DOI: 10.1007/s00267-004-0263-y

Effectiveness of Fish Habitat Compensation in Canada in Achieving No Net Loss

JASON T. QUIGLEY*
Oceans, Habitat and Enhancement Branch
Fisheries and Oceans Canada
Suite 200, 401 Burrard Street
Vancouver, BC, Canada, V6C 3S4

DAVID J. HARPER
Habitat Policy and Regulatory Affairs
Fisheries and Oceans Canada
Suite 12E, 200 Kent Street
Ottawa, ON, Canada, K1A 0E6

ABSTRACT / Fish habitat loss has been prevalent over the last century in Canada. To prevent further erosion of the resource base and ensure sustainable development, Fisheries and Oceans Canada enacted the habitat provisions of the *Fisheries Act* in 1976. In 1986, this was articulated by a policy that a "harmful alteration, disruption, or destruction to fish habitat" (HADD) cannot occur unless authorised with legally binding compensatory habitat to offset the HADD. Despite Canada's progressive conservation policies, the effectiveness of compensation habitat in replicating ecosystem function has never been tested on a national scale. The effectiveness of habitat compensation projects in achieving no net loss of habitat productivity (NNL) was evaluated at 16 sites across Canada. Periphyton biomass, invertebrate density, fish biomass, and riparian vegetation density were used as indicators of habitat productivity. Approximately 63% of projects resulted in net losses in habitat productivity. These projects were characterised by mean compensation ratios (area gain:area loss) of 0.7:1. Twenty-five percent of projects achieved NNL and 12% of projects achieved a net gain in habitat productivity. These projects were characterised by mean ratios of 1.1:1 and 4.8:1, respectively. We demonstrated that artificially increasing ratios to 2:1 was not sufficient to achieve NNL for all projects. The ability to replicate ecosystem function is clearly limited. Improvements in both compensation science and institutional approaches are recommended to achieve Canada's conservation goal.

Canada contains approximately one quarter of the world's wetlands (Rubec 1994), which support a rich biodiversity of more than 198 fish species (Scott and Crossman 1998). Losses of wetlands have occurred at an alarming rate in the last century. In fact, approximately one seventh (20 million ha) of Canada's wetlands have been lost (Rubec 1994). Habitat loss has been identified as a key factor in the decline of Canada's freshwater fisheries resources (Pearse 1988; Beamish and others 1986). In North American freshwaters, 73% of fish extinctions can be attributed to habitat alterations (Miller and others 1989).

To prevent further erosion of the resource base, in 1976 Fisheries and Oceans Canada (DFO) enacted the habitat provisions of the *Fisheries Act*, one of the strongest pieces of environmental legislation in Canada. A "harmful alteration, disruption, or destruction to fish habitat" (HADD) cannot occur unless authorised via Section 35(2) of the *Fisheries Act*. In 1986, the Policy for the Management of Fish Habitats (hereafter the Habitat Policy; DFO 1986) was implemented to ensure sustainable development by requiring authorised HADDs to be offset by legally binding habitat compensation. The guiding principle behind the requirement for habitat compensation is the achievement of no net loss (NNL) of the productive capacity of fish habitats, the primary conservation goal of the Habitat Policy.

Thus, the putative solution for conserving Canada's rich biodiversity of fish and the habitats they depend upon, while allowing development to continue, is through compensation habitat. Canada has received accolades for its progressive conservation policies (Brouha 1993), yet in practice, the effectiveness of compensation habitat in achieving NNL has never been tested on a national scale. Excessive workload in DFO results in reactive, crisis habitat management such that follow-up monitoring and adaptive management do not occur (Harper and Quigley 2005a). In fact, nationally only 2.1% of DFO's habitat management workload is spent conducting follow-up monitoring to

KEY WORDS: Habitat compensation; Effectiveness; No Net Loss; Field evaluation; *Fisheries Act*; Authorisation; Habitat productivity; Policy; Canada

---

*Author to whom correspondence should be addressed; *email:* Jason.quigley@ceaa-acee.gc.ca determine efficacy of compensatory works (Drodge and others 1999). Independent evaluations of the effectiveness of compensation habitat in Canada are even rarer (Harper and Quigley 2005b). Furthermore, the vast majority of evaluations and monitoring that have occurred has been short term (1–3 yrs), judgement based, and qualitative rather than quantitative (Harper and Quigley 2005a). Most studies have based their NNL determinations simply upon area gained or lost rather than scientifically defensible assessments of the true productive capacity of fish habitats. A possible reason for this is the difficulty in assessing productive capacity as it is defined in the Habitat Policy.

Productive capacity is characterised as "the maximum biomass of organisms that can be sustained on a long term basis by a given habitat, analogous to carrying capacity" and "the measure of a habitat to produce fish and/or food organisms in natural or restored conditions" (DFO 1998). Indeed, the difficulty in operationally defining and assessing productive capacity has been recognized (Jones and others 1996; Levings and others 1997) since the inception of the Habitat Policy and has likely impeded applied, practical research into the performance of DFO's conservation policy. Efforts in providing operational definitions of productive capacity have received considerable resources and effort (Minns and Moore 2003; Minns 1995, 1997; Levings and others 1997), as have inventories of the productive capacity of various habitats (Gordon and others 1997; Amiro 1997; Welch 1997; Williams and others 1997). However, with respect to compensation habitat, DFO's core mechanism to conserve habitat, practical evaluations of the attainment of NNL of the productive capacity of fish habitats have rarely been undertaken, and if so have been local in scope (Scruton 1996; Minns and others 1995; Levings and Nishimura 1996).

Productive capacity was intended to measure the capacity of the habitat (carrying capacity potential) and not solely current fish production (Scruton 1996). We agree with Minns (1997) and Levings and others (1997) that the Habitat Policy was drafted to conserve habitat quality and ecosystem productivity akin to the United States' legislation (Section 404, *Clean Water Act*) designed to conserve wetland functionality. Productive capacity can be considered an intrinsic potential property of habitat, which is not only difficult to quantify but is "logically inoperable" (Minns 1997). However, the ability of DFO to achieve NNL of future productivity may be a moot issue if current habitat productivity is not being effectively conserved. Indeed, the productivity of compensation habitats relative to impacted habitats is the key unanswered question of habitat managers in Canada (Metikosh 1997).

As such, we investigated the effectiveness of habitat compensation in achieving NNL of current habitat productivity by measuring both the area and the productivity of compensatory habitats. Consistent with the latest trends in conservation biology (Underwood 1995; Walters and Holling 1990), we treated DFO's management actions with respect to habitat conservation (i.e., compensation projects) across Canada as experiments. In this article, we describe a field evaluation of fish habitat compensation projects completed across Canada to determine effectiveness of compensation projects in achieving NNL of habitat productivity.

Methods

Habitat compensation projects were selected randomly across Canada with geographic stratification in five provinces: British Columbia, Manitoba, Ontario, New Brunswick, and Nova Scotia. Field evaluations were completed from May to October of 2000 and 2001. We selected projects that had been completed between 1994 and 1997, which ensured a postconstruction age range of 4 to 8 years.

A hierarchy of compensation options, from most to least preferred, that compare the habitat type and ecological unit of compensation habitat relative to the lost habitat is provided in the Habitat Policy (DFO 1986, 1998). We described compensation projects based on a modified hierarchy of preferences. This included three basic classifications: (1) like for like habitat: create similar habitat at or near the site in the same ecological unit (e.g., replace off-channel habitat with off-channel habitat); (2) like for unlike habitat: create or increase the productivity of unlike habitat in the same ecological unit (e.g., replace in-channel habitat with off-channel habitat); (3) increasing like habitat productivity: increase the productivity of like habitat at or near the site (e.g., enhance existing in-channel habitat to compensate for in-channel habitat loss). Ecological unit was defined as "populations of organisms considered together with their physical environment and the interacting processes amongst them" (DFO 2002a).

Each compensation project was partitioned into treatment sites (n = 2–4). Unimpacted reference sites (n = 2–4) were selected to represent the HADD site prior to the impact. Pre-impact assessment reports, photographs, and on-site visits with the DFO biologist responsible for the authorisation assisted in reference site selection. In some compensation projects, the HADD site and the compensation habitat were spatially distinct. In these cases, treatment sites were selected in both the HADD site (n = 2–4) and the compensatory site (n = 2–4) and data were pooled to develop mean response values. In this way, we were able to evaluate the habitat productivity of the compensatory, modified (HADD site), and lost habitats (reference site).

For each project, the evaluations consisted of two general components: determining the overall areal extent of habitat change and the magnitude of change per unit area (Minns 1995). Total surface area of gains and losses in habitat were measured and compensation ratios (habitat area gained:habitat area lost) were calculated (*sensu* Quigley and Harper 2005).

Taking an ecosystem approach, we selected four variables as a proxy to productive capacity to quantify magnitude of change in habitat productivity. This multimetric approach included biomass of periphyton, macroinvertebrate density, fish biomass, and areal cover of riparian vegetation. These variables were measured at both treatment and reference sites. For some projects, all four variables were not measured because of logistical constraints or because a given indicator was not applicable for a particular project.

Treatment and reference sites were netted off and the areas were measured so that response variables could be quantified per unit area. Periphyton was sampled from each site by selecting five rocks, using a random stratified approach along a transect in the centre of the channel. Sediment was first removed from each rock with a washbottle. Then a cordless drill with nylon brush was used to emulsify periphyton from a known area on each rock defined by 3.8-cm sections of polyvinyl chloride pipe of varying diameters (5.08 cm, 7.62 cm, or 10.16 cm, depending upon substrate size). Emulsified periphyton was rinsed into sample bottles and quantified in the laboratory by filtration (g/m^2). Five invertebrate samples were randomly taken per site using a Surber sampler (RIC 1997). Densities ($number/m^2$) and diversity of invertebrates were recorded. Fish were sampled by electroshocker (Smith Root 12C), and densities were calculated using a two-pass removal method (Seber and LeCren 1967). Fish biomass (g/m^2) and species diversity were recorded for each site. Riparian vegetation was sampled at each site using a random stratified approach along a transect parallel to the channel. Total percent coverage of 1-m^2 quadrats as well as diversity of woody and nonwoody riparian species were quantified at five locations per site.

Treatment response variables were weighted by the difference in area between the compensation and HADD areas (i.e., compensation ratio). For example, if the total compensation area exceeded the HADD area by a factor of 1.2, then all of the mean treatment response variables would be multiplied by 1.2 to estimate the total production for that variable. Response variables were contrasted between treatment and reference sites. Most projects were composed of an in-channel and a riparian component, which were evaluated separately. A project was deemed to have resulted in a net gain if one or more of the response variables were statistically greater in treatment sites than reference sites and the remaining variables were not different. A project was deemed to have resulted in a net loss if one or more variables were statistically greater in reference sites than treatment sites. Projects achieved NNL if all of their response variables did not differ between reference and treatment sites.

Two additional sets of analyses were also completed whereby artificial ratios of 1:1 and 2:1 were used with the mean treatment response variables rather than the actual compensation ratios measured. These analyses were completed because many projects had compensation ratios less than 1:1 and we wanted to ascertain the effect that larger compensation ratios might have on the achievement of NNL.

It is possible to have no change in production (biomass) in a particular indicator but have a shift in species composition. Diversity of fish species, invertebrate orders, and riparian nonwoody and woody species was measured to capture changes in community structure.

Data Analyses

Data were visually inspected for normality and homogeneous variances. We used log transformations to minimise heterogeneous variances. For each compensation project, we used analysis of variance to compare response variables between reference and treatment sites. Least-square means were used to calculate means for graphical presentations. Values are reported as means ± 1 standard error (SE). Statistical analyses were completed using SAS statistical software, release 8.02 (SAS Institute 2001). All tests were considered to be significant to a $P \leq 0.05$.

Results

A total of 16 habitat compensation projects were evaluated across Canada in British Columbia (n = 7), Manitoba (n = 3), Ontario (n = 2), New Brunswick (n = 2), and Nova Scotia (n = 2) (Figure 1). This sample represents approximately 13% of the total number of authorisations (N = 124) issued in these provinces during 1994 to 1997 inclusive. The mean age of projects was 4.3 years (SE = 0.5) (Table 1). Habitat compensation projects evaluated were a result of the

Figure 1. Location of compensation projects evaluated across Canada ($n = 16$).

following development activities: roads and highways ($n = 7$), urban development ($n = 4$), forestry ($n = 3$), agriculture ($n = 1$), and oil and gas ($n = 1$) (Table 1). The HADDs and compensatory habitats occurred in two habitat categories: in-channel and riparian. Many projects included HADDs and compensation in both habitat categories. Common compensation techniques included riparian revegetation, channel creation, and habitat complexing through addition of boulders, large woody debris, or pools (Table 1).

In the in-channel habitat category, approximately 58% of projects had HADD areas that were larger than authorised. Smaller-than-authorised HADD areas were less common, occurring 8% of the time (Figure 2A). The mean size of the authorised and actual HADDs was 2493 m^2 and 5393 m^2, respectively. In contrast, compensation habitat tended to be smaller than required. Approximately 50% of projects had compensation habitat smaller than required, whereas 17% were larger than required (Figure 2B). The mean size of the

Table 1. Descriptive information for compensation projects studied across Canada

Project	Province	Age (yrs)	HADD description	Compensation description	Hierarchy option
1	Manitoba	5	Highway realignment resulted in a loss of in-channel riverine habitat and of riparian habitat.	River diversion created in-channel riverine habitat and riparian habitat. Constructed riffles and deep pools incorporated as compensation features.	Like for like
2	British Columbia	3	Forestry road realignment and culvert installation resulted in a loss of in-channel riverine habitat and riparian habitat.	Creation of in-channel riverine habitat and riparian habitat. Habitat complexing with large woody debris was a compensation feature.	Like for like
3	Nova Scotia	7	Highway twinning resulted in stream diversion and culvert installation destroying in-channel riverine habitat and riparian habitat.	Habitat complexing was completed to enhance productivity by installing digger logs.	Increase like productivity
4	Ontario	7	Municipal road construction and bridge installation resulted in stream channelisation and diversion. In-channel riverine habitat and riparian habitat was lost.	Creation of in-channel riverine habitat and riparian habitat.	Like for like
5	Manitoba	3	Construction of a dam and spillway to create an agricultural water reservoir resulted in a loss of riverine in-channel habitat and riparian habitat.	Creation of lacustrine/reservoir habitat, riparian habitat and fishway.	Like for unlike
6	British Columbia	3	Installation of an outfall structure for discharge from a water treatment plant resulted in a loss of riparian habitat.	Riparian revegetation.	Like for like
7	New Brunswick	4	Highway construction and installation of twin bridges resulted in a river diversion and channelisation and a loss of riparian and in-channel habitat.	Creation of in-channel habitat complexed with digger logs, boulders, and large woody debris.	Like for like
8	Ontario	3	Road construction, culvert installation and stormwater retention pond to service new subdivision resulted in a loss of in-channel riverine habitat and riparian habitat.	Riparian revegetation and creation of in-channel habitat complexed with large woody debris.	Like for like
9	New Brunswick	2	Highway construction and installation of four culverts, channelisation, and two stream diversions resulted in a loss of in-channel riverine habitat and riparian habitat.	Riparian revegetation and creation of in-channel habitat complexed with digger logs, boulders, and large woody debris.	Like for like
10	British Columbia	3	Major river channelisation and creation of a spur-dyke to protect downstream forestry mill resulted in a loss of in-channel riverine habitat and riparian habitat.	Riparian revegetation and preservation of adjacent side-channel access. Irregular edge habitat and groynes incorporated into rip-rap design as compensation features.	Like for like
11	British Columbia	2	Condominium development resulted in a loss of riparian habitat.	Riparian revegetation.	Like for like

Continued

Table 1. Continued

Project	Province	Age (yrs)	HADD description	Compensation description	Hierarchy option
12	British Columbia	7	River diversion to protect forestry mill resulted in a loss of in-channel riverine habitat and riparian habitat.	Riparian revegetation and creation of in-channel habitat complexed with boulders and large woody debris.	Like for like
13	Nova Scotia	9	Highway construction, culvert installation, and stream diversion and realignment resulted in a loss of in-channel riverine habitat and riparian habitat.	Enhanced productivity of in-channel habitat through installation of digger logs.	Increase like productivity
14	Manitoba	5	Road construction, stream realignment, and bridge installation resulted in a loss of in-channel riverine habitat and riparian habitat.	Creation of in-channel habitat complexed with boulders and deep pools.	Like for like
15	British Columbia	3	River channel hardening and straightening with rip-rap to protect gas pipeline resulted in a loss of in-channel riverine habitat and riparian habitat.	Creation of off-channel habitat complexed with large woody debris and pools and riparian revegetation.	Like for unlike
16	British Columbia	3	Road realignment and channelisation resulted in a loss of riparian habitat.	Riparian revegetation and incorporation of groynes in the rip-rap to create edge habitat.	Like for like

required and actual compensation habitats was 16,245 m^2 and 14,865 m^2, respectively. Overall, 75% of compensation projects had either larger HADD and/or smaller compensation areas than authorised. Consequently, 64% of projects had smaller compensation ratios than authorised, whereas only 27% were larger (Figure 2C). The mean compensation ratio required was 6.8:1 compared to an actual ratio of 1.5:1.

In the riparian habitat category, the trends were similar. Approximately 56% of projects had HADD areas that were larger than authorised. Smaller-than-authorised HADD areas occurred at 13% of the projects (Figure 2D). The mean size of the authorised and actual HADDs was 11,535 m^2 and 11,446 m^2, respectively. Compensation habitat was smaller than required on 50% of projects and larger for 25% (Figure 2E). The mean size of the required and actual compensation habitats was 7667 m^2 and 6730 m^2, respectively. Overall, 88% of compensation projects had either larger HADD and/or smaller compensation areas than authorised. As a result, 75% of projects had compensation ratios smaller than authorised and 19% were larger (Figure 2F). The mean compensation ratio required was 1.2:1 compared to an actual ratio of 0.8:1.

In terms of habitat productivity, 12% (2) of the projects achieved a net gain based on the actual compensation ratios. The mean compensation ratio for these projects was 4.8:1. Approximately 25% (4) of the projects achieved NNL. The mean compensation ratio for these projects was 1.08:1. Approximately 63% (10) of the projects resulted in a net loss of habitat productivity (Figure 3A, Table 2). These projects had a mean compensation ratio of 0.74:1.

Interestingly, with an artificial ratio of 1.0:1, none of the projects would have achieved a net gain, 56% would achieve NNL, and 44% would result in a net loss of habitat productivity (Figure 3B, Table 2). With an artificial ratio of 2.0:1, approximately 31% of projects would achieve a net gain, 50% would achieve NNL, and 19% would result in a net loss of habitat productivity (Figure 3C, Table 2).

We detected a difference in mean periphyton biomass in 50% of compensation projects where it was sampled (Figure 4A) and a difference in macroinvertebrate density in 25% of projects where it was sampled (Figure 4B). A difference in fish biomass was only detected in 8% of projects where it was sampled (Figure 4C). It appears that riparian habitats are much more difficult to compensate for because 57% of projects sampled for this variable resulted in a net loss and no projects achieved a net gain (Figure 4D, Table 2). The differences in riparian productivity were large and unequivocal in these eight projects.

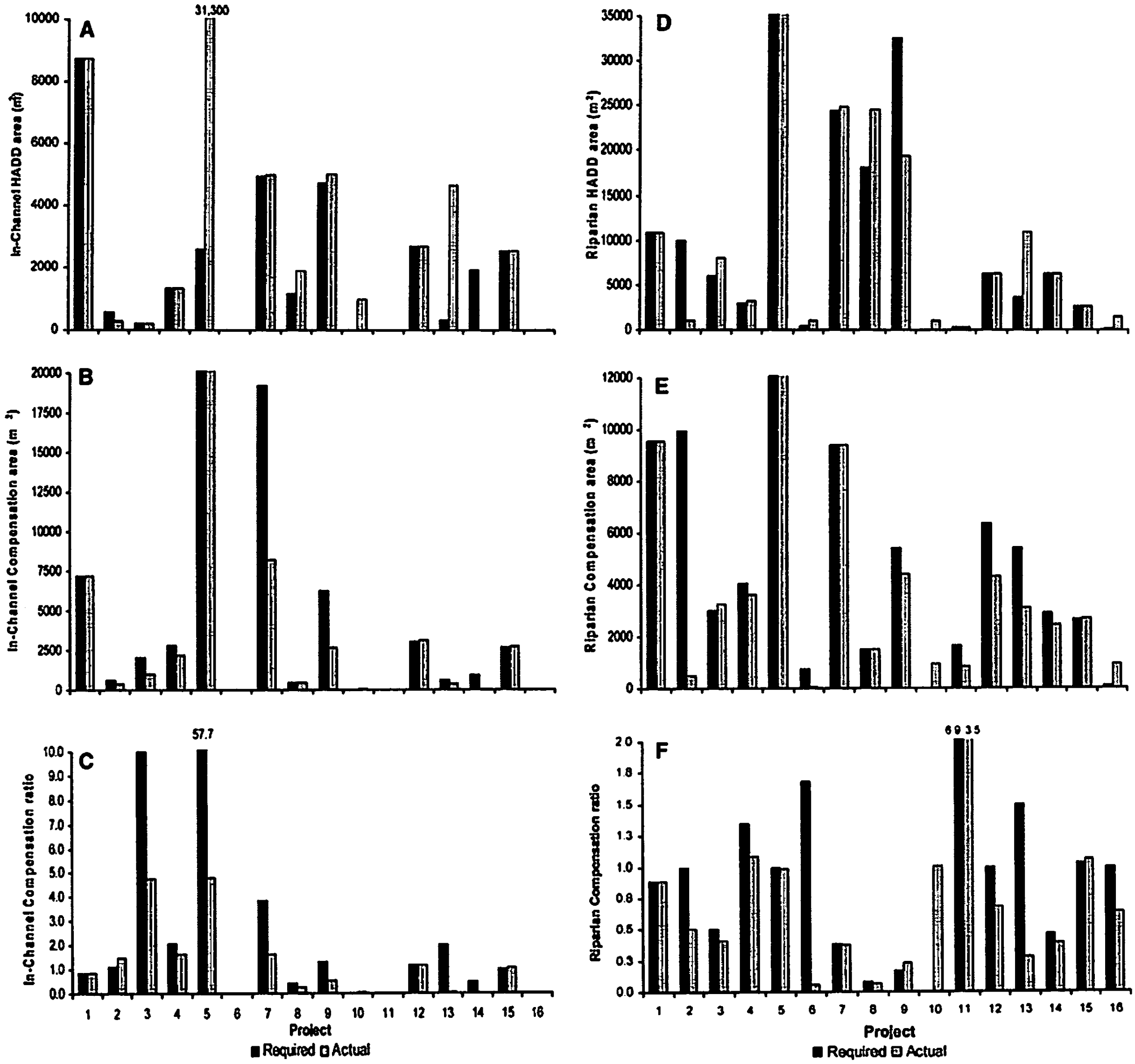

Figure 2. Required and actual HADD areas (**A, D**), compensation areas (**B, E**), and compensation ratios (area gained:area lost) (**C, F**) in the in-channel and riparian habitat categories. Values that exceeded the scale are indicated above the bar except for project 5, which had a required HADD of 60,000 m^2 and an actual HADD of 60,931 m^2 in the riparian category (**D**). Project 5 had a required and actual in-channel compensation area (**B**) of 150,000 m^2 and riparian compensation area (**E**) of 60,000 m^2, respectively. Bars that are absent indicate a zero value except for project 14, in which actual HADD and compensation areas were not measured in the in-channel category.

There were no differences in diversity of fish or invertebrates between treatment and reference sites in any of the projects (Table 3). Three compensation projects had differences in diversity of riparian vegetation between treatment and reference sites. Project 10 had a greater diversity of nonwoody riparian species in reference sites (0.67/m^2) in comparison to treatment sites (0.33/ m^2). Project 6 had a greater diversity of woody riparian species in reference sites (3/m^2) compared to treatment sites (0.5/m^2). Project 11 had a greater diversity of nonwoody species in treatment sites (2.1/m^2) relative to reference sites (0/m^2), yet had a greater diversity of woody species in reference sites (2.0/m^2) compared to treatment sites (0.45/m^2) (Table 3). There were no differences between diversity of nonwoody or woody riparian species in any of the other projects.

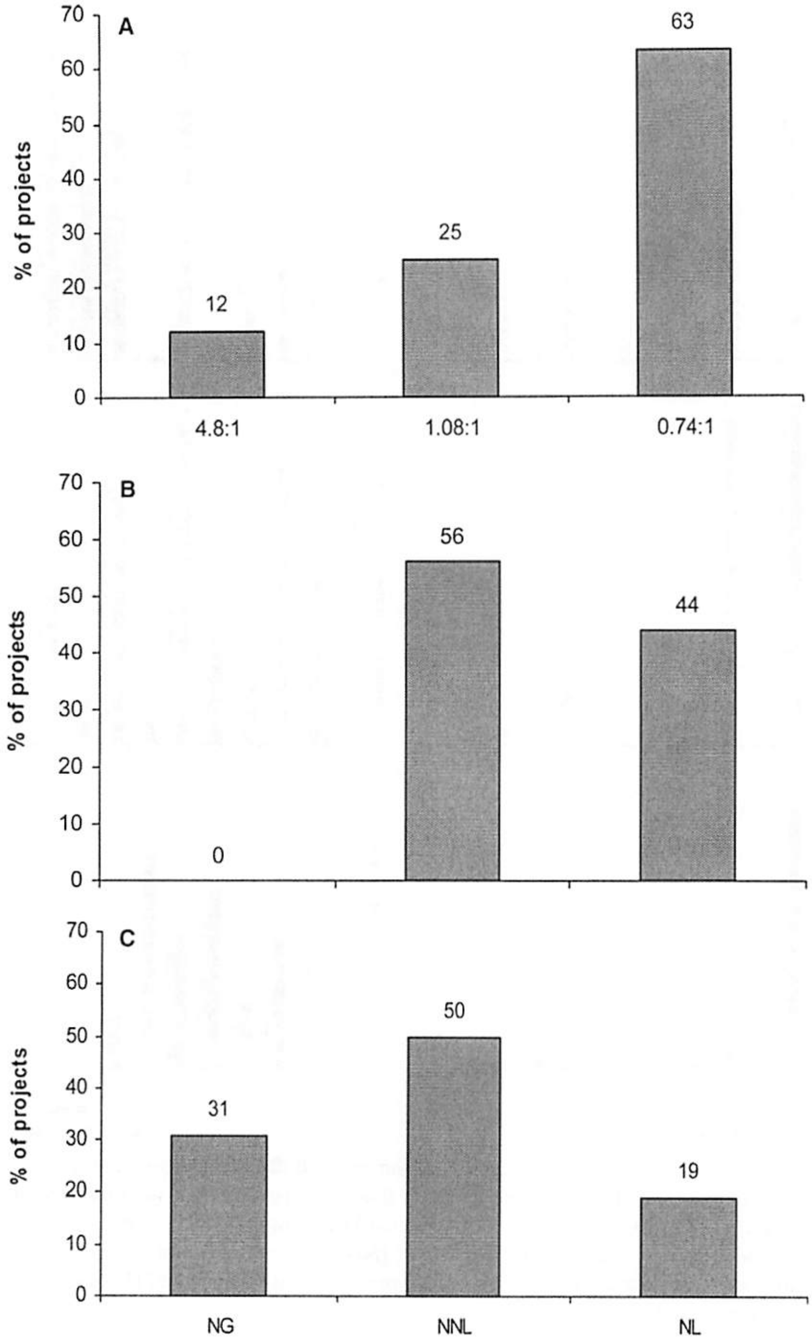

Figure 3. Percentage of projects achieving a net gain (NG), no net loss (NNL), and a net loss (NL) of habitat productivity based on the mean actual compensation ratios (**A**) indicated under each bar, and artificial ratios of 1:1 (**B**) and 2:1 (**C**).

Discussion

Inherent ecosystem variability meant that differences had to be large in order to detect responses. In this respect, our results can be considered conservative because we defaulted to a NNL outcome on many projects that may not have achieved this goal. Indeed, Mapstone (1995) reports that many environmental impact assessments conclude that a development had no effect because an 80–100% change in the measured variable would have been required to detect change. Although more replicates would have assisted in

Table 2. Model statistics for habitat productivity variables to determine if compensation projects achieved a Net Gain (NG), No Net Loss (NNL), or Net Loss (NL) in habitat productivity based on actual compensation ratios (CR) and artificial ratios (ACR) of 1:1 and 2:1.[a] O = Outcome

Project	Variable	Actual CR	*P* value	O	ACR	*P* value	O	ACR	*P* value	O
1	Riparian coverage	0.88:1	0.5507	NNL	1:1	0.6525	NNL	2:1	0.639	NNL
	Periphyton biomass	0.82:1	0.9138	NNL	1:1	0.758	NNL	2:1	0.4323	NNL
	Invertebrate density	0.82:1	0.2575	NNL	1:1	0.1694	NNL	2:1	0.0563	NNL
	Fish biomass	0.82:1	0.9287	NNL	1:1	0.7341	NNL	2:1	0.3102	NNL
2	Riparian coverage	0.5:1	0.0848	NNL	1:1	0.4226	NNL	2:1	0.9129	NNL
	Invertebrate density	1.48:1*	0.0101	NL	1:1*	0.0036	NL	2:1*	0.0239	NG
	Fish biomass	1.48:1	0.1605	NNL	1:1	0.2758	NNL	2:1	0.1197	NNL
3	Periphyton biomass	4.76:1*	0.0179	NG	1:1	0.4977	NNL	2:1	0.0776	NNL
	Invertebrate density	4.76:1	0.2409	NNL	1:1	0.3268	NNL	2:1	0.3331	NNL
	Fish biomass	4.76:1	0.4851	NNL	1:1	0.7906	NNL	2:1	0.8187	NNL
4	Riparian coverage	1.09:1	0.327	NNL	1:1	0.2667	NNL	2:1	0.9842	NNL
	Invertebrate density	1.62:1	0.7373	NNL	1:1	0.9045	NNL	2:1	0.6423	NNL
	Fish biomass	1.62:1	0.2972	NNL	1:1	0.8362	NNL	2:1	0.1719	NNL
5	Riparian coverage	0.98:1	0.9868	NNL	1:1	0.6666	NNL	2:1	0.0001	NG
	Invertebrate density	4.79:1*	0.0524	NG	1:1	0.4188	NNL	2:1	0.1139	NNL
	Fish biomass	4.79:1	0.7441	NNL	1:1	0.5244	NNL	2:1	0.9479	NNL
6	Riparian coverage	0.06:1*	0.0001	NL	1:1*	0.0103	NL	2:1	0.6202	NNL
7	Riparian coverage	0.38:1*	0.0415	NL	1:1	0.4855	NNL	2:1	0.7673	NNL
	Periphyton biomass	1.65:1	0.7521	NNL	1:1	0.2735	NNL	2:1	0.8426	NNL
	Invertebrate density	1.65:1	0.8311	NNL	1:1	0.274	NNL	2:1	0.5191	NNL
	Fish biomass	1.65:1	0.4651	NNL	1:1	0.1865	NNL	2:1	0.7677	NNL
8	Riparian coverage	0.06:1*	0.0011	NL	1:1	0.4341	NNL	2:1	0.9897	NNL
	Invertebrate density	0.26:1	0.3191	NNL	1:1	0.4601	NNL	2:1	0.7227	NNL
	Fish biomass	0.26:1	0.3353	NNL	1:1	0.7581	NNL	2:1	0.8191	NNL
9	Riparian coverage	0.23:1*	0.0008	NL	1:1	0.1624	NNL	2:1	0.1086	NNL
	Periphyton biomass	0.53:1	0.1294	NNL	1:1	0.8587	NNL	2:1	0.2309	NNL
	Invertebrate density	0.53:1	0.398	NNL	1:1	0.2916	NNL	2:1	0.248	NNL
	Fish biomass	0.53:1*	0.0333	NL	1:1*	0.0422	NL	2:1	0.0777	NNL
10	Riparian coverage	1.0:1*	0.0023	NL	1:1*	0.0023	NL	2:1*	0.0112	NL
11	Riparian coverage	3.52:1*	<0.0001	NL	1:1*	0.0001	NL	2:1*	0.0001	NL
12	Riparian coverage	0.68:1	0.4781	NNL	1:1	0.4781	NNL	2:1*	0.0052	NG
	Invertebrate density	1.14:1	0.579	NNL	1:1	0.6143	NNL	2:1	0.4815	NNL
	Fish biomass	1.14:1	0.3896	NNL	1:1	0.2966	NNL	2:1	0.8097	NNL
13	Periphyton biomass	0.08:1*	0.0031	NL	1:1	0.2783	NNL	2:1*	0.0208	NG
	Invertebrate density	0.08:1*	0.0452	NL	1:1	0.7186	NNL	2:1*	0.0397	NG
	Fish biomass	0.08:1	0.1543	NNL	1:1	0.4096	NNL	2:1	0.9046	NNL
14	Riparian coverage	0.39:1*	0.0469	NL	1:1	0.4226	NNL	2:1	0.9268	NNL
	Periphyton biomass	0.5:1*	0.019	NL	1:1*	0.0216	NL	2:1*	0.0299	NL
	Invertebrate density	0.5:1	0.3743	NNL	1:1	0.2084	NNL	2:1	0.1608	NNL
	Fish biomass	0.5:1	0.5667	NNL	1:1	0.4871	NNL	2:1	0.4521	NNL
15	Riparian coverage	1.06:1	0.1633	NNL	1:1	0.1449	NNL	2:1	0.6769	NNL
	Invertebrate density	1.06:1	0.0781	NNL	1:1	0.0739	NNL	2:1	0.1924	NNL
	Fish biomass	1.06:1	0.203	NNL	1:1	0.1829	NNL	2:1	0.8192	NNL
16	Riparian coverage	0.64:1*	0.0002	NL	1:1*	0.0012	NL	2:1*	0.0411	NG

[a]For each compensation ratio, an asterisk indicates variables that differed between treatment and reference sites ($P < 0.05$).

determining differences in habitat productivity, the gross disparity in physical area of compensated versus impacted habitats was an overriding factor for many projects. Unquestionably it is exceedingly difficult to achieve equivalent habitat productivity when replacing only a fraction of the habitat impacted (Quigley and Harper 2005).

However, even if compliance was 100% it is unlikely that the compensation projects would have achieved NNL. Ambrose (2000) also demonstrated that compliance success does not ensure ecological success and highlighted the importance of quantitative rather than subjective evaluations. National guidelines recommend that DFO should "aim for minimum compensation ratios of 1:1" (DFO 2002a), yet in our study close to half of the projects would not have achieved NNL with this ratio. In order to achieve NNL, Minns and Moore (2003) advocate compensation ratios larger than 2:1.

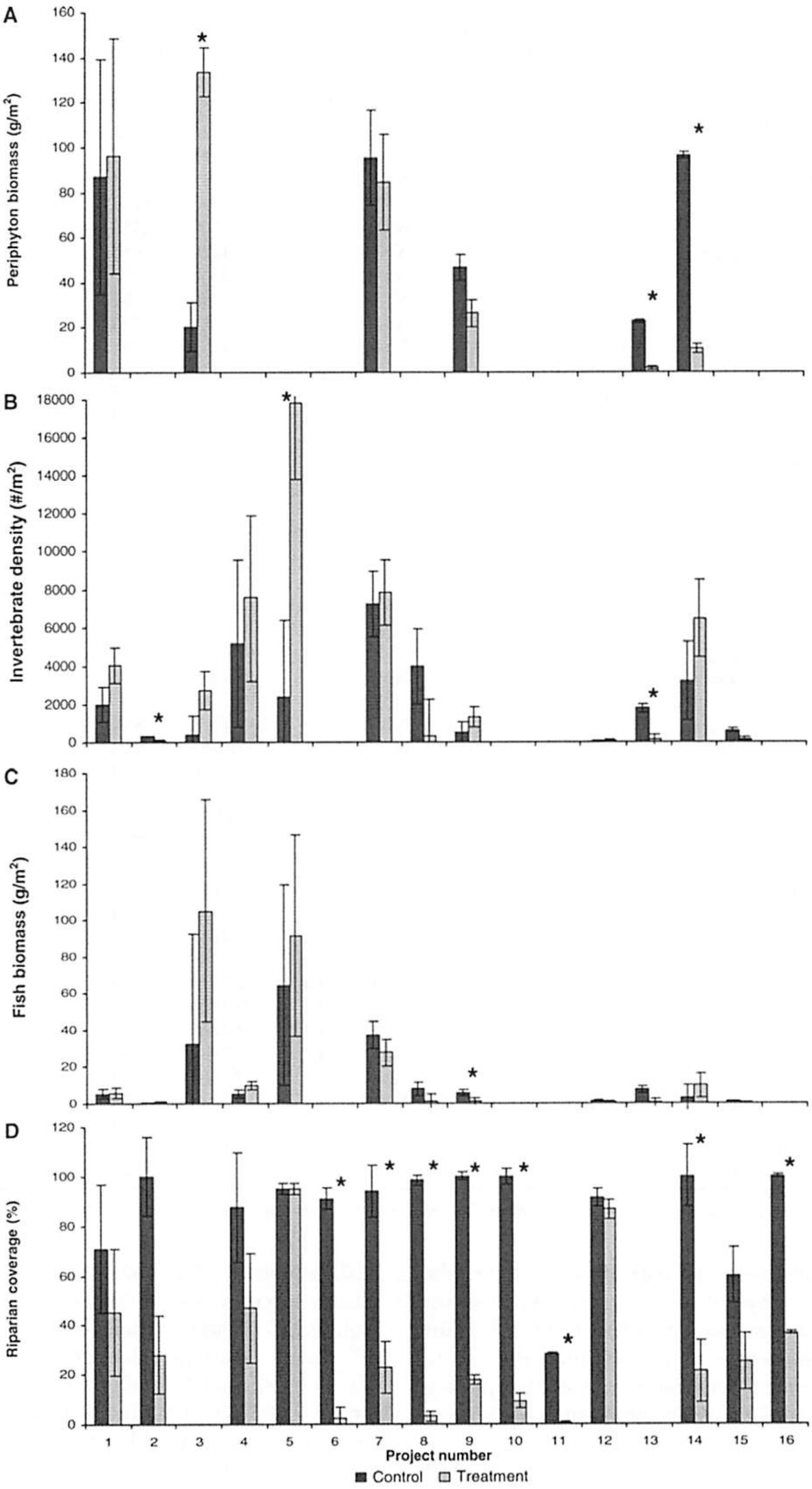

Figure 4. Periphyton biomass (**A**), invertebrate density (**B**), fish biomass (**C**), and riparian coverage (**D**) in control and treatment sites of compensation projects across Canada (based on actual compensation ratios). Asterisk indicates means that differed. Means are based on the number of reference and treatment sites in each project (n = 2–4). Error bars represent 1 SE.

Table 3. Analysis of variance model statistics, their degrees of freedom, and probability levels of significance for the diversity of fish, invertebrates, woody and nonwoody riparian species[a]

Project	Variable	*df*	*F* statistic	*P* value
1	Woody riparian	1,2	13.18	0.0682
	Nonwoody riparian	1,2	0.04	0.8532
	Invertebrate	1,2	0.18	0.7112
	Fish	1,2	0.34	0.6207
2	Woody riparian	1,2	1.46	0.3504
	Nonwoody riparian	1,2	8.54	0.0999
	Invertebrate	1,2	0.00	0.9786
	Fish	1,4	n/a	n/a
3	Invertebrate	1,2	1.71	0.3210
	Fish	1,2	1.88	0.3041
4	Woody riparian	1,2	3.75	0.1924
	Nonwoody riparian	1,2	0.06	0.8301
	Invertebrate	1,2	0.52	0.5459
	Fish	1,2	2.31	0.2678
5	Woody riparian	1,4	0.56	0.4944
	Nonwoody riparian	1,4	0.39	0.5669
	Invertebrate	1,4	0.09	0.7770
	Fish	1,4	3.65	0.1286
6	Woody riparian*	1,4	69.23	0.0011
	Nonwoody riparian	1,4	6.95	0.0578
7	Woody riparian	1,2	9.54	0.0908
	Nonwoody riparian	1,2	0.08	0.8017
	Invertebrate	1,2	0.08	0.8081
	Fish	1,2	0.17	0.7217
8	Woody riparian	1,2	0.14	0.7433
	Nonwoody riparian	1,2	1.02	0.4189
	Invertebrate	1,2	6.48	0.1258
	Fish	1,2	0.01	0.9182
9	Woody riparian	1,2	0.12	0.7577
	Nonwoody riparian	1,2	0.52	0.5466
	Invertebrate	1,2	1.47	0.3495
	Fish	1,2	1.00	0.4226
10	Woody riparian	1,2	4.49	0.1682
	Nonwoody riparian*	1,2	Infinity	<0.0001
11	Woody riparian*	1,2	199.17	0.0050
	Nonwoody riparian*	1,2	587.91	0.0017
12	Woody riparian	1,2	0.63	0.5101
	Nonwoody riparian	1,2	0.22	0.6823
	Invertebrate	1,2	0.44	0.5773
	Fish	1,2	0.00	1.000
13	Invertebrate	1,2	0.00	1.000
	Fish	1,2	0.00	1.000
14	Woody riparian	1,2	0.63	0.5092
	Nonwoody riparian	1,2	3.70	0.1942
	Invertebrate	1,2	1.62	0.3310
	Fish	1,2	0.06	0.8306
15	Woody riparian	1,2	1.73	0.3192
	Nonwoody riparian	1,2	2.27	0.2708
	Invertebrate	1,2	0.56	0.5314
	Fish	1,2	1.97	0.2954
16	Woody riparian	1,2	1.00	0.4226
	Nonwoody riparian	1,2	7.47	0.1118

[a] Asterisk indicates variables that differed between treatment and reference sites ($P < 0.05$). Note that Project 2 contained a single fish species in all sites rendering diversity comparisons between treatment and reference sites not applicable (n/a).

We found that although success improved with artificial ratios of 2:1, a substantial proportion of compensation projects still did not achieve NNL, a finding supported by others (Kistritz 1996). Thus, even if projects were entirely compliant and created twice as much compensation habitat compared to the HADD, the

Habitat Policy goal of NNL would still not always be achieved. This is alarming considering that the average compensation ratio for all projects completed in Canada between 1994 and 1997 was 1.1:1 (Harper and Quigley 2005a), indicating that many projects did not achieve NNL. In the present study, projects that successfully achieved a net gain in habitat productivity were characterised by actual ratios of approximately 5:1, although required ratios were up to an order of magnitude larger for these projects. The need for larger compensation ratios has been echoed in the United States (Allen and Feddema 1996; Brown and Lant 1999).

Based on the simple metric of habitat area, it would appear that Canada should be achieving a net gain of habitat productivity (Harper and Quigley 2005a). However, upon closer analyses, the actual areas of compensation habitats are much less than required and actual HADD areas are much larger than that stated in authorisations (Quigley and Harper 2005). Poor compliance rates, and the inability of file reviews to determine actual gains in habitat areas, are common findings in the United States as well (Ambrose 2000; Zedler and others 2001). In Canada, not only is NNL not being met spatially, but it is also not being achieved temporally and functionally. Temporal losses of habitat productivity are inevitable when compensation habitats are developed after the HADD occurs. Furthermore, temporal losses are exacerbated due to the time lag until compensatory habitats function ecologically in a manner comparable to preimpact conditions. In many cases, the time lag may be considerable because some projects will likely never achieve equivalent functionality. Time between HADD occurrence, compensation development, and compensation functionality was not a leading (and in many cases present) consideration in the authorisations we studied. Similar shortcomings have been identified in the United States (Brown and Veneman 2001; Kunz and others 1988; Zedler 1996).

It seems clear that compensatory works were not successful in completely offsetting the losses of habitat, although they were successful in slowing the rate of habitat loss. This is not altogether surprising, considering the general consensus of habitat managers in Canada is that DFO is not achieving NNL (DFO 1997; Metikosh 1997). Most fish habitat managers and scientists agree that we are losing, and will continue to lose, habitats and species if the magnitude, frequency, and type of anthropogenic disturbances continue (Applegate and others 1996).

However, limited success in achieving NNL to date does not erode or invalidate the value of this goal of the Habitat Policy; rather, it provides an impetus for change. It is important to note that in our study, more than one third of projects evaluated achieved either a net gain or NNL in habitat productivity, indicating potential to build on these successes. Challenges in achieving functional equivalency at compensatory habitats have also been reported in the United States (Sudol and Ambrose 2002), and recommendations for improvement have been compiled (Zedler and others 2001). It is conceivable that NNL may be attained if some fundamental changes to compensation science and institutional approaches are incorporated into DFO's habitat management program. Modifying management approaches based on the results of monitoring and evaluation programs is a critical component of adaptive management, yet often neglected (La Peyre and others 2001). Although broad environmental policy reviews utilising ecological indicators at the national and international level are increasing, they have yet to be integrated into daily environmental decision-making (La Peyre and others 2001). It is critical for Canada's fisheries resources for DFO to engage and respond to feedback loops that foster the refinement, and in particular the implementation, of environmental policies.

Productivity can be considered the current yield of a habitat (Gordon and others 1997), whereas productive capacity incorporates the future potential. Our evaluations were only a snapshot in time, and it could be argued that some of the compensatory habitats will achieve NNL in the future or at a different season of the year. However, the HADDs exist year-round and will doubtless last into perpetuity in many cases. We would argue that compensatory habitats should offset the HADD today, tomorrow, and into perpetuity, rather than in any particular season or future period. Simply stated, compensatory habitat should be achieving NNL on any given day. Otherwise, Canada's habitat base will slowly erode due to accumulating temporal losses of fish habitat.

Lack of pre-impact assessment baseline data and limited monitoring data have challenged researchers' abilities to draw conclusions in NNL studies (Cole and Shafer 2002; Kentula and others 1992; Harper and Quigley 2005a). Only one compensation project we evaluated had quantitative pre-impact data (fish biomass), and none had previously determined reference sites. Ability to detect changes in productivity and power of statistical analyses would be greatly improved if reference sites (Brinson and Rheinhardt 1996) and quantitative pre-impact data were routinely required for compensation projects and rigorous experimental designs were employed in monitoring programs (Underwood 1991, 1993; Stewart-Oaten and Bence 2001; Pearson and others 2005).

The fact that we did not detect considerable differences in diversity of species may be due to the tendency for most of the projects to have implemented in-kind compensation (rather than like for unlike). This practice has been lauded due to its propensity to maintain biodiversity (Race and Fonseca 1996; Allen and Feddema 1996). Lack of an in-kind replacement policy in the United States has resulted in an increase in homogeneous wetland types and a decline in vegetation diversity (Allen and Feddema 1996). However, insistence on like for like in highly disturbed landscapes (such as urbanised areas) is not always advisable because the original landscape has essentially disappeared (Race and Fonseca 1996) and other ecological or biophysical bottlenecks may frustrate compensation attempts. Attention to limiting factors and compensation options lower on the hierarchy of preferences (DFO 1998) would likely be more successful in these instances.

In general, we found that compensation sites were selected opportunistically rather than based on ecological bottlenecks and potential for success, which influenced the success of compensation habitats in achieving equivalent productivity. Natural sites selected for compensation often had environmental and biological limitations that were largely ignored. For example, compensation sites selected for riparian planting tended to have very low success in the present study and others (Cole and Shafer 2002; Robb 2002; Race 1985). The difficulty in establishing vegetation at barren sites is not altogether surprising, because there are generally good reasons why riparian vegetation is not currently flourishing at these locations. An absence of vegetation maintenance programs such as irrigation, fertilisation, and weeding is likely a contributing factor. Vegetation survival and therefore replacement of functional values can be successful in compensation projects that employ maintenance programs (e.g., a large-scale drip irrigation system) (Allen and Feddema 1996; Sudol and Ambrose 2002). However, requiring sites that do not currently support riparian vegetation to be artificially irrigated may not be a wise strategy. If natural hydrologic processes do not support a riparian community, requirements to irrigate may only achieve a partial community and result in sites that are unlikely to be self-sustaining (Sudol and Ambrose 2002). Furthermore, considering poor compliance rates (Quigley and Harper 2005; Zedler and others 2001), irrigation may never occur or certainly be short lived and therefore the site will eventually revert to the natural community it supported prior to compensation efforts.

Our paper quantitatively examined four components of fish habitat, at three distinct trophic levels, to determine efficacy of compensatory habitat in replicating habitat quality. In our study, it appeared that indicators lower on the trophic level such as periphyton and invertebrates were more responsive and/or less variable and thus better at representing gross differences in habitat productivity than fish biomass. However, invertebrates and periphyton are rarely measured in assessments of compensatory projects (Breaux and Serefiddin 1999); rather, fish biomass (Scruton 1996; Scruton and others 1997) and vegetative cover (Allen and Feddema 1996; Breaux and Serefiddin 1999) have primarily been used to infer habitat productivity. Our multimetric approach provided a more complete picture of habitat productivity, rather than simply using fish biomass as an indicator. Invariably, habitat alterations do not exclusively affect a particular species in isolation of other biota (Minns and others 1996). Furthermore, fish can be rather poor indicator species because of their mobility, cyclical populations, exposure to confounding influences (ocean productivity, fisheries, etc.), and divergent life histories. Indeed, for anadromous species it is possible to have low escapements and pristine freshwater habitat, as is the reciprocal.

An array of ecological indicators is preferable to detect responses to habitat alterations (Minns and others 1996). In many cases, selecting one surrogate of habitat productivity, rather than an array of ecological indicators at different trophic levels, would have led to erroneous conclusions. For example, in Project 2, greater biomass of fish was measured at the impacted habitat (culvert) in comparison to the compensatory habitat. However, invertebrate density and riparian vegetation were all negligible at the HADD site in contrast to robust populations in the compensatory habitat. Had we only evaluated fish as an indicator, we would have missed important attributes of the ecological picture of this site.

Compensation science and institutional approaches need to improve in Canada if the conservation policy of NNL of habitat productivity is to be met, as evidenced by the compensation projects assessed in this study, of which only 37% achieved this goal. In the United States as well, replacement of functional values of wetlands has been limited (Sudol and Ambrose 2002; Ambrose 2000; Race and Fonseca 1996; Zedler and others 2001). Canada's poor performance in achieving NNL is especially sobering considering that our study only focused on site-specific impacts and ignored hydrological affects and disruption to landscape processes. Indeed, Hartman and Miles (1997) demonstrated that one of the earliest compensatory spawning channels (created in 1956) failed half a century later due to cumulative watershed impacts from other development activities. The NNL policy would be best practiced in a watershed or ecosystem-based management context to ensure that landscape processes that build and maintain habitats are considered. Although cumulative impacts due to poor performance of Section 35(2) *Fisheries Act* authorisations and associated compensation habitats are likely occurring, our study and the monitoring requirements for habitat compensation in Canada are poorly scaled to capture long-term (>50 yrs) and cumulative ecosystem effects.

Institutional shortcomings such as lack of monitoring and maintenance have been identified as the causes for poor compliance with required compensation areas (Shabman and others 1996; Brown and Lant 1999). Race and Fonseca (1996) argue that "concerns about function are eclipsed by concerns about generating habitat in the first place." The focus on habitat quantity only may be flawed because we demonstrated that artificially increasing compensation areas to ratios of 2:1, by itself, was not sufficient to achieve a net gain in habitat productivity for all projects. Likewise, Sudol and Ambrose (2002) demonstrated compliance with regulatory requirements was not sufficient to replace wetland functions in the United States. Clearly, the ability to replicate ecosystem function is limited, and both improvements in compensation science and institutional approaches are necessary. Recommendations to improve success include larger compensation ratios, creation and documentation of the functionality of compensation habitats prior to and concurrent with HADDs, maintenance programs, increased monitoring and enforcement, and attention to limiting factors on a watershed basis (Zedler and others 2001). Improvements in these areas will advance the success of habitat compensation toward NNL. However, it is important to acknowledge that it is simply not possible to compensate for some habitats. Therefore, the option to compensate for HADDs may not be viable for some development proposals demanding careful exploration of alternative options including redesign, relocation, or rejection. Failure to acknowledge the limitations of compensatory science will hinder Canada's efforts to conserve fish habitat and achieve the goal of NNL.

Acknowledgments

The authors would like to thank the staff in DFO Regional and Area offices for their support and access to files. Technical assistance and field support were provided by James Wilkinson. Earlier versions of this article were greatly improved from reviews by Scott Hinch, Otto Langer, Ryan Galbraith, and three anonymous reviewers. Special thanks are also due to Marcia Vanwely and Louise Archibald of the DFO Pacific Region library for their continued support and excellent service. Funding for this initiative was provided by the Environmental Science Strategic Research Fund.

Literature Cited

Allen, A. O., and J. J. Feddema. 1996. Wetland loss and substitution by the Section 404 permit program in southern California, USA. *Environmental Management* 20:263–274.

Ambrose, R. F. 2000. Wetland mitigation in the United States: assessing the success of mitigation policies. *Wetlands (Australia)* 19:1–27.

Amiro, P.G. 1997. Assessing productive capacity of maritime region rivers to produce Atlantic salmon and other diadromous fish: review of methods used and under development. Pages 49–56 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147.

Applegate, R., P. Bisson, B. Bradbury, P. Delaney, F. Goetz, L. Huner, D. MacDonald, M. McBurney, P. Merritt, J. Nelson, J. Stavinga, C. Steward, and T. Stearns. 1996. Towards Sustainable Fisheries: Building a Cooperative Strategy for Balancing the Conservation and Use of Westcoast Salmon and Steelhead Populations. The Sustainable Fisheries Foundation, 68 pp.

Beamish, F. W. H., P. J. Healey, and D. Griggs. 1986. Freshwater fisheries in Canada. Report on phase I of a National Examination. Canadian Wildlife Federation, Ottawa, Ontario.

Breaux, A., and F. Serefidden. 1999. Validity of performance criteria and a tentative model for regulatory use in compensatory wetland mitigation permitting. *Environmental Management* 24:327–336.

Brinson, M. M., and R. Reinhardt. 1996. The role of reference wetlands in functional assessment and mitigation. *Ecological Applications* 6:69–76.

Brouha, P. 1993. Emulating Canada: recognizing existing aquatic and fish habitat areas as invaluable. *Fisheries* 18:4.

Brown, P. H., and C. L. Lant. 1999. The effect of wetland mitigation banking on the achievement of no-net-loss. *Environmental Management* 23:333–345.

Brown, S. C., and P. L. M. Veneman. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, USA. *Wetlands* 21:508–518.

Cole, C. A., and D. Shafer. 2002. Section 404 wetland mitigation and permit success criteria in Pennsylvania, USA, 1986–1999. *Environmental Management* 30:508–515.

Drodge, G., M. H. Beauchesne, and G. Feltham. 1999. National Habitat Referral Study. Prepared for Department of Fisheries and Oceans. Ottawa, by KPMG, 41 pp.

Fisheries and Oceans Canada (DFO). 1986. Policy for the management of fish habitat. Ottawa, 28 pp.

Fisheries and Oceans Canada (DFO). 1997. No net loss: assessing achievement. Workshop proceedings. Kwantlen University College, Richmond, B.C., 68 pp.

Fisheries and Oceans Canada (DFO). 1998. Habitat conservation and protection guidelines. Second edition. Ottawa, Ontario, Canada, 19 pp.

Fisheries and Oceans Canada (DFO). 2002a. Practitioners guide to compensation. Ottawa, Ontario, Canada, 23 pp.

Fisheries and Oceans Canada (DFO). 2002b. Habitat referral tracking system. Ottawa.

Gordon, D. C., P. D. Keizer, P. Lawton, R. J. Rutherford, and W. L. Silvert. 1997. Assessing the productive capacity of fish habitat: synopsis of current methods used in estuarine and marine habitats, Maritimes region. Pages 57–67 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147.

Harper, D. J., and J. T. Quigley. 2005a. No net loss of fish habitat: a review and analysis of habitat compensation in Canada. *Environmental Management* 35:1–13.

Harper, D. J., and J. T. Quigley. 2005b. A comparison of the areal extent of fish habitat gains and losses associated with selected compensation projects in Canada. *Fisheries* 30:18–25.

Hartman, G. F., and M. Miles. 1997. Jones Creek Spawning Channel: Post-Failure Analysis and Management Recommendations. Prepared for Fraser River Action Plan, Fisheries and Oceans Canada, 94 pp.

Jones, M. L., R. G. Randall, D. Hayes, W. Dunlop, J. Imhof, G. Lacroix, and N. J. R. Ward. 1996. Assessing the ecological effects of habitat change: moving beyond productive capacity. *Canadian Journal of Fisheries and Aquatic Sciences* 53:446–457.

Kentula, M. E., J. C. Sifneos, J. W. Good, M. Rylko, and K. Kunz. 1992. Trends and patterns in Section 404 permitting requiring compensatory mitigation in Oregon and Washington, USA. *Environmental Management* 16:109–119.

Kistritz, R. U. 1996. Habitat compensation, restoration, and creation in the Fraser River estuary: are we achieving a no-net-loss of fish habitat? Canadian Technical Report of Fisheries and Aquatic Sciences 2349, 113 pp.

Kunz, K., M. Rylko, and E. Somers. 1988. An assessment of wetland mitigation practices in Washington State. *National Wetlands Newsletter* 10:2–5.

La Peyre, M. K., M. A. Reams, and I. A. Mendelssohn. 2001. Linking actions to outcomes in wetland management: an overview of U.S. State wetlands management. *Wetlands* 21:66–74.

Lange, M., B. C. Cudmore-Vokey, C. K. Minns. 2001. Habitat compensation case study analysis. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2576, 31 pp.

Levings, C. D., and D. J. H. Nishimura. 1996. Created and restored sedge marshes in the lower Fraser River and estuary: an evaluation of their functioning as fish habitat. Canadian Technical Report of Fisheries and Aquatic Sciences 2126, 143 pp.

Levings, C. D., C. K. Minns, and F. Aitkens. 1997. Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, B.C., May 13–15, 1996. Canadian Data Report of Fisheries and Aquatic Sciences 2147, 109 pp.

Mapstone, B. D. 1995. Scalable decision rules for environmental impact studies: effect size, type I and type II errors. *Ecological Applications* 5:401–410.

Metikosh, S. 1997. No net loss in the "real" world. Pages 8–15 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147, 109 pp.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. *Fisheries* 14:22–38.

Minns, C. K. 1995. Calculating net change of productivity of fish habitats. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2282, 37 pp.

Minns, C. K., J. D. Meisner, J. E. Moore, L. A. Greig, and R. G. Randall. 1995. Defensible methods for pre- and post-development assessment of fish habitat in the Great Lakes. I. A prototype methodology for headlands and offshore structures. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2328, 65 pp.

Minns, C. K., J. R. M. Kelso, and R. G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 53:403–414.

Minns, C. K. 1997. Quantifying "no net loss" of productivity of fish habitats. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2463–2473.

Minns, C. K., and J. E. Moore. 2003. Assessment of net change of productive capacity of fish habitats: the role of uncertainty and complexity in decision making. *Canadian Journal of Fisheries and Aquatic Sciences* 60:100–116.

Pearse, P. H. 1988. Rising to the challenge: a new policy for Canada's freshwater fisheries. Canadian Wildlife Federation, Ottawa, Ontario.

Pearson, M., J. T. Quigley, D. H. Harper, and R. V. Galbraith. 2005. Monitoring and assessment of fish habitat compensation and restoration projects: study design and example case studies. Canadian Technical Report of Fisheries and Aquatic Sciences 2729, 143 pp.

Quigley, J. T., and D. J. Harper. 2005. Compliance with Canada's Fisheries Act: a field audit of habitat compensation projects. *Environmental Management* (in press).

Race, M. S. 1985. Critique of present wetlands mitigation policies in the United States based on an analysis of past restoration projects in San Francisco Bay. *Environmental Management* 9:71–82.

Race, M. S., and M. S. Fonseca. 1996. Fixing compensatory mitigation: what will it take? *Ecological Applications* 6:94–101.

Resources Inventory Committee (RIC). 1997. Freshwater biological sampling manual. Government of British Columbia.

Robb, J. T. 2002. Assessing wetland compensatory mitigation sites to aid in establishing mitigation ratios. *Wetlands* 22:435–440.

Rubec, C. D. A. 1994. Canada's federal policy on wetland conservation: a global model. Pages 909–917 *in* W. J. Mitsch (ed.), Global wetlands: old world and new. Elsevier, New York.

SAS Institute. 2001. SAS users guide. Version 8.02 edition. SAS Institute Inc., Cary, North Carolina.

Scott, W. B., and E. J. Crossman. 1998. Freshwater fishes of Canada. Galt House Publications Ltd, Oakville, Ontario, Canada, 966 pp.

Scruton, D. A. 1996. Evaluation of the construction of artificial fluvial salmonid habitat in a habitat compensation project, Newfoundland, Canada. *Regulated Rivers: Research & Management* 12:171–183.

Scruton, D. A., J. B. Dempson, R. J. Gibson, and M. A. Barnes. 1997. Freshwater/anadromous productive capacity: Newfoundland region. Pages 15–34 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147.

Seber, G. A. F., and E. D. LeCren. 1967. Estimating population parameters from catches large relative to the population. *Journal of Animal Ecology* 36:631–643.

Shabman, L., P. Scodari, and D. King. 1996. Wetland mitigation banking markets. Pages 109–138 *in* L. Marsh, D. R. Porter, D. A. Salvesen (eds.), Mitigation banking: Theory and practice. Island Press, Covelo, California.

Stewart-Oaten, A., and J. R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. *Ecological Monographs* 71:305–339.

Sudol, M. F., and R. F. Ambrose. 2002. The US Clean Water Act and habitat replacement: evaluation of mitigation sites in Orange County, California, USA. *Environmental Management* 30:727–734.

Underwood, A. J. 1991. Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research* 42:569–587.

Underwood, A. J. 1993. The mechanics of spatially replicated sampling programmes to detect environmental impacts in a variable world. *Australian Journal of Ecology* 18:99–116.

Underwood, A. J. 1995. Ecological research and (research into) environmental management. *Ecological Applications* 5:232–247.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. *Ecology* 71:2060–2068.

Welch, H. 1997. Assessment of productive capacity for Canadian Arctic seas and estuaries. Pages 81–87 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147.

Williams, I., M. Bradford, K. Shortreed, J. Hume, S. Macdonald, B. Holtby, G. Ennis, G. Logan, and H. Stalberg. 1997. Productive capacity freshwater freshwater/anadromous Pacific region. Pages 88–101 *in* C. D. Levings, C. K. Minns, and F. Aitkens (eds.), Proceedings of the DFO workshop on research priorities to improve methods for assessing productive capacity for fish habitat management and impact assessment, Sidney, BC, May 13–15. Canadian Data Report of Fisheries and Aquatic Sciences 2147.

Zedler, J. 1996. The challenge of protecting endangered species habitat along the southern California coast. *Coastal Management* 19:35–53.

Zedler, J., L. Shabman, V. Alvarez, R. O. Evans, R. C. Gardner, J. W. Gibbons, J. W. Gilliam, C. A. Johnston, W. J. Mitsch, K. Prestegaard, A. M. Redmond, C. Simenstad, and R. E. Turner. 2001. Compensating for wetland losses under the Clean Water Act. National Academy Press, Washington, D.C., 322 pp.