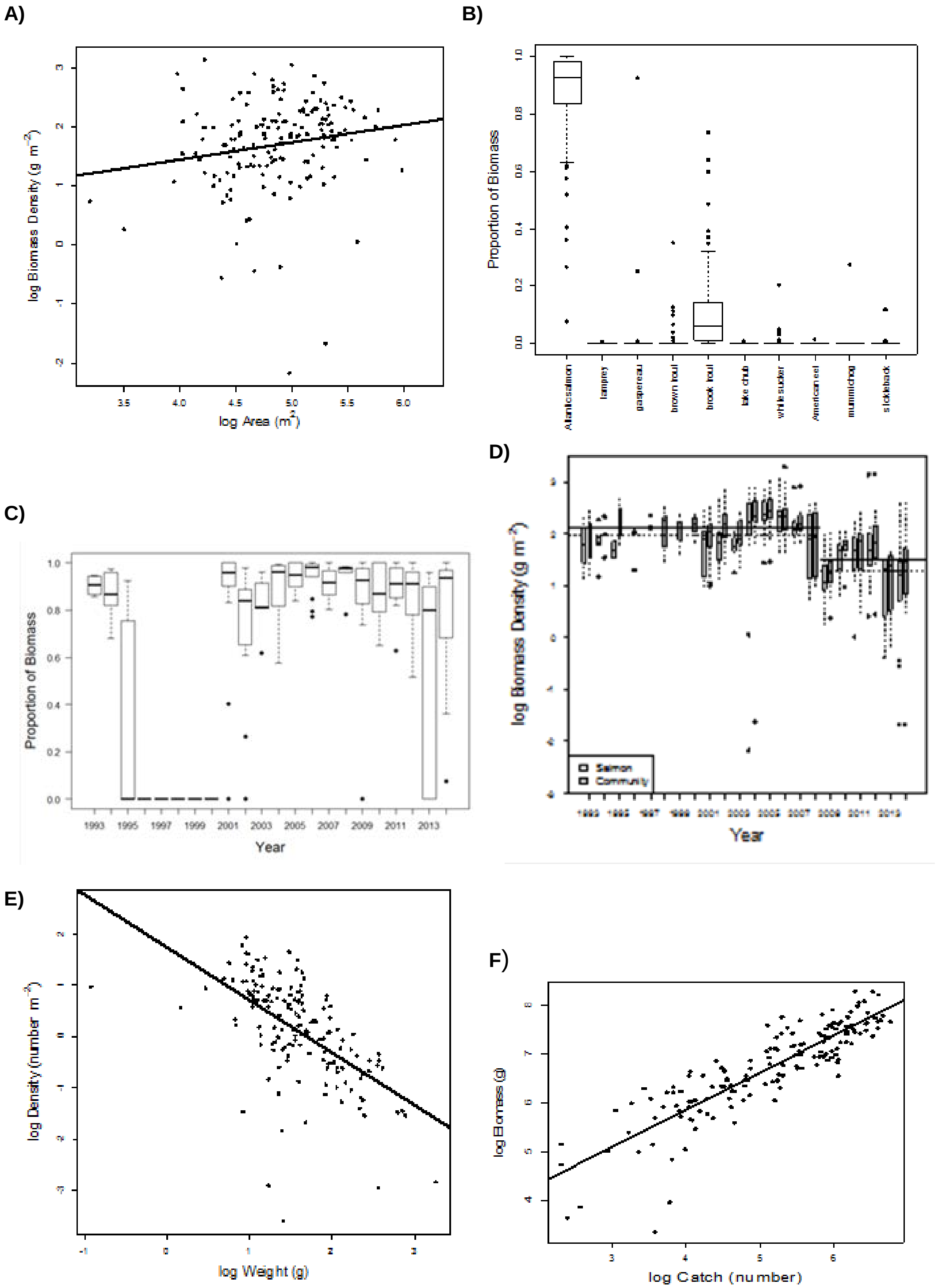

Figure 6. Margaree River benchmark data (Region SFA 18): A) Relationship between site survey area (log m^2) and biomass density (log g m^{-2}); B) Proportional biomass by species; C) Proportion of site biomass that was Atlantic Salmon; D) biomass density by year for Atlantic Salmon and community; E) Correlation between average body size of salmon (g) and density (number m^{-2}) at the survey sites; F) Regression of total catch (numbers) of non-salmon species and total biomass of fishes at the survey sites. Log values are base e.

Electrofishing sites occurred at stream orders (SO) 3 to 5. There was a significant (but weak) difference in average salmon biomass and total fish biomass among the stream orders (ANOVA $P < 0.05$). Biomass density was lowest at SO 5 (3.22 g m^{-2}) and highest at SO 3 (5.92 g m^{-2}) (Tukey-Kramer test $P < 0.05$).

For the period 1991 to 2013, annual salmon biomass density (GM) was 5.47 g m^{-2} (CL: 4.84–6.19), and total fish biomass density, all species, was 6.80 g m^{-2} (CL: 6.17–7.50). Biomass density during these years resulted from adult Atlantic Salmon returns that exceeded conservation requirements (Breau 2013) and was likely at carrying capacity. Total fish community biomass was also likely at ecosystem capacity, as juvenile Atlantic Salmon were the dominant biomass in all years at the Margaree sites.

Restigouche River (Region SFA 15) – New Brunswick

Restigouche River has an average annual discharge of 164 m^{-3} sec^{-1}, a drainage area of about 7,740 km^2 (WSC 01BJ007) and is divided into five main tributaries, Patapedia, Matapedia, Kedgwick, Little Main, and Upsalquitch. Total fluvial area, suitable habitat for juvenile salmon rearing, was estimated to be 29.8 million m^2 (Randall 1984). Mean annual air temperature at Charlo airport was 3.4 ^{o}C. Habitat alterations were considered to have a small effect on salmon (< 5% of salmon affected), with the exception of culverts and agriculture which were judged to have a medium effect (5 – 30%) (COSEWIC 2010).

Recent abundance estimates for Restigouche River for SFA 15, based on an angling exploitation rate of 40%, indicated that spawning requirements were met in 6 of the last 11 years; juvenile salmon densities have remained relatively high (DFO 2012).

Juvenile Atlantic Salmon have been surveyed annually in the Restigouche River since 1972. For this report, survey data from 1993 to 2013 were used (n =16 years). Densities were estimated using the depletion method or by catch per unit effort calibrated to densities (DFO 2012). Catches of juvenile Atlantic Salmon (number captured, weight and biomass) were available for this entire period, whereas catches of other species (number) were available but biomass was not. The number of survey sites in the Restigouche River each year during this period ranged between 11 and 101, with an average of 71 sites per year. The electrofishing survey areas averaged 160.3 m^2 (range 57.0–425.3 m^2).

SR ranged between 1 to 8 species of fishes, with an average per site of 3.01 species. Average richness for each tributary was similar: Kedwick, 3.25; Main Restigouche, 2.81; Little Main, 3.01; Upsalquitch, 3.12; Matapedia, 2.85 and Patapedia, 2.74. In addition to native juvenile Atlantic Salmon, Slimy Sculpin, Brook Trout, Lake Chub, American Eel, White Sucker, stickleback, and Sea Lamprey were sometimes captured. For the period 1993 to 1996, there was a significant but weak decrease in fish density with survey area in Kedgwick (Figure 7) and Matapedia rivers ($R^2 < 0.10$), but not in the other tributaries. Juvenile Atlantic Salmon were ubiquitous and the most abundant fish species at the Restigouche sites, averaging about 40% by numbers of the total catch (all species), with little variation in average annual proportion among years (Figure7).

Juvenile Atlantic Salmon (pre-smolt) in the Restigouche River are largely comprised of three age groups: age 0 fry, and ages 1–2 parr. Restigouche salmon become smolts predominantly at ages 2 and 3 and less frequently at age 4; hence, the largest proportion of parr are ages 1 to 3. Salmon were not aged, but catches were reported as two size groups, fry and parr, that could be distinguished by length-frequency analysis.

Median fish body size of salmon at the sites, all years, was about 4 g (range 2.5–7.4 g). Salmon density decreased with body size in all tributaries (R^2 ranged between 0.15 and 0.35); for example, the regression for the Main Restigouche was $ln(D) = -0.0384 - 0.70\, ln(W)$; $P<0.0001$).

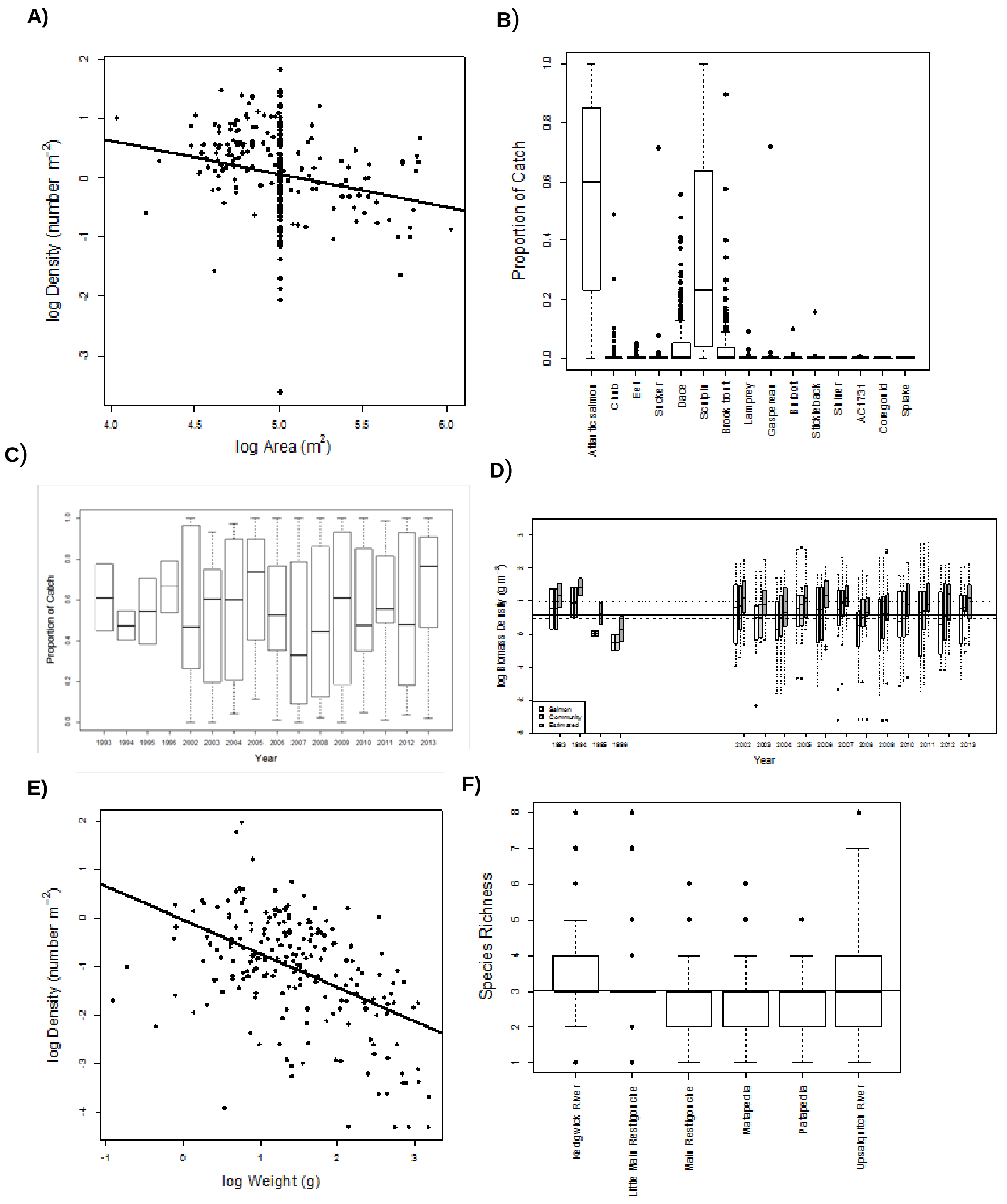

Figure 7. Restigouche River benchmark data (Region SFA 15): A) Relationship between site survey area (log m^2) and density (log g m^{-2}) (Kedgwick); B) proportional biomass by species (Main Restigouche); C) Proportion of site catch that was Atlantic Salmon by survey year (Main Restigouche); D) Biomass density by year for Atlantic Salmon and community (Main Restigouche); E) Correlation between average body size of salmon (g) and density (number m^{-2}) at the Main Restigouche sites. F) Average species richness at the Restigouche tributaries. Log values are base e.

The slopes for most tributaries were not significantly different from -0.75 but were different from -1.0. The slope in the Patapedia was not significantly different from either coefficient. Weights of other species were not reported.

Electrofishing sites occurred at SO 3 to 8. There was a significant difference in average salmon biomass among the stream orders (ANOVA P< 0.01). Average biomass density (GM) was lowest for SO 3 (0.31 g m^{-2}; n = 17) and SO 4 (0.46 g m^{-2}; n = 232), and highest for SO 5 (0.98 g m^{-2}). Excluding SO 3, body size of salmon was largest for SO 4 sites (6.0 g; P< 0.01), and smallest for SO 6 (2.3 g).

For the1993 to 2013 period, annual average salmon biomass densities (g m^{-2}) among tributaries ranged between 1.26 and 1.81: Main Restigouche, 1.50 (CL: 1.30–1.72); Upsalquitch 1.66 (1.45–1.90); Kedgwick 1.57 (1.37–1.80); Little Main, 1.81(1.54–2.12); Matapedia 1.45 (1.21–1.73), and Patapedia 1.26 (1.00–1.58). The biomass of other species was estimated (roughly) by regression from the Miramichi data: *ln*(biomass) = 1.146 + 0.896 *ln*(catch). For these years, total fish biomass, all species, was: Main Restigouche, 2.51 (CL: 2.25–2.80); Upsalquitch 2.64 (2.36–2.95); Kedgwick 2.98 (2.72–3.27); Little Main 3.28 (2.90–3.70) Matapedia 2.32 (2.03–2.65), and Patapedia 2.27 (1.86–2.76); Table 1).

The biomass density of juvenile Atlantic Salmon was relatively high, as spawning requirements were met in most years (DFO 2012) and the cohabiting species in the Restigouche River were assumed to be at or approaching ecosystem capacity.

Miramichi River (Region SFA 16) – New Brunswick

The Miramichi River in northeast New Brunswick provides freshwater habitat for the largest population of anadromous AtlanticSalmon in Atlantic Canada. The watershed area is 13,700 km^2, the total fluvial habitat area is about 55 million m^2 (Amiro 1983), and the mean annual discharge of the Southwest Miramichi at Blackville was 118 $m^3 s^{-1}$ (WSC 01BO001).

Major tributaries are the Northwest (NW), Little Southwest (LSW), Renous and Main Southwest (SW) Miramichi, all of which flow generally eastward and discharge into Miramichi Bay, Gulf of St. Lawrence. Mean annual air temperature at Miramichi (1981 to 2010) was 4.9 °C (Table 1). In SW Miramichi, water conductivity averaged 41.0 µS cm^{-1}, phosphorus concentration was 0.012 mg L^{-1}, and alkalinity averaged 10.9 $CaCO_3$ (Randall et al. 1989b). Multiple threats affect Atlantic Salmon in SFA 16, including fisheries, periodic high water temperature, disease, land use and invasive species (Chaput et al. 2010; Douglas et al. 2013). Habitat alterations were considered to have a low effect on salmon (< 5% of salmon affected), with the exception of transportation-related impacts (culverts) which were judged to have a medium effect (affecting 5–30% of the salmon) (COSEWIC 2010).

Electrofishing surveys at Miramichi sites have been conducted since 1970. Field data from recent years (1994 to 2013) were used for this assessment (Table 2). During this period, the total number of samples was 927, from the main tributaries of SW (364), LSW (119), NW (307) and Renous (137). Average area of survey was 225.0 m^2; averages area among sub-regions was generally similar. Depending on the year and site, fish density was estimated by the catch depletion method, or by linear regression at open sites (Figure 22 in Douglas et al. 2013).

Table 2. Sampling summary for the Miramichi River tributaries from 1994 to 2013.

River	Samples	Total area (ha)	Mean survey area (m^2)
Northwest	307	6.84	223
Little Southwest	119	2.93	246
Renous	137	3.17	232
Southwest	364	8.05	221
Total	927	20.99	225

Species occurrence at the survey sites ranged between 1 to 9, with an average per site of 2.94 species. Among tributaries average richness was: LSW = 2.81, NW = 2.61, Renous = 3.31 and SW = 2.79. In addition to native juvenile Atlantic Salmon, other species captured frequently included Slimy Sculpin, Brook Trout, Blacknose Dace, American Eel and Sea Lamprey (ammocoetes), as well as a number of other species that were captured less frequently (Figure 8). Juvenile Atlantic Salmon were ubiquitous and the most abundant fish species at the Miramichi sites, often averaging >80% by numbers and biomass of the total catch in all tributaries. The proportion of catch of salmon in biomass in the main tributaries ranged from 0.78 at LSW to 0.87 at NW and Renous. The proportion at SW Miramichi was intermediate (0.83). Blacknose Dace was the second highest contributor to community biomass in all tributaries, but contributed < 10% (Figure 8). In terms of resident fish biomass, the main tributaries of the Miramichi historically and currently provide significant area of rearing habitat for juvenile anadromous Atlantic Salmon.

Juvenile Atlantic Salmon inhabiting fluvial habitat in the Miramichi River are largely comprised of three age groups: age 0 fry, and ages 1 and 2 parr. Miramichi juvenile salmon become smolts predominantly at age 3 and less frequently younger (age 2) or older (> age 3).

Juvenile salmon were not aged, but annual catches were reported as two size groups, fry and parr, distinguishable by length-frequency analysis.

For some of the Miramichi tributaries, there was a significant negative relationship between the survey area and salmon number and biomass densities. However, the relationships were weak with a low coefficient of variation (all ≤ 12%). Standardizing by area would have little effect on the density estimates. The slight decrease in density with area is shown for example for the LSW Figure 8.

Density of salmon decreased with body size in all tributaries (Figure 8). However, there was much scatter in the data and the R^2 values were low (<0.20). The slopes for salmon density-body weight ranged from -0.38 to -0.53. The density-body weight regressions for all species combined were weak, often non-significant, and slopes were < 0.2.

Electrofishing sites in the Miramichi occurred at SO 2 to 7, with the majority at SO three to five (median 4). Average SO was 4.1, and was similar among all four tributaries.

For non-salmonid species, the regression of catch in number and biomass was: *ln* (Biomass) = 1.163 + 0.891 *ln* (Catch) ($R^2 = 0.65$; Figure 8). This regression was used to estimate total fish community biomass for sites in the Restigouche River where catch in numbers was known but weights of non-salmonid species were not recorded.

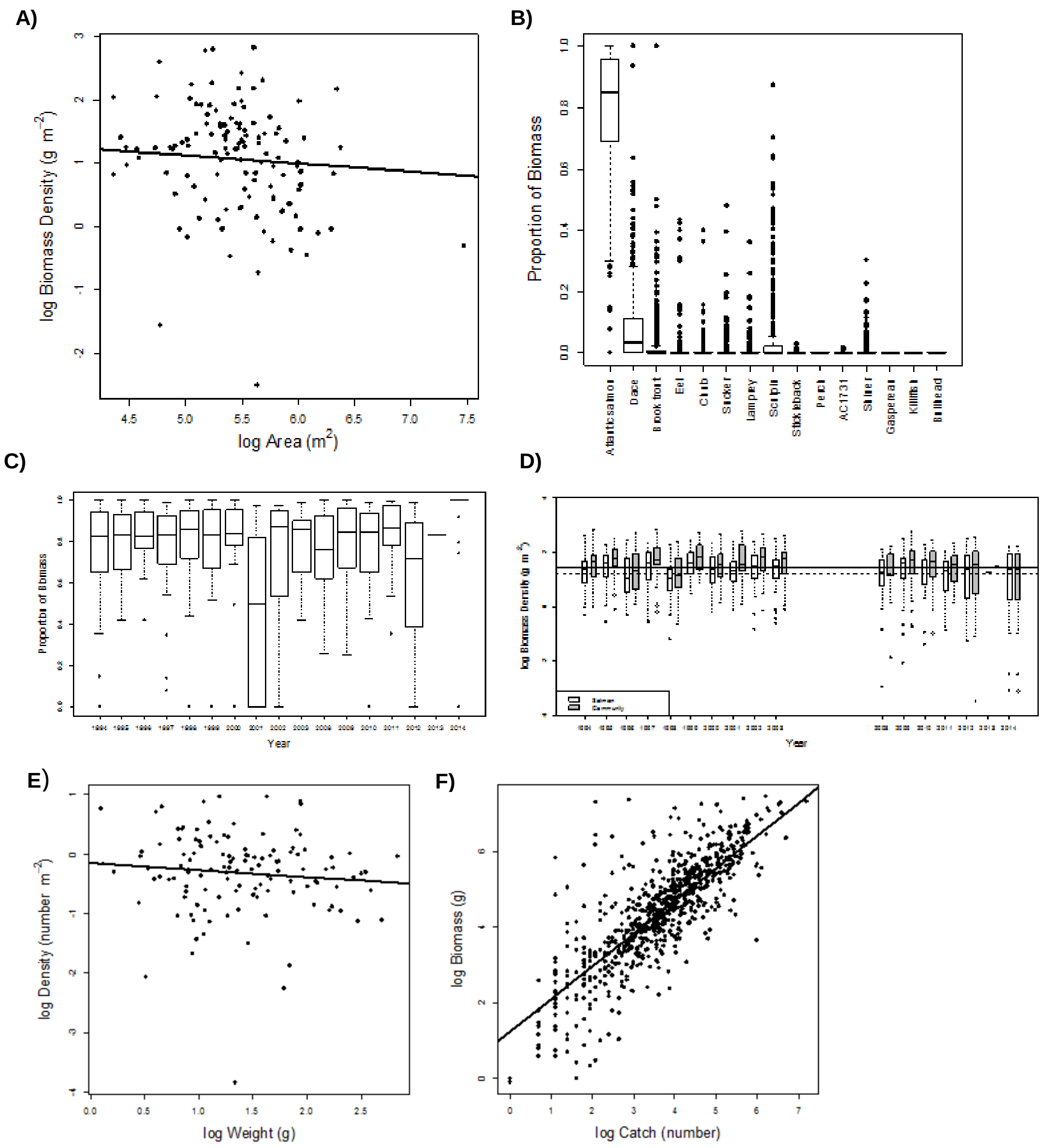

Figure 8. Miramichi River benchmark data (Region SFA 16): A) Relationship between site survey area (log m^2) and biomass density (log g m^{-2}) (LSW); B) Proportional biomass by species (SW); C) Proportion of site biomass that was Atlantic Salmon by survey year (SW); D) Biomass density by year for Atlantic Salmon and community (SW); E) Correlation between average body size of salmon (g) and density (number m^{-2}) at the Little SW Miramichi. F) Relationship between catch in number and total biomass (non-salmonid species). Log values are base e.

Average salmon biomass density (g m^{-2}) for each tributary was: LSW = 1.92 (CL: 1.61–2.29), NW = 3.29 (2.97–3.64), SW = 3.36 (3.08–3.67) and Renous = 2.54 (2.28–2.83). Corresponding values of biomass for the entire fish community were higher: 2.91(CL: 2.51–3.38), 3.95 (3.58–4.36), 4.26 (3.91–4.65) and 2.96 (2.68–3.27) g m^{-2}.

The population status of Atlantic Salmon in the Miramichi was assessed in most years. For the 1994 to 2013 period, spawning requirement were met in some years, and the biomass density of juvenile Atlantic Salmon and the cohabiting species in the Miramichi River were assumed to be at or approaching ecosystem capacity

Catamaran Brook, Miramichi River (Region SFA 16) – New Brunswick

Catamaran Brook is a third order tributary of the Southwest Miramichi that has been monitored as a research watershed since 1990 (Cunjak et al. 1993). Electrofishing surveys conducted at eight sites from 2002 to 2004 were used for this study (results were initially reported in a pilot benchmark study by Randall et al. 2014). Average survey area was 126 m^2 (range: 67–194). Fish density was estimated by the removal method (3 to 5 removals at each site and date, using block nets (Randall et al. 2014). A total of 11 species of fishes were captured. Average fish size was 2.79 g.

Total abundance and biomass of fishes in Catamaran, unadjusted for effort and capture probability, was reported by Randall et al. (2014). Randall and Chadwick (1986) showed that with sufficient effort (five removal passes), the ratio of total numbers of juvenile salmon captured and population estimates were close to unity, averaging about 1.1. Fishing effort at the Catamaran sites was slightly less (usually 3–4 removals), nonetheless average abundance and biomass of fishes were adjusted upwards by 1.1, which was probably slightly conservative.

Density of salmon decreased with body size, with a R^2 value of 0.47 and a slope of -0.82. The relationship between density of all fishes and body size was not significant ($P > 0.05$). Average biomass densities of salmon (geometric means) and the total community were 0.7 (CL: 0.5–0.9) and 1.9 (1.5– 2.4) g m^{-2}, respectively (after adjustment by 1.1).

The abundance and status of fishes at Catamaran Brook for the 2002 to 2004 period relative to ecosystem capacity was unknown.

Gulf Nova Scotia (Region SFA 18) – Nova Scotia

Rivers that flow into the Northumberland Strait coast of Nova Scotia and western Cape Breton Island make up SFA 18. Atlantic Salmon are known to inhabit 55 rivers, of which the Margaree River (assessed above) is the largest (Breau et al. 2009). For mainland NS, electrofishing data from West River (Antigonish), East River (Pictou) and River Philip were used to investigate regional benchmarks. The fluvial habitat area of these rivers was 0.48, 0.73 and 0.96 million m^2, respectively (Breau et al. 2009). Mean annual air temperature at Pugwash NS was 6.7 °C (Table 1). As noted for the Margaree River, habitat alterations were considered to be relatively minor, with the exception of habitat fragmentation (non-compliant culverts) which were judged to have a medium effect (5–30%) on salmon populations (Breau et al. 2009), and possibly on other cohabiting fishes.

Juvenile Atlantic Salmon from anadromous adults was the dominant fish species captured by electrofishing in the West and East Rivers and River Philip. Population status of salmon relative to conservation requirements was not specifically assessed for these three rivers (Breau et al. 2009), but fry and parr densities from 1978 to 2008 often exceeded the normal index of abundance (Elson's norm; Breau et al. 2009). SR at the electrofishing sites ranged from 1 to 5 species, with an average richness of 2.2 species. Juvenile salmon comprised > 80% of the catch, while Brown Trout,Threespine Stickleback, ammocoete Sea Lamprey, White Sucker, Brook Trout and American Eel were also captured (Figure 9). Average SR varied among the three rivers: East 1.8, West 2.2, and Philip 2.6 (Figure 9).

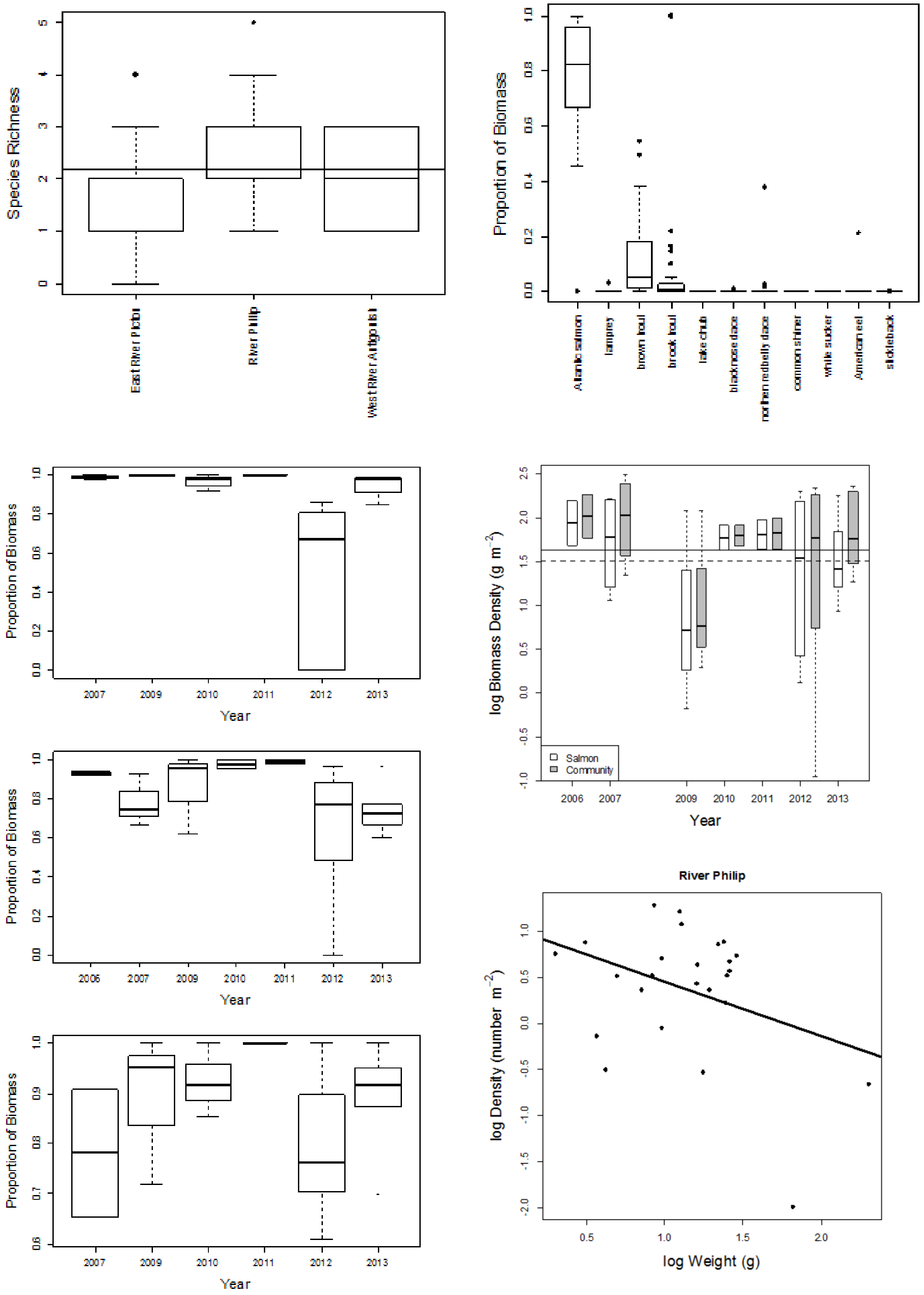

Figure 9. Gulf Nova Scotia benchmark data (Region SFA 18): A) Average species richness by river; B) Proportional biomass by species (River Philip); C) Proportion of salmon biomass (g m^{-2}) by river and survey year (East, upper; Philip, middle; West, lower); D) Average biomass density of Atlantic Salmon and total fish community (River Philip); E) Correlation between average body size of salmon (g) and density (number m^{-2}) at the survey sites. Log values are base e.

For this report, survey data from 2006 to 2013 were used (Table 3). The number of surveys varied by year and river, for a total sample of 71. Catches of juvenile Atlantic Salmon and all cohabiting species were available, including abundance, fish weight and site biomass by species. Densities were estimated using the catch depletion method (Breau 2013). The average survey area was 135.8 m^2 (range 37.5–373.4), and the total area surveyed for this period (cumulative all sites) was about 0.94 ha.

Table 3. Sampling summary for the 2006 to 2013 Gulf Nova Scotia survey data used in the report.

River	Source	Survey Effort		
		Samples	Total Survey Area (ha)	Mean Survey Area (m^2)
River Philip		26	0.33	128
East River Pictou		22	0.29	144
West River Antigonish		23	0.32	138
Total	DFO (C.Breau)	71	0.94	136

The number and biomass of salmon and cohabiting fishes captured in total at survey sites were weakly related to survey area, significant and positive for density in East River only (R^2 = 0.21).

Mean fish weight of salmon ranged between 2.9 to 3.8 g among rivers (Table 1), and from 3.3 to 3.9 g for the total fish community. Salmon density decreased with salmon body weight. Analysis of covariance with river as the treatment, indicated that the slope of the body size-density relationship did not differ among the three rivers, but the intercepts were different, indicating a higher density of salmon for any given fish size at River Philip, than at the other two rivers (R^2 = 0.34; ln (D) = 0.97 - 0.93 ln (W); n = 68, P<0.001). The slope of -0.93 (CL -0.49, -1.46) was not significantly different from -0.75 or -1.0. The relationship between body size and density of the total fish assemblage was similar. The density-fish weight scatterplot for River Philip (as an example) is shown in Figure 9.

Most survey sites in the Gulf Nova Scotia rivers were located in SO two to four. For combined data from all three rivers, there was no significant difference in average biomass density or fish body size of either juvenile salmon or their cohabiting species (ANOVA, P > 0.05) among these SOs.

Total fish biomass at the Gulf NS sites could be predicted from catch in numbers of fish by the regression: ln (B) = 2.635 + 0.714 ln (catch) (R^2 = 0.73, P< 0.001, n = 70).

Average salmon biomass density varied among the three rivers; biomass of salmon was highest at River Philip (4.52 g m^{-2}; CL: 3.45–5.20), and less at West River (2.69 g m^{-2}; 1.81–4.00) and East River (1.96 g m^{-2}; 1.48–2.60). Juvenile Atlantic Salmon dominated the fish biomass at the sites; mean proportion of salmon to total site biomass for all three rivers was > 80% (Figure 9). The total fish community biomass for each river was: River Philip 5.12 g m^{-2} (3.78–6.93), West River 3.12 g m^{-2} (2.09–4.64) and East River 2.17 g m^{-2} (1.64–2.87) (Table 1).

Fish community biomass at the Gulf Nova Scotia sites was known (Breau 2013) or assumed to be at or approaching ecosystem capacity.

Inner Bay of Fundy (Region SFA 22) – Nova Scotia and New Brunswick

For the original pilot study of regional benchmarks, a subset of 11 rivers (26 sites in total) flowing into the upper Bay of Fundy were chosen for inclusion (Randall et al. 2014). The electrofishing data were collected between 2000 and 2003. Average survey area was 672 m^2 (125–1462), and 18 species of fishes were captured during the surveys. Population abundance was estimated using single-pass, multiple pass and mark-recapture methods, depending on the site and year.

For these Inner Bay of Fundy Rivers, Randall et al. (2013) reported an average biomass density (GM) of 7.8 (CL: 5.5–11.0) g m^{-2} and an average HPI 8.1 of g m^{-2} yr^{-1}. (Note that averages in Randall et al. [2014] were originally reported as medians rather than geometric means).

Fish biomass density for Inner Fundy was underestimated and likely below carrying capacity because;

1) some estimates were not adjusted for capture probability, and,
2) Inner Fundy Atlantic Salmon were assessed as Endangered (COSEWIC 2010).

Outer Bay of Fundy, Saint John River (Region SFA 23) – New Brunswick

The Outer Bay of Fundy Atlantic Salmon populations were designated as Endangered in Canada (COSEWIC 2010; Designatable Unit 16). DU 16 is part of SFA 23 and includes 11 rivers with the large Saint John River (SJR) watershed, and nine rivers in southwest New Brunswick that flow into the outer Bay of Fundy and Passamaquoddy Bay. The total drainage area of the SJR is 29,599 km^2 and the outer Fundy complex is 7,615 km^2 (Jones et al. 2014).

Data for this report were collected from a number of rivers in outer Bay of Fundy in 2009 to update the status, current range and densities of juvenile salmon (Jones et al. 2014). For the SJR, the Tobique and Nashwaak Rivers are the largest salmon producing tributaries upstream and downstream, respectively, of the Mactaquac hydro dam. The watershed area of the Tobique River is about 4,300 km^2, and flows into the SJR at Perth-Andover. The fluvial habitat area was estimated at 7.86 million m^2 (Jones et al. 2014). Below the Mactaquac Dam, the Nashwaak River has a drainage area of about 1,700 km^2 (Jones et al. 2014) and flows in a southeasterly direction to its confluence with the Saint John River in Fredericton. The name Nashwaak from the Maliseet language means ‘slow current’. The fluvial habitat area was estimated to be 5.69 million m^2 (Marshall et al. 1997; Jones et al. 2014). Electrofishing surveys to assess the status of Atlantic Salmon have been conducted in the Tobique and Nashwaak Rivers since 1970 (Jones et al. 2014). Population estimates, depending on the site and year, are based on depletion, mark-recapture, or an estimated capture probability of 0.347. Mean annual air temperature at Fredericton was 5.6 °C (Table 1).

Conservation requirements for Atlantic Salmon in SFA 23 (all areas) were set at 2.4 eggs per square metre, but the salmon egg deposition rates have been below this target in recent years in most rivers. Analysis of stock and recruitment data indicated that the Nashwaak River has a relatively low habitat carrying capacity for salmon fry and parr compared to other Maritime rivers (Gibson 2006). Habitat alterations and threats in freshwaters affecting SFA 23 are many (Clarke et al. 2014) and include acidification, extreme water temperature events, silt and sediments, pollutants, military activities, power generation and invasive species.

The number of 2009 survey sites in SFA 23 used in this report was 93, with 48 below Mactaquac on SJR, 33 above Mactaquac SJR, and 12 from other outer Fundy rivers. The survey areas averaged 845.7 m^2 (range 173.3–5,380 m^2). For all sites combined, there was a significant but weak positive correlation between the area surveyed and total fish catch in numbers ($R^2 = 0.07$; $P<0.01$). The relationship between area of survey and total biomass was not significant. Among sites, the minimum SR was 2, the maximum was 10, and the average was 4.9 species of fishes. For all sites combined, the five highest catches were Blacknose Dace, Slimy Sculpin, Atlantic Salmon, Brook Trout and American Eel. In contrast to SFAs 15 and 16 in northeastern NB, Atlantic Salmon were not the most abundant species captured at the SFA 23 sites, reflecting the COSEWIC status of Endangered salmon populations for this DU. However, juvenile Atlantic Salmon were common and averaged about 11% of total numbers and 15% of biomass at the sites, consistently among the three sub-regions.

Although Atlantic Salmon are Endangered in SFA 23, they are a priority species for managers because of their importance historically. Recent investigations have shown that juvenile Atlantic Salmon (pre-smolt) in SFA 23 are largely comprised of age 2 smolts and the remainder were age 3 (Jones et al. 2014). Subsamples of juvenile salmon were aged; catches were reported as fry (age 0) or parr.

Salmon density decreased roughly with increases in salmon body weight, but not significantly ($P=0.08$). Total fish density however decreased significantly with body size ($P<.0001$). Analysis of covariance with sub-region as the treatment indicated that the slopes of the body size-density relationship did not differ among the three sub-regions, but the intercepts were different, indicating a lower density of fishes for any given fish size above Mactaquac, than below Mactaquac and the outer Fundy sites ($R^2 = 0.45$; $ln\ (D) = -0.98 - 0.74\ ln\ (W)$; $P<0.001$; Figure 10). The slope of -0.74 (CL -0.56, -0.91) was not significantly different from -0.75 but was significantly different from -1.0.

Total fish biomass at the SFA 23 sites could be predicted from catch in numbers of fish for each subregion separately (not significant for data above Mactaquac; relationships not shown).

Average (GM) salmon biomass density, all ages, was 0.09 g m^{-2} (CL: 0.06–0.14; n = 53), and total fish biomass density, all species, was 0.54 g m^{-2} (CL: 0.44–0.66; n = 92). Total biomass density was lower above Mactaquac than below or at the other outer Fundy sites (Figure 10). Fish biomass densities at Outer Fundy were assumed to be below ecosystem carrying capacity because the status of Atlantic Salmon was Endangered and because of the influence of hydropower dams on the SJR.

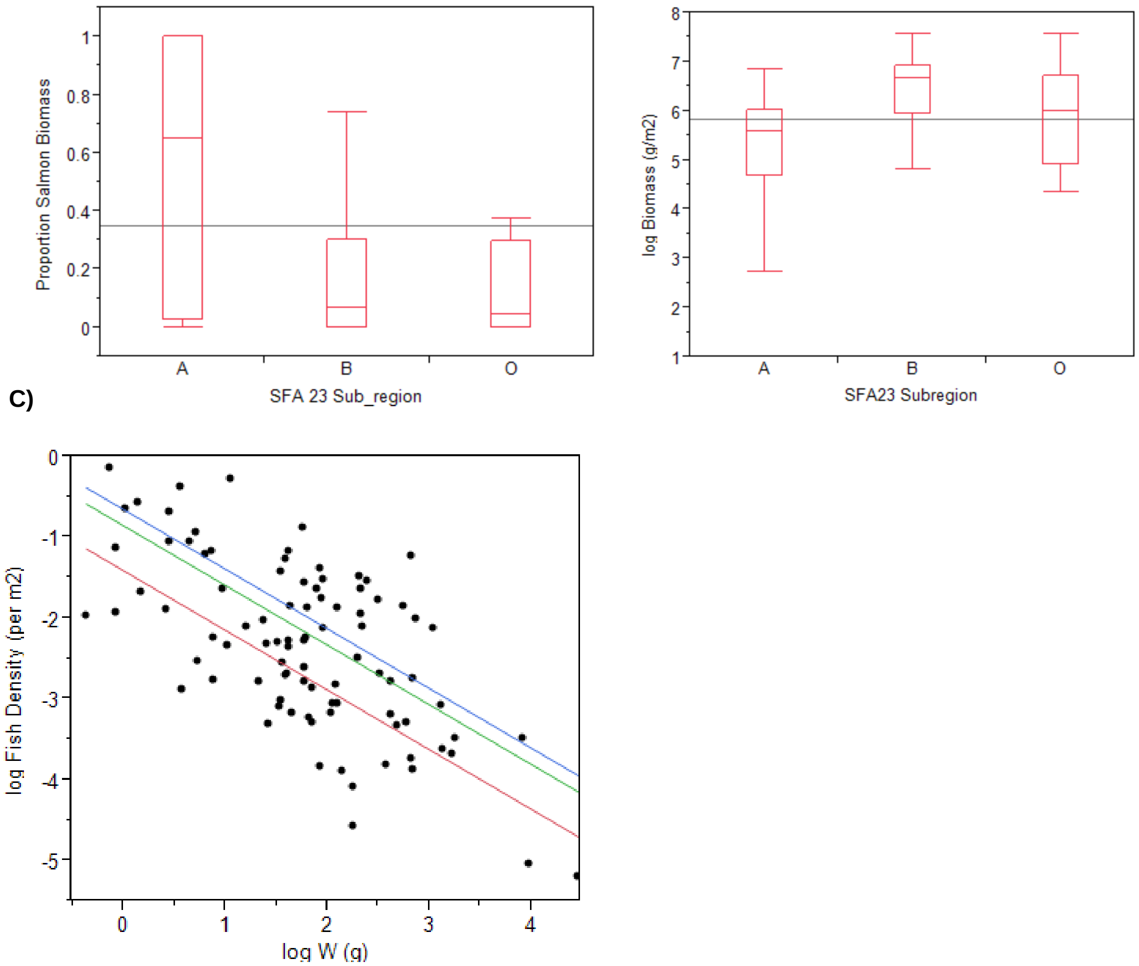

Figure10. Outer Bay of Fundy benchmark data (Region SFA 23): A) Proportion of biomass that was Atlantic Salmon by subarea (A, above Mataquac; B, below; O outer Fundy; B) Community biomass density by subarea; C) Correlation between average body size of fishes (g) and density (number m^{-2}) at the survey sites (red, above; green, outer; blue, below). Log values are base e.

Ganaraska (Ontario Fishing Zones 16 & 17) – Ontario

Electrofishing data from sites in Ganaraska and several other rivers flowing into Lake Ontario were available for 2002, 2003 and 2004 (J. Bowlby, OMNRF, pers. comm.). The rivers included: Ancaster, 16 Mile, Silver, Limestone, Black, Credit, Little Rouge, Duffins, Lynde, Oshawa, Farewell, Bowmanville, Soper, Wilmot, Orono, Graham, Ganaraska, Port Britain, Gages, Cobourg, Barnum House, Shelter Valley, Colborne, Butler and Smithfield. Although the main purpose was to determine the abundance of juvenile salmonids (Rainbow Trout in the Ganaraska for example), catches of other fish species were recorded as well (biomass of non-salmond species was estimated by regression, as described below). Results of catches of juvenile salmonids and other species are reported in the annual reports of the Lake Ontario Management Unit (e.g., OMNR 2005).

A total of 113 samples were collected over the three years (38, 37 and 38 in each year respectively). Average survey area was 291.2 m^2 (range: 50–884). Estimates of density of salmonids, adjusted for capture probability, were based on Jones and Stockwell (1995; yearling salmonids and older) and OMNR 2005 (fry). Densities of other species were based on catches from the survey areas. In total, 40 species of fish were captured (Figure 11), reflecting the high diversity of fishes in southern Ontario. Average SR at the sites was 7.5 (range: 2–16), which did not vary among the three years. In terms of proportional catch, Blacknose Dace, Rainbow Trout, Creek Chub, Brown Trout, Longnose Dace, Slimy Sculpin and White Sucker were important. Rainbow Trout comprised about 31% of the catch (numbers), on average.

There was a significant positive correlation between SR and density of fishes. There was no significant relationship between survey area and density among the survey sites. There was no significant relationship between biomass of salmonids and survey area. The relationship between density and body weight of rainbow trout was negative and significant (P = 0.012) with a slope of -1.12 (one outlier was removed; Figure 11).

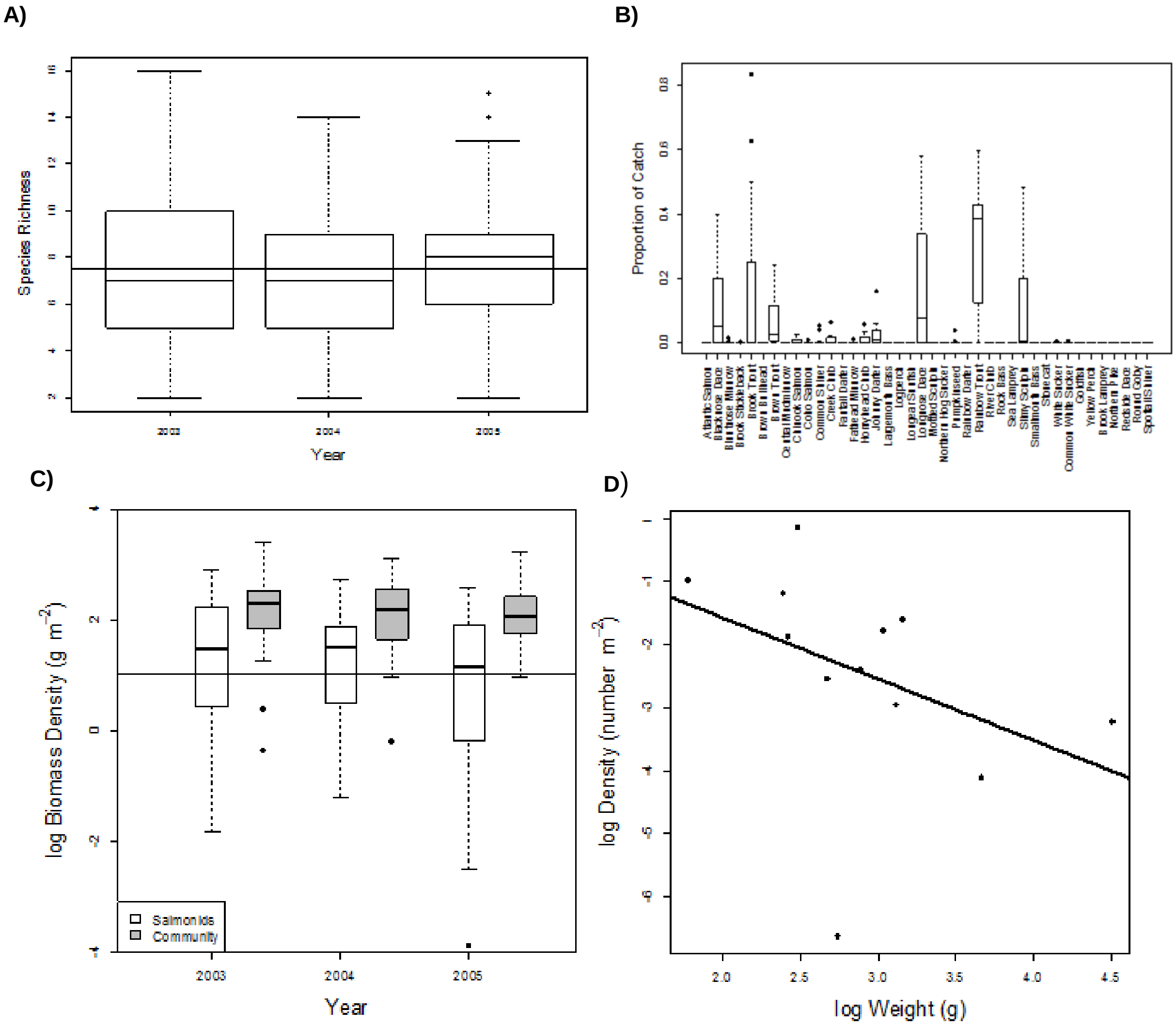

Figure 11. Ganaraska River benchmark data (Region FZ 16/17): A) average species richness among years; B) Proportion of catch (numbers) by species; C) Box plots of average annual fish biomass (g m^{-2}) by year for salmonids and community; D) Correlation between average body size and density (m^{-2}) of rainbow trout at the Ganaraska survey sites. Log values are base e.

Non-salmonid biomass was estimated using the regression from the Toronto data set: *ln* (B) = 3.248 + 0.791 *ln* (catch) (see below).

Biomass density of all species averaged 8.21 g m^{-2} (CL: 7.35–9.21), and biomass density of salmonids alone averaged 2.77 g m^{-2} (CL: 2.16–3.55). Biomass density was similar among the three survey years (Figure 11).

The status of salmonid fish biomass density in the Ganaraska and other rivers was unknown, but was assumed to be at current ecosystem capacity.

Toronto (Ontario Fishing Zone 16) - Ontario

For the Toronto region, quantitative electrofishing (removal method or single-pass electrofishing) data were collected at eight rivers flowing into the north shore of Lake Ontario. The surveys were conducted during September and October 2005 and 2006 to determine the status of Redside Dace, a Threatened species (Reid et al. 2008a), but data for all species captured at the sites were recorded. The rivers and the number of sites in each were: Rouge (12), Lynde (9), Humber (6), Fourteen Mile (4), Duffins (2), Morningside (2), Silver (2) and Sixteen Mile (1). Results of these surveys were reported as a pilot study to determine regional benchmarks by Randall et al. (2014). At that time, total fish catches were used as an index of abundance, but they were not adjusted for capture probability. For this study, catches were adjusted for catch efficiency using the removal method or single-pass electrofishing and estimated capture probability (Reid et al. 2008b), which was species dependent.

Average survey area for the 38 sites was 157 m^2 (range 50–340), for a total survey area of about 0.6 ha. For all surveys, 34 species of fish were captured, with an average of 10.1 (range 5–16) species captured per site. SR at sites varied somewhat by tributary (Figure 12). In terms of proportional biomass, Blacknose Dace, Creek Chub and White Sucker contributed the most weight to the catch, on average (Figure 12). A few salmonids were also captured (Brook Trout, Rainbow Trout and Brown Trout), but they were not abundant at the sites.

There was a correlation between SR and survey area at these species-rich Toronto sites ($R^2 = 0.42$; $P < 0.01$). There was a weak but significant relationship between area and density (Figure 12), but not with biomass density.

There was a significant relationship between *ln* fish weight and *ln* density with a slope of -0.52 (significantly different from a slope of -0.9 ($t = 2.097$; $p < 0.05$) but not from -0.75 ($t = 1.27$; $p > 0.05$) (Figure 12).

The relationship among sites between biomass and catch (non-salmonids) was highly significant: *ln* (B) = 3.248 + 0.791 *ln* (catch) ($R^2 = 0.50$; $P < .01$), providing a predictive equation for sites where only catch data (number caught) were available. This regression (as noted above) was used to calculate biomass of non-salmon species in the Ganaraska River data set.

The overall geometric mean biomass density, all sites combined, was high at 21.9 g m^{-2} (CL: 17.36–27.71). This was the highest average biomass density recorded for any of the regions in this study. Average biomass density is compared among the eight rivers surveyed in Figure 12.

Relatively high, fish biomass in the Toronto region was affected by urbanization but likely close to current ecosystem capacity (assumed). The high biomass in streams of southern Ontario was also recorded by Mahon and Balon (1985) several years earlier.

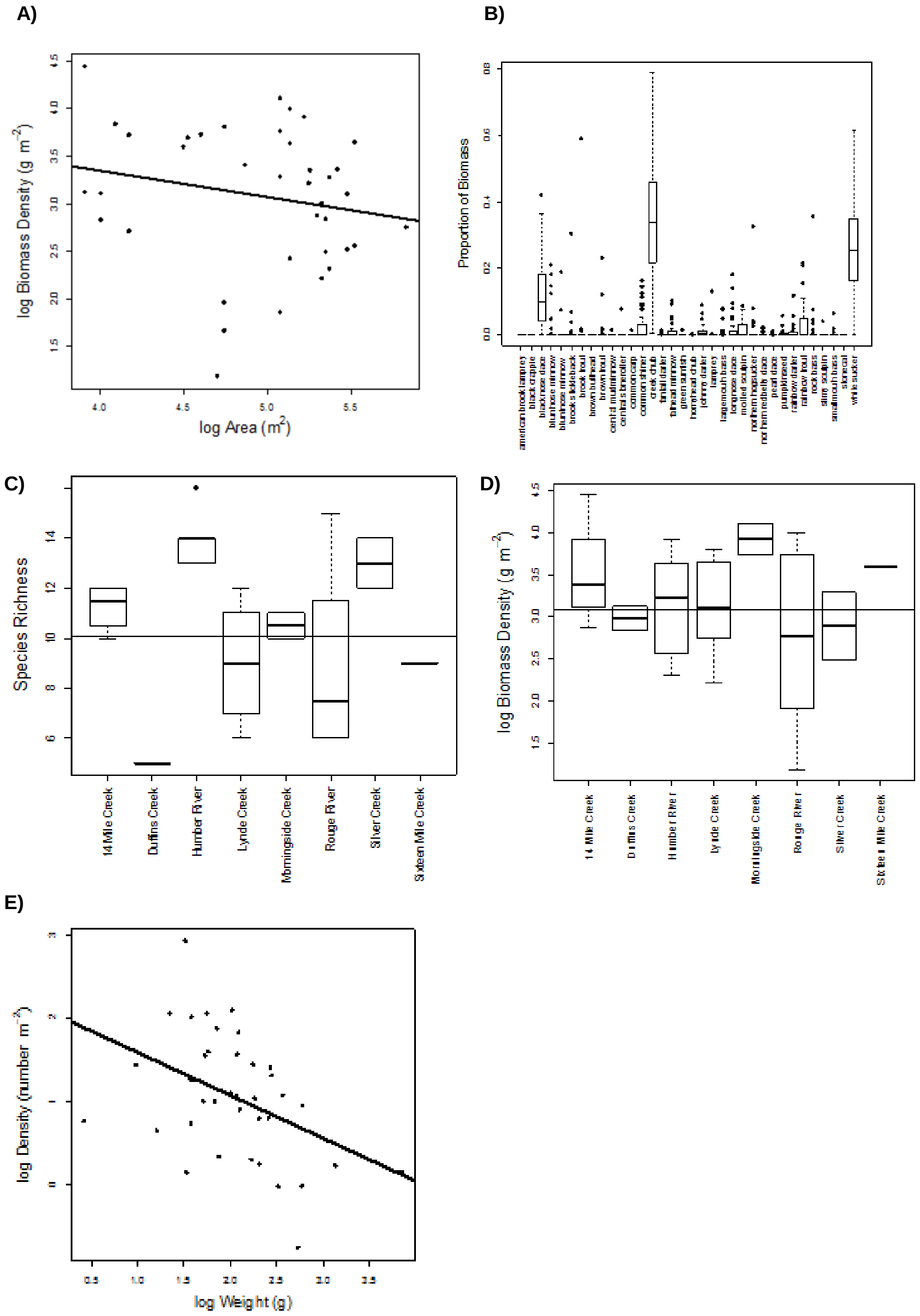

Figure 12. Toronto region benchmark data (Region FZ 16): A) Relationship between site survey area (log m^2) and biomass density; B) Proportion of biomass by species; C) Species richness by tributary; D) Biomass density by tributary; E) Correlation between average body size of fishes (g) and density (m^{-2}) at the survey sites. Log values are base e.

Magpie and Batchawana (Fishing Zone 10) - Ontario

Standardized electrofishing surveys were conducted in the Magpie and Batchawana Rivers, Ontario from 2002 to 2013 (Smokorowski, pers. comm.). Both rivers discharge into northeastern Lake Superior. Fishing survey data in the Magpie River (watershed of about 1,954 km^2 at Wawa) were collected to monitor the effect of hydropower flow regime in tail waters below Steephill Generating Station (operated by Brookfield Renewable Energy Ltd). Average annual flow in the Magpie River (WSC 02BD007) was 19.7 m^3 sec^{-1}. Simultaneous reference data were also collected at Batchawana River (watershed area of about 1,228 km^2, WSC 02BF001; average annual flow, 1967 to 2015, was 21.9 m^3 sec^{-1}). During the 2002–2013 survey period, the total number of electrofishing samples was 822 and 966 for the Magpie and Batchawana Rivers, respectively. Average survey area was 282.6 m^2 (range: 30–3084) for Magpie and 268.2 m^2 (range: 30–1,965) for Batchawana. The survey design involved collecting data from the main river upstream and at various distances downstream of the hydro dam on the Magpie River, and at comparable locations on the Batchawana River. River surveys were conducted by backpack electrofishing at shallow water depths, and habitat was partitioned by water velocity (i.e., sites were classified as ‘fast’ or ‘slow’). Further details of the survey design are available (Smokorowski et al. 2011.).

For both rivers, data were CPUE after one pass through the survey areas. The assumed capture probability was 0.2 (range 0.1–0.3) for the areas fished, but additional habitat was not wadeable and therefore not sampled, potentially further underestimating total biomass density for the systems (K. Smokorowski, pers. comm.). The probable range was given to reflect the uncertainty. Total fish community catches (abundance and biomass) at each site were adjusted by dividing catches by the capture probability.

For all catch data combined (years and sites), SR varied among years and averaged about 7 (Magpie) and 8 (Batchawana) (Figure 13). In the Magpie, proportional biomass was highest for Brook Trout, White Sucker, Longnose Dace, Burbot, Logperch and Slimy Sculpin (Figure 13), but many other species contributed to biomass. Similarly, relatively higher biomass species in the Batchawana were for Brook Lamprey, Brook Trout, Lake Chub, Blacknose Dace, Longnose Dace, Creek Chub, Trout Perch , Mottled Sculpin and Slimy Sculpin. Brook Trout were found in both rivers, but they comprised < 5% of the fish biomass. Biomass density was slightly but significantly higher ($P < 0.01$) where SR was higher at the survey sites in both rivers.

Linear regression results indicated there was no significant trend in biomass density with survey area for the Batchawana River, but there was a significant increase in fish density and body size with survey area in the Magpie River. However, the relationship was weak. There was no significant relationship between fish density and fish weight among survey sites in either river, but this may be a reflection of excluding non-wadeable portions of the rivers. Excluding non-wadeable habitats likely also affected the average size of the fishes captured (larger fishes excluded).

A linear model of catch in numbers and biomass was: $\ln$ (biomass) = 0.0346 + 1.068 $\ln$ (catch) ($P < 0.001$).

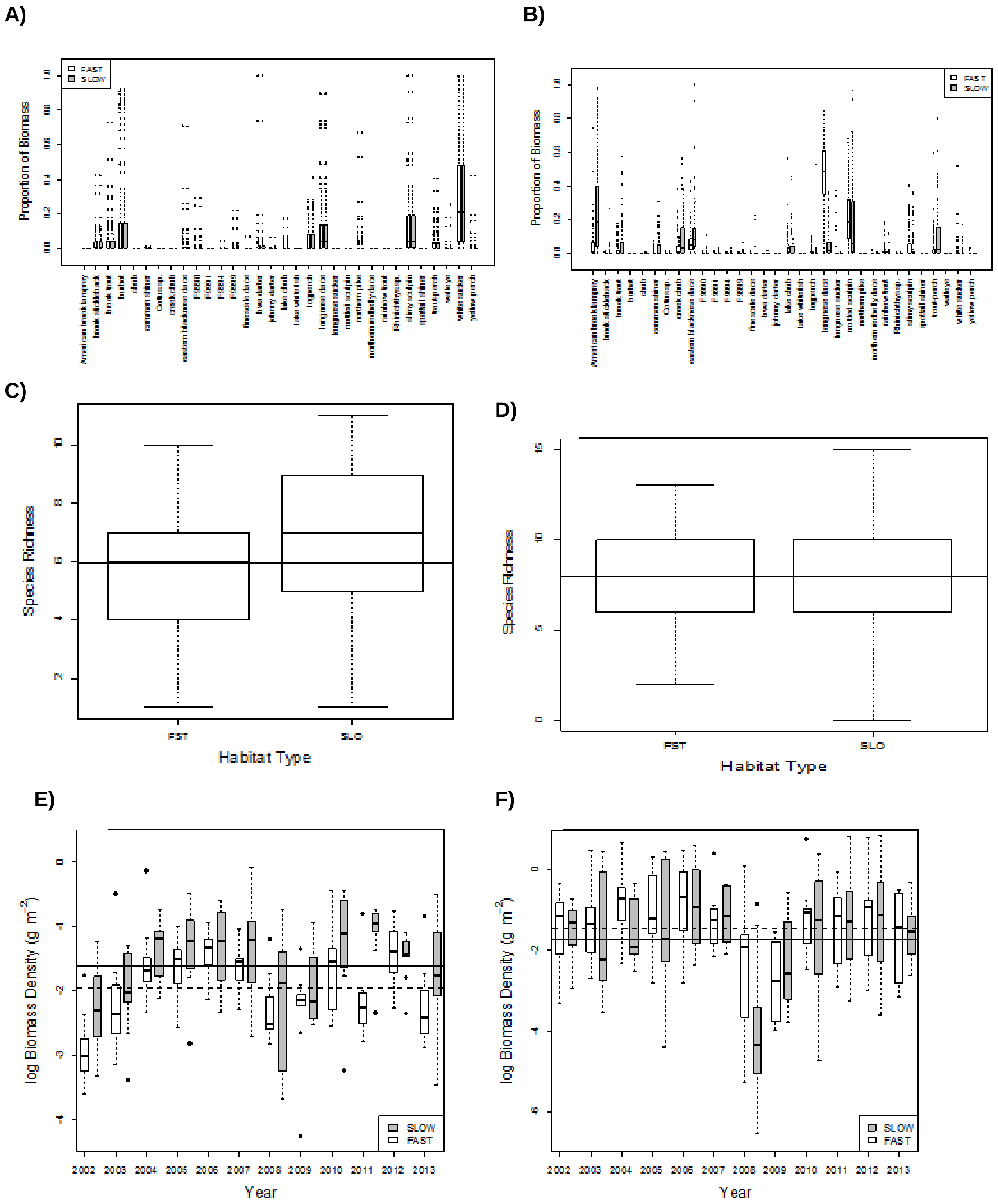

Figure 13. Magpie/Batchawana benchmark data (Region FZ 10): A) Proportion of biomass by species in the Magpie; B) Proportion of biomass by species in the Batchewana; C) Magpie species richness; D) Batchewana species richness; E) Biomass density by year in the Magpie; F) Biomass density by year in the Batchawana. Log values are base e.

Average biomass density varied among years in both rivers, and was on average higher at the Magpie sites (Figureure13). Overall unadjusted mean biomass density at the Magpie was 0.21 g m^{-2} (CL 0.17–0.25), and at Batchawana was 0.17 g m^{-2} (0.15–0.18). Assuming an electrofishing catch efficiency of 0.2, the adjusted density estimates were 1.05 (Magpie) and 0.85 g m^{-2} (Batchawana).

Fish biomass density at Batchawana River was assumed to be at ecosystem capacity but the catch rate for electrofishing was uncertain. Biomass density in Magpie River was affected by flow regime regulation for hydropower (but was similar to Batchawana) and catch rates were uncertain.

Athabasca River - Alberta

Data on biomass density from the Athabasca River were available from 29 sites (de Kerckhove, pers. comm.). These data were collected by non-government agency as part of the environmental assessment of the oil sands development in northeast Alberta. Details of survey areas, survey methods and fish species captured are available if needed. Average (GM) fish biomass was 0.45 g m^{-2} (CL: 0.24–0.85). The ecosystem capacity of the habitat was unknown.

Coastal and interior rivers – British Columbia

Data on biomass density from the interior and coastal rivers in British Columbia were compiled from 48 and 70 sites, respectively (M. Bradford, pers. comm.), mainly drawn from BC Ministry of Environment EcoCat library. These data were collected primarily by provincial agencies (see for example, Ptolemy 1993) to assess the status of salmon and trout populations. Quantitative data on Salmonidae biomass density were collected by backpack electrofishing and the removal method although in some cases single-pass surveys were conducted and an assumed capture probability was used to generate density estimates. Information on non-salmonid species were inconsistently reported and were not included here. Details of survey areas, survey methods and fish species captured are available from individual reports. Average (GM) biomasses were 1.14 (CL: 0.74–1.76) and 1.42 (CL: 1.12–1.80) g m^{-2} for coastal and interior rivers, respectively. The status of the salmonid populations relative to carrying capacity at the time of survey was unknown although many studies were conducted in the 1980s when salmon populations were relatively productive.

Comparison of Average Biomass Densities Among Regions

Generally results of OLS and mixed model regressions were similar, for both the density versus survey area, and the density-body weight regressions, although there were a few exceptions. When mixed regression models were used, estimates of biomass density or fish density-body size regression coefficients were similar. For consistency, only results for OLS regressions are presented in this report.

Geographically, the regional data sets, summarized above, ranged east to west from Stoney River, NL to coastal BC, and north to south from Athabasca River AB to the Toronto region (ON). For all fish communities surveyed, biomass density ranged from 0.5 (Athabasca) to 21.9 (Toronto) g m^{-2} (Table 1; Figure 14). For fish communities known or assumed to be at or near capacity (previous sections), biomass density was significantly different among regions (ANOVA $F_{6,2420} = 92.9$; P<0.001), ranging from 2.5 g m^{-2} to 21.9 g m^{-2} (Table 4). Average SR at sites ranged among all regions from 1.8 to 10.1 species (Table 1).

Table 4. Comparison of region means of community biomass (log g m^{-2}), HPI (ln g m^{-2} y^{-1}) and salmonid species biomass (ln g m^{-2}) using Tukey-Kramer HSD test. Regions not connected by same letter are significantly different

Region	**Tukey-Kramer HSD test**				**Community Biomass**
Toronto	A				3.09
Ganaraska		B			2.11
Margaree		B			1.92
Miramichi			C		1.32
Gulf NS			C	D	1.21
Restigouche				D	0.96
Terra Nova				D	0.93

Region	**Tukey-Kramer HSD test**					**HPI**
Toronto	A					3.35
Margaree		B				2.35
Ganaraska		B				2.19
Miramichi			C			1.87
Gulf NS			C	D		1.73
Restigouche				D		1.56
Terra Nova					E	1.11

Region	**Tukey-Kramer HSD test**			**Salmonid Biomass**
Margaree	A			1.70
Miramichi		B		1.09
GulfNovaScotia		B		1.09
TerraNova			C	0.52
Restigouche			C	0.45
Ganaraska		B	C	0.45

For the same subset of data, HPI also differed among these regions (ANOVA $F_{6,2420}$ = 73.2; $P < 0.001$). HPI ranged between 3.0 to 28.4.0 g m^{-2} y^{-1}. Results of Tukey-Kramer HSD showed significant group differences in community fish densities and HPI (Table 4).

Several of the regional datasets were dominated in terms of proportional biomass (> 50%) by salmonid species. Salmonid species biomass densities varied significantly among the subset of regions ($F_{5,2360}$ = 72.8.0, $P< 0.001$), ranging from 1.6 (Ganaraska) to 5.5 g m^{-2} (Margaree). Results of Tukey-Kramer HSD showed significant group differences in salmonid densities (Table 4).

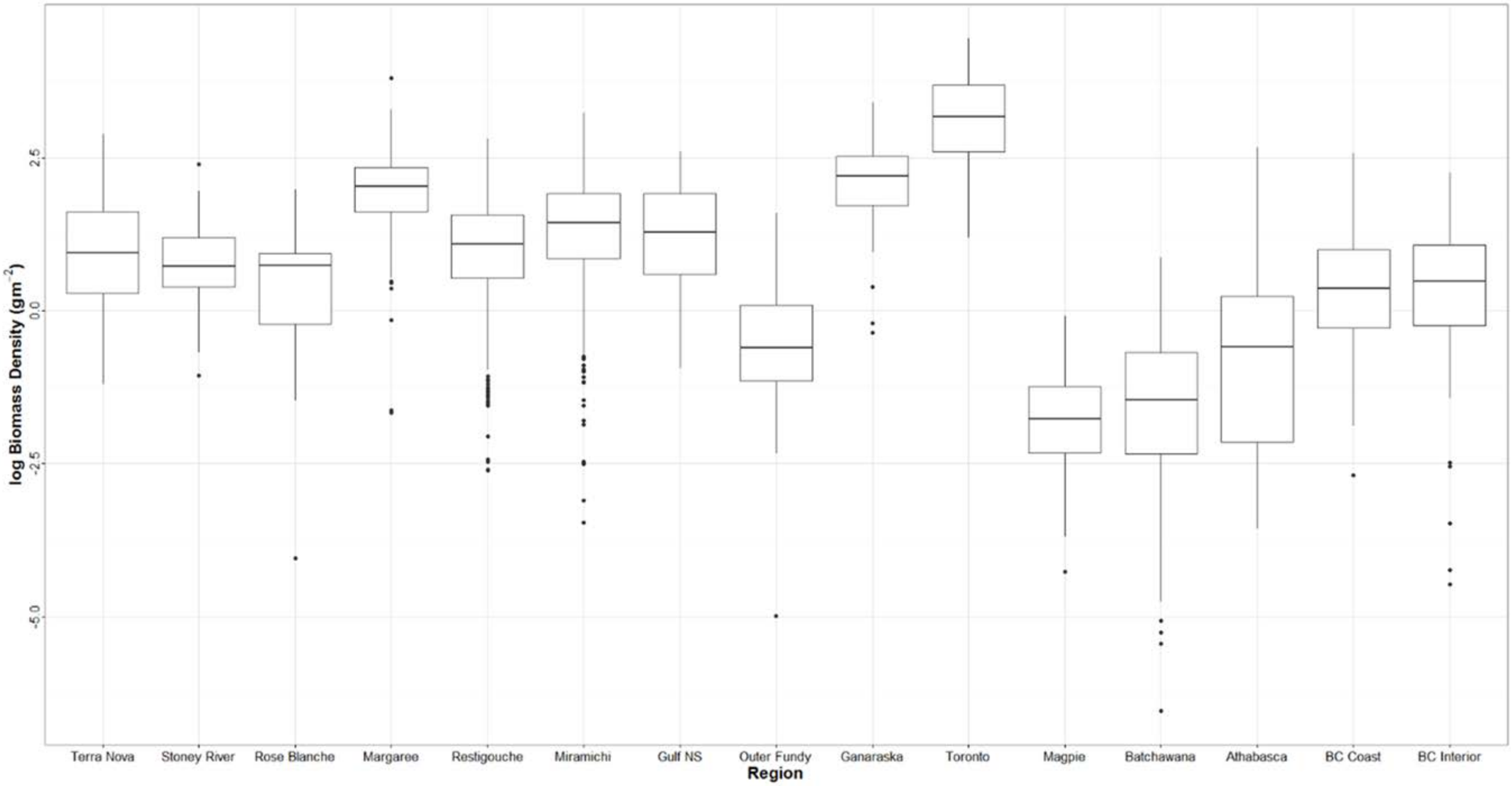

Figure 14. Comparison of average biomass (g m^{-2}) and HPI (g m^{-2} y^{-1}) among regions for the fish community. The BC data are for salmonids only, but these comprise the dominant biomass.

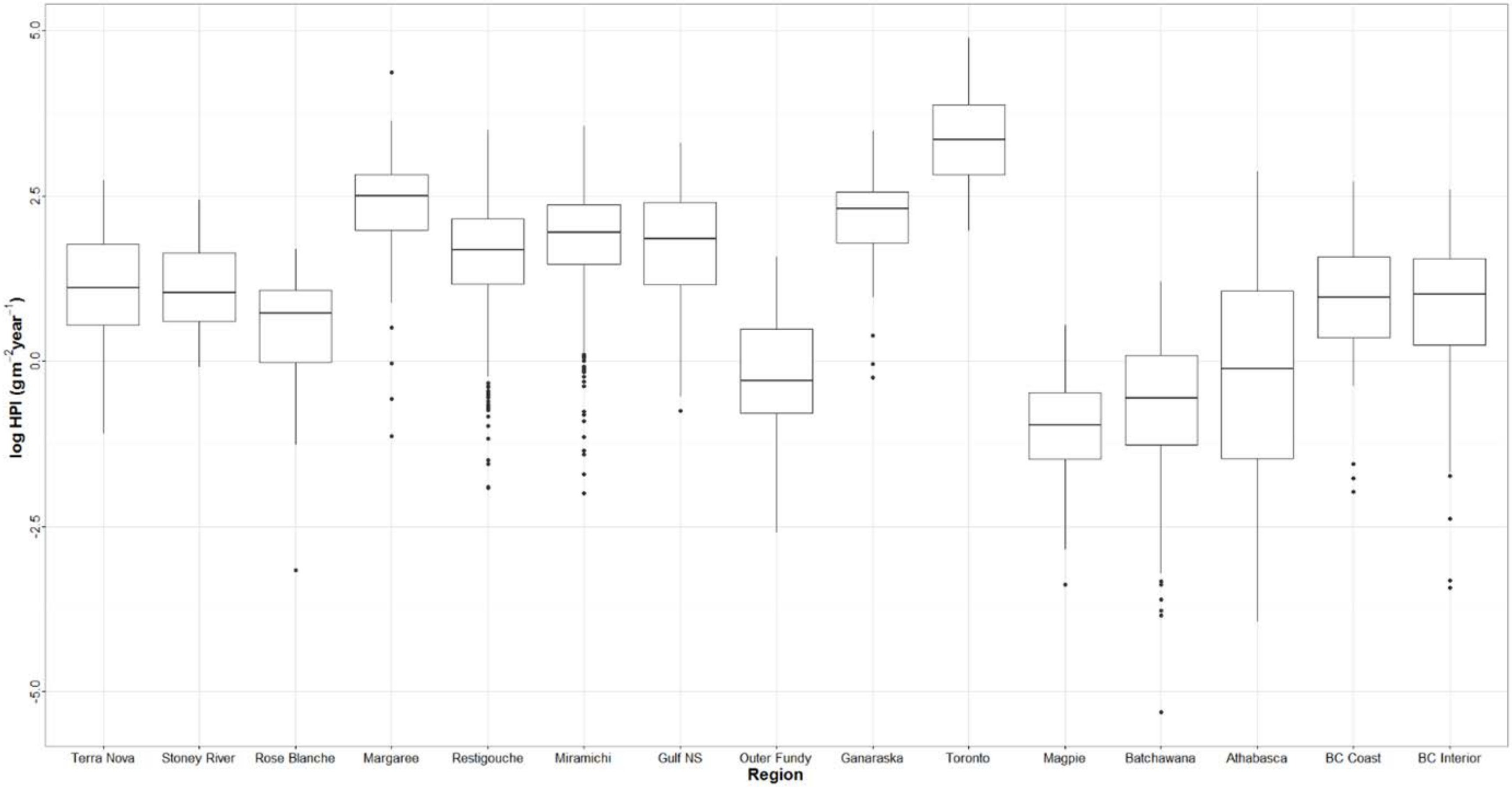

Figure 14 Continued. Comparison of average biomass (g m^{-2}; previous page) and HPI (g m^{-2} y^{-1}) among regions for the fish community. The BC data are for salmonids only, but these comprise the dominant biomass.

SUMMARY OF DENSITY BODY SIZE RELATIONSHIPS

Average community fish weight for the region data sets ranged from 1.26 (Batchawana) to 12.3 g (Rose Blanche) (Figure 15a). Average weight of salmonid fishes ranged between 3.05 g (Stoney) and 18.2 g (Ganaraska and Rose Blanche) (Figure 15b). For Atlantic Salmon, 3 of 17 regressions of body size-density regressions were not significant. For the significant regressions, the average slope was -0.72 which was not different from -0.75 but was significantly different from -0.90 (n = 14; Table 5). Variance in the regressions was high, and many of the individual regressions were weak (most coefficients of determination were < 50%). Results for fish community regressions were weaker: nine of the seventeen community regressions (53%) were not significant (Table 5) and R^2 was often low. Average slope for the community data was -0.75, but not different from -0.9 (n = 8).

Despite the variable and somewhat inconsistent slopes for the individual region and sub-region data, the correlation between region biomass densities summarized above and biomass density of fish for a standard body weight of 10 g was significant ($F_{1,12} = 22.0$, $R^2 = 0.65$; $P<0.01$, n = 14: Figure 16), with a slope close to unity (0.98). Among region differences in biomass density estimated using the two approaches (mean biomass density for the region and biomass density estimated from body size-biomass regression for a 10 g fish) were similar.

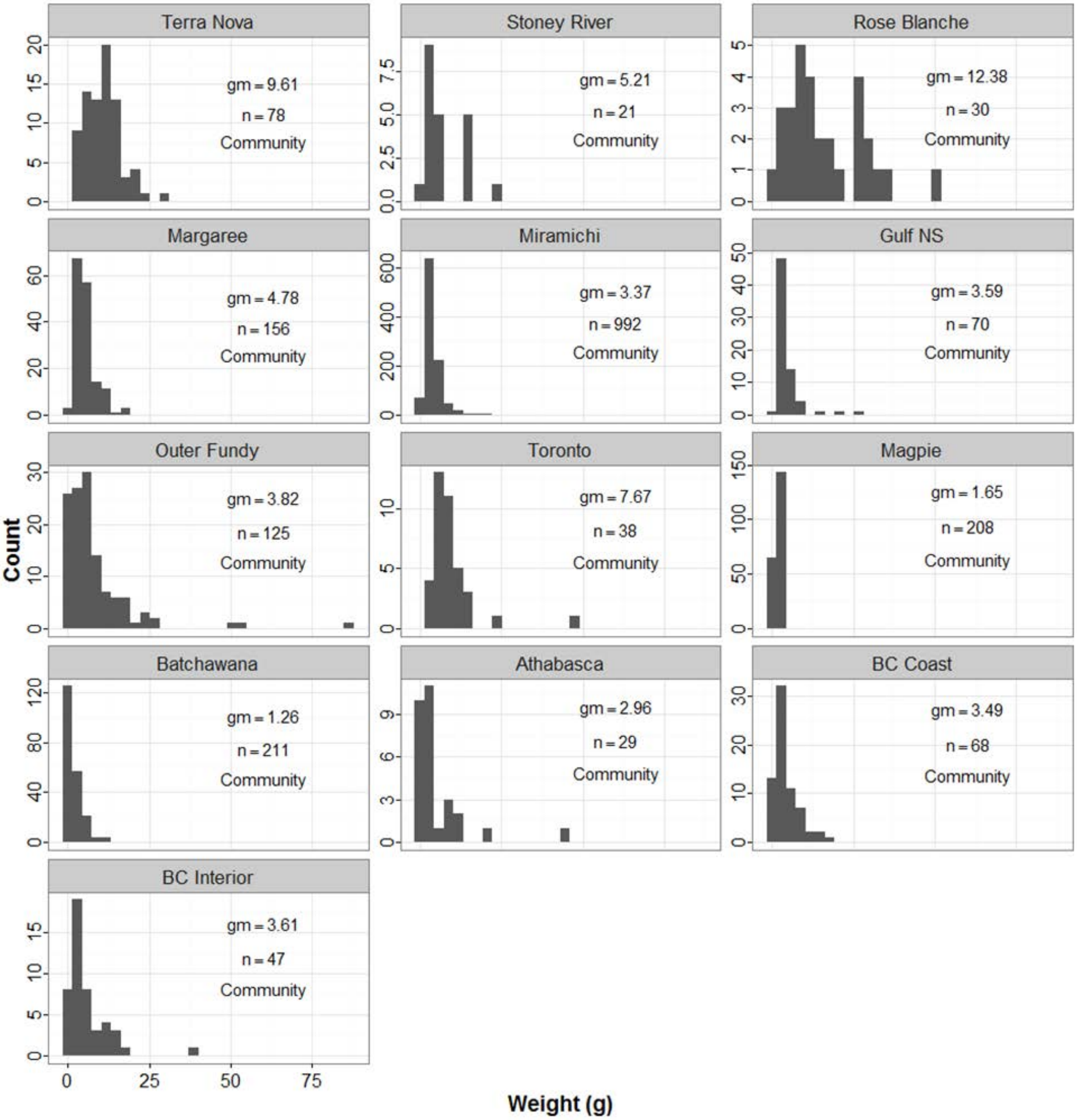

Figure 15a. Frequency distribution of community body-size data (weight, g). Weight was calculated as total site biomass divided by catch in number. n is the total number of sites and gm is geometric mean weight. Restigouche and Ganaraska data sets were excluded because only salmonids were measured for some of the sites. British Columbia data are the sum of all salmonid species present; relatively few non-salmonid fish are present in the samples.

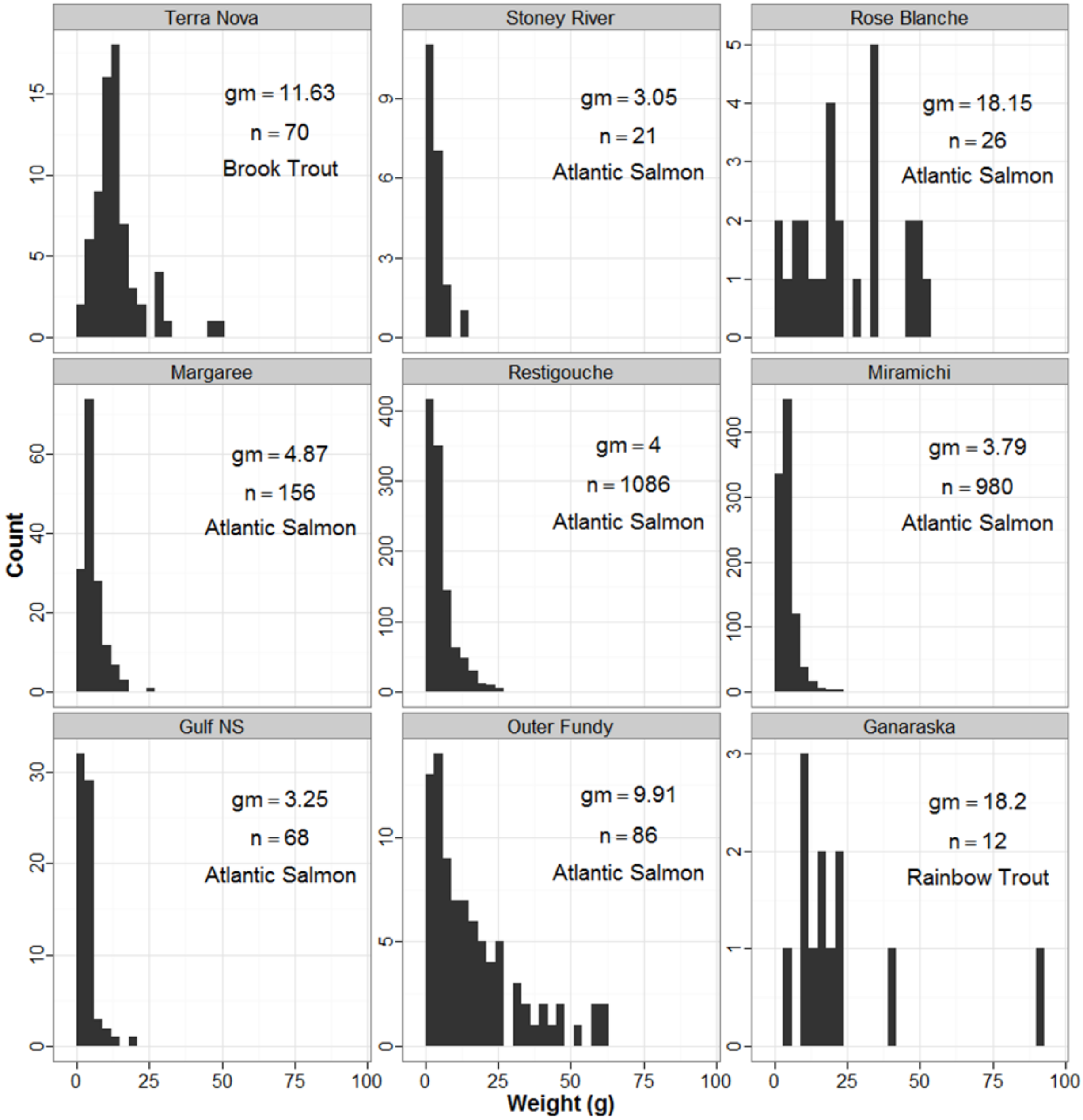

Figure 15b. Frequency distributions of salmon and trout body-size data (weight, g) from the regions. Species are identified for each region data set. Weight was calculated as site biomass for each species divided by catch in number. n is the total number of sites and gm is geometric mean weight.

Table 5. Summary of the density-body size slopes for the regions.

Region	**Subregion**	**Dominant species or community**	**Slope**	**N**	**R^2**	**P**
Terra Nova		Brook Trout	-0.39	70	0.06	< 0.05
		Community	-0.47	78	0.08	< 0.05
Stoney River		Atlantic Salmon	-0.34	21		NS
		Community	-0.35	21		NS
Rose Blanche		Atlantic Salmon	-0.06	26		NS
		Community	-0.06	30		NS
Restigouche	Kedgwick	Atlantic Salmon	-0.82	240	0.27	< 0.01
	Little Main	Atlantic Salmon	-0.66	154	0.22	< 0.01
	Main	Atlantic Salmon	-0.70	214	0.23	< 0.01
	Upsalquitch	Atlantic Salmon	-0.66	268	0.20	< 0.01
	Matapedia	Atlantic Salmon	-0.57	138	0.15	< 0.01
	Patapedia	Atlantic Salmon	-0.88	66	0.35	< 0.01
Miramichi	NW	Atlantic Salmon	-0.41	324	0.14	< 0.01
		Community	-0.02	331		NS
	LSW	Atlantic Salmon	-0.53	124	0.14	< 0.01
		Community	-0.12	125		NS
	Renous	Atlantic Salmon	-0.44	147	0.19	<0.01
		Community	-0.27	147	0.09	<0.01
	SW	Atlantic Salmon	-0.37	385	0.07	<0.01
		Community	-0.03	389		NS
	Catamaran	Atlantic Salmon	-0.82	23	0.47	<0.01
Gulf NS	Margaree	Atlantic Salmon	-1.02	156	0.36	< 0.01
		Community	-0.84	156	0.30	< 0.01
	West River	Atlantic Salmon	-0.93	23	0.26	0.013
		Community	-0.94	23	0.24	0.017
	East River	Atlantic Salmon	-1.28	20	0.50	< 0.01
		Community	-1.01	21	0.53	< 0.01
	River Philip	Atlantic Salmon	-0.59	55		NS
		Community	-1.22	26	0.28	< 0.01
Saint John		Community	-0.74	91	0.45	< 0.01
Toronto		Community	-0.52	38	0.18	< 0.01
Ganaraska		Rainbow Trout	-1.12	12		0.012
Magpie		Community (fast)	-0.16	107		NS
		Community (slow)	-0.11	100		NS
Batchawana		Community (fast)	-0.16	107		NS
		Community (slow)	-0.11	105		NS

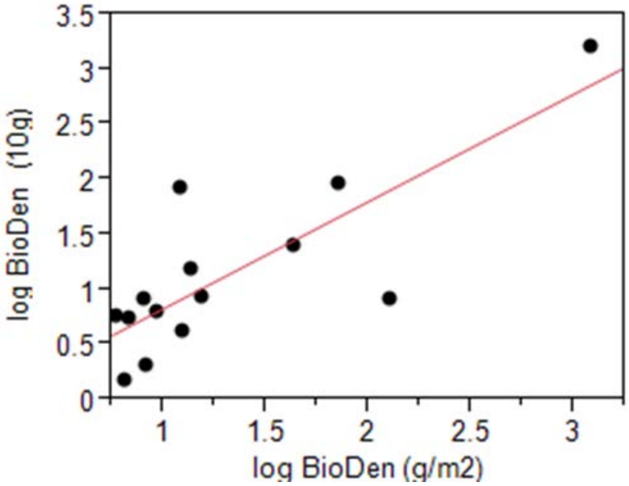

Figure 16. Correlation between biomass density (log g m^{-2}) and the biomass density of fishes with a body weight of 10 g, as estimated from the significant body size-density regressions for the fish community data (Table 1).

Metabolic Theory and Temperature

Using the Environment Canada climate data, there was a strong correlation between the long term average air temperature (1981–2010) and the average temperature during the survey period where available (Table 1; $F_{1,12} = 318.2$; $R^2 = 0.96$, $P<0.001$; n = 14). Because the results were similar, only the long term averages (available for all locations) were used below to compare regional average fish biomass with temperature.

There was a positive and significant relationship between mean annual air temperature (°C) and both the region average community biomass density (g m^{-2}; $F_{1,16} = 19.6$ $R^2 = 0.57$, $P < 0.001$; n = 17) and the average biomass density of individual Salmonidae species (g m^{-2}; $F_{1,15} = 10.3$; $R^2 = 0.42$, $P < 0.01$; n = 16) (Figure 17). Linear regressions were significant in both cases, but the relationships were not necessarily linear. The Salmonidae data were also shown with a quadratic regression plot, to show the possibility of reduced biomass at high temperatures (however the quadratic coefficient was not significant (P = 0.43)). Power and Power (1994) modelled the dynamics of Atlantic Salmon smolt production and showed that production was not linear across a north-south gradient in eastern Canada.

There was also a positive relationship between SR and community biomass ($F_{1,15} = 34.6$; $R^2 = 0.70$; $P<0.001$; n = 17), although the two Toronto vicinity data sets (Toronto and Ganaraska) were outlying influential data points in this relationship, both with relatively high biomass and SR. Both SR and temperature together were significant predictors ($P < 0.05$) of community biomass in a multiple regression ($F_{2,14} = 29.3$; $R^2 = 0.78$; n = 17).

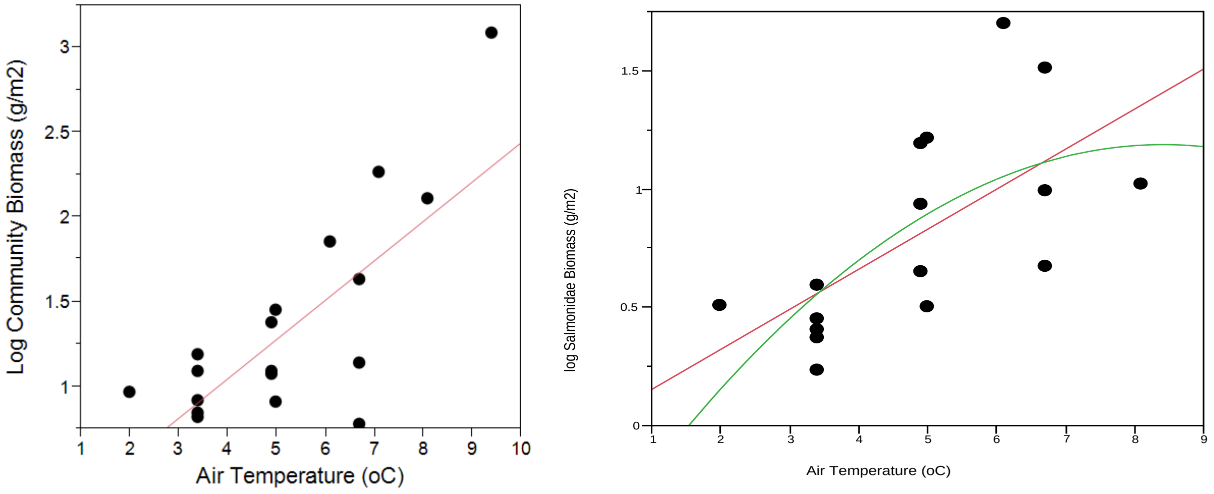

Figure 17. Relationship between mean annual air temperature (^{o}C) and average community biomass density (g m^{-2}; left) and average biomass density of individual salmonid species (g m^{-2}; right). Plot points are averages for regions (and tributaries within regions). Air temperature was from the closest city to the regional river data (Canadian Climate Normals) (Table 1).

PROOF OF CONCEPT

Differences in productivity, evident from the backpack electrofishing data, were proof of concept that region-dependent benchmarks were measurable. The potential application of benchmark data to assess reference condition for offsetting projects (Fisheries Protection Program) is discussed below.

DISCUSSION

Existing electrofishing survey data from streams and rivers, aggregated in this study by fishery management areas and zones, can be used to determine regional benchmarks of fish productivity. Limitations to this approach are that the amount and type of data available to determine benchmarks varies regionally. Also, and more importantly, the status of migratory populations (which often contribute significantly to biomass), habitat capacity and catch probability are often not known as discussed below. Despite these limitations and uncertainties, average biomass density of fishes was shown to be different but predictable among regions.

The feasibility of using existing data for determining regional benchmarks within the spatial context of fishery management areas was a primary outcome of this study. Fishery management areas were used as regional boundaries for this study, but other spatial units smaller or larger than fishery management areas could be used for aggregating the electrofishing data as well.

For the regions where fish populations were near or at capacity, the average biomass density varied among the regions from about 3 to 22 g m^{-2}. These low and high values were roughly similar to published estimates of community fish production rate from these areas in the science literature (Table 6). Production estimates were low from insular Newfoundland, where water fertility and SR are low (Clarke and Scruton 1999). Fish biomass in the lakes of Newfoundland, dominated by Atlantic Salmon and Brook Trout, were also relatively low (Coté et al. 2011). In contrast, fish production in the warm fluvial waters of southern Ontario was high, averaging 29 g m^{-2} y^{-1} (Mahon and Balon 1985), which was similar to the electrofishing HPI estimate from the Toronto region in this study. Biomass density and HPI from Ganaraska River and vicinity were less but still relatively high. Biomass and production at River Philip in Nova Scotia, both in the literature and as estimated in this study, were intermediate between these extremes. This comparison showed that the values of fish biomass and inferred production from the empirical electrofishing data and published values were roughly similar and reasonable.

Table 6. Comparison of biomass (g m^{-2}) and production (g m^{-2} y^{-1}) from this study with production estimates from the literature

Rivers	This study		Rivers	Literature		
	Biomass	**Production (HPI)**		**Biomass**	**Production**	**Reference**
Terra Nova[1]	2.5	3.0	TerraNova[1]	2.9	3.1	Coté 2007[1]
Rose Blanche	1.4	1.5	Copper	1.1–9.4	1.0-6.5	Clarke and Scruton 1999
River Philip	5.1	8.7	River Philip	3.6	5.3	Randall et al.1989a;1995
Toronto	21.9	28.4	S Ontario	20.2	28.5	Mahon and Balon 1985
Ganaraska	8.2	8.9				

[1] same data from Terra Nova were used for both studies (29 sites), but additional sites and years of survey were added for this report (total 88); results are compared to show consistency between the studies.

The biomass density estimates were for fluvial habitat which was surveyed in summer during the growing season for fishes, when water discharge was low and conducive for backpack electrofishing. Each of the cohabiting fishes at the time of survey was using the freshwater habitat for feeding and growth during part of their life history. Importantly, the fluvial habitat was also used seasonally by non-resident fishes for functions other than feeding, such as for migration and reproduction. For Atlantic coast rivers, the habitat is occupied by numerous diadromous species of fishes that use the freshwater habitat for reproduction as well as for early growth. For example, in the Miramichi River, New Brunswick, in addition to juvenile Atlantic Salmon, the migratory species included Gaspereau, Atlantic Tomcod, American Shad, American Eel, and Rainbow Smelt, all of which are harvested. For these species, the majority of fisheries landings are comprised of biomass that is produced in the marine environment (Randall et al. 1989b). Total fisheries yield as a metric of productivity for these rivers is an order of magnitude higher than the relatively low freshwater fluvial biomass and production. For the Miramichi, the fluvial freshwater production per se was estimated to be 4 to 6 g m^{-2} y^{-1}, whereas the total annual yield (expressed per unit area of fluvial habitat) was 55 g m^{-2} y^{-1}, more than 10 times higher (Randall et al. 1989b). Annual landings from fisheries as a metric of productivity would more accurately reflect the total biological and economic value of the freshwater habitat than *in situ* freshwater production by itself. Therefore, there are two productivity metrics that apply to rivers inhabited by diadromous fishes:

1. true freshwater production, the fish biomass derived from freshwater ecosystem resources (food and shelter) during periods of freshwater residency and
2. marine production, the adult fish biomass derived from estuarine and marine ecosystem resources by diadromous species during the sea portion of their life cycle.

The benchmark in this paper applies to the former but not the latter productivity metric. In the context of regional benchmarks, the possible inclusion of marine productivity metrics for diadromous fishes has not yet been addressed.

Biomass density at the regional level was estimated using two approaches: survey area-density and density - body size relationships. Both approaches are based to a large extent on the same data (biomass density and body size), but in the second approach density was standardized for a constant body size (weight). Density-body size relationships would be useful for adjusting the benchmarks for fish size if needed. The observation that the trend in biomass density among regions was similar for both approaches was encouraging and consistent, and suggested that either method could be used to estimate regional productivity. Overall, however, the density-body size relationships had low precision, particularly the relationships which were based on the fish community data. Brown et al. (2004) noted that density-body size relationships applied mainly to the same trophic group. In most cases, the electrofishing data covered multiple trophic groups and species, which probably explains in part the high variability in the density-body size regressions. The relatively low range in average fish size among samples/within regions in some cases possibly makes establishing these relations more difficult, and emphasizes the importance of surveying all habitats Relationships between abundance and body size in ecology also depend on the methods of scaling the data (cross-community, individual size distribution and others; White et al. 2007). With a few exceptions, our preliminary results indicated the OLS and mixed regression models gave similar results, but the mixed models warrant further study in the longer term for their possible use with these empirical field data. In the meantime it was not possible to derive reliable region-specific body size-density relationships from this pilot study, but the results were consistent in showing that a generalized relationship from the literature could be used to scale biomass density with fish body weight.

Absolute measures of fish biomass (g m^{-2}) are a fundamental standard metric for comparing regional differences in fish productivity. The Metabolic Theory of Ecology (MTE) hypothesizes that biomass density is a function of body size and ambient temperature, and links the biology of individuals to the ecology of populations, communities and ecosystems (Brown et al. 2004). Details of the ecology and physics of MTE from individuals to assemblages are beyond the scope of this study. However, the basic premise in this study is that allometric patterns and metrics of MTE have relevance to measures of regional productivity. The basic premise is that metabolic rate varies with body size and temperature, and sets the rate of resource uptake from the environment. Key metrics of MTE are biomass density, body size and ambient water temperature. Results from this study showing the correspondence between region-dependent biomass (community and species), body size and ambient temperature are fundamental and consistent with MTE. The density-body size relationships of fishes captured by electrofishing, although course, are also consistent with MTE. If these relationships hold when more data are incorporated, MTE is relevant and can be used to predict fish biomass density where existing data are limited or absent.

Several limitations and uncertainties in the data were evident, but the value of exploring the combined database, across all regions, was evident. The datasets varied in scope from snapshots of field observations, limited temporally (1 to < 5 yrs) and spatially (Terra Nova, Ganaraska), to larger datasets that covered several years and were spatially more extensive (Margaree, Miramichi). Data are unavailable or limited for some sub-areas within Fishing Areas or Zones, and science-based methods for interpolation and extrapolation from data-rich to data-poor areas will be needed if benchmarks are used as guides. Long time series such as those available for Atlantic Salmon allowed for estimation of carrying capacity by fishery science, while for short data sets there is greater uncertainty in terms of population status and ecosystem capacity. For sites where biomass is dominated with an exploited species or where resource limitations are unknown, uncertainty of carrying capacity, the upper threshold of the productivity-state framework (described by Rice et al. 2015), is a constraint for using electrofishing data to measure regional productivity. Another limitation or constraint yet to be addressed was that existing data were collected with an objective unrelated to regional productivity. Survey designs were biased for habitats of targeted species and often did not randomly sample all habitats. Examples of this were the directed surveys for Atlantic Salmon (Breau 2013) and the Toronto data which targeted Endangered Redside Dace (Reid et. al. 2008a). Surveys based on back-pack electrofishing excluded deep water habitats.

The basis for using existing Salmon Fishing Areas or Fishing Zones to demarcate boundaries of 'regional' productivity for aggregating the electrofishing data was based to some extent on pragmatic rather than ecological reasoning. Historically electrofishing data were often collected within a SFA spatial context (O'Connell et al. 1997); each SFA was associated with an estimate of total fluvial habitat (m^2) and the conservation target for that region (spawning requirements expressed as the number of eggs needed to fully seed the fluvial habitat). Historically, a monitoring strategy within SFAs was employed using salmon counting fences at index rivers to the extent that was feasible (Chadwick 1985). Although the boundaries were jurisdictional (DFO and Provincial), fisheries managers recognized that the biological characteristics of salmon differed geographically with latitude and other factors and, importantly, salmon life-histories were often more similar within than among the Salmon Fishing Areas. More recent examination of Atlantic Salmon COSEWIC Designable Units (DU), based on morphology, meristic and spatial population structure, identified fewer spatial units (16) than the original DFO Salmon Fishing Areas (28) but the two designations shared many features. Both the SFAs and the DUs have an ecological basis. Historically much of the data on fishing landings have been collected and assembled on a Fishing Area or Fishing Zone geographic basis. Also, these areas are likely closely tied to the relevant Fisheries Management Objectives (section 6 of the *Fisheries Act*). Amendments to the FA and the science needed for implementation (Rice et al. 2015), encourages closer ties between fisheries and ecosystem science.

Together, a data base comprised of information from numerous locations and years was valuable, as evident in the regional summaries of average biomass density. The development of a national benchmark data base, comprising survey data from several regions provinces, and fishing areas or zones, is warranted and would be valuable. Much additional data are available from government or industries for rivers and lakes. If abundance was estimated on a relative (CPUE) rather than an absolute scale (g m^{-2}), knowledge or assumptions about fish capture probability is critical. In rivers much work has been done on capture probability which allows absolute estimates of abundance based on single-pass fish catches (Jones et al. 2004; Chaput et al. 2005; Reid et al. 2008b). A meta-analysis of this literature could be synthesized and would be useful to calibrate electrofishing CPUE data as well. Setting a reasonable (literature-based) range in capture probability (e.g., ≥ 0.1 but ≤ 0.3) could provide first order estimates of fish biomass density from electrofishing CPUE with approximate but known bounds.

In the science literature, the term 'reference condition' has a number of meanings and contexts (Stoddard et al. 2006), and is used to describe a standard or benchmark against which current conditions are compared. Reference condition often refers to naturalness of the biota, and implies the absence of significant human disturbance (Stoddard et al. 2006). As an example, water quality impairment was assessed by Reynoldson et al. (1997) using benthic macro-invertebrates (composition and density) as metrics. Reynoldson defined 'reference' condition as the condition represented by a group of 'minimally disturbed' sites as 'selected by physical, chemical and biological characteristics'. For this report, regional benchmark is used in a similar context as reference condition, with fish productivity being the key metric of interest. Although pristine conditions no longer exist in many areas, degree of naturalness or disturbance could be identified (relatively) by ranking areas from those less to more affected by human disturbance. Projects in-water or land-based can be assessed in the spatial context of the regional benchmark. Regional benchmarks can only broadly guide biological assessment of impacts and offsetting programs. Most significant projects would also have detailed and site-specific assessments and monitoring (Smokorowski et al. 2015). Regional benchmarks could be used by proponents and managers to complement the smaller but more detailed project-scale assessment. Regional benchmarks, potentially, not only provide a broad (region) scale framework for assessing productivity, but also provide a broad geographic scale to inform and provide opportunity within the regions for offsetting programs.

The electrofishing data from the different areas are ‘proof of concept’ that existing data can be used to quantitatively measure regional differences in productivity. Data from a specific region can be used to estimate ecosystem capacity in absolute units further refined and apportioned by habitat type if habitat suitability indices are known (Randall et. al. 2014). Productivity for a region where fish data are lacking could be estimated coarsely from the temperature-productivity relationships if validated in future. Predictive models may also be refined further by investigating cofactors (water nutrients, landscape) that are known in the science literature to be important. The establishment of a national database of empirical electrofishing data to inform and quantify regional productivity benchmarks would be useful.

Implications from this study are relevant to establishing Ecologically Significant Areas in freshwater ecosystems. The lessons learned are three-fold:

1. ESAs will likely focus on conserving the productivity of species, but in doing so they will benefit fish communities as well;
2. temperature regime is a fundamental driver of productivity in regions across Canada; and
3. an appropriate spatial scale is paramount: larger areas (whole tributaries) covering habitats that support all life history stages are likely to be more ecologically sound than smaller areas or habitats limited spatially and functionally.

In summary, fish productivity in rivers varied significantly among fish management areas, and was positively related to mean air temperature. Fish management areas or zones provided a pragmatic and reasonable geographic boundary for determining regional benchmarks in productivity. The efficacy of using fishing zone boundaries will likely be compared in future to ecologically-based approaches for determining boundaries elsewhere. Existing electrofishing data are potentially valuable for informing regional benchmarks of productivity: this study provides a ‘proof of concept’. Body size-density relationships both for species and particularly for communities were imprecise for the different regions, but the results were consistent in showing that density can be scaled with body size using allometric relationships from the literature. More research is needed to further investigate mixed models for the density-body size relationships from electrofishing data. The appropriate spatial units, taxonomic groups and methods for summarizing body size-density relationships also need to be investigated. The establishment of a national database of empirical electrofishing data to inform and quantify regional productivity benchmarks is warranted. In addition to quantitative surveys, relative CPUE electrofishing data are also potentially useful and provide increased opportunity of using existing data if adjustment for capture probability is feasible.

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REFERENCES CITED

Allen, A.P., Brown, J.H., and Gillooly, J.F. 2002. Global biodiversity, biochemical kinetics, and the energetic-equivalence rule. Science 297: 1545–1548.

Amiro, P.G. 1983. Aerial photographic measurement of Atlantic Salmon habitat of the Miramichi River, N.B. Can. Atl. Fish. Sci. Adv. Com. Res.Doc. 83/74.

Bradford, M.J., Taylor, G.C., and Allan, J.A. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Amer. Fish. Soc. 126: 49–64.

Breau, C. 2013. Status of Atlantic Salmon (*Salmo salar* L.) stocks in rivers of Nova Scotia flowing into the Gulf of St. Lawrence (SFA 18). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/147. v + 54 p.

Breau, C., Chaput, G., LeBlanc, P.H., and Mallet, P. 2009. Information on Atlantic Salmon (*Salmo salar*) from Salmon Fishing Area 18 (Gulf Nova Scotia) of relevance to the development of a COSEWIC status report. Can. Sci. Advis. Sec. Res. Doc. 2009/076. iv + 53 p.

Breau, C., Chaput, G., and LeBlanc, P. 2010. The migration of Atlantic Salmon (*Salmo salar*) smolts from the Margaree River, Nova Scotia, 2004-2009. Can. Tech. Rept. Fish. Aquat. Sci. 2899. iv + 59 p.

Boudeau, P.R. and Dickie, L.M. 1992. Biomass spectra of aquatic ecosystems in relation to fisheries yield. Can. J. Fish. Aquat. Sci. 49: 1528–1538.

Brown, J.K, and West, G. 2004. One rate to rule them all. New Scientist, 1 May 2004: 38–41.

Brown, J.H., Gillooly, J.F., Allen, A.P., Savage, V.M., and West, G.B. 2004. Toward a metabolic theory of ecology. Ecology. 85: 1771–1789.

Chadwick, E.M.P. 1985. Fundamental research problems in the management of Atlantic Salmon, Salmo salar L., in Atlantic Canada. J. Fish. Biol. 27 (Suppl. A): 9–25.

Chaput, G., Moore, D. and Peterson, D. 2005. Predicting Atlantic salmon (*Salmo salar*) juvenile densities using catch per unit effort open site electrofishing. Can. Tech. Rep. Fish. Aquat. Sci. No. 2600. v + 25 p.

Chaput, G., Moore, D., Hardie, P., and Mallet, P. 2010. Information on Atlantic Salmon (*Salmo salar*) from Salmon Fishing Area 16 (Gulf New Brunswick) of relevance to the development of a COSEWIC status report. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/064. iv + 50 p.

Clarke, C.N., Ratelle, S.M., and Jones, R.A. 2014. Assessment of the recovery potential for the outer Bay of Fundy population of Atlantic Salmon: threats to populations. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/006. v + 103 p.

Clarke, K.D., and Scruton, D.A. 1999. Brook Trout production dynamics in the streams of a low fertility Newfoundland watershed. Tran. Amer. Fish. Soc. 128: 1222–1229.

COSEWIC. 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 p.

Coté, D. 2007. Measurements of salmonid population performance in relation to habitat in eastern Newfoundland streams. J. Fish Biol. 70: 1134–1147.

Coté, D., Adams, B.K., Clarke, K.D., and Langdon, M. 2011. Salmonid biomass and habitat relationships for small lakes. Environ. Biol. Fish. 92: 351–360.

Cunjak, R.A., Caissie, D., El-Jabi, N., Hardie, P., Conlon, J.H., Pollock, T.L., Giberson, D.J., and Komadina-Douthwright, S. 1993. The Catamaran Brook (New Brunswick) Habitat Research Project: biological, physical and chemical conditions (1990–92). Can. Tech. Rep. Fish. Aquat. Sci. 1914.

DFO. 2012. Stock status of Atlantic Salmon (*Salmo salar*) in DFO Gulf Region (Salmon Fishing Areas 15 to 18). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/040.

DFO. 2014. Assessment of freshwater Ecologically and Biologically Significant Areas (EBSA) and Ecologically Significant Species (ESS) criteria. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/025.

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

DFO. 2016. Proceedings of the national peer review of Science Advice on Regional Productivity Benchmarks; September 29 to October 1, 2015. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2016/037.

Douglas, S.G., Chaput, G., Hayward, J., and Shesgreen, J. 2013. Assessment of Atlantic Salmon (*Salmo salar*) in Salmon Fishing Area 16 of the southern Gulf of St. Lawrence. Canadian Science Advisory Secretariat Research Document 2012/104. v + 63 p.

Downing, J.A., and Plante, C. 1993. Production of fish populations in lakes. Can. J. Fish. Aquat. Sci. 50: 110–120.

Enders, E.C., Clarke, K.D., Pennell, C.J., Neil Ollerhead, L.M., and Scruton, D.A. 2007. Comparison of PIT and radio telemetry to evaluate winter habitat use and activity patterns of juvenile Atlantic Salmon and Brown Trout. Hydrobiologia 582: 231–242.

Gavaris, S. 2009. Fisheries management planning and support for strategic and tactical decisions in an ecosystem approach context. Fish. Res. 100: 6–14.

Gibson, A.J.F. 2006. Population regulation in eastern Atlantic Salmon (*Salmo salar*) populations. Can. Sci. Advis. Sec. Res. Doc. 2006/016. vi + 36 p.

Grant, J.W.A., and Kramer, D.L. 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. Can. J. Fish. Aquat. Sci. 47: 1724–1737.

Jones, M.L. and Stockwell, J.D. 1995. A rapid assessment procedure for the enumeration of salmonine populations in streams. N. Amer. J. Fish. Manage. 15: 551–562.

Jones, R.A., Anderson, L., and Goff, T. 2004. Assessments of Atlantic salmon stocks in southwest New Brunswick, an update to 2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/019. ii + 70 p.

Jones, R.A., Anderson, L., and Clarke, C.N. 2014. Assessment of the recovery potential for the outer Bay of Fundy population of Atlantic Salmon (*Salmo salar*): status, trends, distribution life history characteristics and recovery targets. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/008. vi + 94 p.

Jonsson,B., Jonsson, N., and Ugedal, O. 2011. Production of juvenile salmonids in small Norwegian streams is affected by agricultural land use. Freshw. Biol. 56: 2529–2542.

Keeley, E.R., and Grant, J.W.A. 1995. Allometric and environmental correlates of territory size in juvenile Atlantic Salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. 52: 186–196.

Kerr, S.R., and Dickie, L.M. 2001. The biomass spectrum: a predator-prey theory of aquatic production. Columbia University Press, New York. 320 p.

Kim, M., and Lapointe, M. 2011. Regional variability in Atlantic Salmon (*Salmo salar*) riverscapes: a simple landscape ecology model explaining the large variability in size of salmon runs across Gaspé watersheds, Canada. Ecol. Freshw. Fish 20: 144–156.

Mahon, R., and Balon, E.K. 1985. Fish production in warmwater streams in Poland and Ontario. Can. J. Fish. Aquat. Sci. 42: 1211–1215.

Marshall, T.L., Jones, R., and Pettigrew, T. 1997. Status of Atlantic Salmon stocks of southwest New Brunswick, 1996. DFO Can. Sci. Advis. Sec. Res. Doc. 97/27. 70 p.

McGarvey, D.J., Johnston, J.M., and Barber, M.C. 2010. Predicting fish densities in lotic systems: a simple modeling approach. J. N. Am. Benthol. Soc. 29: 1212–1227.

McGarvey, D.J., and Johnston, J.M. 2011. A simple method to predict regional fish abundance: an example in the McKenzie River Basin. Fisheries 36: 534–546.

Ontario Ministry of Natural Resources (OMNR). 2005. Lake Ontario fish communities and fisheries. 2004 Annual Report of the Lake Ontario Management Unit. Ontario Ministry of Natural Resources, Picton, Ontario.

O'Connell, M.F., Reddin, D.G., Amiro, P.G., Caron, F., Marshall, T.L., Chaput, G., Mullins, C.C., Locke, A., O'Neil, S. F, and Cairns, D.K. 1997. Estimates of conservation spawner requirements for Atlantic Salmon (*Salmo salar* L.) for Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 1997/100. 58 p.

Oxford University Press. 2015. Oxford Dictionary.

Peters, R.H. 1983. The ecological implications of body size. Cambridge University Press, New York: Cambridge University Press. 1983. xii + 329 p.

Poff, N.L., and Huryn, A.D. 1998. Multi-scale determinants of secondary production in Atlantic Salmon (*Salmo salar*) streams. Can. J. Fish. Aquat. Sci. 55, 201–217.

Power, M., and Power, G. 1994. Modeling the dynamics of smolt production in Atlantic Salmon. Trans. Am. Fish. Soc. 123: 535–548.

Ptolemy, R.A. 1993. Maximum salmonid densities in fluvial habitats in British Columbia. Pages 223-250 *In* Proceedings of the Coho Workshop, May 26–28. Edited by L. Berg and P.W. Delaney, Nanaimo, B.C. p. 223–250.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rago, P.L. 1984. Production forgone: an alternative method for assessing the consequences for fish entrainment and impingement losses at power plants and other water intakes. Ecol. Mod. 24: 79–111.

Randall, R.G. 1984. Number of salmon required for spawning in the Restigouche River, N.B. Can. Atl. Fish. Sci. Adv. Com. Res.Doc. 84/16.

Randall, R.G. 2015. Using habitat area-production relationships for assessing the productive capacity of fish habitat. *In* Managing the impacts of human activities on fish habitat: the governance, practices and science. Edited by N. Fisher, P. LeBlanc, C.A. Rose, and B. Sadler. American Fisheries Society, Symposium 78, Bethesda, Maryland. p. 189–212.

Randall, R.G., and Chadwick, E.M.P. 1986. Density as a factor affecting the production of juvenile Atlantic Salmon (*Salmo salar*) in the Miramichi and Restigouche Rivers, New Brunswick. Pol. Arch. Hydrobiol. 33: 391–409.

Randall, R.G., and Minns, C.K. 2000. Use of fish production per unit biomass ratios for measuring the productive capacity of fish habitat. Can. J. Fish. Aquat. Sci. 57: 1657–1667.

Randall, R.G., and Minns, C.K. 2002. Comparison of a Habitat Productivity Index (HPI) and an Index of Biotic Integrity (IBI) for measuring the productive capacity of nearshore areas of the Great Lakes. J. Great Lakes Res. 28: 240–255.

Randall, R.G., Claytor, R.R., Chadwick, E.M.P., and Mortensen, E. 1989a. Comparative production of *Salmo salar* (Atlantic Salmon) and *Salmo trutta* (Brown trout) in a small Nova Scotia stream. Proc. N.S. Inst. Sci. 39: 99–109.

Randall, R.G., O'Connell, M.F., and Chadwick, E.M.P. 1989b. Fish production in two large Atlantic coast rivers: Miramichi and Exploits. *In* Proceedings of the International Large River Symposium. Edited by D.P. Dodge. Can. Spec. Publ. Fish. Aquat. Sci. 106: 292-308.

Randall, R.G., Kelso, J.R.M., and Minns, C.K. 1995. Fish production in freshwaters: are rivers more productive than lakes? Can. J. Fish. Aquat. Sci. 52: 631–643.

Randall, R., Cunjak, R., Gibson, J., Reid, S., and Velez-Espino, A. 2014. Using electrofishing data to determine regional benchmarks of habitat productive capacity. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/095. iv + 13 p.

Reid, S.M., Jones, N.E., and Yunker, G. 2008a. Evaluation of single-pass electrofishing and rapid habitat assessment for monitoring Redside Dace. N. Amer. J. Fish. Manage. 28: 50–56.

Reid, S.M., Yunker, G., and Jones, N.E. 2008b. Evaluation of single-pass backpack electric fishing for stream fish community monitoring. Fish. Manage. Ecol. 16:1–9.

Reynoldson, T.B., Norris, R.H., Resh, V.H., Day, K.E., and Rosenberg, D.M. 1997. The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. J. N. Am. Benthol. Soc. 16:833–852.

Rice, J, Bradford, M.J., Clarke, K.D., Koops, M.A., Randall, R.G., and Wysocki, R. 2015. The science framework for implementing the Fisheries Protection Provisions of Canada's *Fisheries Act*. Fisheries 40(6): 268–275.

Robertson, M.J., Clarke, K.D., Scruton, D.A., and Brown, J.A. 2003. Interhabitat and instream movements of large Atlantic Salmon parr in a Newfoundland watershed in winter. J. Fish Biol. 63: 1208–1218.

SAS Institute Inc. 2012. JMP® 10 Basic Analysis and Graphing. Cary, NC: SAS Institute Inc.

Scruton, D.A., Clarke, K.D., Roberge, M.M., Kelly, J.F., and Dawe, M.B. 2005. A case study of habitat compensation of hydroelectric development: effectiveness of re-watering and habitat enhancement of an intermittent flood overflow channel. J. Fish Biol. 67 (Supplement B): 244–260.

Smokorowski, K.E., Metcalfe, R.A., Finucan, S.D., Jones, N., Marty, J., Power, M., Pyrce, R.S., and Steele, R. 2011. Ecosystem level assessment of environmentally-based flow restrictions for maintaining ecosystem integrity: a comparison of a modified peaking vs unaltered river. Ecohydrology. 4: 791–806.

Smokorowski, K.E., Bradford, M.J., Clarke, K.D., Clément, M., Gregory, R.S., and Randall, R.G. 2015. Assessing the effectiveness of habitat offset activities in Canada: Monitoring design and metrics. Can. Tech. Rep. Fish. Aquat. Sci. 3132: vi + 48 p.

Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K., and Norris, R.H. 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecological Applications 16: 1267–1276.

White, E.P., Ernest, S.K.M., Kerkhoff, A,J., and Enquist, B.J. 2007. Relationships between body size and abundance in ecology. Trends Ecol. Evol. 22: 323–330.

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Adam Van Der Lee	DFO	Analysis
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Doug Watkinson	DFO	Data

APPENDIX 2. COMMON AND LATIN NAMES

Common name	Latin name
Alewife or Gaspereau	*Alosa pseudoharengus*
American Eel	*Anguilla rostrata*
American Shad	*Alosa sapidissima*
Arctic Char	*Salvelinus alpinu*s
Atlantic Salmon	*Salmo salar*
Atlantic Tomcod	*Microgadus tomcod*
Blacknose Dace	*Rhinichthys atratulus*
Brook Lamprey	*Lampetra lamottei*
Brook Trout	*Salvelinus fontinalis*
Brown Trout	*Salmo trutta*
Burbot	*Lota lota*
Creek Chub	*Semotilus atromaculatus*
Gaspereau	see Alewife
Lake Chub	*Couesius plumbeus*
Logperch	*Percina caprodes*
Longnose Dace	*Rhinichthys cataractae*
Mottled Sculpin	*Cottus bairdi*
Ninespine Stickleback	*Pungitius pungitius*
Rainbow Smelt	*Osmerus mordax*
Rainbow Trout	*Oncorhynchus mykiss*
Redside Dace	*Clinostomus elongatus*
Sea Lamprey	*Petromyzon marinus*
Slimy Sculpin	*Cottus cognatus*
Threespine Stickleback	*Gasterosteus aculeatus*
Trout Perch	*Percopsis omiscomaycus*
White Sucker	*Catostomus commersoni*