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Restoration of common loons following the North Cape Oil Spill, Rhode Island, USA

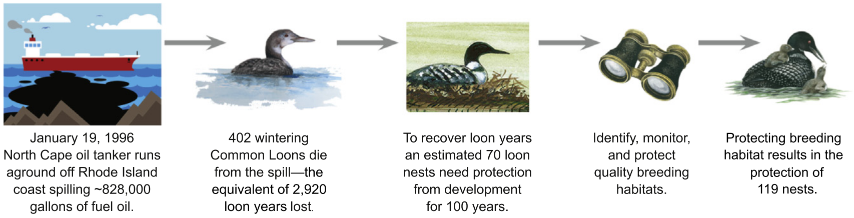
David C. Evers [a,*], Molly Sperduto [b], Carrie E. Gray [a], James D. Paruk [c], Kate M. Taylor [a]

[a] *Biodiversity Research Institute, 276 Canco Road, Portland, ME 04103, USA*
[b] *U.S. Fish and Wildlife Service, 70 Commercial St., Suite 300, Concord, NH 03301, USA*
[c] *St. Joseph's College, 278 Whites Bridge Rd, Standish, ME 04084, USA*

HIGHLIGHTS

- The North Cape Oil Spill killed 402 loons, which was equivalent to 2,920 loon-years.
- Loon surveys were conducted on 70 lakes in 4 regions of Maine.
- Reproductive data collected from 184 loon territories and 866 loon-territory years
- Compensatory loon-years needed for 100 year period was 70 nests, with 119 nests protected.
- Local surveys of proposed restoration area should be conducted for NRDAR models.

GRAPHICAL ABSTRACT



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ABSTRACT

Oil spills are a widespread problem in the marine environment and can have extensive acute and chronic adverse impacts to resident and migratory biota. On 19 January 1996, the North Cape oil tanker caught fire and grounded on the coast of Rhode Island resulting in the spill of 828,000 gal (3134 metric tonnes) of home heating oil. It resulted in the estimated death of nearly 2300 birds, including a projected 402 common loons (*Gavia immer*) and 12 red-throated loons (*Gavia stellata*). Based on existing demographic data, a resource equivalency analysis (REA) calculated that the total loss, as measured through dead adults and their foregone young over their expected lifetimes, was 2920 discounted loon-years. To generate compensatory loon years, it was initially estimated that 25 common loon nests would need protection from development for 100 years. Following a $3 million settlement with the parties responsible for the spill, we conducted surveys to identify the highest quality breeding loon habitat for protection. Monitoring efforts included 184 loon territories from 2000 to 2009, representing 866 loon territory-years on 70 lakes in four regions of Maine. To evaluate restoration effectiveness, an updated REA was conducted using productivity data collected from these surveys. Results from the updated REA indicated that were these site-specific data available when the REA was originally generated, 70 nests would have been required to offset the lost loon-years – this project permitted the protection of 119 nests. Future REAs should incorporate site specific productivity data whenever possible to most accurately scale restoration to injury. Ranking lake habitat quality further optimizes restoration effectiveness. Our results indicate breeding success was highest on 24–81 ha lakes and that emphasizing protection of lakes with loon territories in this size class is optimal. Our results demonstrate a need for site-specific restoration plans to achieve the greatest restoration benefits.

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* Corresponding author.
E-mail addresses: david.evers@briloon.org (D.C. Evers), molly_sperduto@fws.gov (M. Sperduto), carrie.e.osborne@maine.edu (C.E. Gray), jparuk@sjcme.edu (J.D. Paruk), kate.taylor@briloon.org (K.M. Taylor).

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1. Introduction

Oil spills are a chronic problem in the marine environment (Atlas and Hazen, 2011). Approximately 5.21 million metric tonnes of oil was spilled worldwide as a result of oil tanker accidents from 1970 to 2013 (ITOPF, 2013). While the total oil spilled by tankers has decreased per decade due to improvements in the safety technology of vessels (e.g., from 2,898,000 to 193,230 metric tonnes for 1970–1979 and 2000 to 2009, respectively), the ecological and financial consequences of oil spills are significant and often result in long-term damages to natural resources (ITOPF, 2013). For example, oil pollution can have deleterious effects on every component of the marine ecosystem, from organisms, to habitats and community structure (Burger, 1993; Peterson et al., 2003; Whitehead, 2013). Seabirds, in particular, are at risk from oiling. Oiled seabirds may die from drowning or hypothermia. Oiled feathers easily become water-logged and their associated loss of buoyancy can quickly lead to drowning or they lose their ability to form cross bridges with other feathers, allowing water to reach their skin which leads to heat loss, a compensatory increase in metabolic rate and eventually, hypothermia (Jennsen and Ekker, 1991; Newman et al., 2000; O'Hara and Morandin, 2010; Haney et al., 2017).

Oil consists of polycyclic aromatic hydrocarbons (PAHs), which are highly mutagenic, carcinogenic, and toxic to wildlife (Dubansky et al., 2013; Fallon et al., 2018). Ingestion of oil, via preening or through consumption of contaminated prey, results in a variety of sublethal effects, such as anemia, immunosuppression, organ damage, loss of osmoregulatory function and weight loss (Leighton et al., 1983; Golet et al., 2002; Dubansky et al., 2013; Paruk et al., 2016; Fallon et al., 2018). In addition, ingestion of PAHs may reduce productivity and long-term survival (Zuberogoitia et al., 2006; Alonso-Alvarez et al., 2007; Iverson and Esler, 2010).

On 19 January 1996, the *North Cape* oil tanker caught fire and grounded on the coast of Rhode Island resulting in the uncontrolled release of approximately 3, 134 metric tonnes of home heating oil. The oil spread throughout much of Block Island Sound and within coastal salt ponds that lie along the southern Rhode Island coastline resulting in the death of invertebrates (lobsters, surf clams, etc.) and vertebrates (fish, birds) (USFWS, 2005). The clear majority of the estimated 2292 birds killed were marine birds (2082), including loons, grebes, gulls and waterfowl (Sperduto et al., 2003). Approximately 20%, or a projected 402 of those seabirds killed were common loons (*Gavia immer*) and 12 were red-throated loons (*Gavia stellata*). United States law (U.S. EPA, 1990), 33 U.S.C. § 2701, et seq.) authorizes state and federal natural resource trustees to seek compensation for natural resources injured by oil pollution. Under the Natural Resource Damage Assessment and Restoration (NRDAR) framework, trustees strive to make the public whole for injuries to natural resources and natural resource services.

NRDAR is a multi-stepped process; for oil spills the process is outlined in the Oil Pollution Act (15 CFR Part 990). The first phase (preassessment) involves a preliminary assessment to determine whether an injury to natural resources has occurred and whether feasible restoration alternatives exist to address the injuries. During the second phase (restoration planning), trustees determine the amount of natural resources or natural resource services that were impacted, select appropriate restoration, and calculate the cost to implement the restoration (damages). Restoration in the NRDAR context refers to any project designed to offset the loss of natural resources and their services resulting from an oil spill. The third or final phase (restoration implementation) focuses on implementing restoration and monitoring and evaluating its effectiveness.

Restoration to mitigate seabird mortalities often involves management, protection, or enhancement of breeding habitat that may or may not be within the oil spill area. In the case of the estimated 402 common loons (*Gavia immer*) and 12 red-throated loons killed in the *North Cape* Oil Spill (NCOS) the preferred restoration method was to bolster fledging production of common loons through protection of quality breeding habitat. Restoration focused on common loons, since the majority of loons killed (97%) were common loons. Common loons breed on freshwater lakes in northern USA and Canada and winter in predominately marine environments (Evers et al., 2010). Previous studies documenting the recovery and re-sighting of known, uniquely banded individuals in addition to satellite tracking data indicated that the loons killed by the NCOS on their wintering waters off the coast of Rhode Island represented breeding populations in Maine, Massachusetts, New Hampshire, and Vermont (BRI, unpublished data). The total Common loon population in New England, including Maine, Massachusetts, New Hampshire, and Vermont was estimated at 2124 territorial pairs (Evers et al., 2010); therefore, the 402 loons killed in the spill may have represented approximately 9.5% of New England breeding loons. While "restocking" was an appropriate restoration strategy for some of the species affected by the spill and is preferred, the direct replacement of loons through field rearing had not been established at the time. The placement of artificial nesting platforms on lakes with suitable foraging and nursery habitat was considered, however, the trustees determined the compensation of this injury would instead focus on the protection through purchase of lake shoreline breeding habitat in northern New England.

The overall objective of this study was to monitor and assess the effectiveness of Common loon restoration implementation efforts following the NCOS and to discuss considerations for future NRDARs involving Common loons.

2. Methods

The following methods were used to: 1) quantify injury and scale restoration; 2) select sites for restoration implementation; and 3) monitor and assess the effectiveness of restoration efforts.

2.1. Injury quantification and restoration scaling

Sperduto et al. (2003) quantified the total injury to Common loons incurred as a result of the NCOS and estimated the amount of restoration necessary to compensate for the injury utilizing a resource equivalency analysis (REA). The principal concept underlying the REA is that one can quantify in a common metric the loss attributable to the oil spill and the gain to be achieved by the implementation of restoration projects over time, to determine the proper scale of the restoration effort to replace the total quantity of past, current, and future loss of the species injured by the oil spill (Unsworth and Bishop, 1994; Zafonte and Hampton, 2005). The demographic variables within a REA include productivity rates, annual subadult (<3 years of age) and adult survival, lifespan, and more (Table 1). Microsoft Excel spreadsheets were utilized to perform the scaling calculations, as described in Sperduto et al. (2003).

Using REA, Sperduto et al. (2003) calculated an estimate of lost "discounted loon-years" that accounted for the total number of loon-years lost as a result of the spill and the loss of loon-years associated with the foregone production of first generation (F1) individuals that would otherwise have been produced. The losses, calculated on a year-by-year basis, were expressed in 1996 bird-years (the year of the spill) using standard economic approaches. The total common loon restoration debit was estimated to be 2835 discounted loon-years and the total estimated injury to Red- throated Loons (*Gavia stellata*) was estimated to be 85 discounted loon-years. The injuries from the two species were summed and then adjusted with an increase of 3% annually to account for the four-year delay from the date of the spill to the date of settlement. The injury was then reduced to account for an expected increase in survival for adult loons breeding in the territories protected through the restoration project. This resulted in a total injury of 3193 discounted lost loon-years (Sperduto et al., 2003). The long-term protection of nesting sites that might otherwise be lost to shoreline

Table 1

Biological parameters used to calculate total loon-years gained per nest protected in North Cape Oil Spill restoration plan for three different scenarios: A) original calculations from Sperduto et al., 2003; B) actual measured productivity and original demographic parameters from Sperduto et al., 2003; and C) actual measured productivity and refined demographic parameters based on Mitro et al., 2008 (adult survival), Piper et al., 2012 (juvenile survival), and Evers et al., 2010 (overall productivity and maximum age).

Demographic parameter	Scenario A	Scenario B	Scenario C
Productivity gain in protected area	0.5 fledglings/nest	0.22	0.22
Productivity of offspring	0.54 fledgling/territorial pair	0.54	0.48
1st year survival rate	0.76	0.76	0.81
Adult survival rate	0.88	0.88	0.81 in year 2 0.81 in year 3 $0.92 > 3$ yrs
Average life expectancy of a newly hatched loon (discounted)	4.95 yr	4.95 yr	5.58
Average age at first breeding	5 yr	5 yr	6 yr
Maximum age	24 yr	24 yr	30 yr
Proportion of adult loons that maintain territories	0.80	0.80	0.80
Discount rate	0.03 yr^{-1}	0.03 yr^{-1}	0.03 yr^{-1}
Number of nests needed to compensate for the NCOS loss	25	57	51/70[a]
Loon years fledged/nest over 100-yr project life span	129	57	64

[a] A total of 50 nests would be needed to compensate for the losses as originally calculated from the NCOS; however, if the updated demographic parameters are utilized to re-calculate the injury then it would increase, resulting in a protection requirement of 70 nests.

development was anticipated to prevent future losses in productivity. To calculate the total loon years produced per nest over the 100-year project timeline, the estimated productivity gain (fledglings/nest) was multiplied by the expected lifespan of a bird. The loon years attributable to these offspring were summed for the 100-year project timeline. The loon years attributable to the second-generation offspring were also calculated and added to determine the total number of loon-years produced per nest over the 100- year project lifespan. Credit for fledglings produced beyond the second generation was not included in the scaling. As depicted in Table 1, the protection of 25 nests for 100 years was expected to compensate for the lost loon-years.

2.2. Selecting sites for restoration implementation

Funds paid by the responsible party for the lost loon-years were administered through the U.S. Fish and Wildlife Service (USFWS) on behalf of the Trustees for the NCOS (National Oceanic and Atmospheric Administration, State of Rhode Island, and USFWS) to permanently protect nesting habitat, through conservation easements and fee acquisitions.

To identify the highest quality breeding loon habitat for protection, surveys were conducted on lakes that were potentially available for acquisition to find and evaluate loon territories. Loon territories were evaluated with a quantitative ranking matrix developed by Evers et al. (2002) to rapidly assess overall habitat quality for breeding common loons. The matrix was based on 10 parameters considered logistically feasible to measure and ecologically relevant to breeding loons, including: lake territory type (i.e., whole, partial, or multiple), magnitude of water level fluctuations associated with dam controls, availability of nesting islands, shoreline development, presence of boat ramps, accessibility of the water body to humans, maximum depth, pH, apparent color, and clarity of water. The ten parameters received equally-weighted ranking values (deemed suitable for the coarse resolution of information needed) and were summed for each territory and divided by the number of possible points to determine the territory's relative value. These values ranged from 0.00 to 1.00 and were divided into seven habitat quality categories ranging from extra-low to extra-high. Nest protection projects were prioritized using the habitat quality rankings. Areas selected for acquisition ranked "moderate", "moderate-high", "high", and "extra-high for habitat quality". Lake shoreline areas with a ranking below "moderate" were not considered for protection.

Through partnerships with other existing land conservation initiatives ($3 million dollars in settlement funds were combined with over $100 million in other non-spill related funds), nearly 607,028 ha (1.5 million acres) of Maine forests and waters were acquired to support an estimated 184 territorial pairs (USFWS, 2005). Shoreline breeding habitat totaling 703 km was protected through fee acquisitions and conservation easements in four regions of Maine: the West Branch of the Penobscot River (Area 1, $n = 141$ km), Allagash Lakes (Area 2, $n = 255$ km), Rangeley Lakes (Area 3, $n = 75$ km), and Downeast Lakes (Area 4, $n = 232$ km) (Fig. 1).

2.3. Monitoring and evaluating the restoration effort

Following the acquisition of these lands, we monitored reproductive success of territorial pairs for three to ten consecutive years (2000–2009) in the four regions to determine average overall productivity. The site-specific productivity was used to model regional demographics over time and evaluate important landscape parameters impacting reproductive output, as well as to recreate the REA to evaluate the success of the restoration effort.

To ensure that productivity data was robust for the region, we also surveyed territories outside of the acquisition boundaries that were either part of the same water body or were on a water body within close proximity to the protected shoreline areas. The Allagash Lakes study area consisted of 27 lakes ranging in size from 25 to 1859 ha. The Downeast Lakes study area included 28 lakes ranging in size from 23 to 4170 ha in the St. Croix River, Machias River, East Machias River, and Dennys River watersheds. The Rangeley Lakes study area contained eight lakes ranging in size from 19 to 6620 ha. The West Branch of the Penobscot River study area included 13 lakes ranging in size from 18 to 30,308 ha.

Ground surveys were conducted across the four regions during the common loon breeding season, mid-May to late August to determine occupancy of territorial pairs and document territory boundaries, number of nesting pairs, chick hatching success, and chick fledging rates. Survey methods were consistent with those reported in Evers (2007). All known or potential loon territories and surrounding areas were surveyed using 10× binoculars with occasional use of a 15–45× spotting scope. Motorized boats were used on large water bodies; canoe or kayak was used on small water bodies or moderate- and large-sized lakes with poor road access or launching facilities. All known territorial pairs were generally surveyed once per week. Variations in this schedule resulted mainly from prohibitive weather conditions or logistical infeasibility. Every effort was made to gather information from the greatest distance possible from the loons to minimize impacts on nesting and brooding activities.

Loon territories were delineated according to observed territorial behavior by a pair, such as close physical association, defensive posturing and vocalizing along borders. Nesting pairs were defined as those laying at least one egg and successful pairs as those that hatched at least one chick. Chicks hatched were recorded as those that hatched completely out of their eggs, not necessarily departing from the nest. Chicks fledged refers to individuals >6 weeks of age. Loon chicks that survive past six weeks of age have a survival rate > 0.95 (Evers et al., 2010).

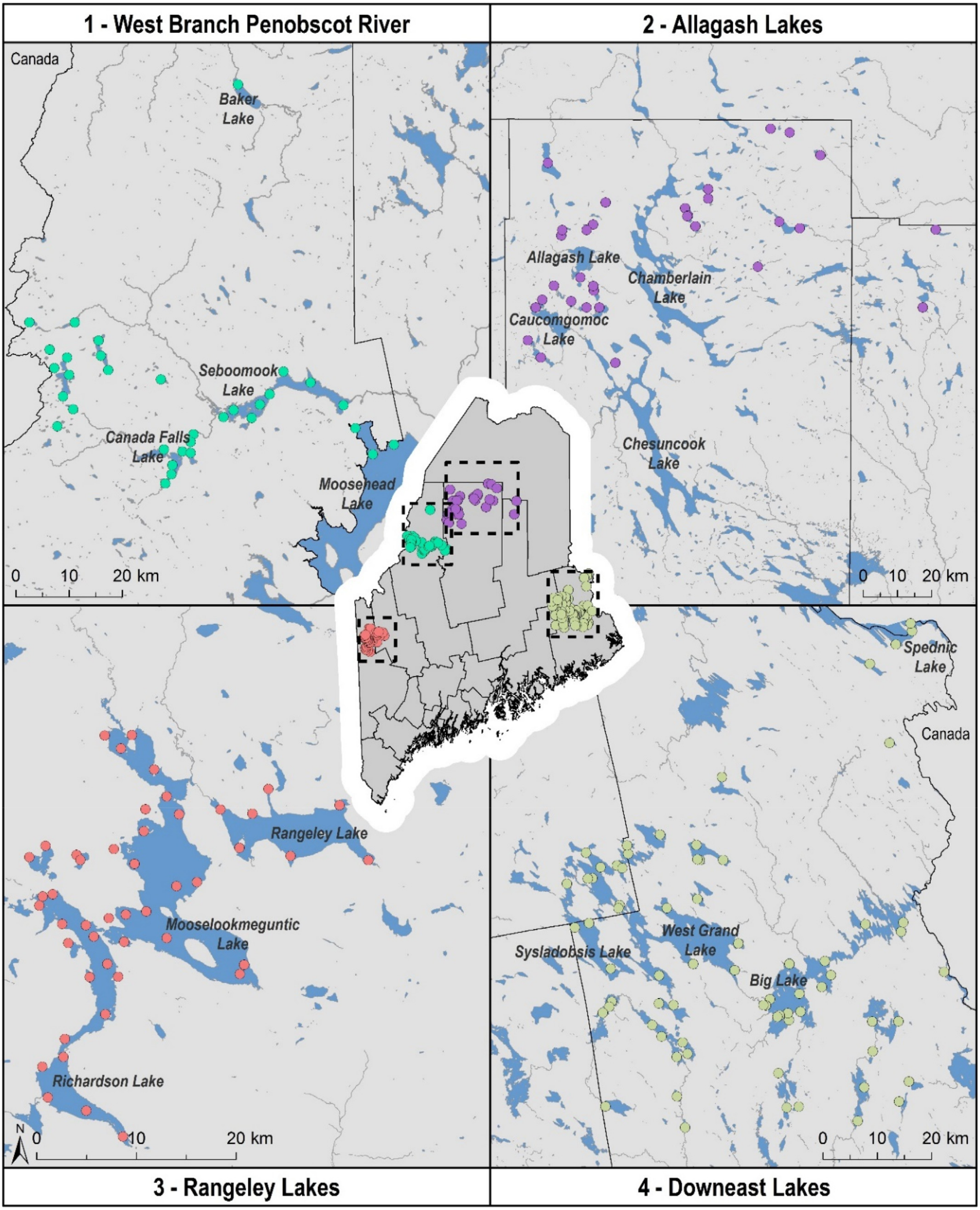

Fig. 1. Distribution of territorial pairs protected with the purchase of fee acquisitions and conservation easements in four regions of Maine: Allagash Lakes, Downeast Lakes, Rangeley Lakes, and the West Branch of the Penobscot River.

2.4. Reproductive success and habitat analysis

Reproductive success among study regions and habitat ranking categories were evaluated according to four parameters: nesting frequency (NF), hatching frequency (HF), chick survivorship (CS) and overall productivity (OP). Nesting frequency was defined as the number of nesting pairs per total territorial pairs (on average, 68% of the territorial pairs nest in a given year; Evers et al., 2010). This measure indicates the percent of the total potential breeding population that attempts to reproduce each season. The rate of success by these pairs, or hatching frequency, was measured through the number of chicks hatched by these pairs. Chick survivorship was defined as the number of chicks fledged divided by the number of chicks hatched. Overall productivity is a combination of the prior three parameters and measured through fledged young per territorial pair. These parameters were determined for each study region and were examined for each habitat ranking category previously described. Reproductive success was also examined by lake size, which was assigned to one of six size classes (ha): <24, 24–81, 82–202, 203–809, 810–1619, and ≥1619. These were based on categories from Cross (1979); however, two modifications were made based on known breeding loon ecology. For example, we changed the smallest lake size category from <20 ha to <24 ha based on observations that loons that nest on lakes that are <24 ha require multiple lakes for their breeding territories (Piper et al., 1997). The other modification included creating the 24–81 ha size in lieu of Cross (1979) 21–40 and 41–81 ha size classes. Long-term observations indicate that lakes that support more than one pair of loons were all >81 ha (BRI unpubl. Data). Therefore, the 24–81 ha size class represents individual territories that are comprised of a single whole lake.

2.5. Resource equivalency analysis

To evaluate the success of the restoration effort, we utilized the approach in Sperduto et al. (2003) to compute the benefits from three scenarios (Table 1). Scenario A, utilized inputs from Sperduto et al. (2003). Scenario B employed site-specific productivity measures and Scenario C used site-specific productivity and refined survival and life history information. Specifically, Mitro et al. (2008) examined 10 years of common loon banding data in New England and published an updated adult survival estimate of 0.92 for loons >3 years old, compared to 0.88 used in Scenario A (Table 1). Additionally, Piper et al. (2012) determined that the survival estimate for juvenile birds was 0.81 each year for the first three years of life until it reaches adulthood, whereas the original REA calculation used an estimate of 0.76 for the first year and the adult survival estimate for each subsequent year. Other life history parameters were updated according to Evers et al., 2010, including: (1) a refined productivity rate necessary for maintaining a stable population of 0.48 that had previously been determined to be 0.54; (2) the average first age of breeding at 6 years of age that had previously been considered to be 5 years of age; and (3) the average lifespan of 30 years which had previously been considered to be 24 years.

3. Results

3.1. Reproductive success

Seventy-nine lakes were surveyed for breeding loons during 2000 to 2009, of which 184 territories were documented on 70 lakes representing 866 loon territory years (Table 2). The Allagash Lakes region was surveyed from 2000 to 2004; the Downeast Lakes region from 2005 to 2009; the Rangeley Lakes region from 2000 to 2009; and the West Branch region from 2004 to 2006. The number of territories occupied by territorial loon pairs within a given survey year were averaged across survey years and found to be highest in the West Branch region (2004 and 2006) at $\bar{x} = 0.99 \pm 0.02$ followed by the Rangeley Lakes region at $\bar{x} = 0.85 \pm 0.18$ (2000 to 2009). However, while occupancy of territories for the Rangeley Lakes region was generally above 0.90 between 2000 and 2006, the rate decreased to 0.75 in 2007, 0.43 in 2008, and then improved slightly to 0.72 during the last year of surveys for this project in 2009. Mean occupancy rates in the other regions were: $\bar{x} = 0.67 \pm 0.07$ (range: 0.59 to 0.76) between 2000 and 2004 in the Allagash Lakes region and $\bar{x} = 0.67 \pm 0.15$ (range: 0.54 to 0.90) between 2005 and 2009 in Downeast Lakes region.

Table 2
Total average number of common loon territories surveyed per year in acquisition areas and non-acquisition areas by four regions in Maine, 2000–2009.

Shoreline type	Total loon territories				Total
	West Branch Penobscot River	Allagash Lakes	Rangeley Lakes	Downeast Lakes	
Acquisition area	20	23	18	58	119
Non-acquisition area	13	8	32	12	65
Total	33	31	50	70	184

Mean annual productivity across all regions was 0.22 ± 0.11. Mean annual overall productivity was highest in the Rangeley Lakes region ($\bar{x} = 0.27 \pm 0.14$); however, no significant differences between regions were detected (Table 3). Productivity rates for all regions were lower compared to nearby New Hampshire lakes ($\bar{x} = 0.53 \pm 0.09$) monitored by the Loon Preservation Committee (Moultonborough, NH), where the breeding loon population is considered to be growing or at a self-sustaining level. Kruskal-Wallis test results indicated that annual nesting frequency varied significantly among regions ($\chi^2 = 11.94$, $p = 0.001$) and comparisons for all pairs using the Steel-Dwass method showed that the Downeast region ($\bar{x} = 0.46 \pm 0.07$) was significantly lower than the Rangeley Lakes region ($\bar{x} = 0.64 \pm 0.09$) ($p = 0.03$); no other significant differences were detected among regions (Table 3). Hatching frequency was highest in the Downeast region ($\bar{x} = 0.79 \pm 0.10$); however, this region also had the lowest chick survivorship ($\bar{x} = 0.53 \pm 0.10$). Chick survivorship was highest in the West Branch region ($\bar{x} = 0.71 \pm 0.09$); none of the differences in hatching frequency or chick survivorship between regions was significant.

3.2. Habitat ranking and lake size

Quantitative habitat ranking of moderate to highly ranked loon territories within the study area resulted in 24% ranked as “moderate” breeding loon habitat quality ($n = 47$), 34% “moderate-high” ($n = 69$), 30% “high” ($n = 59$), and 12% extra-high ($n = 25$). Mean annual productivity was highest in the high habitat quality category: $\bar{x} = 0.24 \pm 0.14$ (Fig. 2). However, no significant differences in annual productivity were observed among habitat quality categories; moderate ($\bar{x} = 0.17 \pm 0.13$); moderate-high ($\bar{x} = 0.21 \pm 0.11$); and extra-high ($\bar{x} = 0.19 \pm 0.19$). No significant differences in chick survivorship were observed between habitat quality categories: moderate ($\bar{x} = 0.67 \pm 0.21$); moderate-high ($\bar{x} = 0.55 \pm 0.23$); high ($\bar{x} = 0.59 \pm 0.19$); and extra-high ($\bar{x} = 0.46 \pm 0.31$). Similarly, no difference was detected in hatching frequency: moderate ($\bar{x} = 0.60 \pm 0.41$); moderate-high ($\bar{x} = 0.73 \pm 0.26$); high ($\bar{x} = 0.68 \pm 0.20$); and extra-high ($\bar{x} = 0.66 \pm 0.34$). Nesting frequency also did not differ significantly: moderate ($\bar{x} = 0.43 \pm 0.20$); moderate-high ($\bar{x} = 0.57 \pm 0.11$); high ($\bar{x} = 0.57 \pm 0.05$); and extra-high ($\bar{x} = 0.50 \pm 0.26$).

Kruskal-Wallis rank sums test indicated that mean annual overall productivity varied among lake size classes ($\chi^2 = 22.40$, $df = 5$, $p < 0.001$) (Fig. 3). Mean annual productivity was highest on the single territory lake size class (24–81 ha) ($\bar{x} = 0.40 \pm 0.28$) and pairwise comparisons using the Steel-Dwass method revealed that it was significantly greater than productivity observed on the smallest lake size class, <24 ha ($\bar{x} = 0.05 \pm 0.16$, $p = 0.03$) and the 82–202 ha size class ($\bar{x} = 0.10 \pm 0.11$, $p = 0.04$), but not the other lake size classes. Productivity on the <24 ha lakes was also significantly lower than productivity

Table 3
NCOS study sites by region and years surveyed for loon demographic variables (i.e., territorial (TP), nesting pair (NP), chicks hatched (CH) and chicks survived (CS)).

Region	Years Surveyed	Total Lakes Surveyed	Territory Years	Mean (SD) Annual TP	Mean (SD) Annual NP	Mean (SD) Annual CH	Mean (SD) Annual CS	Mean (SD) Annual Nesting Frequency	Mean (SD) Annual Hatching Frequency	Mean (SD) Annual Chick Survivorship	Mean (SD) Annual Overall Productivity
NCOS study sites											
Allagash	2000 to 2004	27	90	18 (2)	9 (3)	5 (1)	3 (2)	0.51 (0.11)	0.57 (0.21)	0.58 (0.34)	0.17 (0.10)
Downeast	2005 to 2009	31	298	58 (9)	26 (3)	21 (4)	11 (4)	0.46 (0.07)	0.79 (0.10)	0.53 (0.10)	0.19 (0.06)
Rangeley	2000 to 2009	8	386	39 (8)	24 (3)	17 (5)	10 (5)	0.64 (0.09)	0.72 (0.16)	0.56 (0.17)	0.27 (0.14)
West branch	2004 to 2006	13	92	29 (2)	12 (2)	8 (4)	6 (2)	0.42 (0.07)	0.64 (0.31)	0.71 (0.09)	0.19 (0.08)
NCOS study sites combined	2000 to 2009	79	866	144 (6)	71 (3)	51 (4)	30 (3)	0.55 (0.12)	0.69 (0.18)	0.58 (0.19)	0.22 (0.12)
Regional comparisons[a]											
New York	1999 to 2007	44	541	44 (13)	35 (11)	36 (12)	26 (9)	0.80 (0.05)	1.08 (0.19)	0.72 (0.09)	0.62 (0.16)
New Hampshire	2000 to 2009	265	2196	220 (20)	149 (20)	148 (17)	115 (12)	0.68 (0.04)	0.99 (0.13)	0.78 (0.05)	0.53 (0.09)

[a] Regional comparisons' data are from unpublished data provided by the Adirondack Center for Loon Conservation in New York and the Loon Preservation Committee in New Hampshire.

rates observed on all other lake size classes ($p < 0.05$) except the 82–202 ha size class. Low chick survivorship appeared to be the greatest contributing factor on <24 ha lakes ($\bar{x} = 0.10 \pm 0.22$); however, no significant differences were detected between size classes; 24–81 ha: $\bar{x} = 0.71 \pm 0.33$; 82–202 ha: $\bar{x} = 0.48 \pm 0.47$; 203–809 ha: $\bar{x} = 0.56 \pm 0.33$; 810–1619 ha: $\bar{x} = 0.68 \pm 0.22$; >1619 ha: $\bar{x} = 0.54 \pm 0.20$. Kruskal-Wallis rank sums test indicated that mean annual hatching frequency varied significantly among lake size classes ($\chi^2 = 11.95$, df = 5, $p = 0.04$). Hatching frequency was highest on the single territory lake size class (24–81 ha; $\bar{x} = 1.23 \pm 0.47$) and pairwise comparisons using the nonparametric Steel-Dwass method showed that it was significantly greater than hatching frequency on the largest lake size class (>1619 ha) ($\bar{x} = 0.63 \pm 0.19$, $p = 0.001$). No other significant differences in hatching frequency were detected between lake size classes [<24 ha ($\bar{x} = 0.75 \pm 0.71$), 82–202 ha ($\bar{x} = 0.60 \pm 0.42$), 203–809 ha ($\bar{x} = 0.74 \pm 0.43$), 810–1619 ha ($\bar{x} = 0.80 \pm 0.14$), <1619 ha ($\bar{x} = 0.63 \pm 0.19$)]. Little variation was observed in mean annual nesting frequency among lake size classes and no significant differences were detected: <24 ha ($\bar{x} = 0.58 \pm 0.40$); 24–81 ha ($\bar{x} = 0.52 \pm 0.24$); 82–202 ha ($\bar{x} = 0.52 \pm 0.25$); 203–809 ha ($\bar{x} = 0.43 \pm 0.11$); 810–1619 ha ($\bar{x} = 0.49 \pm 0.11$); and >1619 ($\bar{x} = 0.61 \pm 0.09$).

3.3. Resource equivalency analysis

3.3.1. Scenario A

During the development of the NCOS restoration plan, the number of loon-years each protected nest would generate over a 100-year project lifetime was based on an estimated 0.50 productivity gain per nest (Sperduto et al., 2003). Based on available demographic information at the time, an estimated 129 additional loon-years would be generated per nest, resulting in the requirement of 25 protected nests (Table 1, Scenario A).

3.3.2. Scenario B

The observed productivity rate for the study sites was lower than projected: 0.22 versus 0.50. Using the observed average productivity rate for the 4 study areas of 0.22 and the original demographic parameters, it was determined that 57 loon-years would be generated per nest, which would require the protection of at least 57 nests to compensate for the losses from the NCOS (Table 1, Scenario B).

3.3.3. Scenario C

The observed productivity rate of 0.22 and the refined demographic parameters for adult survival, juvenile survival, lifespan, and average first breeding age were used for a third analysis. The results indicated that 64 loon-years would be generated per nest, which would require the protection of 51 nests to compensate for the losses as originally calculated from the NCOS. If the updated demographic parameters (other than the site-specific productivity) were utilized to re-calculate the injury, the calculated injury would increase, resulting in a protection requirement of 70 nests.

4. Discussion

Common loons are a classic example of a K-selected species. They are long-lived with an estimated lifespan of around 30–35 years,

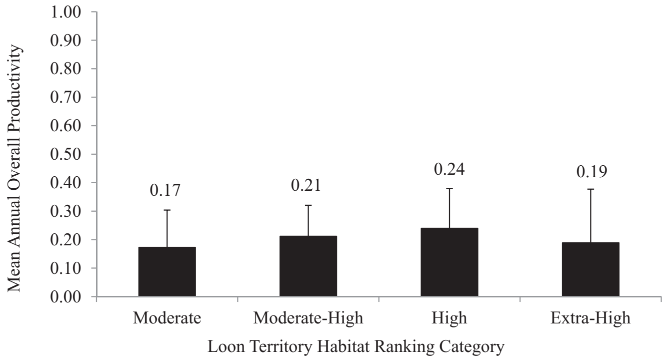

Fig. 2. Mean plus standard deviation annual productivity of common loons according to habitat ranking category of breeding territory among sites surveyed in Maine, 2000 to 2009. Sample sizes for overall productivity estimates are based on years when the territory was occupied by a territorial loon pair, territory years (TY): Moderate (n = 148 TY), Moderate-High (n = 280 TY), High (n = 287 TY), Extra-High (n = 84).

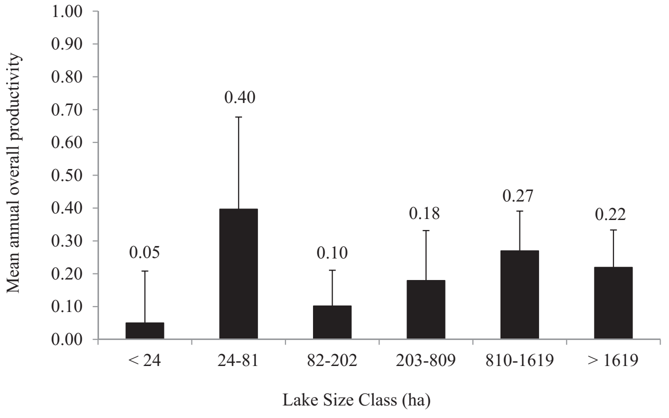

Fig. 3. Mean plus standard deviation annual productivity of common loons according to size of the breeding lake among sites surveyed in Maine, 2000 to 2009. Sample sizes for overall productivity estimates are based on years when the territory was occupied by a territorial loon pair, territory years (TY): <24 (n = 17 TY), 24–81 (n = 69 TY), 82–202 (n = 45 TY), 203–809 (n = 188TY), 810–1619 (n = 106 TY), >1619 (n = 428 TY).

experience delayed onset of sexual maturity with average age of first-breeding at 6 years and have a low average lifetime reproductive output of 8–10 young (Evers et al., 2010). Restoration scaling for common loons injured as a result of the NCOS was based on reproductive parameters obtained from long-term monitoring results of New Hampshire's common loon population, which exhibited nesting frequency, hatching success, and chick survivorship at higher rates than found in the four Maine study sites for the NCOS restoration. Using the productivity estimates and demographic parameters from New Hampshire resulted in the development of a restoration plan that required the protection of 25 nests to compensate for losses from the NCOS.

However, monitoring efforts of breeding loon territories in habitat acquired in Maine, as part of the NCOS restoration, indicated productivity estimates that were 49% to 68% less than New Hampshire estimates. If these productivity data were available when the plan was developed, an additional 32 nests (total 57) would have been required for protection. Further, several demographic parameters were refined since the development of the NCOS restoration plan. Sensitivity of the REA to changes in these parameters (e.g., survival) also had an impact on our results. The analysis using the refined adult survival estimate of 0.92, compared to 0.88, and minor refinements with other demographic variables resulted in the creation of seven additional loon years per nest. These additional loon years generated per nest helped to offset the input of lower observed productivity (0.22) into the model, resulting in 51 nests needing protection to restore the originally calculated loon-years lost from the NCOS. If the refined adult survival and other demographic variables are also utilized to calculate the injury, 70 nests are required to offset the loss. This is considered to be the most accurate estimate.

Site-specific data collected from the monitoring of breeding loons within the restoration project area indicated that the use of productivity data from New Hampshire was not optimal for the development of a restoration plan for the study sites in Maine. Lower occupancy, nesting frequency, hatching success, and chick survivorship contributed to poorer overall productivity of common loons within the study area compared to New Hampshire. Factors that may have contributed to the lower reproductive success of common loons in Maine included but were not limited to: inadequate prey base, limited number of nesting islands, water level fluctuations, high predator population densities, human disturbance (based on >20 years of monitoring loon reproductive success for Federal Energy Regulatory Commission regulatory purposes on eight Maine reservoirs) and mercury (Evers et al., 1998, 2003, 2008), especially since northern Maine is considered a biological mercury hotspot (Evers et al., 2007).

Additionally, landscape level effects may explain differences in productivity rates observed among study regions, including lake size, and breeding population density. A demographic aspect that warrants further consideration is annual variation in occupancy rates across a wide geographic range and time period. For example, our monitoring efforts revealed a 56% decrease in occupancy of loon territories in the Rangeley Lakes region between 2006 and 2008; however, half of those vacancies were refilled by the following year. It is uncertain whether these variations occur frequently enough to contribute to population declines. Hazards in loon wintering waters, where loons have high annual site fidelity (Paruk et al., 2015), such as oil spills and cyanobacteria outbreaks related to poor water quality (Evers et al., 2010), must be considered when determining potential causes for drastic annual declines in loon breeding territory occupancy rates.

Habitat protection through the acquisition of private lands is an important restoration tool in the NRDAR process intended to promote natural recovery of injured resources by removing the threat of development activities. Landscape and habitat features and how they relate to population dynamics of the focal species must be carefully examined when considering purchase of land acquisitions for restoration projects. The breeding habitat ranking of "high" was associated with the highest productivity rates. The use of the quantitative ranking matrix developed by Evers et al. (2002), which was confirmed by productivity information, was a key factor when determining restoration sites, which included lakes in the moderate, moderate-high, high, and extra-high habitat categories. However, to maximize productivity gains per nest site, we recommend greater emphasis on acquisition of the highest quality habitat categories rather than moderate quality habitats, particularly in regions where productivity is low. In total, 703 km of shoreline on 79 lakes was protected, 92% of which comprised shoreline along active loon territories.

Based on our findings in Maine, lake size was related to overall productivity and is therefore an important consideration for restoration planning purposes. Specifically, multiple lake territories (<24 ha) tended to have the lowest productivity rates and single territory lakes (24–81 ha) tended to have the greatest productivity rates. Therefore, protection of breeding pairs on other lake sizes may not be as cost-effective as protection of single territory lakes. Common loons are susceptible to nest disturbance; therefore, we recommend that restoration plans involving land acquisitions maintain no less than a 150-m vegetated buffer zone between existing, historical, and potential nesting sites and development areas (Lewis et al., 1999; Hammond, 2009).

It is critical that potential regional variation of demographic parameters is assessed and, if possible, that site-specific inputs are obtained through preliminary monitoring for calculation of REAs, to ensure development of a restoration plan with the capacity for full compensation of injuries to wildlife populations. Regionally-based productivity rates were well above site-specific productivity rates for all four study areas, which resulted in an underestimation of the required restoration. Sensitivity analyses showed that the number of nests required to be protected for restoration is greatly dependent on the estimated productivity, especially as productivity decreases (Fig. 4). Due to the overestimation of productivity in the initial analyses, the calculated restoration requirement of 25 protected loon nests was insufficient to restore fully the injuries to loons from the NCOS. Fortunately for the purposes of recovering the loon-years lost, NCOS settlement money was combined with, and helped to leverage more than $100 million in other funding and an estimated 119 nests were ultimately protected (Table 2). These results highlight how the effectiveness of compensatory mitigation plans can be diminished by a lack of site-specific robust estimates of demographic parameters, such as reproductive success. Surveys of the proposed restoration area should be conducted to determine local demographic parameters for model input before finalizing NRDAR restoration plans.

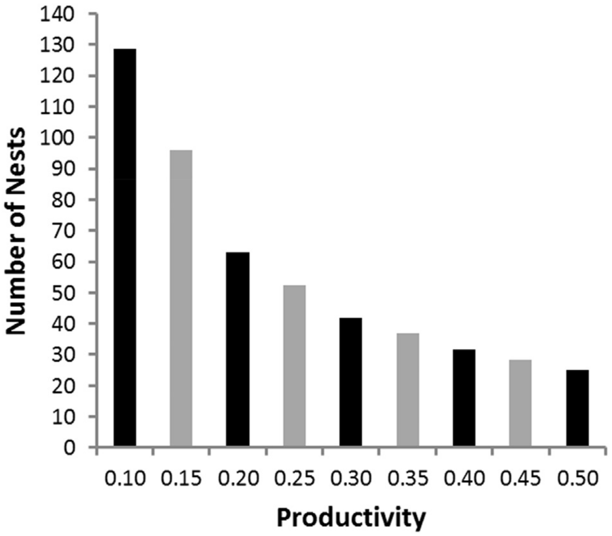

Fig. 4. Number of nests required to be protected to generate lost loon-years in relation to overall productivity rates (i.e., chicks fledged/territorial pair) based on Scenario C models from this paper.

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