RIVER BIRDS AS INDICATORS OF CHANGE IN RIVERINE ECOSYSTEMS

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By Erynn Call

Dissertation Advisor: Dr. Malcolm L. Hunter, Jr.

An Abstract of the Dissertation Presented
in Partial Fulfillment of the Requirements for the
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River-associated birds may be valuable indicators of environmental change in riverine ecosystems because they are predators of fishes and therefore often top predators in the aquatic food web. To evaluate the likely scope of one form of change - river restoration through dam removal and the expected return of abundant diadromous fish prey- we: 1) developed an appropriate river bird survey protocol; 2) documented the relative importance of sea-run fish in the diet of four river bird species, bald eagle (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), belted kingfisher (*Megaceryle alcyon*), and tree swallow (*Tachycineta bicolor*); 3) documented nest distribution and brood size of osprey; and 4) investigated the relationships between river bird abundance and various habitat parameters. We expect these measures will reflect changes to the river system post-dam removal as diadromous fish populations recover, proliferate, and integrate into the food web. Based on species accumulation curves and first-order Jacknifes, we concluded that biweekly or triweekly 15 minute surveys are sufficient to meet our objectives. Within the Penobscot River, stable isotope analysis of river bird diets indicated that marine nutrients are consumed by bald eagle, osprey, and belted kingfishers that reside below the lowermost dam, but not tree swallows. Despite greater connectivity for and abundance of spawning diadromous fishes (particularly river herring), in the Kennebec and Sebasticook Rivers as compare to the Penobscot River, osprey brood size was not significantly larger. We suspect other factors such as competition with bald eagles may be limiting the benefit of large river herring runs to nesting osprey. Finally, an ordination of 26 river bird species and 5 single-species (invertivore - spotted sandpiper, piscivore – osprey; piscivore - bald eagle; insectivore - tree Swallow; and omnivore - American black duck) generalized linear models, I revealed associations between estimated species abundance and water flow, water level, distance from the river mouth (river kilometer), site position in relation to a dam (e.g. above, below, or not at a dam), and adjacent land cover composition.

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Use of wild birds in this research was authorized by the University of Maine IACUC Protocol #A2011-04-09 (tree swallow) and A2011-06-01 (fish collection), US Fish & Wildlife Service Scientific Collection Permit #6400, and Maine Department of Inland Fisheries & Wildlife Scientific Collecting Permit #2012-205.

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EVALUATING THE FRAMEWORK OF A NEW RIVER BIRD SURVEY METHOD

Abstract

River bird assemblages can serve as beacons of environmental change associated with restoration or degradation. River birds regularly rely on riverine resources at some point in their life cycle, vary in the scale of temporal and spatial of use, and forage at multiple levels of the food web (e.g. fish, aquatic plants, aquatic or emergent insects). We present a novel river bird survey method that is more easily employed and less intrusive than river bank transect or boat surveys, and encompasses a wide suite of species and year-round time frame. We evaluate the relative efficacy of different levels of survey duration (20, 15, 10, or 5 minutes), number of surveys (every two weeks in spring and fall and every three weeks in summer and winter), and number of sites on the survey's ability to document species richness and bird abundance. We used two statistical approaches, species accumulation curves (for duration, number of surveys, and number of sites) and first-order Jackknifes (for duration). We conclude that a biweekly or triweekly survey, 25 sites in the focal river, and survey duration of at least 15 minutes is sufficient to meet our objectives. This logistically efficient survey approach facilitates monitoring complex and long-term change such as that associated with river restoration and dam removal.

key words: point count, species accumulation curve, species-richness inventories, river restoration, river bird.

Introduction

Birds are useful indicators of environmental change (Pearson 1995, O'Connell et al. 2000, Buckton and Ormerod 2002, Feck and Hall 2004) due to their sensitivity at both fine and coarse scales (Saab 1999, Buckton and Ormerod 2002, MacFaden and Capen 2002, Clear et al. 2005). Assessing response is often achieved through comparing population sizes and identifying trends. A variety of population survey approaches have been developed depending upon the suite of bird species, habitat, degree of rarity, and other considerations (Bibby et al. 2000, Thompson 2002). For example, there are auditory point counts for territorial passerines (Hutto et al. 1986), broadcast surveys for secretive marsh birds (Conway 2009), aerial or boat direct counts for colonial nesting and flocking species such as seabirds, waterbirds, and waterfowl (U. S. Fish and Wildlife Service and Canadian Wildlife Service 1987, Walsh et al. 1995), and adaptive sampling approaches for rare species (Thompson 2002).

Bird population surveys could also be useful for evaluating riverine systems that are under threat from stressors such as pollution, development, and fragmentation from damming and malfunctioning culverts (WCD 2001). River birds are integrators of environmental change and are linked to riverine food web in multiple ways with many species relying on both riverine and adjacent areas (Steinmetz et al. 2003). Thus riverine birds may be proxies for the ecosystem's biotic production, quality, and hydrogeomorphology (Iwata et al 2003, Collier 2004, Feck and Hall 2004, Mattson and Cooper 2006), and because birds function at a larger spatial scale than many other taxa, they are highly relevant to understanding the linkages between river, riparia, and watershed (Robinson et al. 2002).

In eastern North America the suite of birds that rely on rivers at some point in their life cycle is diverse including piscivores such as Osprey (*Pandion haliaetus*), Bald Eagle (*Haliaeetus leucocephalus*), Belted Kingfisher (*Megaceryle alcyon*), Double-crested Cormorant (*Phalacrocorax auritus*), invertivores such as Spotted Sandpiper (*Actitis macularius)*, insectivores such as Tree Swallow (*Tachycineta bicolor*) and Cedar Waxwing (*Bombycilla cedrorum*), and generalists such as Ring-billed Gull (*Larus delawarensis*) and American Crow (*Corvus brachyrhynchos*). This group of species is an effective ecological indicator of the full complexity of the riverine system because of this variation in diet and feeding techniques (Dale and Beyeler 2001).

Prior research has examined riparian territorial/breeding season passerines (Saab 1999), waterfowl and waders (Weller 1995), or a limited number of river bird species (Loegering and Anthony 1999). A broader suite of species has been surveyed through bank transect (Carter 1989, Bryce et al. 2002) and boat (Fletcher and Hutto 2006) surveys, however these methods likely are more intrusive to birds, and logistically difficult to apply across extensive spatial and temporal scales (i.e. multiple seasons within a year and multiple years). Transect surveys present challenges due to lack of access to private lands and difficulties of traversing rugged terrain. Boat surveys would limit involvement to those with skills and access to suitable boats, and reduce access during high and low flow periods (i.e. dangerous or inadequate water for navigation).

The Penobscot River Restoration Project in Maine offers an opportunity to evaluate the role of birds as an indicator of environmental change in river systems. Current restoration efforts are focusing on improving the river's connectivity for sea-run spawning fishes through dam removal. Maine rivers once contained an abundant, diverse diadromous fish community, including of alewives (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), sturgeon (*Acipenser* spp.), smelt (*Osmerus mordax*), American Shad (*Alosa sapidissima*), sea lamprey (*Petromyzon marinus*), and Atlantic salmon (*Salmo salar*), but populations have plummeted because of barriers to migratory routes (Saunders et al. 2006). The majority of research on the Penobscot restoration examines abiotic characteristics and fish, but understanding how it will affect river-associated birds is a valuable addition.

In this context, it was our goal to develop a survey protocol that could be easily applied across a diverse suite of river bird species, and broad spatial and temporal scales (multiple rivers, multiple years, and all four seasons). Here we present and evaluate a new approach for surveying riverine birds that is not intrusive, and allows substantial temporal and spatial coverage due to efficient logistics.

Methods

Study site

Maine contains more undeveloped, free-flowing rivers than any other state in the Eastern United States, approximately 48,000 km of rivers and streams, or about 1.6 linear km/ km^2 land surface (Maine Department of Inland Fisheries and Wildlife 1982). We conducted river bird surveys at 91 sites, 26 sites directly above and below dams (11 on the Penobscot and 15 sites on 11 other Maine rivers) and 65 sites at non-dam locations (33 Penobscot River, 32 on 11 other Maine rivers). Survey site areas ranged from 0.003 to 1.033 km^2 (average ± SD = 0.1888 ± 0.2188) depending on the position within the river (which affects river width and thus survey site area) and their distance from the river mouth ranged from 0.16 to 172 km.

Survey site selection and design

Survey sites were selected with two main criteria: 1) an experienced citizen-scientist birder was available nearby to facilitate convenient, long-term monitoring, and 2) the standing location was safely accessible to allow year-round visitation with expansive views of the river (i.e., even during floods or deep snow). Sites were usually chosen on the east bank to avoid poor visibility from morning sun glare. The survey area included the river and an approximately 30-m-wide riparian zone. Boundaries were established with clear landmarks on the opposite bank to assure that the survey area was the same for each visit and constant throughout the year (even through winter leaf-off).

Survey protocol

Surveys were 20 minutes in duration and conducted approximately every 2 weeks during spring (April through June) and fall (September through November) and every 3 weeks in summer and winter (if site was iced over surveys were not conducted). Sampling was less frequent in the summer and winter as bird abundance and activity was presumed to be lower than in spring and fall. Observations were separated into four, 5-minute time periods, in which prior and newly arriving river birds (see Appendix A, Table A.1 for complete list of river bird species) within each time band were distinguished and counted. Sex and age were noted when possible, and general behavior exhibited by the majority of birds for the longest proportion of surveyed time was documented. The data sheet listed what we expected to be the most common species but left space for other river bird species observed (see Appendix A.1 for example data sheet and complete survey protocol). Surveys were conducted in the morning (prior to 12:00 pm EST) and not conducted on days where conditions such as extreme wind (> 19 km/h), rain, snow, or fog could alter detection or bird movements. Efforts to limit effects of variation in observer skill level on data collection included recruiting experienced observers and completing training with each observer during in-person, one-on-one meetings at each site prior to initiation of surveys.

Evaluating survey effort

In conducting surveys, it is important to consider the potential biases (observer differences, weather, or time of day) and the influence of sample size. Both observed species richness within a site (alpha diversity) and data from pooled sites (beta diversity) are dependent on sample size because of species turnover or composition (Colwell et al. 2004). The effect of bias can be diminished through designing balanced sampling regimes. Longer, more frequent surveys, or more survey sites may result in more species/individuals observed, however there is a level of effort past which few new birds are observed. To balance both survey efficiency and completeness, it is important to assess different levels of effort.

We considered two approaches to evaluate the importance of survey effort, species accumulation curves (SAC) and the nonparametric first-order Jackknife for estimating total species richness within a site (alpha diversity). Both approaches were applied to the pooled dataset (all years, seasons) and to each season independently (spring, summer, fall, and winter across all years). We evaluated efficiency with respect to the number of surveys and survey duration using the full dataset to construct species accumulation curves with the program Vegan (Oksanen et. al 2011) in the statistical package R (R Development Core Team 2011). We used the same approach to evaluate the number of sites in a limited data set: 20-minute surveys for sites on the Penobscot River that had more than 25 surveys. We also evaluated survey duration and survey results using the first-order Jackknife.

As effort (e.g., number of surveys, sites, and duration) increases, a SAC curve should approach an asymptote where sampling effort is considered sufficient. The curves for riverine surveys, which possess open populations, will likely never completely reach an asymptote because most survey methods are composed of representative samples of the regional community and may not document the rarest species, especially among birds, which have high levels of vagrancy (Blocksom et al. 2009, Gotelli and Colwell 2001). We investigated the influence of rare species by comparing the slope of the curve with and without those species present in < 1% of surveys for the 20-minute pooled data.

To examine survey duration and the number of surveys, SAC curves were created by randomly shuffling the samples (surveys) and calculating an average species richness value per site. This removes the effect of sample order on the species accumulation curve and produces a smoothed curve. Differences in site area do not confound abundance as each site is treated independently. These curves are especially useful when sample sizes (number of surveys) for data subsets (survey sites) are different. Each site had varying number of surveys because of differences in when the site was founded (most were initiated in the spring of 2009) and observer variation. We applied sample-based accumulation curves (as opposed to individual-based which select individuals randomly from the entire data set) because this approach takes site information into account. Curves and associated 95% confidence intervals were plotted and examined visually for asymptotic behavior, and areas along the curves with confidence interval overlap were considered similar (Colwell et al. 2004, Kiraly 2012).

Decreasing the number of sites could also improve efficiency. To address this, SAC's were created by randomly selecting different numbers of Penobscot River sites (n = 40, 20-minute survey duration, only sites with > 25 surveys) and generating a SAC for the entire river. The plateau of the curve denotes the minimum number of surveys necessary to achieve a species richness value comparable to surveying all sampled sites on the Penobscot River.

In addition to evaluating survey effort in terms of the number of surveys and sites, we also examined subsets of survey length. Because the data were recorded in 5 minute intervals, it was possible to subset and plot curves for 20, 15, 10, and 5 minutes, where 15 minutes represents the first 15 minutes of the survey, 10 is the first 10 minutes, etc. The second approach to evaluate effort in terms of survey duration is the first-order Jackknife that estimates the total number of species across the area of inference (as opposed to the average species richness per site with SAC) (Smith and van Belle 1984).

We also examined patterns of bird abundance by plotting the average number of birds per site against 5, 10, 15, and 20 minute subsets of survey duration; we expected the average number of birds per site to be a direct linear function of survey duration.

Results

Survey duration

We conducted 4204 surveys and observed 97 river bird species between September 2008 and July 2012. The raw data show that the number of birds detected was a linear function of survey duration (Figure 1.1). The richness estimates for the four survey durations were similar for the pooled data (i.e., 95% confidence intervals overlapped) and after 60 surveys per site, the species accumulation curves indicated that the pooled mean species richness per site was 28, 26, 24, and 21 for the 20, 15, 10 and 5-minute survey lengths, respectively (whole year, Figure 1.2). Similarly, duration did not strongly affect richness estimates in the seasonal data (Figure 1.3). The high values of the species accumulation curves were unstable because the sample size of sites was low for high numbers of surveys (i.e., sample sizes decreased from 91 sites with at least one survey to 25 sites with 60 surveys along the curves in Figure 1.2).

Figure 1.1. Average number of birds detected per site as a function of 5, 10, 15, and 20 minute survey duration (± 2SE).

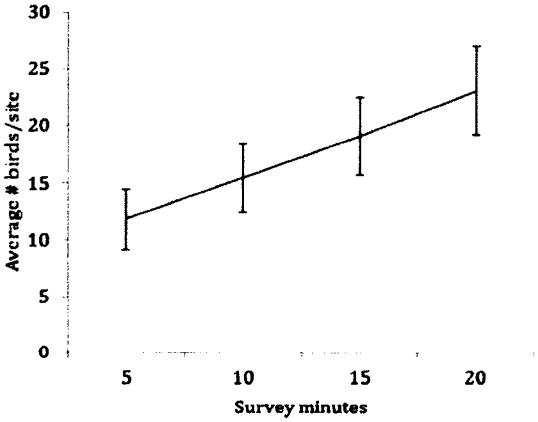
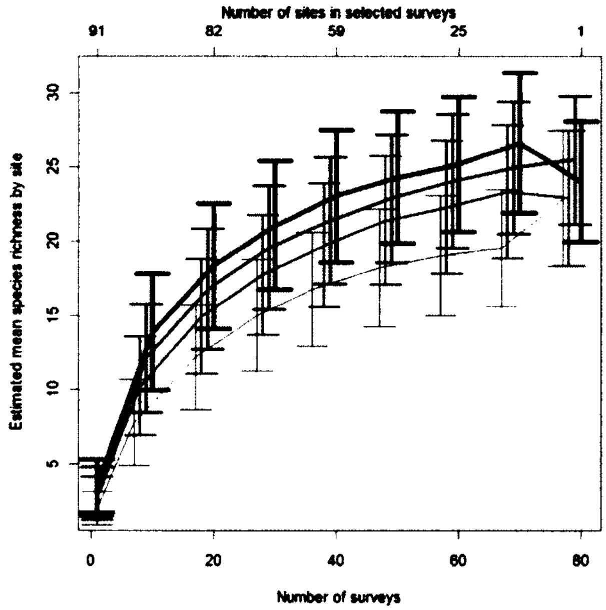


Figure 1.2. Species accumulation curves (± 2SE) of survey length (20, 15, 10, 5 minutes (thickest to thinnest CI respectively; CI slightly offset for ease of comparison).



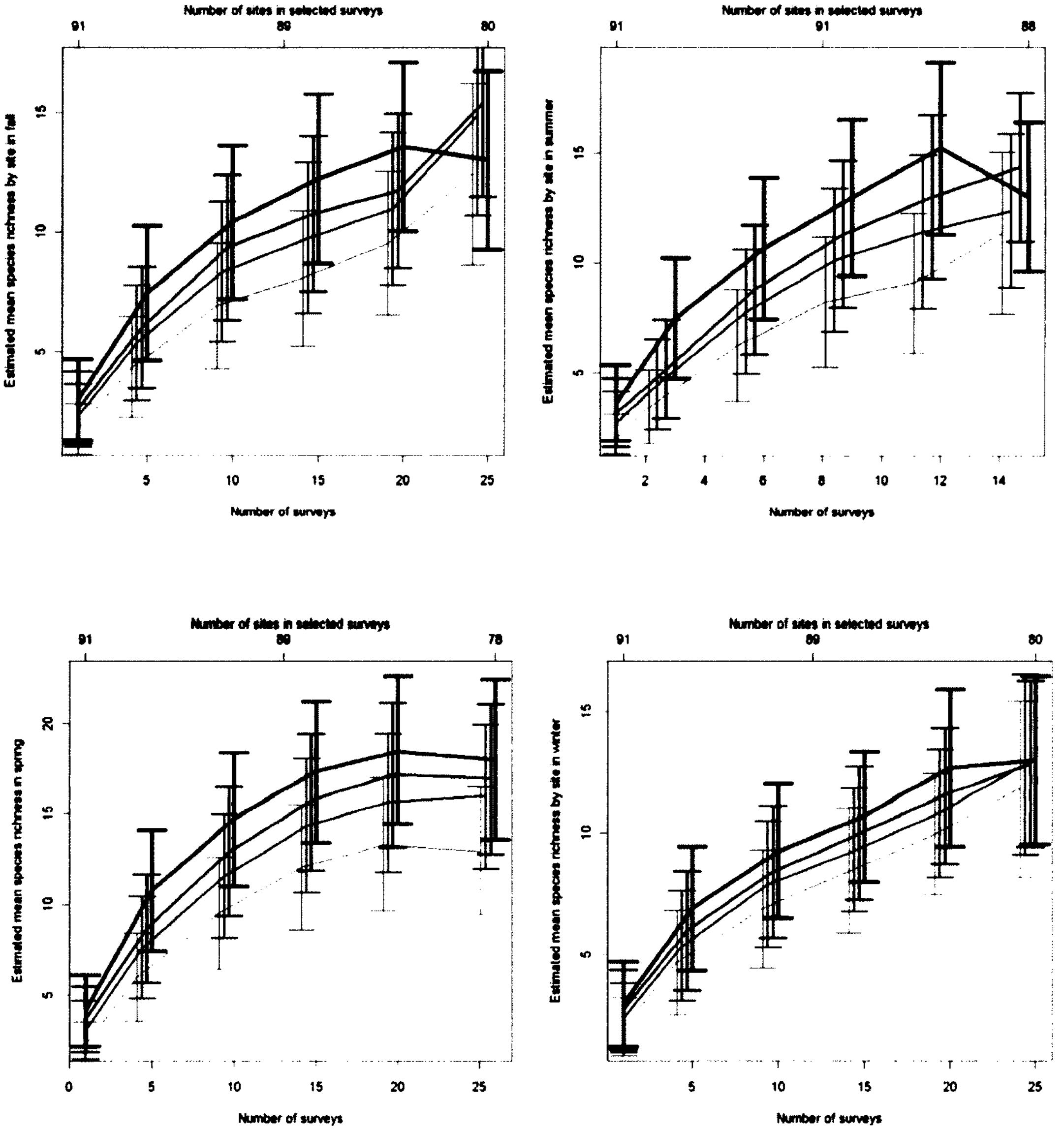


Figure 1.3. Species accumulation curves (± 2SE) for each season (spring: Apr-Jun, summer: July-Aug, fall: Sept-Nov, winter: Dec-Mar) and survey length (20, 15, 10, 5 minutes (thickest to thinnest CI respectively; CI are slightly offset for ease of comparison).

First-order Jackknife values of the total estimated species richness per site were similar between 20, 15, 10, and 5 minute survey lengths, with the exception that the 5-minute interval estimate was lower than the 20-minute estimate for both the pooled and summer data (Table 1.1).

Number of surveys

The survey schedule of every two weeks in the spring and fall and every three weeks in the summer and winter generated approximately 16 surveys per site per year. With this number of surveys the pooled data curves did not apparently reach an asymptote; however, after approximately 40 surveys per site (i.e. after 2-3 years) the slopes were rising less steeply (Figure 1.2). The curves did not reach an asymptote because of the continual observation of new species at the sites. To illustrate this effect on the slope, rare species (those present in < 1% of surveys, 67 out of the 97 species) were omitted using the 20-minute pooled data (Figure 1.4). As expected, the slope of the "common species" curve reached an asymptote sooner than for the total species data set.

Similarly to the pooled data, the slope of the season subset curves did not reach an asymptote. However, the spring curves were less steep after about 15 surveys and reached higher estimated species richness values, relative to the other seasons (Figure 1.3).

Table 1.1. Average first-order Jackknife estimates for total species richness per site for the pooled data and seasonal data (1SE).

	Survey Length	Average Number of Species/Site	Jackknife Estimate	Standard Error	Lower Limit	Upper Limit
Pooled	20	23	30	3	27	33
	15	22	29	3	26	32
	10	20	27	3	24	30
	5	17	23	3	20	26
Spring	20	17	22	3	19	25
	15	16	21	3	18	24
	10	14	19	3	16	22
	5	12	17	2	15	19
Summer	20	12	16	2	14	18
	15	11	15	2	13	17
	10	10	14	2	12	16
	5	8	11	2	9	13
Fall	20	11	15	2	13	17
	15	10	14	2	12	16
	10	9	13	2	11	15
	5	7	11	2	9	13
Winter	20	8	11	2	9	13
	15	8	11	2	9	13
	10	7	10	2	8	12
	5	6	9	2	7	11

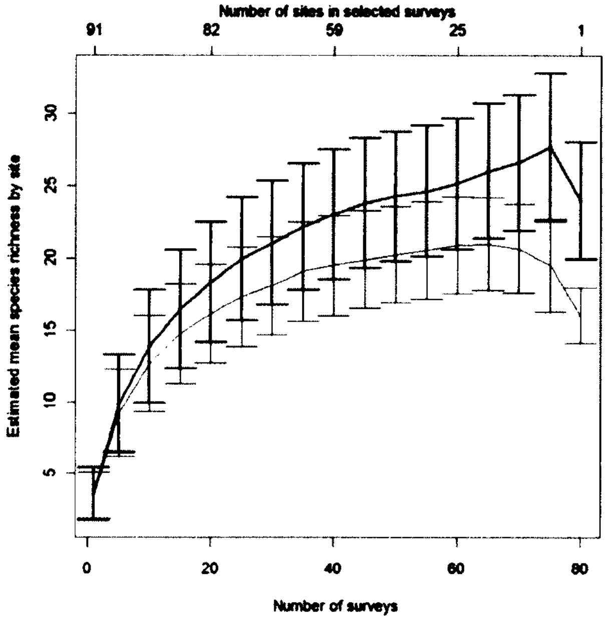


Figure 1.4. Species accumulation curves (± 2SE) for the whole data set (97 species, top) and only 30 common species (bottom).

Number of sites

The pooled Penobscot River data from all 40 sites had an estimated mean species of 76. The value was similar (SR = 73) at 25 sites (Figure 1.5). Even at fewer than 25 sites, the drop in species richness was a consequence of losing species that were observed rarely at a few sites in low numbers. When rare species (those present in < 1% of surveys, 47 out of the 76 species) were removed, the estimated species richness was essentially the same (SR = 28 with 5 sites versus SR = 29 with 40 sites). Within each season the curves did not reach an asymptote, similar to the pooled data, however the common species (29 of the 76 species) were represented.

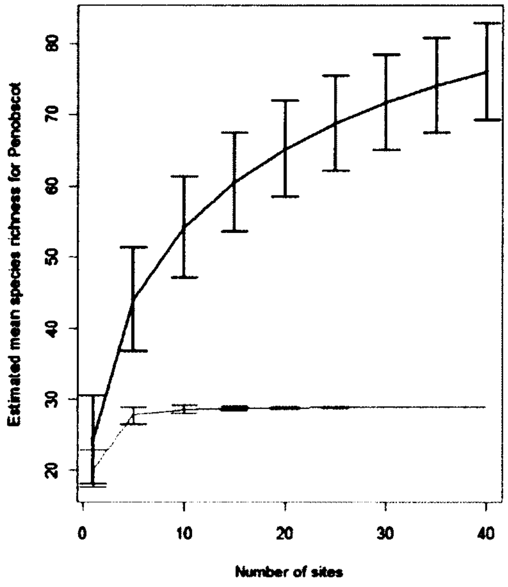


Figure 1.5. Penobscot River species accumulation curve (± 2SE) for the number of sites in the whole dataset (76 species, top) and only 29 common species (bottom).

Discussion

Survey duration

We describe an efficient river bird survey method and evaluate the approach in terms of survey duration and number of surveys using species accumulation curves and the first-order Jackknife. The analysis indicates that survey durations of 10, 15, and 20 minutes generate similar estimates of species richness and that numbers of birds detected is a simple linear function of duration (Figure 1.1). To recommend optimal duration we also sought informal feedback from volunteer surveyors to learn how they felt about the tradeoffs between time invested in travel (i.e., if duration was short relative to the time spent traveling to a site, the effort may seem inefficient to a volunteer) versus boredom and fatigue with longer durations. A clear majority asserted that longer periods were appropriate given the time invested in travel. Thus, considering the statistical results and the preferences of the volunteers we recommend survey duration of at least 15 minutes for studies similar to ours. For efforts using professional surveyors, especially with short travel times between sites, 10-minute surveys might suffice for species richness estimates. Shorter surveys would limit the number of detections of any given species and that could constrain documenting population trends of particular species. Estimates of changes to relative abundance may require longer surveys because of the open system and movement of birds in and out of the survey. However, longer surveys would increase the chance of individuals leaving the survey area then returning.

Number of surveys

For the pooled data, the species accumulation curves did not apparently reach an asymptote, suggesting that new, rarely observed species are continuously detected and added. Studies in other systems such as tropical forests and marine benthos (Erwin 1991, Sanderson 1996) found similar non-asymptotic behavior attributed to rare species. The spring curves, in contrast, nearly reached an asymptote and resulted in higher relative estimated species richness values than other seasons. Depending on the objectives and resources of a particular research project, the spring may provide the best opportunity to quantify the species assemblage with fewer surveys conducted.

The number of surveys conducted at each site could decrease overall if rarely observed species were removed from the analysis. Naturally, this decision depends on the research goals. If riverine surveys are concerned with the ecological function of the avifauna (e.g., interactions between birds and fishes), a common species approach may be appropriate. However, studying the entire avifauna may be necessary to monitor overall community diversity, passage migrants, or rare species of conservation concern, such as Barrow's Goldeneye (*Bucephala islandica*) in the case of Maine. Because the river bird study objectives emphasize ecological function and use of the river by bird species that would benefit from dam removal and diadromous fish restoration, the number of surveys conducted at each site could decrease.

Number of sites

The Penobscot River bird assemblage will be monitored on a more limited scale through the dam removal process and afterwards as the vegetation, invertebrate, fish, mammal, and bird communities respond to the restoration of river connectivity and return of diadromous fish. Our analysis indicates the number of sites can readily be decreased from 40 to 25 without losing much information on species richness of the overall river bird assemblage. For purposes of monitoring change associated with dam removal, we suggest these 25 sites should include all dam locations and paired, control non-dam locations. In fact, for monitoring just the common river birds one could decrease the number of sites to about 10 but there would be a risk of missing uncommon species of conservation concern such as Barrow's Goldeneye.

Potential application and modification

The novel river bird survey method we present here provides a number of benefits over methods applied in previous research. Unlike point counts for forest-breeding passerines, which traditionally rely on the detection of seasonally variable territorial songs, the river bird survey method is primarily visual and can be conducted year-round. Considering the differences in composition of season-specific bird assemblages and the potential for each to track environmental change, the ability to monitor year-round is important (e.g. unfrozen areas within the river become important features in the winter). Aerial surveys of rivers might work for larger waterbirds, but would miss some smaller species, such as Belted Kingfishers or Spotted Sandpipers. Previous approaches for surveying river birds have used transects either by boat (Fletcher and Hutto 2006) or by walking along the shore (Carter 1989, Bryce et al. 2002). In our situation using transect approaches would diminish the number of survey sites and number of surveys conducted at each site. Deploying boats would require more time, limit access to some sites because of dams or rapids, and would not have been suitable for many of our volunteers. Boats could also disturb the birds and affect results. Walking transects along the shore would present challenges in terms of private property, rugged terrain and thick vegetation, changes in water levels, snow and ice during winter months, and possibly disturbance to birds. The key distinction is that our river bird survey method assures easy access to a survey point year-round, which promotes the involvement of more surveyors and use of more survey sites than would be possible with transects.

Depending on the study objectives, our approach may have disadvantages and thus there are opportunities for potential improvements or modifications of the river bird survey method. In particular, placement of the sites along the river should reflect the goals of the research. Within our study, we wanted sites to encompass a range of within-river and upland habitat features across multiple rivers and succeeded in achieving this (see Figure 4.2). Site selection was also determined by ease of access and the availability of a qualified surveyor in the area to facilitate long-term monitoring. Random placement of sites would improve experimental design and could be possible within limited spatial scales. If riparian wetlands are present, a call-back survey could be combined with the river bird survey method to incorporate hard-to-detect species. Timing of the survey could be expanded to include evening activity. If rare species are of concern, the number of sites and number of surveys conducted at each site could be increased.

Another consideration in design of a monitoring protocol is determining the level of changes to abundance or species richness it can detect. Variables such as species-specific response, differences in detection probabilities, and differences between years affect power of a monitoring program. Analyses of simulated data by Popescu et al. (2012) suggest that large changes (> 20%) in the species assemblage are necessary before survey approaches can detect it. They suggested that the power of monitoring schemes could be improved with balanced designs, more control sites, and at least three seasons before impact.

This survey method provides an opportunity to track river bird changes at numerous points over long time frames. More specifically, because of the large investment in river restoration associated with dam removal, this survey protocol would provide a cost-effective approach to monitor changes associated with these efforts.

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CHAPTER 2

MARINE NUTRIENT INPUTS IN THE DIETS OF NESTLING BALD EAGLE, OSPREY, BELTED KINGFISHER, AND TREE SWALLOW IN AN IMPOUNDED RIVER

Abstract

Prior to the construction of dams on the Penobscot River in Maine, prolific populations of diadromous fish contributed nutrients either directly through consumption by piscivores or indirectly through deposition of carcasses, eggs, or feces and uptake into the river food web. The present-day relative importance of these marine inputs to river associated birds was studied using $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ stable isotope values of feathers from nestling bald eagle (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), belted kingfisher (*Megaceryle alcyon*), and tree swallow (*Tachycineta bicolor*), from marine/below dam to freshwater/above dam sections. The results indicate marine nutrients are consumed by bald eagle, osprey, and belted kingfisher who reside below the lowermost dam, but not tree swallows. Our data suggest nestlings above the lowermost dam did not consume marine-derived nutrients with the exception of some assimilation in the uppermost river section by bald eagles.

key words : marine-derived nutrients, dam removal, diadromous fishes, bald eagle, osprey, belted kingfisher, and tree swallow.

Introduction

Diadromous fish play a crucial ecological role through contribution of nutrients assimilated from marine systems to coastal and freshwater environments through their spawning activities. The nitrogen (N), sulfur (S), and carbon (C) inputs are referred to as marine-derived nutrients and are delivered to the river food web directly and indirectly. Fish, their eggs, and excreta are either consumed directly or nutrients return to an inorganic state and are taken up indirectly by primary producers (plants, phytoplankton) to reenter the food chain and serve as key drivers of food webs (Kline et al. 2007). Significant contributors include Pacific salmon on the west coast of North America (Gende et al. 2002, Naiman et al. 2002, and Hilderbrand et al. 2004), and alewife (*Alosa pseudoharengus*) along the east coast (Walters et al. 2009). However, the entire suite of diadromous fish species and variation in spawning times create opportunities for nutrient transfer between marine/freshwater (Kline et al. 1990) and aquatic/terrestrial systems (Nakano and Murakami 2001) throughout much of the year.

Recent studies have found a dramatic decline in many North Atlantic diadromous fishes from historical levels (Limburg and Waldman 2009), mostly due to the construction of dams (Gephard 2008). In particular, dams alter habitat and longitudinal connectivity for spawning diadromous fish and exchange between freshwater and marine systems. Currently, there are 66,000 dams on rivers in the United States (USGS 2009). While dams offer benefits, they also are the primary physical threat to river ecosystems, fragmenting and transforming 46% of global primary watersheds. Fish passage is often required by law, but is ineffective in many cases (Brown et al. 2013). The benefits have often not outweighed the economic, social, and environmental costs and alternatives are not always carefully considered (WCD 2001).

Diadromous fish are important prey to many bird species (Willson et al. 1995) and birds may serve as valuable indicators of the status and transfer of marine nutrients in riverine and riparian ecosystems. Birds are increasingly recognized as particularly important ecological actors (Sekercioglu 2006). Some species are top predators in aquatic systems (Steinmetz et al. 2003) and most are highly mobile. Accordingly, birds have more potential for subsidy tracking compared with ground-based fauna (Sabo and Power 2002) and have been used to track the flow of marine-derived nutrients from spawning areas to distant breeding colonies (Polis and Hurd 1996, Anderson and Polis 1999, Payne and Moore 2006), nutrient flow in lakes (Tamisier and Boudouresque 1994), and land-to-water nutrient transfers (Wetzel 1990).

Stable isotopes can be used to determine the relative importance of freshwater and marine food sources because marine-derived materials tend to be enriched in $\delta^{15}N$ and $\delta^{13}C$, relative to freshwater or terrestrially derived material (Lott et al. 2003). Sulfur ($\delta^{34}S$) is most valuable in distinguishing marine and freshwater nutrients in marine environments (MacAvoy et al. 2009). This approach has been used to determine the relative importance of freshwater and marine sources in the diets of species such as cormorants (*Phalacrocorax carbo*), marbled murrelets (*Brachyramphus marmoratus*) and laughing gulls (*Larus atricilla*) (Hobson 1990, Bearhop et al. 1999, MacAvoy et al. 2000, Knoff et al. 2002).

Here we focus on documenting the relative importance of marine-derived nutrients in the diet of nestlings of four representative river bird species (bald eagle, osprey, belted kingfisher, and tree swallow), along a coastal/marine to inland/freshwater gradient in an impounded system, the Penobscot River in Maine, using carbon, nitrogen, and sulfur stable isotopes from feathers and representative prey items. Bald eagle (*Haliaeetus leucocephalus*) and osprey (*Pandion haliaetus*) directly consume diadromous fish and the marine-derived nutrients therein, and the belted kingfisher (*Megaceryle alcyon*) could obtain these nutrients either directly or indirectly. In contrast, the tree swallow (*Tachycineta bicolor*) represents an indirect route through consumption of insects that potentially incorporate marine-derived nutrients deposited within the riparian food web. These species cover a range of foraging distances (bald eagle, 1.5 km [Livingston et al. 1990], osprey ~5 km, [Poole 1989], belted kingfisher 0.4 – 2.2 km, [Brooks and Davis 1987]) and tree swallow 98 – 198 m, [McCarty and Winkler 1999]). Nestlings were sampled because the stable isotope values within their newly forming feathers represent prey consumption during the period of peak spawning activity (May and June) for many of the diadromous fishes.

The Penobscot is New England's second largest river draining 22,196 km^2, about one-third of Maine. It once contained an abundant diadromous fish community including millions of alewives, blue-back herring (*Alosa aestivalis*), American shad (*Alosa sapidissima)*, striped bass (*Morone saxatilis*), American eel (*Anguilla rostrata*), Atlantic (*Acipenser oxyrinchus* oxyrinchus) and short-nose sturgeon (*Acipenser brevirostrum*), rainbow smelt (*Osmerus mordax*), tomcod (*Microgadus tomcod*), and Atlantic salmon (*Salmo salar*). Although populations of these species plummeted because of barriers to migratory routes associated with the construction of hundreds of dams starting in the 1830s (Saunders et al. 2006), it is uncertain how the current status of diadromous fishes and the marine nutrients they deposit are influencing the river food web. The Penobscot provides an opportunity to examine nutrient flow within impounded conditions.

Our objectives were to:

1) compare mean consumer $\delta^{13}C$ stable isotope values of the two lower river sections below the lowermost dam (Veazie) to two upper sections,
2) document mean consumer $\delta^{34}S$ stable isotope values below the lowermost dam, and,
3) infer diet composition within river sections for bald eagle, belted kingfisher, and tree swallow or nest group for osprey using a C and N stable isotope mixing model (SIAR, Parnell et al. 2010).

Methods

Study area

The Penobscot is the largest river basin in Maine (2.2 million hectares) and the second largest in New England. The river is characterized by a predominantly (95%) forested coverage and regular rainfall (104 cm/year, NOAA 1998). Beginning in the 1820s, dam construction along the main stem (Veazie, Great Works, and Milford Dams) and tributaries (more than 250 saw mills and associated milldams) resulted in blockage of migratory fish spawning (Atkins and Foster 1869). The combination of fragmentation and overfishing resulted in a dramatic decline in migratory fish populations (Montgomery 2003). For our study, we delineated four sections of the river based upon differences in the fish community from marine to freshwater habitats (Figure 2.1).

Feather and prey collection

In our study, we assume that the feathers from nestlings represent their diet and applied standard fractionation values for $\delta^{15}N$ and $\delta^{13}C$ (mean value of 3.4‰ with a standard deviation of ± 1‰ and 0.4‰ ± 1.3‰ respectively, Post 2002). Feather and prey sample collection corresponded to peak spawning of several diadromous fishes such as alewife, blueback herring, American shad, and sea lamprey (*Petromyzon marinus*) (Saunders 2006).

Nestling bald eagle, osprey, and belted kingfisher archived feathers were donated by the Biodiversity Research Institute (Figure 2.2 a – c, Table 2.1). Bald eagle feathers were collected between May and June, 2006, 2007 and 2010; osprey between July and August 2007 and belted kingfisher July 2007. Further details on methods of bald eagle, osprey, and belted kingfisher feather collection can be found in DeSorbo et al. 2009, 2013, and Lane et al. 2004. Tree swallow feathers were collected from nestling birds in 20 nest boxes located at nine sites along the river in June 2011 (Figure 2.2 d, Table 2.1). Nest boxes were spaced to obtain samples from upriver/freshwater to downriver/marine locations. All feathers were collected from the Penobscot River Watershed at varying distances from the river mouth and designated to four river sections based on dam locations and where the river becomes an estuary (A=South of Frankfort, B=between Veazie Dam and Frankfort, C=between Milford and Veazie Dams, D=above the Milford Dam, Table 2.1).

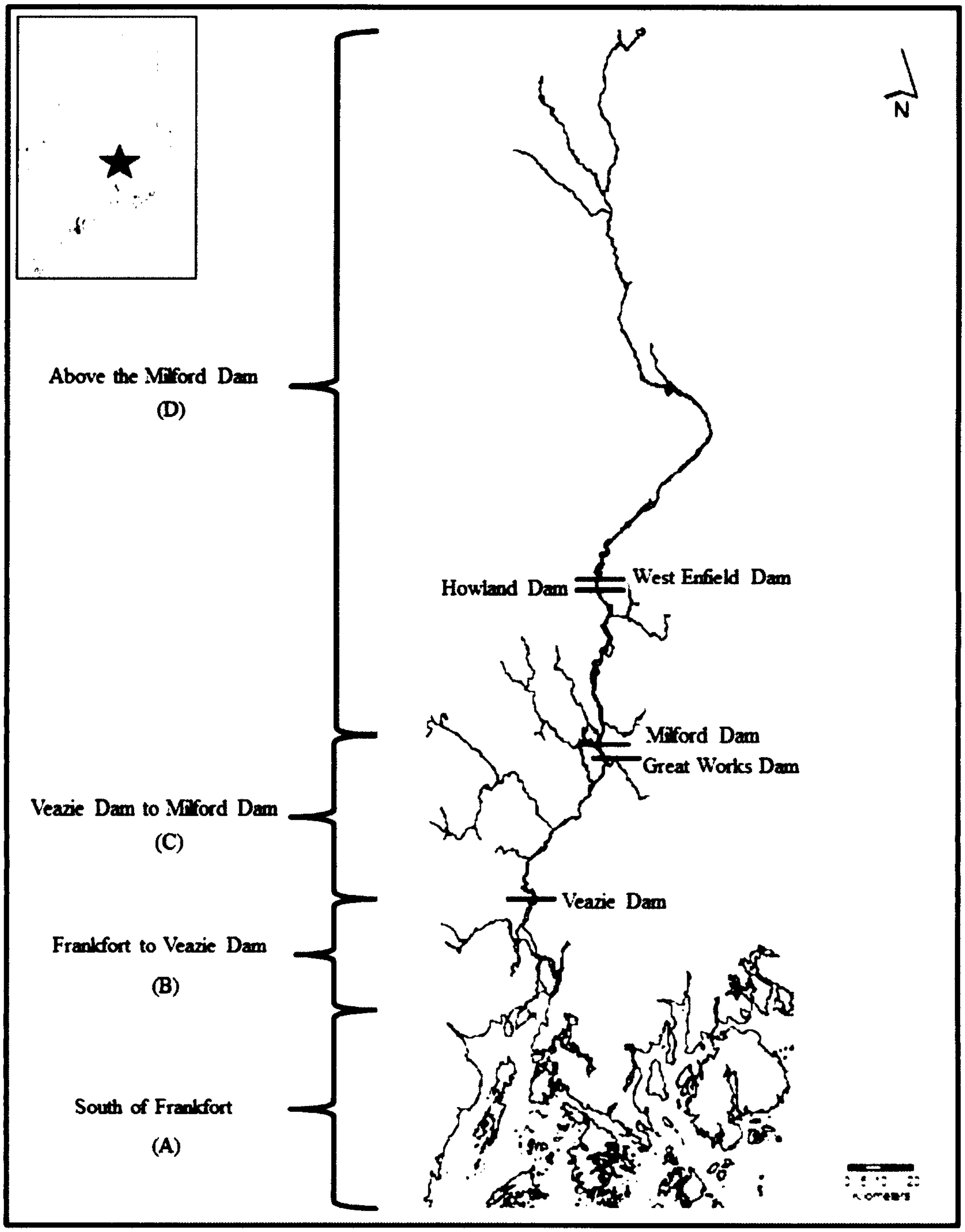

Figure 2.1. Map of study area, four sections of the Penobscot River, Maine.

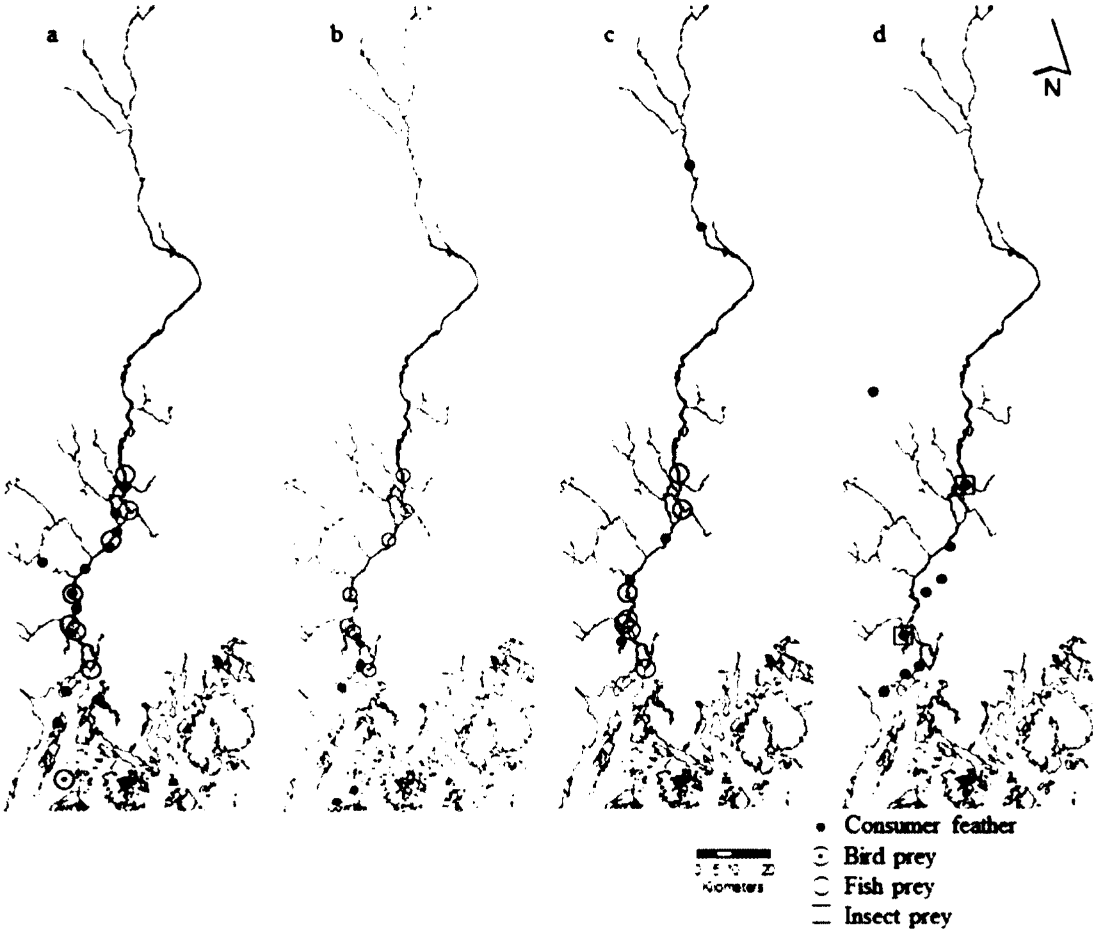

Figure 2.2. Maps of the Penobscot River, Maine, illustrating consumer nestling feather and representative prey stable isotope sampling sites (bald eagle [a], osprey [b], belted kingfisher [c], and tree swallow [d]).

Osprey samples were only available within the lowest river section, thus samples were grouped by nest instead of river section. Osprey nests are present in upriver sections but are logistically difficult to sample due to the structural instability of nest trees (Chris DeSorbo, personal communication, 2010, Biodiversity Research Institute).

Table 2.1. Nestling feather samples collected from the Penobscot River, 2006 – 2011.

Bird species	River section (river km[1])	Total # nests	Total # individuals[2]
Bald eagle	A (-16 to13)	4	8
	B (21 to 46)	5	8
	C (51 to 58)	2	4
	D (66)	1	6
Osprey	A(-38 to 11)	7	16
Belted kingfisher	A (10)	1	5
	B (31)	1	5
	C (48)	1	2
	D (162 to 182)	2	10
Tree swallow	A (-7 to 12)	5	19
	B (27 to 46)	5	16
	D (67 to 96)	9	18

[1] Nest location range, river kilometer 0 set at mouth of Penobscot River near Searsport, ME. Negative river kilometers indicate distance from the river mouth into the bay.

[2] Number of individuals per nest are listed in Appendix B.1.

We inferred possible marine and freshwater prey items of appropriate size ranges (Table 2.2) indirectly based on review of the literature (Todd et al. 1982, Cash et al. 1985, Glass and Watts 1989, McCarty and Winkler 1999, and Lane et al. 2004) and, in the case of bald eagles, prior nest prey studies from Maine (BRI unpublished data). We assumed this represented the diet of nestling study birds. Common eider (*Somateria mollissima*) nestling feathers, representing prey for bald eagles, were collected from Compass Island, Penobscot Bay in June 2011 (Figure 2.2 a). Fish were collected by gillnet or boat electroshocking between May and June 2011 in four river sections (Figure 2.2 a – c) and insects were collected with malaise traps in June 2011 in one upper and one lower river section (Figure 2.2 d). Insect samples (emergent aquatics only) were identified to order and separated into paraspecies groups. Samples were then selected for SI analysis to include orders known to be important in tree swallow diets (Diptera, Odonata, Ephemeroptera, and Plecoptera) and to be most abundant (number of individuals).

Stable isotope analysis

All feather and prey samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$; samples in the lower marine sections of the river (below the Veazie Dam) were also analyzed for $\delta^{34}S$ values. Feathers were washed with de-ionized water, and dried for 2 days at 60°C. A 15 mg dorsal muscle sample was obtained from the fish, freeze-dried and ground into a homogeneous fine power using a mortar and pestle. Whole insects were dried for two days at 60°C. Multiple fish (n = 2 to 5, Appendix B.1) and insects (n = 3 to many, Appendix B.1) comprised a single (pooled) sample, whereas feathers from an individual bird represented a single sample. Each sample was weighed into a tin (0.4 - 0.6 mg for a carbon and nitrogen sample and 5.0 mg for a sulfur sample) and combusted in an elemental analyzer (Costech ECS 4010, Valencia CA) coupled to a ThermoFinnigan Delta Plus XP (Bremen, Germany) Isotope Ratio Mass Spectrometer (IRMS). Isotopic ratios of samples (R_{sam}) were compared to the isotopic ratio of the standard (R_{std}) for that element. R is the ratio of the heavy to light isotope of the element, and differences in the ratios are expressed in the "delta" (δ) notation and are reported in per mil (‰, parts per thousand):

$$\delta\ (‰) = ((R_{sam} - R_{std}) / R_{std}) * 1000$$

Table 2.2. Potential prey items (fish prey length 15 – 35 cm for bald eagle and osprey, 6 – 17 cm for belted kingfisher), collected in the Penobscot River, ME, 2011.

Bird species	Marine prey species[1]	Freshwater prey species[1]
Bald eagle & osprey	Alewife (*Alosa pseudoharengus*)	Black crappie (*Pomoxis nigromaculatus*)
	Atlantic silverside (*Menidia menidia*)	Common shiner (*Luxilus cornutus*)
	Blueback herring (*Alosa aestivalis*)	Fallfish (*Semotilus corporalis*)
	Common eider (*Somateria mollissima*) fledgling[2]	Golden shiner (*Notemigonus crysoleucas*)
	Rainbow smelt (*Osmerus mordax*)	Pumpkinseed (*Lepomis gibbosus*)
	Tomcod (*Microgadus tomcod*)	Redbreast sunfish (*Lepomis auritus*)
	Winter flounder (*Pseudopleuronectes americanus*)	White sucker (*Catostomus commersonii*)
Belted kingfisher	Alewife (*Alosa pseudoharengus*)	Brown Bullhead (*Ameiurus nebulosus*)
	American shad (*Alosa sapidissima*)	Fallfish (*Semotilus corporalis*)
	Blueback herring (*Alosa aestivalis*)	Pickerel (*Esox reticulatus*)
	Rainbow smelt (*Osmerus mordax*)	White sucker (*Catostomus commersonii*)
	Tomcod (*Microgadus tomcod*)	
Tree swallow[3]	Diptera 1[4]	Diptera 4
	Diptera 2	Diptera 5
	Diptera 3	Ephemeroptera
	Odonata 1	Odonata 3
	Odonata 2	Plecoptera

[1] Numbers of individuals per sample listed in Appendix B.1

[2] Bald eagle prey only.

[3] Emergent aquatic insects captured at a marine and freshwater location.

[4] Five unique Diptera and 3 Odonata groups were distinguished.

The standards for ^{15}N, ^{13}C and ^{34}S are atmospheric nitrogen (AIR), Vienna Pee Dee Belemnite (VPDB) and Vienna Canyon Diablo Troilite (VCDT), respectively (Lajtha and Michener 1994). Precision and accuracy for $\delta^{13}C$ measurements was 0.2 ‰ or better, 0.3 ‰ or better for $\delta^{15}N$ and 0.5 ‰ or better for ^{34}S. Analyses of all samples were performed by the Washington State University Stable Isotope Core Lab (Pullman, Washington).

To obtain the relative importance of marine and freshwater food sources, we used a stable isotope mixing model (SIAR), which allows the inclusion of isotopic signatures, elemental concentrations, and fractionation together with the uncertainty of these values within the model (Parnell and Jackson 2013). These models estimate the proportional contribution of prey sources within the consumer and thereby infer diet composition (Parnell et al. 2010). The SIAR model is fit with a Markov Chain Monte Carlo (MCMC) approach and provides simulations of plausible values of dietary proportions of sources (Parnell et al. 2010). Upper and lower credibility intervals described the range of likely contributions for each diet item. Here we applied the SIAR model to compare prey sources for different river section groups (Inger et. al. 2010). Prey items were grouped by river section for bald eagle, belted kingfisher, and tree swallow and by nest for osprey.

Mean consumer ^{13}C values were compared above and below the lowermost dam, Veazie Dam, and ^{34}S stable isotope values were documented below the lowermost dam. Within each river section, we used carbon and nitrogen stable isotope biplots of the raw data and matrix and histogram plots displaying model output to interpret the relative importance of marine and freshwater prey items in the bald eagle, belted kingfisher and tree swallow diet. The raw isotopic data were plotted with trophic enrichment factors added to the prey rather than subtracted from the nestling feathers. Because osprey data were collected only in the lowest river section, the data were grouped by nest (n = 7 nests) and analyzed in a similar manner. Statistical analyses were conducted in R (R Core Team 2013). All tests were two-tailed, and statistical significance was defined as $P < 0.05$.

Results

Bald eagle

We analyzed feather samples from 22 nestling bald eagles and 24 prey samples from four sections of the Penobscot River (Appendix B.1). Nestlings below the Veazie Dam (river sections A and B) had carbon values reflecting consumption of a relatively more marine diet (mean (±SD), $\delta^{13}C = -18.4 \pm 3.5$, n = 16 individuals), compared to fledglings from above the Veazie Dam (river sections C and D) which averaged -24.3 ± 1.9 $\delta^{13}C$ (n = 6 individuals, Figure 2.3 a). Sulfur stable isotopes averaged 13.6 ± 4.0 (n = 16 individuals) below the lowermost dam.

Nestling bald eagles from river sections B and D had isotopic values between those of marine and freshwater prey sources, indicating contributions from both prey groups, whereas bird samples from section A and C imply exclusive consumption of marine and freshwater prey, respectively (Figure 2.4). The bald eagle SIAR model performed well (indicated by low correlations [< 0.7] in the matrix plot, Appendix C.1) in distinguishing proportions of marine and freshwater prey sources, however it could not determine an accurate contribution of each prey item due to high model uncertainty (indicated by wide 50% credibility intervals, Figure 2.5). Overall, from the plots, we can conclude that marine prey is relatively more important for coastal birds below the Veazie dam (river section A and B). For example, eagle diets in river section A have a higher marine prey composition, in contrast to eagles in river section D that have higher proportions of freshwater prey in their diet (Figure 2.5).

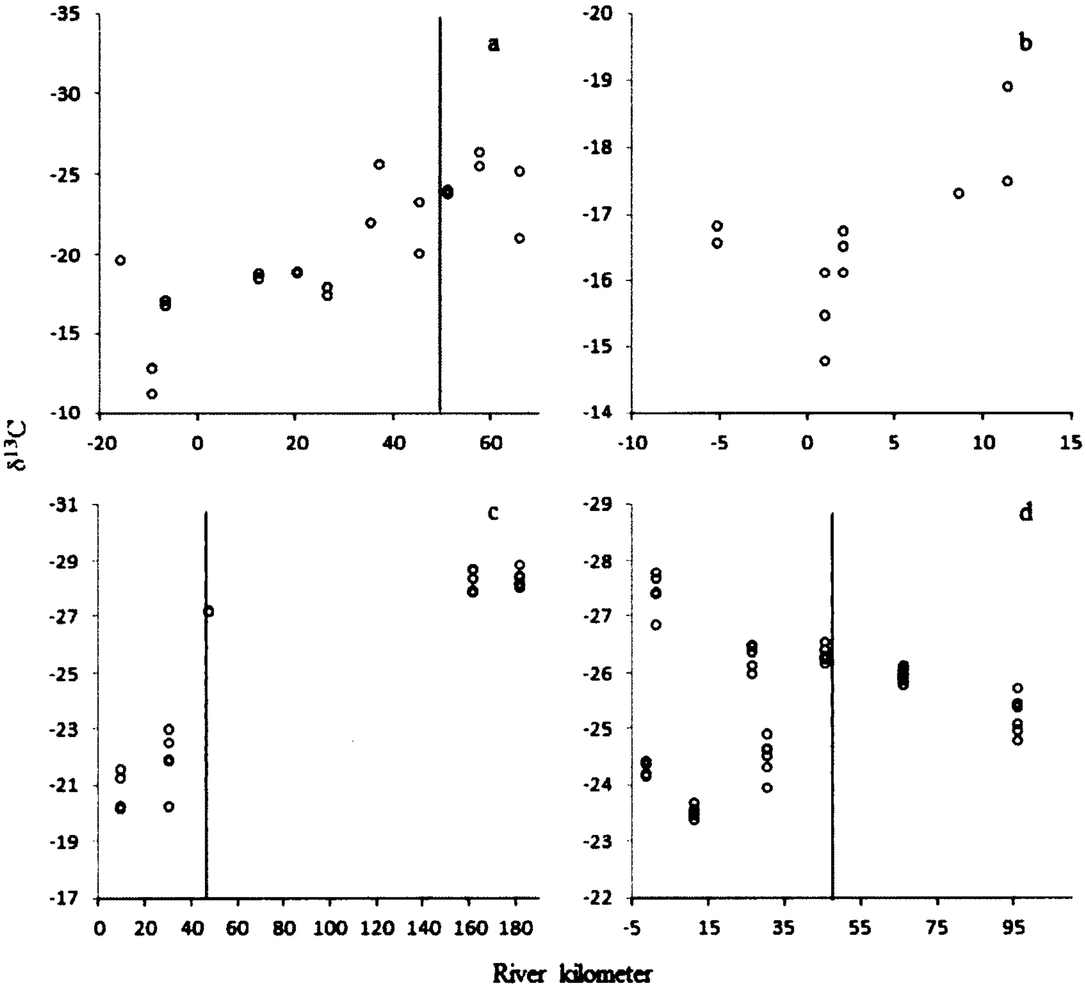

Figure 2.3. Pattern of stable carbon isotopes values for feathers of nestling bald eagle (a), osprey (b), belted kingfisher (c), and tree swallow (d) along and marine/downriver to freshwater/upriver gradient in the impounded Penobscot River. Dams are positioned at 48 (line - Veazie), 59 (Great Works), 62 (Milford), and 99 (West Enfield) river kilometers starting (0 km) from Searsport, Maine (negative values represent distance below 0 km). Note the river kilometer and $\delta^{13}C$ axis differs for each plot to best display the variation of individual birds.

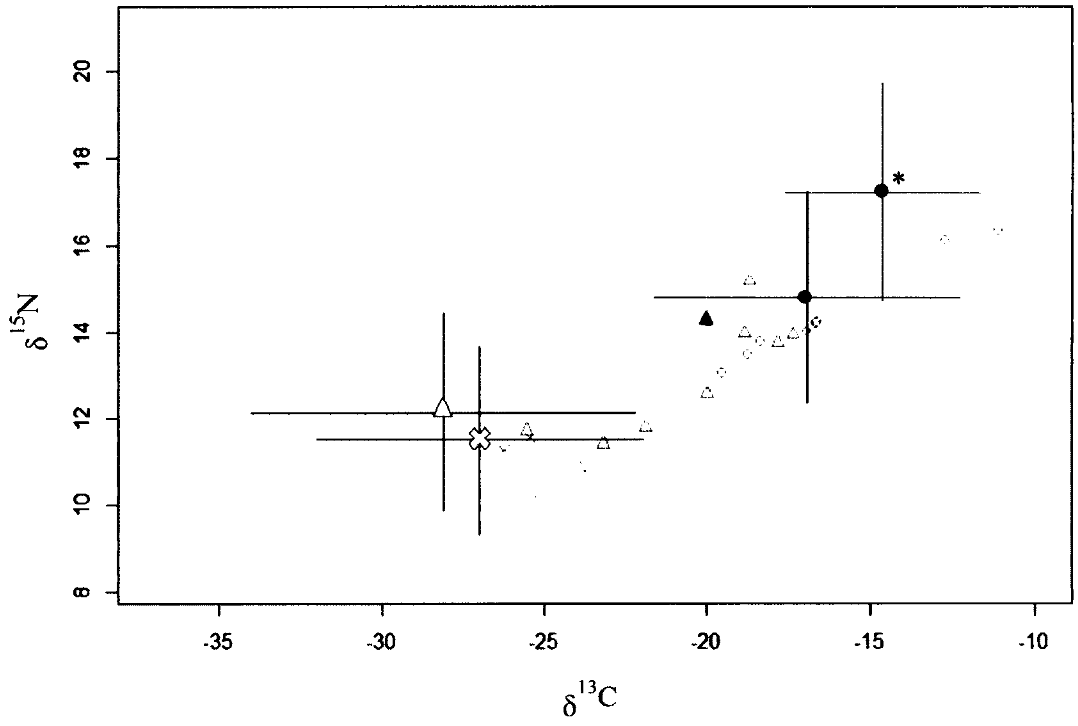

Figure 2.4. Isospace plot of stable isotopes nitrogen and carbon of nestling bald eagle feather samples from four river sections of the Penobscot River, Maine. Individual bald eagle nestlings are plotted as [A/marine (o), B/marine (Δ), C/freshwater (×), and D/freshwater (◊)]. Mean isotopic values for representative marine (solid symbols) and freshwater (open symbols) fish prey items from each river section are displayed ± 2 S.D (where ✠ is river sections C and D combined). Upper right hand marine bird prey indicated by *.

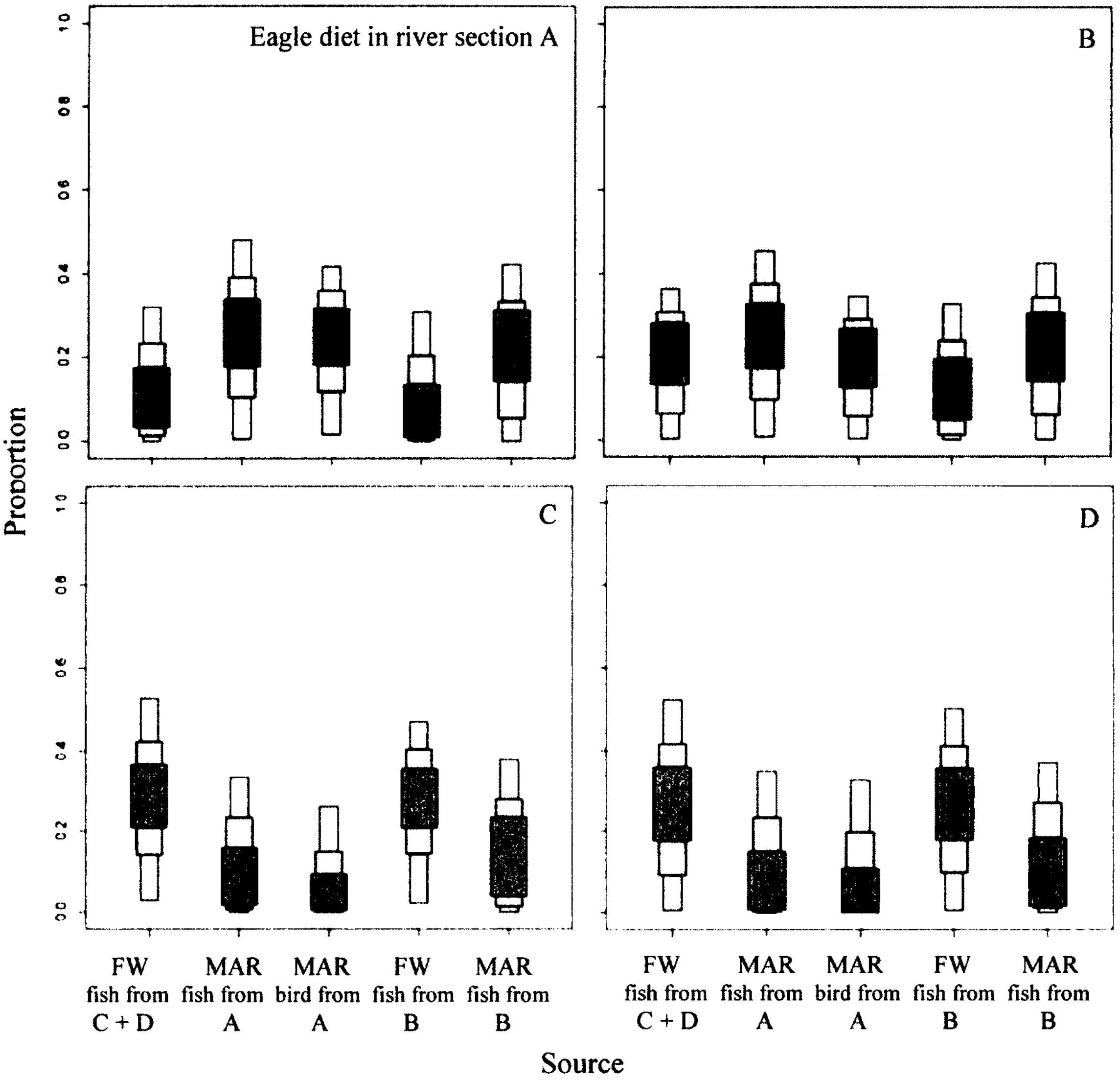

Figure 2.5. Probability density function of dietary proportions for nestling bald eagles from four sections of the Penobscot River, Maine [A/marine, B/marine, C/freshwater, and D/freshwater are positioned from farthest downriver to upriver respectively], illustrating the relative dietary contributions made by freshwater (FW) and marine (MAR) fish and bird prey according to samples collected from each river section. Boxes represent 95, 75, and 50% credibility intervals.

Osprey

We analyzed feather samples from 16 nestling osprey and 19 prey samples (Appendix B.1) from the lowest river section (A) in the Penobscot River. Feather samples (grouped by nest rather than river section) reflected a strong marine input with a carbon average of -16.8 ± 0.96 (Figure 2.3 b)[1]. Sulfur stable isotopes averaged 18.3 ± 0.77. According to the biplot, nestling osprey from river section A (marine) have values that lay exclusively within those of marine prey sources (Figure 2.6). The osprey SIAR model performed well (indicated by low correlations [< 0.7] in the matrix plot, Appendix D.1) in distinguishing proportions of marine and freshwater prey sources; however it could not determine an accurate contribution of each prey item due to high model uncertainty (indicated by wide 50% credibility intervals, Figure 2.7). Overall, from the plots we can conclude that marine prey is incorporated into the diet of osprey within river section A.

Belted kingfisher

We analyzed feather samples from 22 nestling belted kingfisher and 15 prey samples from four sections of the Penobscot River (Appendix B.1). Belted kingfisher samples from the lower sections of the river (A, B) had $\delta\ ^{13}C$ feather values (-21.3 ± 1.0, n = 10) indicating a greater proportion of marine prey as compared to birds in upper river sections (C, D) (-28.1 ± 0.6, n = 12, Fig. 3c). Sulfur stable isotopes averaged 12.7 ± 1.6 (n = 11 individuals) below the lowermost dam (river sections A, B).

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[1] Below the Veazie Dam, intranest variation of bald eagle was compared to intranest variation of osprey and no differences were found (Appendix E.1).

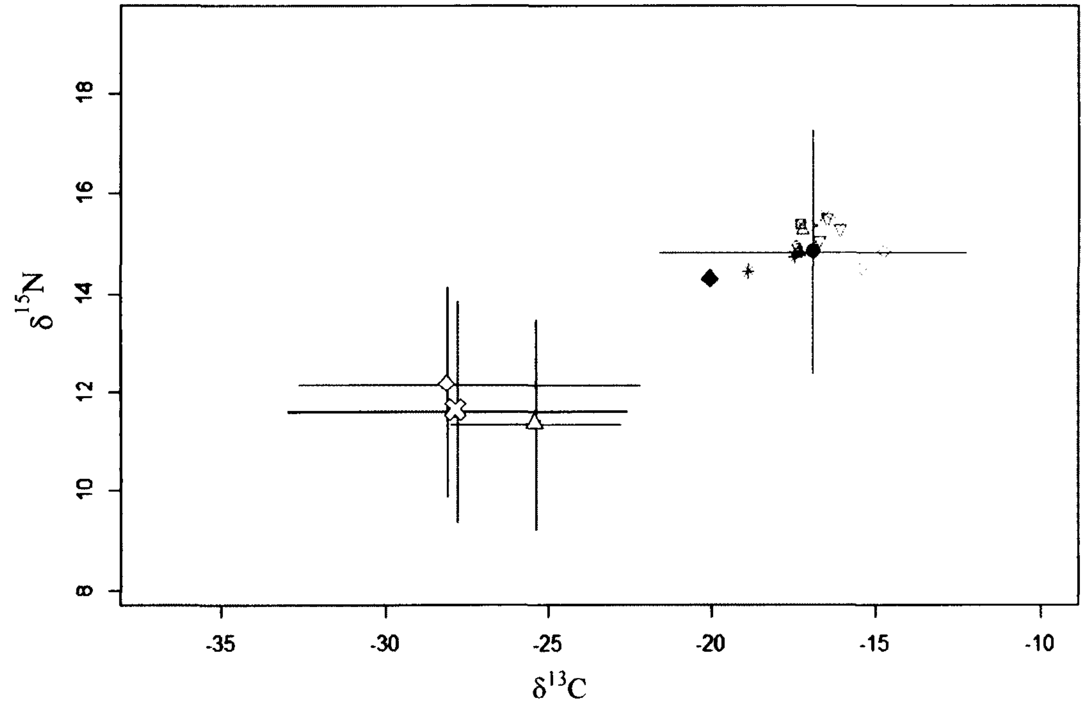
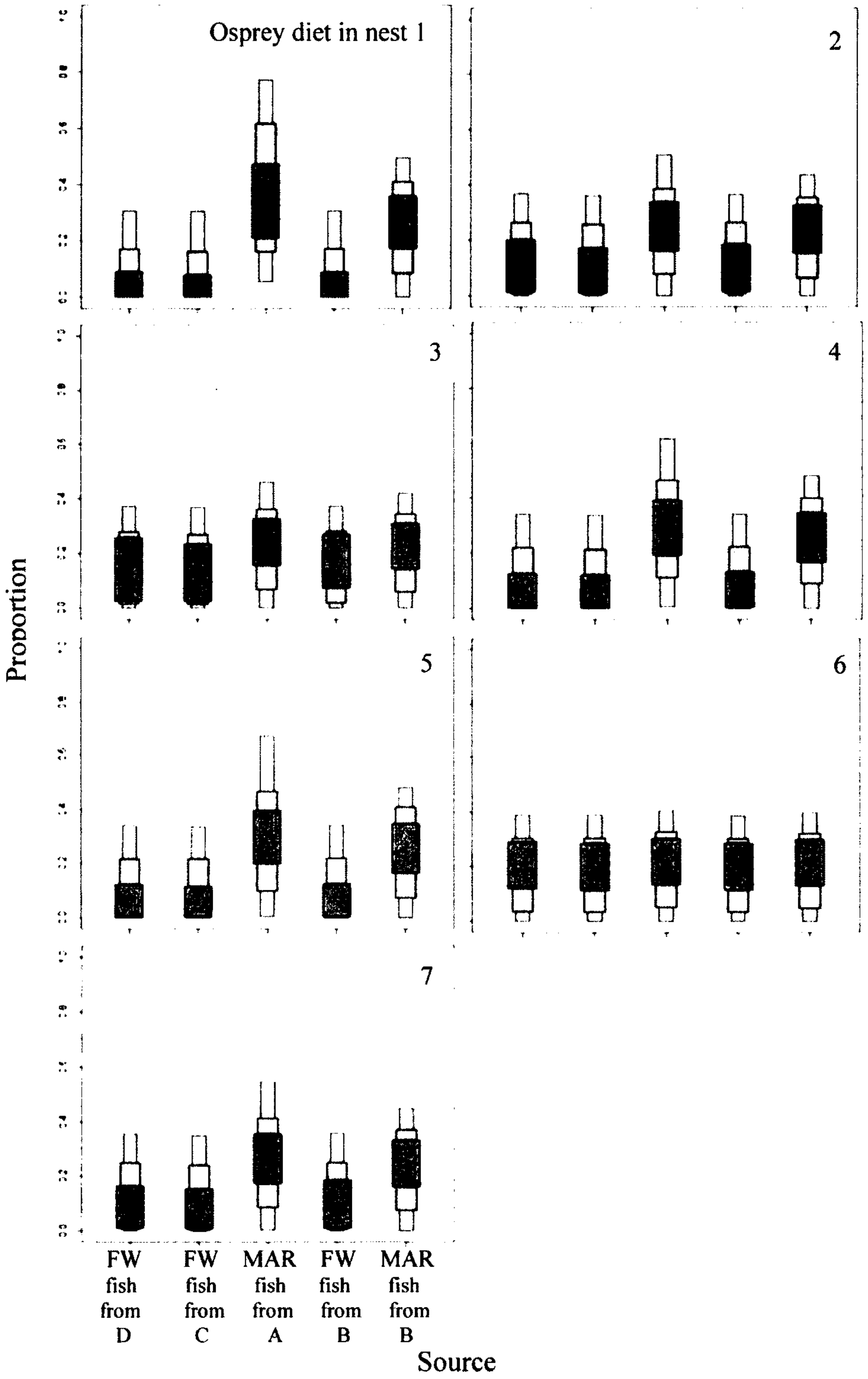


Figure 2.6. Isospace plot of stable isotopes nitrogen and carbon of nestling osprey feather samples from seven nests in the lowest river section. Mean isotopic values for representative fish prey were collected from four sections of the river [A/marine (o), B/marine (Δ), C/freshwater (×), and D/freshwater (◊) are positioned from farthest downriver to upriver respectively, marine (solid symbols) and freshwater (open symbols)] and are displayed ± 2 S.D. Individual consumers (nestling ospreys) are shown.


Osprey diet in nest 1
2
3
4
5
6
7
Proportion
FW fish from D
FW fish from C
MAR fish from A
FW fish from B
MAR fish from B
Source

In the raw data biplot, nestling belted kingfisher from river sections A, B have values that lay between those of marine and freshwater prey sources, indicating contributions from both prey groups, whereas birds from sections C, D imply consumption of freshwater prey exclusively (Figure 2.8). There were very low correlations between freshwater and marine fish prey, suggesting that inclusion of one in the model does not affect the other (see matrix plot in Appendix F.1). For birds in river section D, the model is not able to distinguish between freshwater prey sources well (river section D versus C fish prey, correlation = 0.99, Appendix F.1), but is able to identify the greater contribution of freshwater fish prey relative to marine fish prey (Figure 2.9, river section D).

Tree swallow

We analyzed feather samples from 53 nestling tree swallows and 10 prey samples from three sections (A, B, and D) of the Penobscot River (Appendix B.1). Tree swallow feathers and prey collected from the lower (A, B) and upper river section (D) did not reflect a distinct contrast between freshwater and marine prey consumption [(A, B, -25.3 ± 1.3, n = 35), (D, -25.7 ± 0.4, n = 18), Figure 2.3 d]. Sulfur stable isotopes averaged 7.95 ± 1.0 (n = 30 individuals) below the lowermost dam (A, B).

Inspection of the raw data biplot do not reveal any differences between river section A and D trees swallows (Figure 2.10) and similarly, the prey collected at the lower marine river section (A) and upriver, freshwater section (D) had similar values (Figure 2.10).

Six of the individuals in the D river section had lower $\delta^{15}N$ values than the other birds as well as prey sources suggesting prey items that were not collected were part of the tree swallow diet (Figure 2.10). The matrix plot contains high correlations for each river section group (-1.00), also suggesting the model cannot distinguish between A marine and D freshwater prey sources (Appendix G.1).

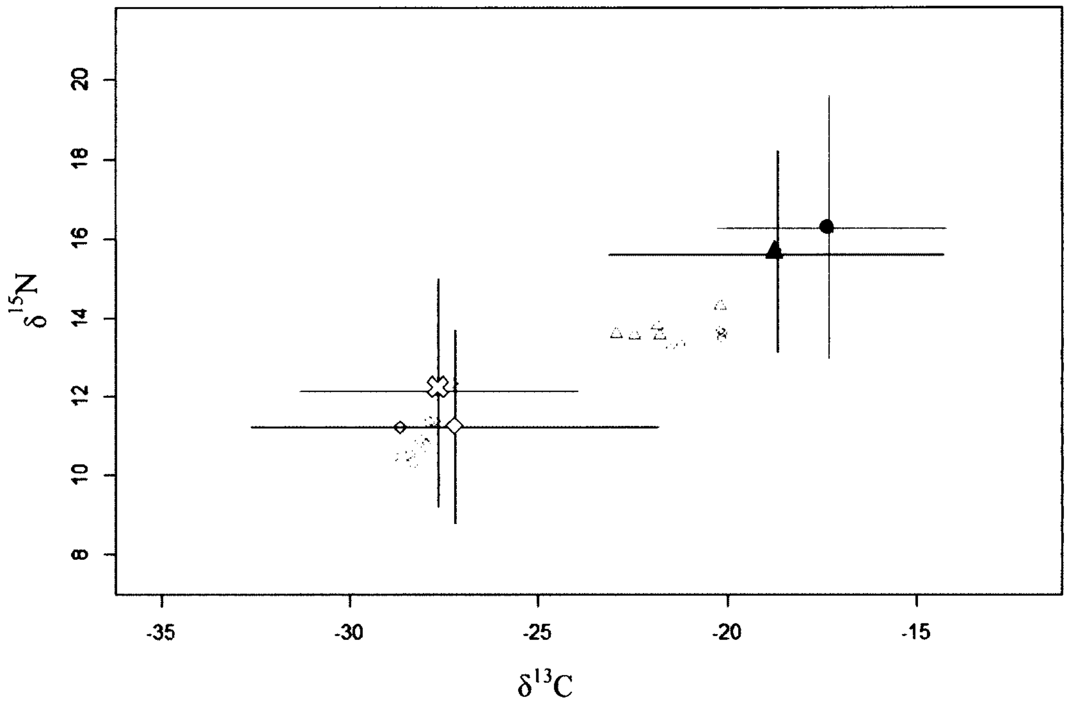


Figure 2.8. Isospace plot of stable isotopes nitrogen and carbon of nestling belted kingfisher feather samples from four river sections of the Penobscot River, Maine [A/marine (o), B/marine (Δ), C/freshwater (×), and D/freshwater (◊) are positioned from farthest downriver to upriver respectively]. Mean isotopic values for representative marine (solid symbols) and freshwater (open symbols) fish prey are displayed ± 2 S.D, individual consumers (nestling belted kingfisher) are shown.

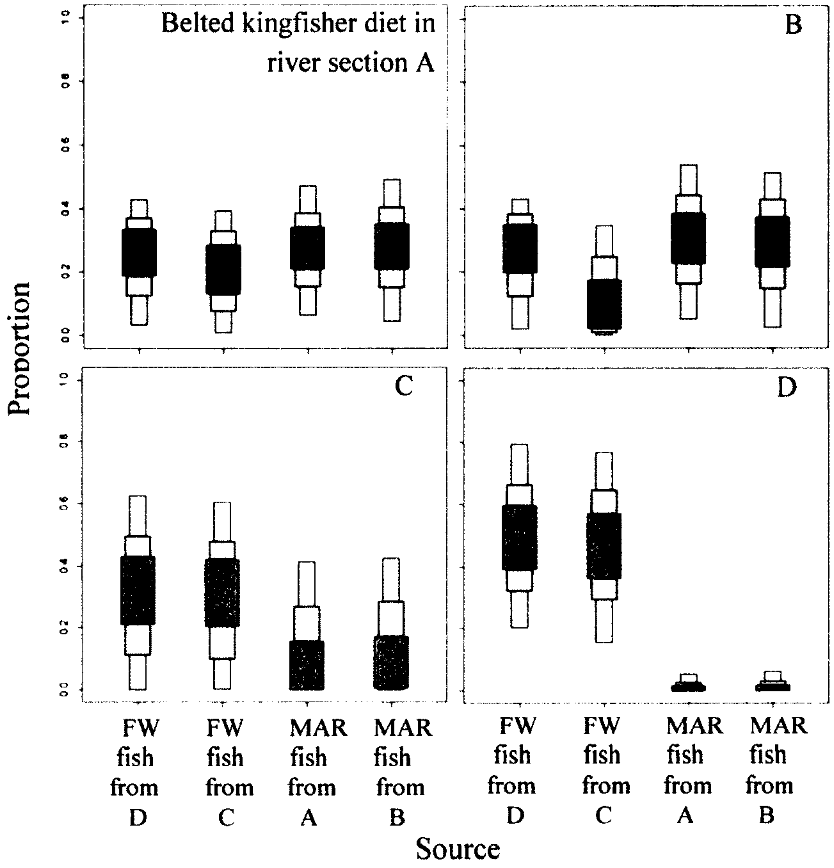


Figure 2.9. Probability density function of dietary proportions for nestling belted kingfisher from four sections of the Penobscot River, Maine [A/marine, B/marine, C/freshwater, and D/freshwater are positioned from farthest downriver to upriver respectively], illustrating the relative dietary contributions made by freshwater (FW) and marine (MAR) fish prey according to sample collection from each river section (95, 75, and 50% credibility intervals).

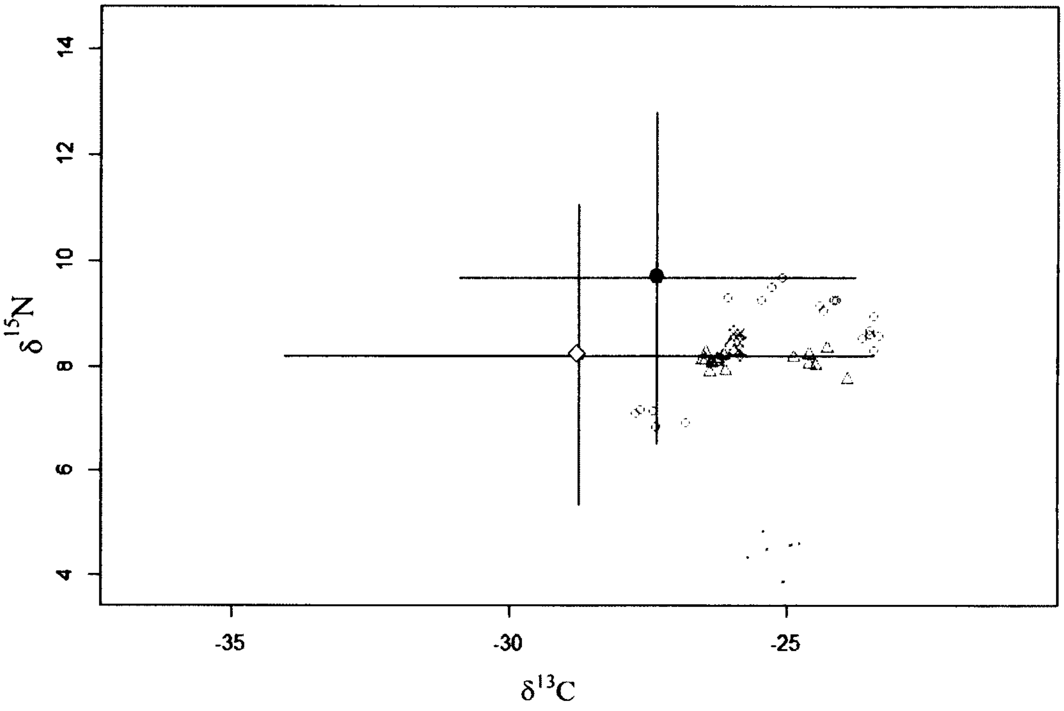


Figure 2.10. Isospace plot of stable isotopes nitrogen and carbon of nestling tree swallow feather samples from three river sections of the Penobscot River, Maine [A/marine (○), B/marine (Δ), and D/freshwater (×) are positioned from farthest downriver to upriver respectively]. Mean isotopic values for representative marine (solid symbols) and freshwater (open symbols) insect preyare displayed ± 2 S.D, individual consumers (nestling tree swallow) are shown.

Discussion

Stable isotope analysis of nestling feathers from representative river birds provide insights into the relative importance of marine and freshwater nutrients in avian diets within the impounded Penobscot River, Maine that are not easily obtained by other methods. Overall, we can conclude that bald eagle, osprey, and belted kingfisher are consuming marine nutrients below the lowermost dam, whereas this is not evident for tree swallow. Consumption of freshwater nutrients was predominant for all species above the lowermost dam.

Nestling bald eagles showed a greater marine signal in the river sections (A, B) below the lowermost dam (Veazie) compared to above the dam (C, D) and incorporation of marine nutrients in the uppermost section was a possibility (Figures 2.4 and 2.5, section D nestling value between freshwater and marine prey). Marine contributions to eagle diets in the uppermost section may reflect stocking of Atlantic salmon smolts raised on a marine nutrient based feed. These stockings were increased from 0 to 37% from 2006 to 2007 (Cox, personal communication, Maine Department of Marine Resources, 2014), equating to ~ 200,000 individuals released less than 3 km upriver from the nest where nestlings exhibited some marine nutrient assimilation (note: feathers from this nest were collected on June 21st 2007, smolts were stocked in late April making this assimilation a possibility). Belted kingfisher carbon isotope feather values also showed a greater marine signal in the river sections (A, B) below the lowermost dam (Veazie) compared to above the dam (C, D, Figures 2.8 and 2.9). Availability of osprey feather samples was limited to the lowest river section (A), preventing comparisons to upper river sections, however, diet within the section also reflected a marine nutrient diet input (Figures 2.6 and 2.7). Tree swallows did not show any differences in carbon values between the lower and upper river sections (Figures 2.10 and 2.11) suggesting marine nutrients are not flowing up the food web in detectable amounts.

These results are similar to prior research in the tidal freshwater of Virginia tracking incorporation of marine derived nutrients from anadromous river herring (*Alosa* spp.) into different fish species based on their foraging guild, with only direct consumers (predators) showing enrichment similar to the sea-run fish (MacAvoy et al. 2009). It may be that marine derived nutrient deposition on the east coast is lower, both because many anadromous fishes are iteroparous and numbers are greatly reduced, and only direct consumers are being subsidized. This is in contrast to west coast systems where nutrient loads are higher and thus are taken up by secondary consumers (Reimchen et al. 2002).

Prior research has demonstrated consumption of diadromous fish (and presumably marine nutrients) by a variety of taxa, including by birds in river systems (Cedarholm et al. 1989, Garman et al. 1998, Payne and Moore 2006) through methods such as collection of food remains at bald eagle breeding sites (Todd et al. 1982), observation of osprey nest provisioning (Glass and Watts 2009), and collection of belted kingfisher pellet and stomach samples (Cairns et al. 1998, Lane et al. 2004). These techniques do not document the assimilation of marine nutrients into nestling diet as we are able to do with the stable isotope approach. Furthermore, collection of food remains from nests and stomach samples does not measure actual assimilation due to confounding factors such as differential prey digestibility (Cairns et al. 1998). Additionally, food remains represent a snapshot sample which may not necessarily represent the integrated diet of assimilated foods over the period of feather growth.

We anticipated that tree swallows might also be a suitable indicator of marine-derived nutrient assimilation based upon prior research documenting: 1) aquatic-to-terrestrial transfer of contaminants via consumption of emergent aquatic insects by tree swallows (Echols et al. 2004, Longcore et al. 2007, Alberts et al 2013), 2) uptake of marine derived nutrients by emergent aquatic insects (Reimchen et al. 2002), and 3) a positive association of swallow densities with anadromous salmon spawning (Gende and Willson 2001). Furthermore, research has documented negative implications of impounded rivers on biomass of emergent aquatic insects (Jonsson et al. 2013). Marine nutrients may be at a low level in the current impounded system and therefore were not detectable in our tree swallow diets, but if diadromous fish populations increase after dam removal, tree swallows may reflect higher marine nutrient inputs.

Expanding the taxonomic breadth of prey sampling and the spatial coverage of nestling feathers would provide a more complete picture of marine and freshwater nutrient importance in the river bird diet. In the case of bald eagle and tree swallow, sampling across seasons could highlight the contribution of terrestrial prey sources (Todd 2004, Beck et al. 2013) In addition to fish, eagles are also scavengers and incorporate mammals into their diet (Todd 2004). Nitrogen values not only provide insights on trophic level, but also will increase as the consumer relies more on aquatic versus terrestrial resources (Fry 2006). Representative prey items for tree swallows were selected based upon their abundance in the malaise traps; it would have been preferable to base the selection on examination of boluses delivered by adults to nestlings. Kingfisher prey sampling included the most important taxa based on prior diet studies, but could be expanded to include less important items such as crayfish, amphibians, and insects (Cairns et al 1998, Lane et al. 2004).

The two lowermost dams within the Penobscot River were removed in 2012 and 2013 and improvements for fish passage on other dams are in progress. Diadromous fish will have access to historical spawning areas and their populations are likely to increase dramatically. We expect marine nutrients will comprise a greater portion of river bird diets in the restored river system within both marine and especially upriver sections. Developing a better understanding of how dams affect diadromous fish and the uptake of marine nutrients by wildlife is even more critical due to both continued dam construction and a new focus on dam removal and river restoration.

The U.S. experienced a "golden age of dam building" between 1950 and 1970, and now has over 75,000 dams greater than 2 m in height (Graf 1999). Approximately 85% of these dams will be near the end of their operational lives by 2020 (FEMA 1999, Bednarek 2001). As these dams continue to degrade and the ecological benefits of removal are recognized, the opportunities for restoration will increase. The recovery of diadromous fish migrations between fresh and saltwater has been particularly emphasized in the dam removal process. The restoration of connectivity and subsequent migration, spawning, and deposition of marine-derived nutrients by diadromous fishes has potential ramifications for the entire river food web as well as terrestrial systems and species (Nakano and Murakami 2001).

Given the growing awareness of the ecological impacts of dams (Hart and Poff 2002) paired with the costs of maintaining aging dams, the option of removal is becoming more prevalent. Removal is an expensive endeavor; it is estimated that the Penobscot River restoration will cost $55 million (Opperman et al. 2011). Establishing ecological baselines and repeating monitoring protocols in the restored system will provide a clear picture as to how wildlife benefit from a free-flowing river and return of diadromous fishes. While river response to restoration is complex, river-associated birds provide an opportunity to efficiently track the integration of fish prey into the food web.

These data improve understanding and highlight the importance of river-associated birds and their relationship to diadromous fish resources. It is our hope that this may foster collaborations between fisheries and wildlife biologists and inspire outreach and education focused on land stewardship of surrounding riparian areas and improving river connectivity. We provide insight into marine nutrient assimilation within an impounded river system that can serve as a baseline measure in a unique before-after analysis to inform cost-benefit considerations of dam removal and river restoration.

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CHAPTER 3

WATERSHED CONNECTIVITY FOR SPAWNING DIADROMOUS FISHES: EFFECTS ON OSPREY NEST DISTRIBUTION AND BROOD SIZE

Abstract

Efforts to restore river connectivity for diadromous fishes through dam removal have been successful in improving the population of these species, but indirect influences of impoundments are poorly characterized. We describe nest distribution and brood size of osprey in two Maine watersheds with different levels of connectivity. Abundance of spawning diadromous fishes, particularly river herring [collectively alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*)], — an important prey source — differed among sites. Aerial surveys were conducted in July of 2011 and 2012 in the Penobscot and Kennebec River watersheds. Data were analyzed separately for the Sebasticook River, a major tributary of the Kennebec with the largest river herring run on the East Coast. Connectivity for diadromous fish is greater within lower regions of the Kennebec and Sebasticook watersheds as compared to the Penobscot. Brood size was significantly lower in the Sebasticook as compared to the Kennebec ($P = 0.01$) and Penobscot (marginal, $P = 0.07$), despite a large difference in the abundance of diadromous fishes (e.g. total river herring counted during study duration, 2011 and 2012: 2,093 [Penobscot), 4,672,196, (Kennebec including Sebasticook), 4,454,993 (Sebasticook only). Factors such as osprey nesting chronology and competition with bald eagles may limit the benefit of large river herring runs to nesting ospreys.

key words: diadromous fishes, osprey nest, and river herring.

Introduction

Awareness of the ecological impacts and costs of maintaining aging dams has changed approaches to water management and led to dam removals. Removal has been particularly prevalent, as over 500 dams in the U.S. have been removed in the past two decades (Stanley and Doyle 2003). The U.S. experienced a "golden age of dam building" between 1950 and 1970, and now over 75,000 dams greater than 2 m in height are present (Graf 1999), and approximately 85% of these dams will be out of operation by 2020 (FEMA 1999, Bednarek 2001). Hart and Poff (2002) reviewed the impacts of dams on the structure and function of river systems by the alteration of the following key parameters: flow regimes and physical habitats, channel shape, sediment transport, water temperature and chemistry, and populations of algae, benthic macroinvertebrates, riparian vegetation, and resident and migratory fishes.

The recovery of diadromous fishes has been particularly emphasized in the dam removal process. The restoration of connectivity and subsequent migration, spawning, and deposition of marine-derived nutrients by diadromous fishes has potential ramifications for the river food web as well as terrestrial systems and species (Nakano and Murakami 2001). Diadromous fishes play an important role in the river food web either through direct consumption by mammals and birds or indirect uptake of marine-derived nutrients by aquatic macroinvertebrates (Kline et al. 2007). Therefore, top predators in these food webs can likely serve as indicators of the success of restoration following dam removal. The purpose of this study was to investigate the feasibility of using one such predator, the osprey (*Pandion haliaetus*), to monitor the recovery of river ecosystems following dam removal.

The osprey's diet comprises fishes from marine, estuarine, and freshwater systems and previous research has highlighted the importance of diadromous fishes in its diet in areas where they are available (Jamieson 1982). Because ospreys are exclusively piscivorous, we hypothesize that this species may be a sensitive indicator of varying levels of river connectivity for diadromous fishes. Brood size ranges from one to four fledglings and is a superior metric to overall osprey productivity (brood size x nest success) for our purposes because overall productivity can be confounded by factors such as disturbance and contaminants (Steenhof 1987). Increase in food abundance has been positively correlated to brood size in raptors (Newton 1979). We hypothesized that improved river connectivity leads to more diadromous fishes, surplus food for nestlings, and an increase in brood size (Pool et al. 2002).

We compare the breeding biology of ospreys on three rivers with varying degrees of diadromous fish connectivity: the Kennebec, Sebasticook, and Penobscot Rivers. Connectivity was improved on the Kennebec River after removal of the lowermost dam (1999) and diadromous fish populations responded (Limburg and Waldman 2009); however, the current lowermost dam has limited fish passage. Likewise, fish passage improved along a tributary of the Kennebec, the Sebasticook, after removal of the lowermost dam (Fort Halifax, 2008) and improvements to fish passage at dams farther upstream (including Benton Falls Dam). The Penobscot had limited fish passage during the course of this study, but has since improved with the removal of the two lowermost dams (Great Works [2012] and Veazie [2013]). Our objectives were to: 1) Document osprey nest distribution within three watersheds of varying connectivity for diadromous fishes and, 2) compare mean brood sizes among these rivers.

Methods

Study area

For the purpose of this study, focal areas within each watershed were delineated based partially upon osprey foraging distances (Hagan and Walters 1990) and hydrologic unit codes (HUC 10), which is a national standard hierarchical classification system that distinguishes natural and artificial barriers that may influence fish movement and consumption by osprey (Figure 3.1). Nests within these focal areas were included in the brood size and nest distribution comparisons among watersheds. We assumed birds outside of the focal areas did not have access to diadromous fishes within the river based upon the HUC boundaries and greater foraging distances.

The Penobscot River is tidal from Veazie to its mouth in Bucksport, and drains an area of 22,196 square kilometers, the riparian is primarily (~95%) forested, and precipitation varies by month but is abundant annually (~104 cm/year, NOAA 1998). Beginning in the 1820s, dam construction along the main stem (Veazie, Great Works, and Milford Dams) and tributaries (more than 250 saw mills and associated milldams) blocked migratory fish spawning (Atkins and Foster 1869). A collaboration between tribal, nonprofit, industry, state, and federal agencies, resulted in the removal of the two lowest dams, Great Works and Veazie, (2012 and 2013 respectively), and progress towards improving fish passageways at the remaining dams. The removal of these two main stem dams restored 42% of the Penobscot watershed's historical habitat (Hall et al. 2010, MBSRFH 2007, MDEP 2009).

The Kennebec River drains an area of 15,203 square kilometers and is 82% forested (USGS 2001). The Edwards Dam was built at the head of tide in 1837 and removed in 1999 to improve access to spawning diadromous fishes. The Ft. Halifax Dam, located on the Sebasticook River, was removed in 2008, restoring 45% of the original lacustrine habitat (Hall et al. 2010). During the study period (2011 and 2012, May - July), a total of 4,454,993 river herring were counted at the Benton Falls Dam on the Sebasticook, plus 217,203 at the Lockwood Dam on the Kennebec River (Claire Enterline, personal communication, Maine Department of Marine Resources 2014).

We highlighted river herring because these species are likely the most numerically abundant of the diadromous fishes in these river systems (Claire Enterline, personal communication, Maine Department of Marine Resources 2014), and their spawning period of May through June overlaps with the osprey nesting season. These rivers also host other diadromous fish species that are suitable prey of osprey such as American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), Atlantic tomcod (*Microgadus tomcod*), sea lamprey (*Petromyzon marinus*), and American eel (*Anguilla rostrata*). Potential fish prey that are not diadromous include common shiner (*Luxilus cornutus*), golden shiner (*Notemigonus crysoleucas*), fallfish (*Semotilus corporalis*), pumpkinseed (*Lepomis gibbosus*), redbreast sunfish (*Lepomis auritus*), smallmouth bass (*Micropterus dolomieu*), and white sucker (*Catostomus commersonii*) (Glass and Watts 1989, Hughes 1983).

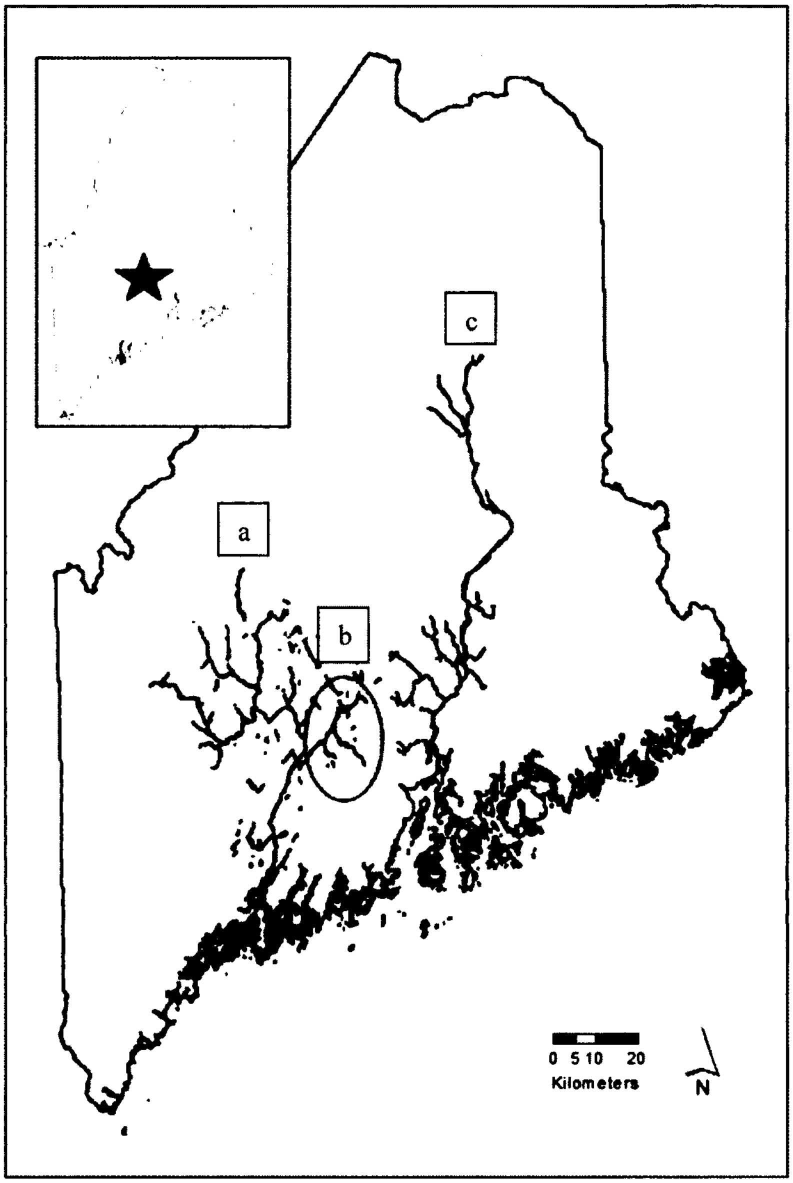

Figure 3.1. Kennebec (a), Sebasticook (b, within oval), and Penobscot Rivers (c) watershed focal study areas, and hydrologic unit boundaries (light gray, HUC 10), Maine.

Aerial surveys

All flights were conducted in a fixed-wing aircraft (Cessna 172 Skyhawk). Survey speeds were generally 177 - 209 km per hour at altitudes 90 – 215 meters above the surface. Flight tracks and reference locations were recorded on a portable GPS unit. All traditionally known nests (i.e. inventoried from prior years by MDIFW) were surveyed in 2011 and 2012, and all new nests found in 2011 were rechecked in 2012 within each watershed. In Maine, ospreys nest between May and August. Classification of occupied (1-2 adults present) versus active nests (young present) followed the criteria of Postupalsky (1977). Nests were visited in July, to determine whether the nest was active or not. Brood size was estimated as the number of fledglings per successful pair.

Statistical analyses

We calculated average brood size for each watershed focal study area. Average brood size is reported as the average number of young produced by osprey pairs (Poole 1989, Steenhof and Newton 2007). Brood size was compared between: 1) Penobscot and Kennebec Rivers (with inclusion of the Sebasticook nests with the Kennebec), 2) Penobscot and Sebasticook, and 3) Kennebec and Sebasticook focal study areas using the nonparametric Wilcoxon rank sum test for 2011 and 2012 surveys.

Results

Osprey nest distribution

We surveyed 911 potential nests and a subset of these fell within the boundaries of the Penobscot, Kennebec (excluding Sebasticook), and Sebasticook River focal study areas (299, 67, 37 nests respectively, Figure 3.2).

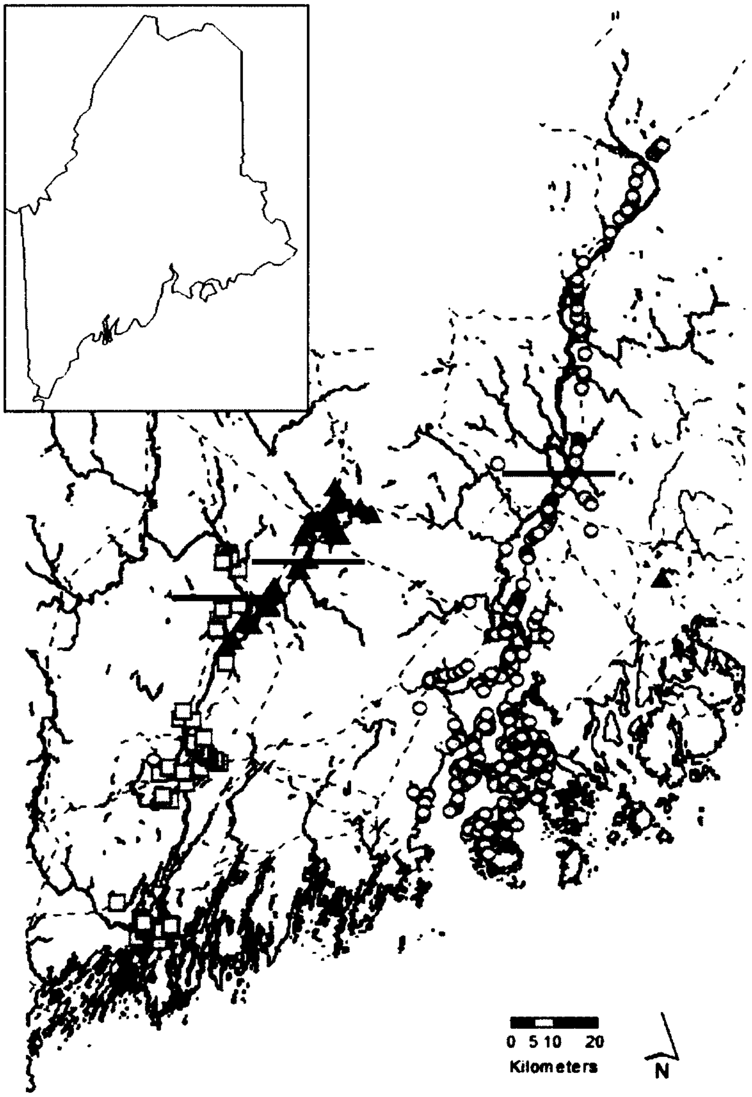

Figure 3.2. Osprey nest distribution in the Kennebec (□), Sebasticook (Δ), and Penobscot River (○) focal study areas, Maine. Dashed lines display powerline corridors and horizontal line displays lowermost dam on each watershed.

Osprey brood size

Of the 299 nests within the Penobscot River study region, 183 nests contained ≥ 1 fledgling, with a mean brood size and standard deviation of 1.50 ± 0.57 and no significant differences between years (1.50 ± 0.58, n = 97 [2011], 1.51 ± 0.57, n = 86 [2012], Wilcoxon sum rank test [W = 4090.5], *P* = 0.80). Among the 104 Kennebec River (including Sebasticook) nests, 77 nests contained ≥ 1 fledgling, with an average brood size of 1.52 ± 0.58, and there was no significant difference between years (1.44 ± 0.55, n = 39 [2011], 1.61 ± 0.59, n = 38 [2012], W = 630, *P* = 0.20). Of the 67 nests on the Kennebec River (excluding Sebasticook), 52 nests contained ≥ 1 fledglings, with an average brood size of 1.63 ± 0.60, and no difference between years (1.56 ± 0.58, n = 25 [2011], 1.70 ± 0.61, n = 27 [2012], W = 296, *P* = 0.40). Of the 25 nests on the Sebasticook, 25 nests contained ≥ 1 fledgling, with an average brood size of 1.28 ± 0.46 (1.21 ± 0.43, n = 14 [2011], 1.36 ± 0.5, n = 11 [2012], W = 65.5, *P* = 0.44).

There were no significant differences in average brood size between the Penobscot and Kennebec Rivers (pooling years, n = 260, W = 6934.5, *P* = 0.82). Relative to the Sebasticook River, brood sizes were marginally larger on the Penobscot (n = 208, W = 2734, P = 0.07), and larger on the Kennebec, (n = 102, W = 853.5, *P* = 0.01).

Discussion

Abundant fish prey is known to positively influence brood size and overall osprey reproductive success (Poole 1989) and have implications for nest distribution (Hagan and Walters 1990). The Kennebec and Sebasticook watersheds provide more accessible habitat for diadromous fishes and consequently contain a greater abundance (~ 2000 times more river herring in the Kennebec and Sebasticook than in the Penobscot River), yet brood size in the Sebasticook was lower. The timing of the run may be too early for osprey broods to fully benefit because during this period adults are tending to their eggs or young hatchlings. It is possible that other non-diadromous fishes play an important role in the osprey diet, especially after the peak of the herring run in early June (Mullen et. al 1986), thus limiting the influence of diadromous species on brood size.

Many factors may be affecting osprey reproduction beyond watershed connectivity and the associated abundance of diadromous fishes. Investigation of other influences may provide further insights into variation of brood size such as: 1) proximity to suitable foraging areas (Vana-Miller 1987), or major rivers and coastal waters (Martinez 2008); 2) whether birds were nesting colonially (which occurs if food is plentiful [Hagan and Walters 1990] and reduces the time to locate prey because of social foraging [Flemming 1988]); 3) high wind and turbidity (which can inhibit the prey detection [Grubb 1977, Stinson 1978]); 4) foraging along a salinity gradient (where fishes in high salinity areas are lower quality prey [Glass and Watts 2009]); and 5) human disturbance (Vana-Miller 1987, Martinez 2008); density dependence (Bretagnolle et al. 2008); and clutch initiation date (Steeger and Ydenberg 1993).

Competition with bald eagles may also influence brood size and nest distribution. Bald eagle populations have rebounded in Maine, with over 600 pairs documented in 2013 (Todd 2013). Unlike osprey, eagles are tending older young that require more food during the river herring run. Eagles may also directly affect prey delivery rates (and thus osprey brood size) through kleptoparasitism (Ogden 1975). Osprey on the Sebasticook may be experiencing high rates of competition not only from local breeding eagles but also from abundant subadults that aggregate during the river herring run (BioDiversity Research Institute 2014). Eagles also are known to outcompete osprey for prime nesting sites (and thus affect nest distribution, [Todd, personal communication, MDIFW, 2013]), and eat osprey eggs (Grubb and Shields 1977) or nestlings (Flemming and Bancroft 1990, Liston 1996). The abundance of river herring on the Sebasticook may lead to increased competition between eagles and osprey, causing lower mean brood size as compared to the Kennebec and Penobscot Rivers. Given ongoing changes in terms of dam removal and river restoration activities on the Penobscot, the abundance of diadromous fishes could eventually be a predominant influence. Observations of bald eagle-osprey social interactions at locations of concentrated prey abundance may provide insights into the implications for osprey brood size. Additional surveys will be required to track the response of osprey and their competitors as the diadromous fish community continues to recover.

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CHAPTER 4

RIVER BIRD-HABITAT RELATIONSHIPS; MONITORING RIVERINE CHANGE

Abstract

Monitoring riverine degradation and restoration can be facilitated by a better understanding of how river bird species relate to their habitats and lead to more informed management decisions. I describe current associations between river bird assemblages and river habitat variables to inform future analysis of river system alteration. Multi-year (2009-2012) bird surveys documented bird density in relation to site- and survey-specific river habitat variables. Ordination analyses of 26 river bird species and 5 single-species general linear models (invertivore - Spotted Sandpiper, (*Actitis macularius*); piscivore – Osprey, *Pandion haliaetus*; piscivore - Bald Eagle, *Haliaeetus leucocephalus*; insectivore - Tree Swallow, *Tachycineta bicolor*; and omnivore - American Black Duck, *Anas rubripes*) revealed associations between estimated species densities and water flow, water level, distance from the river mouth (river kilometer), site position in relation to a dam (e.g. above, below, or not at a dam), and adjacent land cover composition.

key words: river bird, river restoration, and ecological indicators.

Introduction

Rivers and the ecosystem services they provide are critical to wildlife and human populations and are facing multiple challenges. Dams, overfishing (Saunders et al. 2006, Hall 2011), pollution (nitrogen, phosphorus, acidification, and sedimentation [MacRae 2006, Moring 2005, Sunderland et al. 2012]), urban sprawl (Robinson 2004, Stein et al. 2005, Konrad and Booth 2005), and loss of forests and wetlands (Dahl 1990, White et al. 2009) are stressors that may act in concert within rivers. Climate change is expected to influence river hydrology in terms of water levels, water temperature, and flow dynamics with negative implications for marine productivity, diadromous fishes, and the entire river food web (Dudley and Hodgkins 2002, Mastin et al. 2011). Urbanized and impounded rivers will be more compromised with respect to climate change than protected and free-flowing rivers (Palmer et al. 2009). Regulations associated with water quality and extraction, riparian zoning, wetland protection, fishing, as well as recognition of the ecological, economic, and cultural benefits of dam removal and restoring river connectivity have resulted in positive changes to some rivers (Johansson 2000, Kibler and Tullos 2013). Tracking the implications of restoration and improvement to rivers as well as understanding factors associated with degradation can inform stewardship decisions (Loomis et al. 2000, Niemi and McDonald 2004).

Measuring function and change within large river systems is difficult but river bird assemblages are increasingly recognized as useful ecological indicators for assessing biotic integrity (Mattson and Cooper 2006), degradation or remediation (Vaughan et al. 2007), and water quality (Feck and Hall 2004). Bird-based indices are particularly useful for detecting changes at both fine (e.g. microhabitat or local vegetation characteristics) and coarse scales (e.g. landscape cover type and land uses) (Saab 1999, Buckton and Ormerod 1997, MacFaden and Capen 2002). In particular, birds operate throughout their lifespan at a larger spatial scale than many other taxa, and thus are relevant to understanding the linkages between river, riparia, and watershed (Robinson et al. 2002). The relationships between avian use of rivers and river biotic production, integrity, quality, and hydromorphology have been examined (Ormerod and Tyler 1991, Feck and Hall 2004). Birds also typically forage at relatively high trophic levels and thus integrate across lower levels (Petersson et al. 1995, Steinmetz et al. 2003, Sullivan et al. 2006). Because birds also are readily observed and attract popular appeal as "headline indicators" of wider environmental trends, data collection is easier and can be mobilized at lower cost (D'Amico and Hemery 2003).

To monitor river bird assemblages as indicators, it is important to recognize that certain species may be more sensitive than others to various restoration or degradation scenarios (as reflected in their abundance) with some species responding positively and others negatively. Environmental variables were selected based upon their hypothesized sensitivity to restoration (i.e. dam removal, riparian habitat restoration/creation) or degradation (i.e. dam construction, riparian habitat loss/urbanization, and climate change). Restoration and degradation scenarios affect water flow, water level, and in-stream habitat (i.e. exposed bank and emergent rock perches). Additionally, documenting bird abundance as a function of proximity to the coast (river kilometer) is relevant in terms of potential changes to marine productivity (climate change) and riparian connectivity (dam removal/construction). Habitat variables reflect the structure of the environment rather than biotic measures such as food availability, competition, and predation. Abundance data was expected to be more sensitive to environmental change than presence-absence (Rhodes et al. 2006).

To use bird assemblages to monitor river condition and change, a baseline understanding of how bird species relate to environmental variables must be established over appropriate spatial and temporal scales. I conducted surveys of river-associated birds to determine how bird abundance is influenced by specific environmental factors associated with the presence of dams, riparian land cover, water level and flow, within-river habitats including rock perches and exposed river bank width, and proximity to the coast.

Methods

Study area

Maine contains approximately 48,000 km of rivers and streams (Maine Department of Inland Fisheries and Wildlife 1982), with more undeveloped, free-flowing rivers than elsewhere in the eastern United States. The state is 89% forested and is in the transition between temperate broadleaf and boreal forests.

River habitat variables

Sampling sites were selected in multiple watersheds to represent the variation in habitat variables and to distinguish between site-specific and other population drivers. River habitat variables reflect changes associated with urbanization (e.g. riparian land use), river connectivity (sites directly above, below, or not at a dam), marine productivity (based on distance from the river mouth, here called river kilometer), and factors that may be influenced by climate change (e.g., water flow). The closest U.S. Geological Survey (USGS) flow gauge (non-tidal sites [http://waterdata.usgs.gov/nwis/rt, accessed 10/12) and National Oceanic and Atmospheric Administration (NOAA) tidal data (http://tidesandcurrents.noaa.gov/, accessed 10/12) were obtained for each site during each survey period. Mean river flow (m^3/s), gauge and tidal values were assigned to low, medium, and high water flow categories by dividing site-specific ranges into thirds. To describe bird densities as a function of the river habitat variables, we assigned site characteristics of each visit based on the water level during the visit. For example, surface flow types were visually estimated during low, medium, and high water levels as the percentage of the site composed of rapids, low- (< *ca* 0.02 m/sec), and high- (> *ca* 0.02 m/sec) velocity water. Only rapids and low velocity water were used for analyses to avoid variable summation to 100% (Manly 2004). The percent of area composed of emergent rocks, and exposed bank width (from water's edge to the bankfull margin, m) were also visually estimated for the three water levels. All visual estimates were conducted by the same observer to limit variation. For each bird survey conducted, the percentage of low velocity water (variable subsequently coded as LVW), rapids (RAP), emergent rock perches (RCK), and exposed bank width (BNK) were assigned based upon the water level (WLV) values (low, medium, high) for the date and time the survey was conducted. Environmental variable values from the bird surveys were averaged over years within each sampling REP. Each site was described in terms of its distance from the mouth of the river [river kilometer, RVK]) and whether the site boundaries included an area immediately above (DMA), below (DMB), or not at a dam (DMN).

Maine river classification maps (1:24,000, [U.S. Geological Survey et al. 1997]) were used to delineate the 100-m boundaries along the banks within survey sites, thus incorporating an additional 50 meters beyond the survey site boundary where birds were counted (see Appendix A, Figure A.1), and inferring that birds observed may be influenced by habitat within 100 m of the river bank. Site-specific land-cover maps were derived from the 27 habitat values 2004 Maine Land Cover Dataset (MELCD) (1:5,000) (Maine Office of Geographic Information Systems [MEGIS] 2004) which were subsequently reclassified in two ways into categories that were hypothesized to influence river bird abundance (Gregory et al. 1997, Lock and Naiman 1998, Mazieka et al. 2007, Vaughan et al. 2007): 1) into eight categories (no vegetation/bare ground/developed/impervious surface [MELCD original field values: 0, 1, 3, 16, 20], wild field [8], herbaceous modified/row crops/ lawn [4, 5, 6, 7, 22], deciduous forest [9], coniferous forest [10], mixed forested [11, 23, 24, 25, 26], shrub scrub [12, 27], and wetland [13, 15, 19, 21), of which one, wetland (WET) is used in the analysis, and 2) into three categories, non-forested/field/agriculture/shrub scrub/ wetland [6, 7, 8, 12, 13, 15, 19, 20, 21, 22, NOF]), developed (0, 1, 2, 3, 4, 5, 16, DEV), and forested (9, 10, 11, 23, 24, 25, 26, 27, FOR). Among the three land cover types (wetland, non-forested, and development) the forested classification category was removed to avoid variable summation to 100% (Manly 2004). The percent cover of each category was also verified in the field at each survey site through comparison of aerial photos to onsite visual inspection. There were additional gathered site variables that were not used in the analysis due to lack of variation across sites (e.g., presence of bridges, buoys, cribworks, wires, tributaries, and islands).

River bird surveys

For the purposes of this study, we defined river birds as those species that use the river at some point in their life cycle (i.e., gulls, kingfishers, piscivorous raptors [Bald Eagle and Osprey], waders, shorebirds, waterfowl, and some passerines [e.g. swallows and crows,]) and that forage exclusively or opportunistically on aquatic biota. We surveyed individual bird species at 86 point-count locations along 10 Maine rivers (Figure 4.1). Survey sites (0.3 - 103 ha) included the river and an approximately 50-m-wide riparian zone on either bank of the survey site. It was assumed that bird densities were independent of survey site size (i.e. larger survey sites may have more birds but not higher densities than smaller sites). Boundaries were identified using clear landmarks (e.g. a bridge or a prominent tree). Each observer was trained during in-person, one-on-one meetings at each site prior to survey initiation (see Chapter 1 for more details on river bird survey protocol).

All individual observed birds within the site boundary were counted during 20-minute surveys conducted approximately every 2 weeks during spring (April through June) and fall (September through November) and every 3 weeks in summer (July and August) and winter (December through March, whenever a site was not iced over) from January 2009 to November 2012. Sampling was less frequent in the summer and winter as bird abundance and activity was presumed to be lower than in spring and fall. The 2- and 3- week periods were placed into temporal sampling blocks (REPS = 21 per year), with years and rivers pooled. All bird surveys were conducted by experienced, trained observers on suitable days (wind < 19 km/h, no rain, snow, or fog), from sunrise to 12:00 pm EST. Observations were conducted within this timeframe to limit the effects of changes in bird activity throughout the day. Surveys were predominantly visual and did not rely on sunrise peak singing activity.

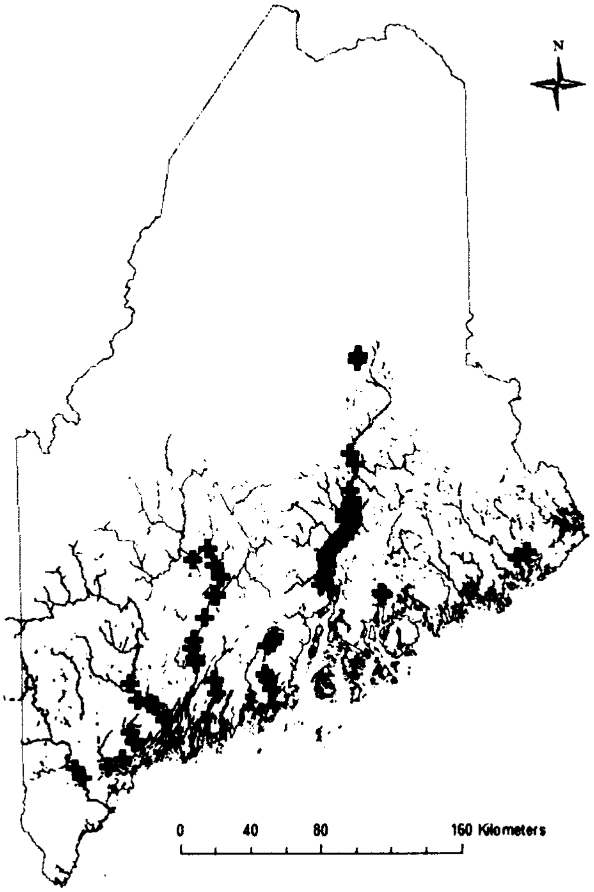


Figure 4.1. Study site, showing the distribution of 86 points surveyed in Maine, USA, in the years 2009 – 2012.

Data analysis

I investigated association between river habitat variables and bird assemblages using two analytical approaches. The first incorporated all species and site data (non-metric multidimensional scaling [NDMS]), while the second allowed for examination of species-specific response to the most relevant habitat parameters (general linear models [GLM]). I used NMDS with Bray-Curtis similarity measure (Clarke 1993) to compare the positions of multi-species bird densities (abundance divided by sites area in hectares) and river variables within multi-dimensional space (Oksanen 2012). NMDS does not make assumptions about the underlying statistical distributions of the bird densities (which were non-normal), and organizes data along a continuum, rather than into discrete groupings (McCune and Mefford 1999). No standardization of the response was used because the data were bird densities, rather than absolute counts (Quinn and Keough 2002). River habitat was standardized to zero mean and unit variance to allow for direct comparisons among the NDMS coefficients.

The data were subsampled to obtain a period during which bird densities were relatively constant (e.g., during breeding season, mid-April through September (REPS 6 – 16) based on examination of box plots), and years were pooled to obtain average conditions from 2009 – 2012. It was important to examine data that represented average conditions to better understand how habitat variables influenced abundance independent of factors that contribute to variation such as migration or inter-annual changes. Species observed on fewer than 5 % of the sites were removed, leaving 26 species for analysis. I conducted NMDS analysis on the 68 sites that did not contain outlying values for any of the 26 species (Table 4.1, based on examination of Cleveland dotplots, Cleveland 1993, Zuur et al. 2009) to avoid compressing the distribution of remaining sites (Gauch 1982).

I used the vegan (Oksanen et al. 2013) package in R (R Core Team 2013) for species ordination, and the function ‘envfit’ to examine correlations between ordination axes and river variables, where significance was assessed using randomizations with 1000 iterations (McCune and Mefford 1999, Oksanen 2012). Significant variables from the NMDS results should not be interpreted to “predict” a certain percentage of the

Table 4.1. List of 26 most abundant bird species detected during surveys in Maine, including four-letter alpha codes (Pyle and DeSante 2014) used in non-metric multidimensional scaling plots.

Bird name	Code
American Black Duck	ABDU
American Crow	AMCR
Bald Eagle	BAEA
Bank Swallow	BANS
Barn Swallow	BARS
Belted Kingfisher	BEKI
Canada Goose	CAGO
Cedar Waxwing	CEDW
Chimney Swift	CHSW
Cliff Swallow	CLSW
Common Merganser	COME
Double-crested Cormorant	DCCO
Eastern Kingbird	EAKI
Eastern Phoebe	EAPH
Great Black-backed Gull	GBBG
Great Blue Heron	GBHE
Great-crested Flycatcher	GCFL
Green-winged Teal	GWTE
Herring Gull	HERG
Hooded Merganser	HOME
Mallard	MALL
Osprey	OSPR
Ring-billed Gull	RBGU
Spotted Sandpiper	SPSA
Wood Duck	WODU
Tree Swallow	TRES

variability in bird abundance; rather the goal is to find the "gradients" in the data (Oksanen et al. 2013, Oksanen 2013). A single factor analysis of similarities (ANOSIM) procedure was used to test the H_0 of no difference in the bird assemblages between the three dam groups (above, below, or not at a dam). To assess NMDS model fit: 1) a Monte Carlo test was used to compare stresses of randomized to observed data to determine if data has significantly lower stress (i.e. better model fit) compared to a random distribution of the data and, 2) examined a Shepard diagram (stressplot function, R Core Team 2013).

To understand survey- and species-specific response (site and species assemblage response with NMDS), five additional single species models were created for species that were hypothesized to represent different foraging/life history groups including: Spotted Sandpiper (invertivore/shorebird), Osprey (piscivore/raptor), Bald Eagle (piscivore/raptor), Tree Swallow (aerial insectivore/passerine), and American Black Duck (invertivore/waterfowl). We applied a zero-inflated generalized linear model fitted with a Poisson distribution (ZIP GLM), a log-link function for Spotted Sandpiper, and negative binomial GLM (NB GLM) for the other four species (Zuur et al. 2009). Zero-inflated models are appropriate when the response variable contains more zeros than expected based on a Poisson or negative binomial distribution. Species abundance is modeled as the product of two processes: (1) species abundance when present (as Poisson or negative binomial distribution), and (2) species presence (occupancy). The negative binomial GLM contains a dispersion parameter which accommodates for Poisson overdispersion (when the variation in the data exceeds the expected amount of variability based on the Poisson distribution assumptions [Zuur et al. 2013]). The Vuong non-nested hypothesis test-statistic was used to determine which model (ZIP or NB) provides a better fit to the data (Vuong 1989). The response variable was the total abundance of the target species per REP, with an offset variable to account for differences in survey site area (log of survey site area in hectare). Outlying abundance values were not removed in single-species models as their inclusion did not affect model fit (based on examination of Cleveland dotplots, Cleveland 1993, Zuur et al. 2009). Relevant predictor variables were selected for each single-species model based upon knowledge of its life history. Square root transformations were applied when needed to normalize continuous predictor variables. For each species analysis we selected REPS where abundance was relatively constant approximately April through October (Spotted Sandpiper = 7-16, Osprey = 5-14, Bald Eagle = 5-16, Trees Swallow= 6-13, American Black Duck = 5-15) to remove effects associated with migration. Model selection was conducted with Akaike Information Criteria (AIC) values. The overall significance of the top-ranked model was assessed with a chi-squared test on the difference of log likelihoods (model fits the data significantly better than the null model [i.e. the intercept only model]). Model fit was also examined using the dispersion parameter for ZIP and the ratio of residual deviance and degrees freedom for NB models. The R-package pscl (Jackman et al. 2012) was used for ZIP models and package vegan for NB models (Oksanen et al. 2013).

Results

In 2,745 surveys (581, 698, 734, 732 during 2009 – 2012, respectively), 98 river bird species were recorded; however the ordination (Figure 4.2) was limited to the 26 most abundant species. Species and sites positioned at the perimeter of the plot in the direction of the arrow are associated with relatively higher values of the river habitat variables, those in the center with average values, and those opposite the arrows with low values. Species density and sites cannot be directly related, only indirectly through the river habitat variables. Longer arrows represent stronger relations, while shorter arrows represent weaker relations.

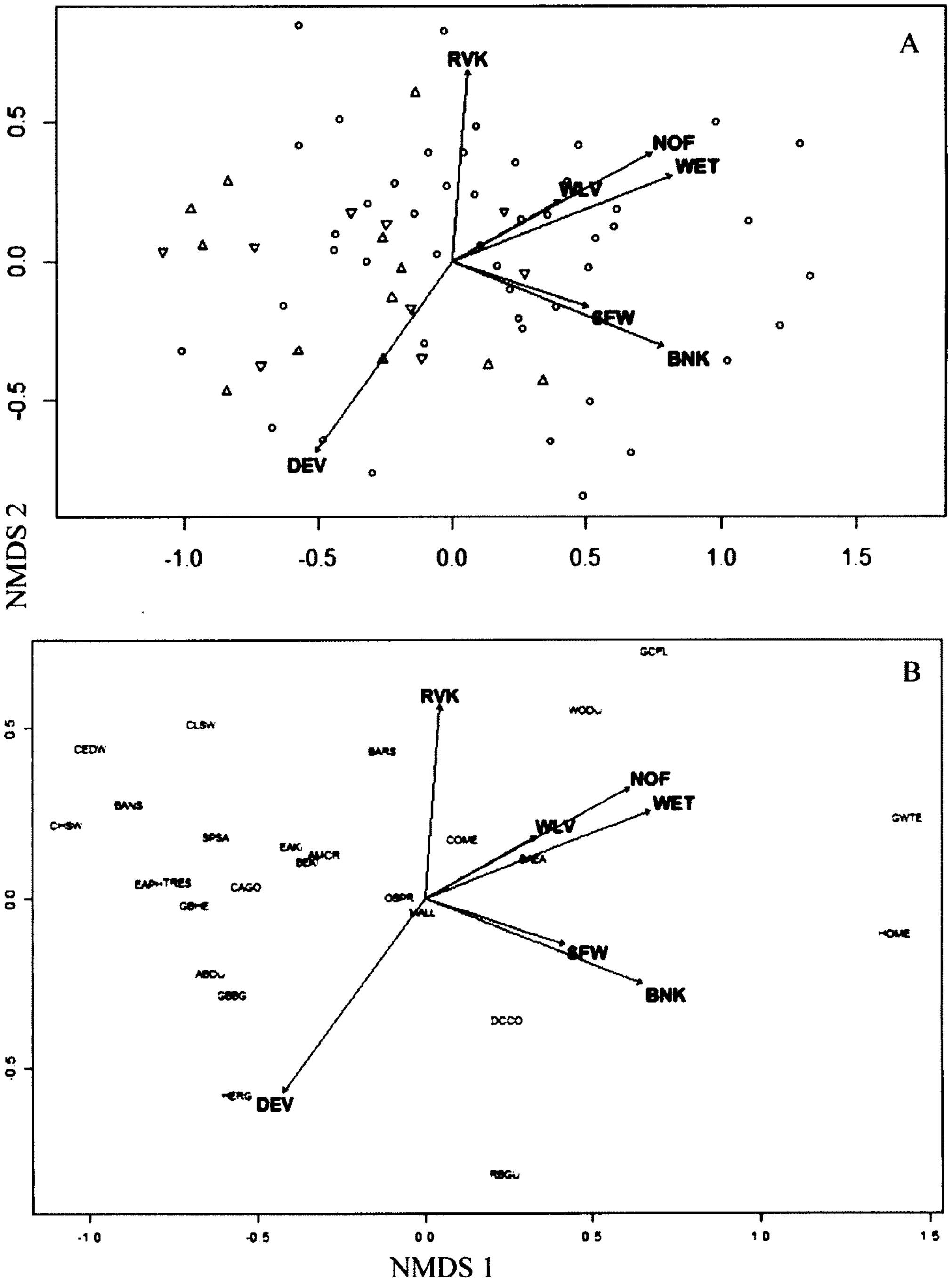
All river variables were significant except rapids (Table 4.2). There were no significant difference in species composition between the three dam groups (above, below, and not at a dam) (Pairwise ANOSIM; $R = 0.02$, $P = 0.35$). Good model fit was indicated by the stress value (0.16), Monte Carlo test ($P = 0.01$), and stressplot function (non-metric fit, $R^2 = 0.974$).

Species were associated positively with river kilometer (e.g. Cliff Swallow, Wood Duck, Great-crested Flycatcher), development (Herring and Ring-billed Gull), and interaction of river kilometer and development (e.g. Chimney Swift and Bank Swallow), whereas, other species were associated with average values of all river variables as indicated by their position near the center of the plot (e.g. Osprey, Mallard, Common Merganser, and Bald Eagle). Some species were associated positively with the non-forest, wetland, and exposed bank variables (e.g. Great-crested Flycatcher, Wood Duck, Green-winged Teal, and Hooded Merganser [Figure 4.2]).

The top single-species models were overall significant (Table 4.3; chi-squared, $P < 0.05$) and model fit was suitable (i.e., dispersion values ~1, ratio of residual deviance and degrees freedom < 1, models within $\Delta = 4$ AIC are also presented). The Poisson top model for spotted sandpiper showed a significant negative effect of river kilometer, wetland, and low velocity water, and a positive effect of rock perches and sites above dams.

Table 4.2. River habitat variable definition and range of values for the 86 points surveyed in Maine. Significance level (**<0.01, ***<0.001), coefficient of determination (R^2) given for non-metric multidimensional scaling results.

Variable	Code	Definition	Min	Max	Median	R^2
Dam	DMA, DMB, DMN	Classify sites as above, below, or not at a dam	na	na	na	
River kilometer (km)	RVK	Distance of the site to the mouth of the river	0.16	172	46.8	0.21**
Non-forested (% of site)	NOF	Field/agriculture/wetland land cover	0.09	0.88	0.61	0.31***
Developed (% of site)	DEV	Impervious surface 50 to 100 percent	0	91	0.22	0.32***
Wetland (% of site)	WET	Forested, estuarine, palustrine scrub-shrub, emergent vegetation	0.09	0.86	0.56	0.33***
Low velocity water (% of site)	LVW	Water velocity < *ca* 0.02 m/sec	0	1	0.9	0.12**
Rapids (% of site)	RAP	Flowing water over rocks creating whitewater	0	0.53	0	
Exposed bank width (m)	BNK	Distance from water's edge to the bankfull margin	0	35.14	1.69	0.31***
Water level	WLV	Classify as low (0), medium (1), or high (2) based on flow gauge data for each survey (GLM) or average for each site (NMDS)	0.37	1.39	0.95	


A
RVK
NOF
WET
WLV
SFW
BNK
DEV
0.5
0.0
-0.5
-1.0
-0.5
0.0
0.5
1.0
1.5
NMDS 2
B
GCFL
WODU
BARS
CLSW
CEDW
BANS
CHSW
SPSA
EAKI
AMCR
BEKI
EAPH TRES
CAGO
GBHE
OSPR
MALL
COME
GREA
GWTE
HOME
ABDU
GBBG
DCCO
HERG
RBGU
RVK
NOF
WET
WLV
SFW
BNK
DEV
0.5
0.0
-0.5
-1.0
-0.5
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1.0
1.5
NMDS 1

Species	Covariate Set	Covariates	Dispersion	Residual deviance/ DF	AIC	ΔAIC	w_i
Spotted sandpiper[1]	A[2]	**DMA(+)**, DMB(+), DMN(+), **RVK(-)**, DEV(+), **WET(-)**, **LVW(-)**, **RCK(+)**	0.99	NA	1280.00	0	0.701
	A[3]	**DMA(+)**, DMB(+), DMN(+), **RVK(-)**, DEV(-), WET(+), LVW(-), RCK(-)	-	-	-	-	-
	B[2]	REP(+), **DMA(+)**, DMB(+), DMN(+), **RVK(-)**, DEV(+), **WET(-)**, **LVW(-)**, **RCK(+)**	0.99	NA	1282.00	2	0.258
	B[3]	**DMA(+)**, DMB(+), DMN(+), **RVK(-)**, DEV(-), WET(+), LVW(-), RCK(+)	-	-	-	-	-
Osprey[4]	C	**DMA(-)**, **DMB(+)**, **DMN(+)**, **RVK(-)**, WET(-), **LVW(+)**	1.47	0.53	1215.15	0	0.698
	D	REP(-), **DMA(-)**, **DMB(+)**, **DMN(+)**, **RVK(-)**, WET(-), **LVW(+)**	1.47	0.53	1216.90	1.7	0.291
Bald eagle[4]	E	**DMA(-), DMB(+), DMN(+), WET(+), LVW(+)**	0.95	0.84	2147.50	0	0.996
Tree swallow[4]	F	**REP(-)**, DMA(+), **DMB(+)**, DMN(+), **RVK(-)**, **WET(-)**, **LVW(+)**, **NOF(+)**	2.72	0.84	2458.13	0	0.712
	G	**REP(-)**, DMA(+), **DMB(+)**, DMN(-), **RVK(-)**, DEV(+),**WET(-)**, **LVW(+)**, **NOF(+)**	2.75	0.84	2460.05	1.9	0.272
Black Duck[4]	H	**DMA(-)**, **DMB(+)**, DMN(-), **RVK(-)**, **DEV(+)**, WET(+), **LVW(+)**	0.54	0.19	682.96	0	0.69
	I	REP(+), **DMA(-)**, **DMB(+)**, DMN(-), **RVK(-)**, **DEV(+)**,WET(-), **LVW(+)**	0.68	0.19	684.53	1.6	0.31

[2] Abundance

[3] Occurrence

The negative binomial model also indicated a positive effect of sites above dams and negative effect of river kilometer. Osprey abundance was negatively associated with sites above dams and river kilometer and positively associated with sites below or not at a dam or those with low velocity water. Bald Eagle abundance follows a similar pattern except for the inclusion of a significant positive effect of wetland and lack of a significant effect of river kilometer. Tree swallow abundance was negatively associated with survey replicate (because abundance decreases through time), river kilometer, and wetland. Sites below dams, low velocity water, and non-forested habitat had significant positive associations. American Black Duck was significantly negatively associated with sites above dams and river kilometer and positively with sites below dams, development, and low velocity water.

Discussion

A riverscape perspective (Mazeika et al. 2007) was incorporated to consider both within-river characteristics and the surrounding riparian area with the goal of identifying key river variables that significantly influence bird abundance along Maine rivers. Species-specific responses to key river habitat variables – river kilometer, presence of dams, water flow, water level, and riparian land cover composition – provide benchmarks to assess management and restoration in the context of increasing challenges to rivers. River kilometer was a significant factor influencing abundance of many species, thus supporting prior research in which lower sections of watersheds provide a greater variety of habitats and food resources (Spackman 1982, Mazeika et al. 2007). Specifically, river kilometer was significant in the GLMs for target species, with sites lower in the watershed supporting substantially higher abundances. Piscivores, waterfowl (with the exception of Wood Duck), and generalists such as American Crow and Mallard were also largely associated with lower to middle river reaches, while many insectivores (e.g. Chimney Swift and Tree Swallow) seemed to experience the opposite trend.

Lower to middle sections may support higher abundances of some species, especially piscivores (with the exception of above-average values of river kilometer in the ordination for Bald Eagle and Common Merganser), and gulls (Great Black-backed, Herring, and Ring-billed), in part due to marine-derived nutrient subsidies of diadromous fishes (Todd et al. 1982, Poole et al. 2002). However, it is important to note that most of our study sites are on rivers in which dams and pollution have led to drastic declines in diadromous fishes compared to historical population levels (Limburg and Waldman 2009) and thus marine nutrient subsidies may not be substantial enough to influence species that would benefit indirectly (insectivores/invertivores/herbivores). In systems with more extensive marine-nutrient contributions, such as spawning Pacific salmon (*Oncorhynchus* spp.), indirect uptake of nutrients has been associated with higher abundance of terrestrial and aquatic invertebrates and potential linkages to higher densities of forest passerines (Gende and Willson 2001).

The effects of site position relative to a dam indicated positive associations of Osprey, Bald Eagle, Tree Swallow, and American Black Duck abundance with sites immediately below dams (for Spotted Sandpiper, $P = 0.09$), sites not at dams (Osprey and Bald Eagle [+]), and mixed results for sites above dams (Osprey, Bald Eagle, American Black Duck [-] and Spotted Sandpiper [+]) in the GLM (no effect with NMDS). Osprey and Bald Eagle may concentrate below dams because diadromous fishes aggregate when attempting to move upriver, thus providing a concentrated prey source. Rapids below dams also increase oxygenation, creating more suitable habitat, and increasing prey abundance and availability for some species of fish. Non-piscivorous bird species may also experience better foraging below dams because higher oxygenation and increased food delivery rates in riffle reaches downstream of dams often benefit macroinvertebrate populations. However, erratic and rapid changes in flow patterns at dams can have deleterious impacts to some macroinvertebrates communities (Munn and Brusven 1991). It is important to consider these localized effects of dams in the context of the wider impacts of these structures. At a larger scale, dams have altered river habitat, connectivity, and thus reduced the distribution and abundance of diadromous fishes overall.

Recognition of the ecological degradation of dams combined with the costly upkeep of aging structures has led to many river restoration and dam removal projects. In Maine, the deconstruction of the lowermost dam on the Kennebec River in 1999, and on a major tributary, the Sebasticook River, in 2008, led to increases in diadromous fish (e.g., alewife [*Alosa pseudoharengus*] and blueback herring [*Alosa aestivalis*]) abundance within both rivers (Crane 2009). Within New England's second largest river, the Penobscot, dam removals on tributaries (Sedgeunkedunk and Marsh Streams) and the main stem (Veazie and Great Works Dams) between 2009 and 2013 are expected to have a similar effect. These removals have led to a diverse program of monitoring changes in ecosystem status.

Water level and flow are known to influence within-river characteristics and river biodiversity including bird community composition (Fuller 1982, Poff et al. 1997). We found a positive relationship between low velocity water and Osprey, Bald Eagle, Tree

Swallow, and American Black Duck and a negative one with Spotted Sandpiper abundance, but no significant relationship was detected for any of the five focus species with respect to water level or exposed bank in the GLM analysis. Low velocity water may provide good visibility for Osprey, and suitable habitat for macrophytes and calm-water foragers like the American Black Duck. Freshwater snails prefer low velocity water and are also a major prey for American Black Duck (Longcore et al. 2000). Mallards and mergansers may benefit from subdued flows (Buckton and Ormerod 1997), as reflected in the association with average flow values in the NMDS. Spotted Sandpiper's negative association with low velocity water and positive association with the presence of emergent rocks may correspond to abundant invertebrate prey in well-oxygenated fast-flowing water and this bird's reliance on emergent rocks to access prey.

Climate change will intensify the effects of stressors already present and influence river hydrology in terms of water level, flow, and temperature, thus affecting a broad spectrum of biotic and abiotic processes and, specific to this research, those birds that utilize river systems (Bunn and Arthington 2002, Brown et al. 2013, Chaput et al. 2005, Dudley and Hodgkins 2002, Harley et al. 2006, and Steinmetz et al. 2003). Winter precipitation is expected to increase in the Northeast, leading to more erratic and higher spring flows (Palmer et al. 2008). These changes will affect the majority of Maine rivers and those species that benefit from low velocity water such as Osprey. Tracking the response of Osprey and other river birds that are significantly affected by water flow and water levels both statewide and within watersheds will help managers understand and distinguish stressors and the actions taken (e.g. riparian management) to diminish their influence on river function.

In the examination of riparian land cover, we found positive relations between development and American Black Duck (GLM, NMDS), Great Black-backed Gull, Herring Gull, Ring-billed Gull, and Double-crested Cormorant (NMDS) consistent with prior research (Rosa et al. 2003 [Lesser Black-backed gull], Donaldson et al. 2007 [American Black Duck, Double-crested Cormorant, Gull spp.], DeLuca et al. 2008). Previous work on riverine birds has described environmental variables related to human presence such as: percent of riparian margin that was developed (Rosa et al. 2003, Donaldson et al. 2007, DeLuca et al. 2008), non-treated points of sewage discharge (Raven and Coulson 2001, Rosa et al. 2003), and the average number of people in the study block (Rosa et al. 2003). Sewage discharge can result in higher prey densities (Hill et al. 1993) and urban gulls consume more garbage than their non-urban counterparts (Brousseau et al. 1996, Marzluff 1997).

Tree Swallow utilize open areas for foraging, and therefore their positive relation to natural, non-forested was expected (Robertson et al. 1982). In our analysis, we examined only general habitat categories in order to examine broad trends in river bird assemblages. Further research should analyze more distinct habit types, as these results may pinpoint more intricate relations to specific bird species.

Rivers and the services they provide are under increasing jeopardy due to the effects of multiple stressors. In our study, the positive relation between lower river sections and river bird abundance could provide insights into spatial prioritization of management actions. We highlight the importance of considering both the local and regional impact of dams and the role climate change will have on water flow dynamics. While urbanization does not have an overwhelming influence on most Maine rivers, river bird abundance can be used to track implications of pro-active management actions such as dam removal, riparian protection and restoration, and control of pollution (Nielsen et al. 1999, Morse et al. 2003, and Yoder and Hersha 2009).

River-associated birds serve as valuable bio-indicators because of their broad and fine-scale response. The linkages between this species assemblage and habitat features that reflect river function will be integral to document change within these complex systems, guide and prioritize restoration efforts, improve approaches, and monitor long-term ecosystem integrity at local and regional scales.

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APPENDIX A: MAINE RIVER BIRD SURVEY PROTOCOL

Overview

The overall goal is to better understand the ecology of bird populations associated with Maine rivers.

What?

The primary focus is on counting riverine and generalist birds that directly or indirectly feed on aquatic food resources including species such as cormorants, bald eagle, osprey, belted kingfisher, common loon, common grackle, American crow, common raven, raptors, waterfowl, herons, shorebirds, gulls, and *some* songbirds that forage extensively on aquatic insects such as swallows, swifts, flycatchers, Eastern kingbirds, gray catbird, Northern mockingbird, and waxwings (see Table A.1 for the full list of river bird species).

Where?

We need volunteers to survey several different Maine rivers. Surveys will be undertaken at designated points along river shores, selected for ease of access (e.g. public boat landings), features that may attract birds (e.g., falls and dams), good visibility (e.g. west-facing views are preferable to avoid backlighting by morning sun), and being generally representative of river conditions.

Table A.1. List of all potential river bird species from the official checklist of Maine birds. The most common river bird species are listed on the data sheet.

SWANS, GEESE & DUCKS
*_Fulvous Whistling-Duck_
Greater White-fronted Goose
Snow Goose
*_Ross's Goose_
Brant
*_Cackling Goose_
Canada Goose B-N1
Mute Swan rb-N1
Tundra Swan
*_Whooper Swan_
Wood Duck B
Gadwall rb
Eurasian Wigeon
American Wigeon rb
American Black Duck B
Mallard B-N1
Blue-winged Teal B
Northern Shoveler rb
**_Northern Pintail_ ib
*_Garganey_
Green-winged Teal B
Canvasback
Redhead
Ring-necked Duck B
*_Tufted Duck_
Greater Scaup
**_Lesser Scaup_ ib
*_Steller's Eider_
King Eider
Common Eider B
Harlequin Duck
Surf Scoter
White-winged Scoter
Black Scoter
Long-tailed Duck
Bufflehead
Common Goldeneye B
Barrow's Goldeneye
Hooded Merganser B
Common Merganser B
**_Red-breasted Merganser_ rb
**_Ruddy Duck_ ib

LOONS
Red-throated Loon
Pacific Loon
Common Loon B

GREBES
Pied-billed Grebe B
Horned Grebe
Red-necked Grebe
*_Eared Grebe_
*_Western Grebe_
*_Clark's Grebe_

PELICANS
*_American White Pelican_
*_Brown Pelican_

CORMORANTS
Double-crested Cormorant B
Great Cormorant rb

BITTERNS, HERONS & IBISES
American Bittern B
Least Bittern B
Great Blue Heron B
Great Egret rb
*_Western Reef-Heron_
Snowy Egret B
Little Blue Heron rb
Tricolored Heron rb
**_Cattle Egret_ rb
Green Heron B
Black-crowned Night-Heron B
**_Yellow-crowned Night-Heron_ ib
*_White Ibis_
Glossy Ibis B
*_White-faced Ibis_

STORKS
*_Wood Stork_

AMERICAN VULTURES
Black Vulture
Turkey Vulture B

KITES, EAGLES & HAWKS
Osprey B
*_Swallow-tailed Kite_
*_Mississippi Kite_
Bald Eagle B
Northern Harrier B
Sharp-shinned Hawk B
Cooper's Hawk B
Northern Goshawk B
Red-shouldered Hawk B
Broad-winged Hawk B
*_Swainson's Hawk_
Red-tailed Hawk B
Rough-legged Hawk
**_Golden Eagle rb_

FALCONS
American Kestrel B
Merlin B
Gyrfalcon
Peregrine Falcon rb-N2

RAILS, GALLINULES & COOTS
*_Yellow Rail_
*_Corn Crake_
*_Clapper Rail_
*_King Rail ib_
Virginia Rail B
Sora B
Purple Gallinule
Common Moorhen rb
American Coot rb

CRANES
Sandhill Crane rb

PLOVERS
*_Northern Lapwing_
Black-bellied Plover
American Golden-Plover

Table A.1 continued. List of all potential river bird species from the official checklist of Maine birds. The most common river bird species are listed on the data sheet.

PLOVERS cont.
**Pacific Golden-Plover*
**Wilson's Plover*
**Common Ringed Plover*
Semipalmated Plover
Piping Plover B
Killdeer B

OYSTERCATCHERS
American Oystercatcher rb

STILTS & AVOCETS
Black-necked Stilt
American Avocet

SANDPIPERS & PHALAROPES
Greater Yellowlegs
Lesser Yellowlegs
Solitary Sandpiper
Willet B
Spotted Sandpiper B
Upland Sandpiper B
† Eskimo Curlew
Whimbrel
**Long-billed Curlew*
Hudsonian Godwit
**Bar-tailed Godwit*
Marbled Godwit
Ruddy Turnstone
Red Knot
Sanderling
Semipalmated Sandpiper
Western Sandpiper
**Red-necked Stint*
Least Sandpiper
White-rumped Sandpiper
Baird's Sandpiper
Pectoral Sandpiper
Purple Sandpiper
Dunlin
**Curlew Sandpiper*
Stilt Sandpiper
Buff-breasted Sandpiper
Ruff
Short-billed Dowitcher
Long-billed Dowitcher
Wilson's Snipe B
American Woodcock B
***Wilson's Phalarope* ib
Red-necked Phalarope
Red Phalarope

SKUAS, GULLS, TERNS & SKIMMERS
Great Skua
**South Polar Skua*
Pomarine Jaeger
Parasitic Jaeger
**Long-tailed Jaeger*
Laughing Gull B
**Franklin's Gull*
Little Gull
Black-headed Gull rb
***Bonaparte's Gull* rb
**Mew Gull*
Ring-billed Gull B
Herring Gull B
Iceland Gull
Lesser Black-backed Gull
Glaucous Gull
Great Black-backed Gull B
Sabine's Gull
Black-legged Kittiwake
**Ivory Gull*
**Gull-billed Tern*
Caspian Tern
Royal Tern
Sandwich Tern
Roseate Tern B
Common Tern B
Arctic Tern B
Forster's Tern
Least Tern B
**Bridled Tern*
**Sooty Tern*
**White-winged Tern*
Black Tern B
Black Skimmer

CUCKOOS
Black-billed Cuckoo B
Yellow-billed Cuckoo B

GOATSUCKERS
Common Nighthawk B
**Chuck-will's-widow*
Whip-poor-will B

SWIFTS
Chimney Swift B

KINGFISHERS
Belted Kingfisher B

TYRANT FLYCATCHERS
Olive-sided Flycatcher B
Eastern Wood-Pewee B
Yellow-bellied Flycatcher B
Acadian Flycatcher
Alder Flycatcher B
Willow Flycatcher B
Least Flycatcher B
Eastern Phoebe B
**Say's Phoebe*
**Ash-throated Flycatcher*
Great Crested Flycatcher B
**Variegated Flycatcher*
**Tropical Kingbird*
Western Kingbird
Eastern Kingbird B
***Scissor-tailed Flycatcher* ib
Fork-tailed Flycatcher

SHRIKES
**Loggerhead Shrike xb*
Northern Shrike

VIREOS
White-eyed Vireo
**Bell's Vireo*
Yellow-throated Vireo B
**Plumbeous Vireo*
Blue-headed Vireo B
Warbling Vireo B
Philadelphia Vireo B
Red-eyed Vireo B

Table A.1 continued. List of all potential river bird species from the official checklist of Maine birds. The most common river bird species are listed on the data sheet.

CROWS
American Crow B
Fish Crow rb
Common Raven B

SWALLOWS
****Purple Martin*** B
Tree Swallow B
Northern Rough-winged Swallow B
Bank Swallow B
Cliff Swallow B
**Cave Swallow*
Barn Swallow B

MOCKINGBIRDS & THRASHERS
Gray Catbird B
Northern Mockingbird B
**Sage Thrasher*
Brown Thrasher B

WAXWINGS
Bohemian Waxwing
Cedar Waxwing B

BLACKBIRDS & ORIOLES
Red-winged Blackbird B
Yellow-headed Blackbird
Rusty Blackbird rb
**Brewer's Blackbird*
Common Grackle B
**Shiny Cowbird*
Brown-headed Cowbird B
Orchard Oriole rb
**Bullock's Oriole*
Baltimore Oriole B

LEGEND

* *Rare (species name italicized): Written descriptions and, if possible, photographs and/or audio recordings should be submitted for any occurrence of these species in the state. Please send all reports to: Bill Sheehan, 1125 Woodland Center Road, Woodland, ME 04736 (email: me-brc@maine.rr.com), or Peter Vickery, Center for Ecological Research, P.O. Box 127, Richmond, ME 04357 (email: petervickery@adelphia.net).*

** *Rare Breeder (species name italicized): Written descriptions and, if possible, photographs and/or audio recordings should be submitted for any breeding records of these species in the state.*

B *Breeds regularly*
rb *Rare, very local, or less than annual breeder*
ib *irregular breeder, only one or two isolated records*
xb *No recent breeding; over 20 years since last breeding*

NOTE: Reports of breeding by any species that is an irregular breeder (ib), that bred historically (xb), or that is not listed as having bred in Maine should be documented. Please send information to the addresses above.

N1 *Introduced and established breeding population*
N2 *Populations successfully re-established and breeding in areas of former occurrence*
N3 *Domesticated species with feral populations established and breeding in the wild*
† *Extinct*

When?

Pilot surveys were conducted beginning in Sept. 08 and spring '09 marked the start of the "official" data collection period. Surveys should be conducted every two weeks during spring (from ice-out to early June) and fall (late August to November) and every 3 weeks otherwise. At sites that remain ice-free in winter we are encouraging winter surveys. Surveys can be undertaken between sunrise and noon and last 20 minutes per sample site. If your site is tidally influenced, try to capture different tide cycles within each season by surveying at different times during the morning period.

Getting started

Initially we need to ask you three key questions: 1) are you an experienced birder able to correctly identify the suite of target species, 2) what town or towns are you willing to work in, and 3) how many sites are you willing to survey? Ideally, we hope each volunteer can agree to survey multiple sites, clustered for ease of travel between them, but if you can only do a single site that may be okay. If there are any particular sites (e.g. in front of your house, near your workplace) that you would prefer to survey please let us know, but ultimately we will need to assign observers to sites in a pattern that achieves broad and comprehensive coverage.

Instructions

Determining the survey area

After your general survey sites are determined (for example, the boat landings in Brewer and Eddington) these need to be translated into specific areas with reasonably clear boundaries so that the area you survey is the same during each visit. Ideally, this will require identifying a rectangular survey area defined by your shore, the opposite shore, and two imaginary lines across the river. Birds flying or perched within approximately 30 feet of the shoreline can be counted as within the boundary. Carefully study Figure A.1 and its legend to see how this can be done. In some circumstances, islands, river bends, etc. will dictate using something other than a rectangular area. Make sure when setting up your survey boundary that visibility is the same throughout all seasons (don't include areas where visibility changes in summer versus winter because of leaf-off). The size of the survey area should limited so you can detect small birds such as spotted sandpipers equally well as a bald eagle. Obviously if you choose to work on private land be sure to ask for permission; so far we have had 100% success in gaining permission.

Survey timing

Spring and fall surveys should happen every two weeks; summer and winter surveys can be less frequent (every 3 weeks) if you prefer. Days can be adjusted slightly to accommodate your schedule or bad weather. If you are delayed, survey at the next earliest opportunity. IMPORTANT: If you are unable to meet the survey schedule by more than a few days due to various reasons, such as a vacation or illness, please let me know as "back-up" birders are available.

To avoid bias it is important that you plan the timing of your surveys in advance and do not react opportunistically. For example, imagine that you usually do your surveys on Saturdays but on Thursday evening you noticed a huge flock of mergansers on the river; it is important to resist the temptation to switch your survey to Friday. Surveys should occur between sunrise and noon, preferably early but fog may prevent this on some days. If you are surveying a tidal section of a river, you should record the tide state and try to sample at different times in the tidal cycle within each season.

We will collect sighting in four time "bands" that are 5 minutes long each: 0-5 minutes, 5-10 minutes, 10-15 minutes, and 15-20 minutes. To facilitate this it will be very handy to have a count-down timer that you can set for 5 minutes. Some electronic watches have this function; you could also use a kitchen timer normally used for baking a cake. In each 5 minute interval you will count all birds. For birds that you are confident were observed in a prior interval, circle the number on the datasheet. It will be easy to recognize additional species as new but it may take some judgment to decide if that eagle that flew by at 8 minutes was the same one that flew by during the first 5 minute interval. During the 2nd, 3rd, or 4th period you may discover an inconspicuous bird (e.g. a perched kingfisher) that was almost certainly missed during your first period. In these cases record it only for the period you found it; do **not** add it to the earlier counts. In your notes at the bottom of the page, mention that this bird was probably present but overlooked earlier.

Filling out the data form

Your **name, location, date,** and **time** are straightforward. Spell out months because 5/6/2008 is May 6 to some people and 5 June to others. Note that this survey is designed for observations by only one person. If you have an occasional companion, they should watch silently but should *not* help you find or count birds because four eyes are better than two (you will see more birds with two people and this will not be related to a biological cause). If you routinely have a second observer, let us know because there is a particular way to collect observations that can give useful insight into bird detection. Essentially one person records and silently documents birds they see that the other observer does not by noting with their initial next to the data point.

Record **equipment** used (scope and/or binoculars and their magnification, at least 8x) and try to use the same equipment consistently.

Record some general **weather** and **water level** observations. Weather includes temperature, wind (NO WIND, LIGHT, or GUST), precipitation (LIGHT RAIN, INTERMITTENT RAIN, or SNOW), and cloud cover (CLEAR, PCLOUD (partly cloudy), OVERCAST (100% cloud cover), or FOG). Water level at tidal sites = LOW, MID, or HIGH, and nontidal sites = LOW, REGULAR, HIGH, or FLOOD (if the standing spot is under water). The survey should not be conducted if fog, heavy rains, or snow impede visibility or if there are high winds (top of trees moving). If your site is flooded and you are still able to see your entire survey area you can conduct a survey. If you are prevented from surveying, get out again at your first available opportunity.

Record **numbers of individuals** by **species.** Do your best to avoid counting the same individual twice in the same 5 minute survey period. We recognize this can be a judgment call: is that osprey flying downriver the same one that flew upriver 2 minutes ago?

In each 5 minute period count all birds observed. Put a circle on your datasheet around birds you are confident were observed in prior intervals (if you submit your data electronically you can bold and underline birds observed in prior intervals). Review the attached example datasheet to familiarize yourself with more complex observation scenarios. In the example for common mergansers, 2 males were observed in the first 5 minutes, in the second 5 minute interval 1 female joined the count, in the third interval, 3 more females joined, in the last interval, 2 males from the prior interval left, and 3 new males and 1 female arrived. For the bald eagle example, it was observed in one interval, left the survey and returned in a later interval. Remember if you are unsure if the bird(s) were observed in a prior interval then just count them as new individuals.

Record numbers by **age** and **sex** when possible, using the following abbreviations:

A = adult, J = juvenile, YOY = young of year (chicks), M = male, and F = female.

It is okay to use U = Unknown frequently because this information is of secondary importance. Thus you should not compromise getting a good count on a cormorant flock by staring at a kingfisher, waiting for it to turn around so that you can identify whether it is male or female.

To record **primary behavior** try to select the one major activity that characterizes that species during the overall 20-minute observation period by roughly multiplying the number of birds performing a behavior by the amount of time they were doing it. Use the following categories: *Stationary, Walking, Swimming, Flying upriver, Flying downriver, Flying (any flying that is not up and down river). Flying upriver/downriver* can be used if there is about the same number of birds flying up and down. If you only heard a bird that you believe is within the survey boundary, record *Hear* in this space.

If you are reasonably confident about what the birds are doing also record the following **secondary behavior:** *Resting* (including preening, sleeping, etc.), *Foraging* (including both searching for food and eating; for species like kingfishers this might include sitting and scanning the water), *Social interactions* (all interactions with members of the same species). Note that behavior observations are of tertiary importance after species, age, and sex.

In the **few blank lines on the bottom of the survey**, record **other river birds that are not listed** but may forage on river food resources as a generalist (American crow, common raven, common grackle) or any kind of hawk, heron, egret, waterfowl, tern, gull, swallow, swift, flycatcher, shorebird and **aquatic mammals** (that is otter, mink, beaver, and muskrat) and record in each interval. If you are **unsure of the species** you can denote DUCK, SHOREBIRD, TERN, SWALLOW, etc.).

In the **survey notes** at the bottom of the datasheet you can record:

1) any river birds that you detect before or after your survey begins, or which never enter your survey area. Note that it is important not to start your survey prematurely (for example, as soon as you step out of the car to record that pair of wood ducks you flushed).

2) unusual behavior or behavior that is not captured by our system. For example consider a flock of mergansers that flew upriver and landed in your survey area soon after the survey began, foraged for about 10 minutes, then continued flying upriver, your behavior data would record swimming and foraging as the dominant activity but it would be interesting to note that the flock was moving upriver.

3) birds that are detected in your 2nd, 3rd, or 4th survey that were probably missed in an earlier survey (e.g. a perched immature eagle).

4) note any disturbances such as construction, boat traffic, airplanes, or other people that are present during the survey and note what intervals they occurred.

Also feel free to record any birds that are not associated with the river per se in this space, especially if you notice them foraging on aquatic insects. Try to avoid placing effort on non-river associated species (such as rock doves). While attention is directed to observing and documenting a rock dove, cardinal, or blue jay (for example), a river associated bird species could be missed.

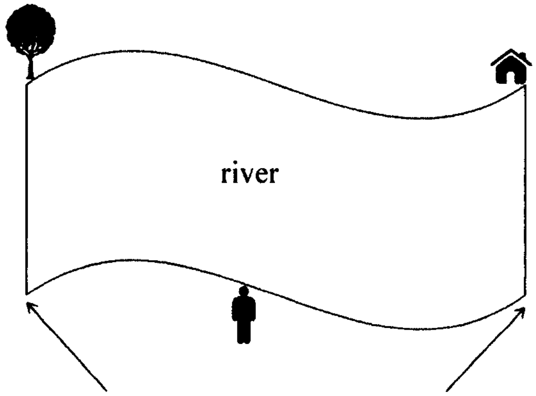
Submit data electronically via email, regular mail, or fax:

erynn.call@maine.edu

Erynn Call
Department of Wildlife Ecology, 5755 Nutting Hall
University of Maine, Orono, ME 04469-5755

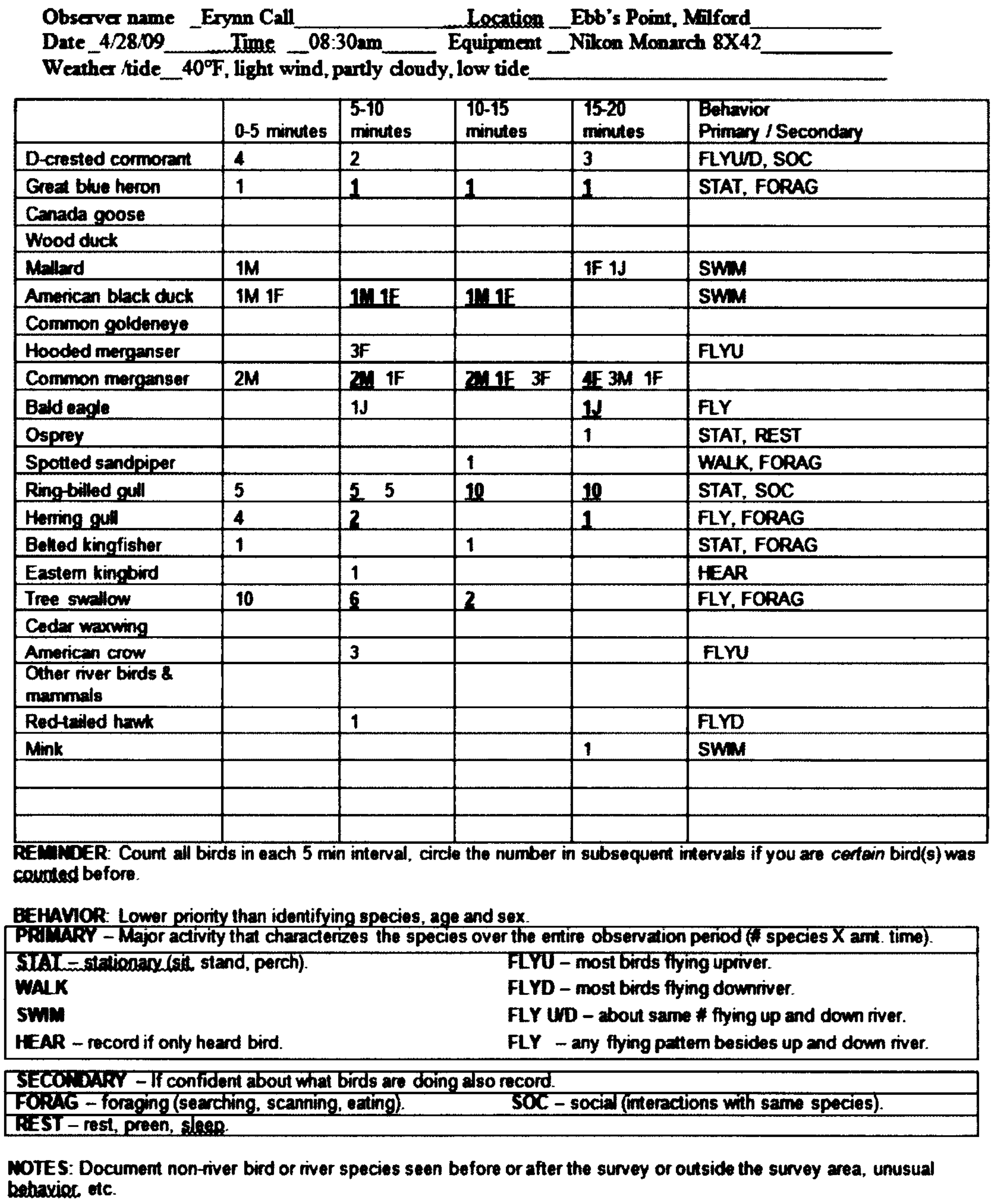
Fax: 581-2858

Figure A.1. Defining a survey area begins by identifying three fixed points. First, you need a survey spot where you will stand or sit--obviously a safe, comfortable place with a good view. Make certain that your survey area is equally visible in all seasons (leaf on and off). Next you will need two points on the opposite shore that define the upstream and downstream boundaries of your survey area. These need to be readily recognized features like a dock, a dam, or a distinctive rock or tree. At most sites it will work well if these points are roughly as far upstream and downstream as the width of the river. From these two points imaginary lines will extend back to your shore to define the rectangular area from within which all your data will be gathered. In the future we will visit each site and use a range finder to determine the length and directions of the sighting lines from the survey spot to these points and thus estimate the size of the area you are surveying. In the meantime, please describe all three points thoroughly in your notes, including compass bearings along the sighting lines if possible, in case you are run over by a boat or bus.



Site boundaries delineated by landmarks on opposite bank.

Figure A.2. Example Maine river bird survey form.



Observer name _Erynn Call_______________Location __Ebb's Point, Milford___________
Date _4/28/09_______Time __08:30am_____ Equipment __Nikon Monarch 8X42___________
Weather /tide__40°F, light wind, partly cloudy, low tide________________________________

	0-5 minutes	5-10 minutes	10-15 minutes	15-20 minutes	Behavior Primary / Secondary
D-crested cormorant	4	2		3	FLYU/D, SOC
Great blue heron	1	1	1	1	STAT, FORAG
Canada goose					
Wood duck					
Mallard	1M			1F 1J	SWIM
American black duck	1M 1F	1M 1F	1M 1F		SWIM
Common goldeneye					
Hooded merganser		3F			FLYU
Common merganser	2M	2M 1F	2M 1F 3F	4F 3M 1F	
Bald eagle		1J		1J	FLY
Osprey				1	STAT, REST
Spotted sandpiper			1		WALK, FORAG
Ring-billed gull	5	5 5	10	10	STAT, SOC
Herring gull	4	2		1	FLY, FORAG
Belted kingfisher	1		1		STAT, FORAG
Eastern kingbird		1			HEAR
Tree swallow	10	6	2		FLY, FORAG
Cedar waxwing					
American crow		3			FLYU
Other river birds & mammals					
Red-tailed hawk		1			FLYD
Mink				1	SWIM

REMINDER: Count all birds in each 5 min interval, circle the number in subsequent intervals if you are *certain* bird(s) was counted before.

BEHAVIOR: Lower priority than identifying species, age and sex.

PRIMARY – Major activity that characterizes the species over the entire observation period (# species X amt. time).

STAT – stationary (sit, stand, perch).	**FLYU** – most birds flying upriver.
WALK	**FLYD** – most birds flying downriver.
SWIM	**FLY U/D** – about same # flying up and down river.
HEAR – record if only heard bird.	**FLY** – any flying pattern besides up and down river.

SECONDARY – If confident about what birds are doing also record.

FORAG – foraging (searching, scanning, eating). **SOC** – social (interactions with same species).

REST – rest, preen, sleep.

NOTES: Document non-river bird or river species seen before or after the survey or outside the survey area, unusual behavior, etc.

APPENDIX B: STABLE ISOTOPE VALUES

The following pages outline stable isotope values in Table B.1.

Table B.1 Sulfur stable isotope values for river bird and associated prey collected from the marine sections (below the Veazie Dam) of the Penobscot River. Standard deviation is given in parenthesis when more than one analysis was made.

	Sample		#							
River Section[1]	Bird	Prey[2]	individuals per sample	# samples	$\delta^{34}S$	$\delta^{34}S$ SD (range[3])	$\delta^{13}C$	$\delta^{13}C$ SD (range)	$\delta^{15}N$	$\delta^{15}N$ SD (range)
A	BAEA[4] 1		1	2	14.49	0.1 (14.42 - 14.56)	-11.94	1.15 (-12.75- -11.13)	16.27	0.14 (16.17 - 16.37)
	BAEA 2		1	2	12.95	0.23 (12.78 - 13.11)	-18.58	0.28 (-18.77- -18.38)	13.68	0.22 (13.52 - 13.83)
	BAEA 3		1	3	18.89	0.26 (18.71 - 19.19)	-16.46	0.65 (-16.96 - -16.65)	14.16	0.12 (14.07 - 14.27)
	BAEA 4		1	1	11.58	—	-19.57	—	13.09	—
		Atlantic silverside	5	1	16.25	—	-17.76	—	11.58	—
		Common eider fledgling	1	5	14.20	2.9 (11.42 - 17.50)	-15.03	0.74 (-16.01 - -14.34)	13.83	0.75 (12.92 - 14.85)
		Rainbow smelt	2	1	16.44	—	-19.25	—	12.11	—
		Tomcod	4	1	16.08	—	-19.59	—	10.72	—
		Winter flounder	5	1	16.13	—	-17.74	—	11.53	—
B	BAEA 5		1	2	9.49	2.26 (7.89 - 11.08)	-21.60	2.26 (-23.19 - -20.00)	12.01	0.83 (11.42 - 12.59)
	BAEA 6		1	2	17.43	0.12 (17.34 - 17.51)	-17.61	0.32 (-17.83 - -17.38)	13.87	0.14 (13.77 - 13.97)

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[1] SF=South Frankfort, VF=between Veazie Dam and Frankfort, MV=between Veazie and Milford Dam, AM=above Milford Dam.

[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

[5] Enough individuals to make a sample weight suitable for analysis.

Table B.1 continued.

	Sample		#							
River Section[1]	Bird	Prey[2]	individuals per sample	# samples	$\delta^{34}S$	$\delta^{34}S$ SD (range[3])	$\delta^{13}C$	$\delta^{13}C$ SD (range)	$\delta^{15}N$	$\delta^{15}N$ SD (range)
B	BAEA 7		1	2	12.60	0.07 (12.55 - 12.65)	-18.79	0.11 (-18.86 - - 18.71)	14.61	0.86 (14.00 - 15.21)
	BAEA 8		1	1	6.42	—	-25.57	—	11.73	—
	BAEA 9		1	1	8.49	—	-21.90	—	11.80	—
		Alewife	5	1	18.56	—	-20.39	—	11.65	—
		Black crappie	5	1	6.86	—	-31.11	—	8.89	—
		Blueback herring	5	1	19.22	—	-20.90	—	12.03	—
		Golden shiner	5	1	6.01	—	-27.52	—	7.98	—
		Redbreasted sunfish	2	1	5.67	—	-30.20	—	8.85	—
		Tomcod	2	1	14.28	—	-19.59	—	10.72	—
		White sucker	4	1	5.88	—	-25.26	—	9.30	—
C	BAEA 10		1	2	—	—	-23.88	0.14 (-23.98 - -23.78)	10.94	0.18 (10.81 - 11.06)
	BAEA 11		1	2	—	—	-25.69	0.50 (-26.27 - -25.45)	11.25	0.31 (11.28 - 11.55)
		Common shiner	5	1	—	—	-27.17	—	8.67	—
		Fallfish	5	1	—	—	-26.16	—	8.25	—
		Golden shiner	5	1	—	—	-31.36	—	7.51	—
		Pumpkinseed	5	1	—	—	-28.18	—	8.34	—

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[1] SF=South Frankfort, VF=between Veazie Dam and Frankfort, MV=between Veazie and Milford Dam, AM=above Milford Dam.

[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

[5] Enough individuals to make a sample weight suitable for analysis.

Table B.1 continued.

River Section[1]	Sample		# individuals per sample	# samples	δ^{34}S	δ^{34}S SD (range[3])	δ^{13}C	δ^{13}C SD (range)	δ^{15}N	δ^{15}N SD (range)
	Bird	Prey[2]								
D	BAEA 12		1	2	—	—	-23.04	2.95 (-25.12 - - 20.95)	11.43	1.71 (10.22 - 12.64)
		Fallfish	5	1	—	—	-25.87	—	8.19	—
		White sucker	4	1	—	—	-25.72	—	7.69	—
A	OSPR 1		1	3	18.94	0.12 (18.83 - 19.07)	-17.43	0.03 (-17.44 - -17.39)	14.85	0.10 (14.81 - 14.96)
	OSPR 2		1	2	19.26	0.11 (19.18 -19.34)	-17.30	0.08 (-17.36 - -17.24)	15.04	0.31 (14.82 - 15.26)
	OSPR 3		1	3	18.41	0.42 (18.06 - 18.88)	-16.44	0.32 (-16.73 - -16.10)	15.28	0.22 (15.06 - 15.50)
	OSPR 4		1	3	17.63	0.41 (17.27 - 18.07)	-15.43	0.67 (-16.09 - -14.75)	14.94	0.48 (14.52 - 15.47)
	OSPR 5		1	2	18.48	0.26 (18.29 -18.66)	-16.62	0.17 (-16.82 - -16.55)	15.47	0.10 (15.36 - 15.56)
	OSPR 6		1	2	17.05	0.23 (16.88 - 17.21)	-18.19	0.10 (-18.89 - -17.48)	14.59	0.20 (14.45 - 14.73)
	OSPR 7		1	1	17.71	—	-17.31	—	15.37	—
A	BEKI 1		1	5	13.96	0.62 (13.02 - 14.59)	-20.66	0.67 (-21.52 - -20.14)	13.45	0.20 (13.20 - 13.67)
		Alewife	5	1	19.12	—	-18.35	—	11.91	—
		Rainbow smelt	2	1	16.79	—	-17.14	—	13.80	—
B	BEKI 2		1	5	11.18	0.89 (9.96 - 11.96)	-21.95	0.95 (-22.95 - -20.22)	13.69	0.34 (13.52 - 14.34)
		Alewife	5	1	19.49	—	-18.46	—	11.88	—
		American shad	5	1	16.67	—	-20.97	—	11.46	—
		Blueback herring	3	1	19.65	—	-20.14	—	11.90	—

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[1] SF=South Frankfort, VF=between Veazie Dam and Frankfort, MV=between Veazie and Milford Dam, AM=above Milford Dam.

[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

[5] Enough individuals to make a sample weight suitable for analysis.

Table B.1 continued.

River Section[1]	Sample: Bird	Sample: Prey[2]	# individuals per sample	# samples	$\delta^{34}S$	$\delta^{34}S$ SD (range[3])	$\delta^{13}C$	$\delta^{13}C$ SD (range)	$\delta^{15}N$	$\delta^{15}N$ SD (range)
B		Rainbow smelt	5	1	16.21	—	-16.37	—	13.53	—
		White sucker	2	1	4.25	—	-26.36	—	10.23	—
		Tomcod	5	1	12.07	—	-19.55	—	12.38	—
C	BEKI 3		1	2	—	—	-27.14	0.10 (-27.14 - -27.13)	12.33	0.00 (12.33 - 12.33)
		Brown bullhead	5	1	—	—	-28.85	—	7.72	—
		Chain pickerel	4	1	—	—	-28.80	—	10.15	—
		Fallfish	3	1	—	—	-26.11	—	8.77	—
C		White sucker	5	1	—	—	-28.39	—	8.24	—
D	BEKI 4		1	5	—	—	-28.31	0.30 (-28.83 - -27.97)	10.53	0.22 (10.34 - 10.85)
	BEKI 5		1	5	—	—	-28.25	0.41 (-28.67 - -27.78)	11.33	0.14 (11.20 - 11.52)
		Brown bullhead	5	1	—	—	-27.88	—	7.85	—
		Fallfish	3	1	—	—	-25.12	—	8.50	—
		White sucker	5	1	—	—	-29.80	—	7.11	—
A	TRES 1		1	4	9.12	0.19 (8.85 - 9.27)	-24.34	0.22 (-24.42 - -24.13)	8.63	0.87 (9.05 - 9.24)
	TRES 2		1	4	9.22	0.25 (8.86 - 9.40)	-25.40	0.41 (-26.08 - -25.11)	9.46	0.19 (9.23 - 9.67)
	TRES 3		1	5	7.06	0.29 (6.81 - 7.52)	-23.51	0.11 (-23.66 - -23.37)	8.66	0.17 (8.52 - 8.94)

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[1] SF=South Frankfort, VF=between Veazie Dam and Frankfort, MV=between Veazie and Milford Dam, AM=above Milford Dam.

[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

[5] Enough individuals to make a sample weight suitable for analysis.

Table B.1 continued.

River Section[1]	Sample		# individuals per sample	# samples	$\delta^{34}S$	$\delta^{34}S$ SD (range[3])	$\delta^{13}C$	$\delta^{13}C$ SD (range)	$\delta^{15}N$	$\delta^{15}N$ SD (range)
	Bird	Prey[2]								
	TRES 4		1	1	8.23	—	-23.46	—	8.28	—
	TRES 5		1	5	8.67	0.20 (8.37 - 8.92)	-27.40	0.35 (-27.75 - -26.84)	7.02	0.15 (6.83 - 7.17)
		Diptera 1	4	1	-1.02	—	-31.89	—	3.93	—
		Diptera 2	many[5]	1	2.50	—	-30.08	—	3.80	—
		Diptera 3	many	1	-8.03	—	-25.55	—	4.76	—
		Odonata 1	2	1	5.82	—	-29.20	—	5.17	—
		Odonata 2	4	1	4.49	—	-29.05	—	6.30	—
B	TRES 6		1	3	6.89	0.53 (6.33 - 7.38)	-24.67	0.20 (-24.89 - -24.49)	8.06	0.09 (8.00 - 8.16)
	TRES 7		1	1	6.96	—	-24.61	—	8.22	—
	TRES 8		1	2	6.52	0.52 (6.15 - 6.89)	-24.11	0.25 (-24.29 - -23.93)	8.04	0.42 (7.74 - 8.33)
	TRES 9		1	5	—	—	-26.33	0.14 (-26.54 - -26.14)	8.11	0.12 (7.88 - 8.21)
	TRES 10		1	5	7.49	0.12 (7.28 - 7.6)	-26.35	0.27 (-26.48 - -25.96)	8.13	0.14 (7.90 - 8.28)
D	TRES 11		1	3	—	—	-25.50	0.18 (-25.71 - -25.37)	4.56	0.25 (4.35 - 4.84)
	TRES 12		1	3	—	—	-24.93	0.15 (-25.08 - -24.78)	4.34	0.42 (3.86 - 4.60)
	TRES 13		1	1	—	—	-26.10	—	8.39	—
	TRES 14		1	1	—	—	-25.76	—	8.20	—

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[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

[5] Enough individuals to make a sample weight suitable for analysis.

Table B.1 continued.

	Sample									
River Section[1]	Bird	Prey[2]	# individuals per sample	# samples	δ^{34}S	δ^{34}S SD (range[3])	δ^{13}C	δ^{13}C SD (range)	δ^{15}N	δ^{15}N SD (range)
D	TRES 15		1	1	–	–	-25.86	–	8.63	–
	TRES 16		1	1	–	–	-26.11	–	8.14	–
	TRES 17		1	1	–	–	-25.77	–	8.53	–
	TRES 18		1	5	–	–	-25.91	0.10 (-26.02 - -25.87)	8.61	0.20 (8.30 - 8.76)
	TRES 19		1	1	–	–	-25.85	–	8.10	–
	TRES 20		1	1	–	–	-25.86	–	8.44	–
		Odonata 3	3	1	–	–	-26.50	–	6.61	–
		Diptera 4	6	1	–	–	-27.29	–	7.24	–
		Ephemeroptera	6	1	–	–	-31.25	–	4.20	–
		Diptera 5	many	1	–	–	-25.46	–	6.20	–
		Plecoptera	6	1	–	–	-28.22	–	7.02	–

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[1] SF=South Frankfort, VF=between Veazie Dam and Frankfort, MV=between Veazie and Milford Dam, AM=above Milford Dam.

[2] Osprey prey same as bald eagle prey except except for common eider fledlging.

[3] Range in sample stable isotope values.

[4] BAEA = bald eagle nest, OSPR = osprey nest, BEKI = belted kingfisher nest, TRES = tree swallow nest.

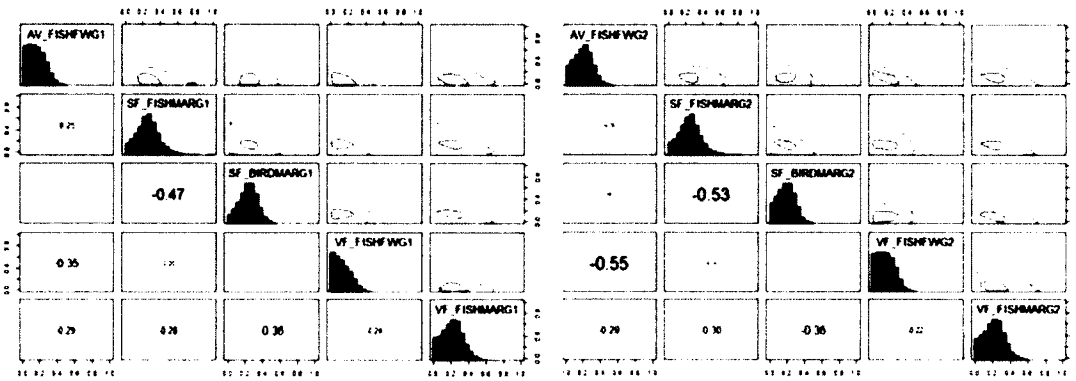
[5] Enough individuals to make a sample weight suitable for analysis.

APPENDIX C: BALD EAGLE DIETARY PROPORTIONS

Figure C.1 Matrix plots of each Penobscot River section of the posterior dietary proportions obtained from the bald eagle data. Diagnostic matrix plots allow further interpretation of the model output and display the joint behavior of the dietary proportions and support the conclusions made from the biplot and boxplots (Figures 2.3 and 2.4). The figures above the diagonal display contour plots illustrating the extent and direction correlations between variables; the diagonal shows histograms displaying the same dietary proportion data in Figure 2.3; and below the diagonal are the correlations between the different prey sources. Larger values are displayed in larger font size. Negative correlations correspond to exclusive contribution of one or the other prey item, whereas positive correlation are additive.

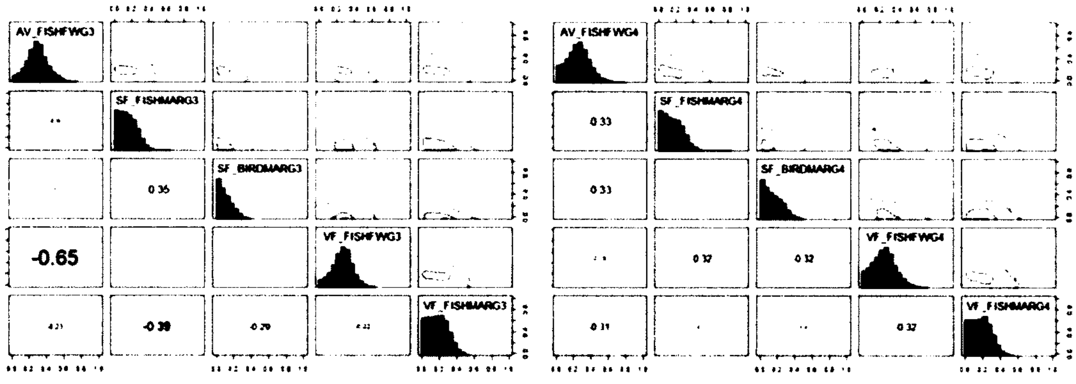
South Frankfort (SF)

Veazie to Frankfort (VF)



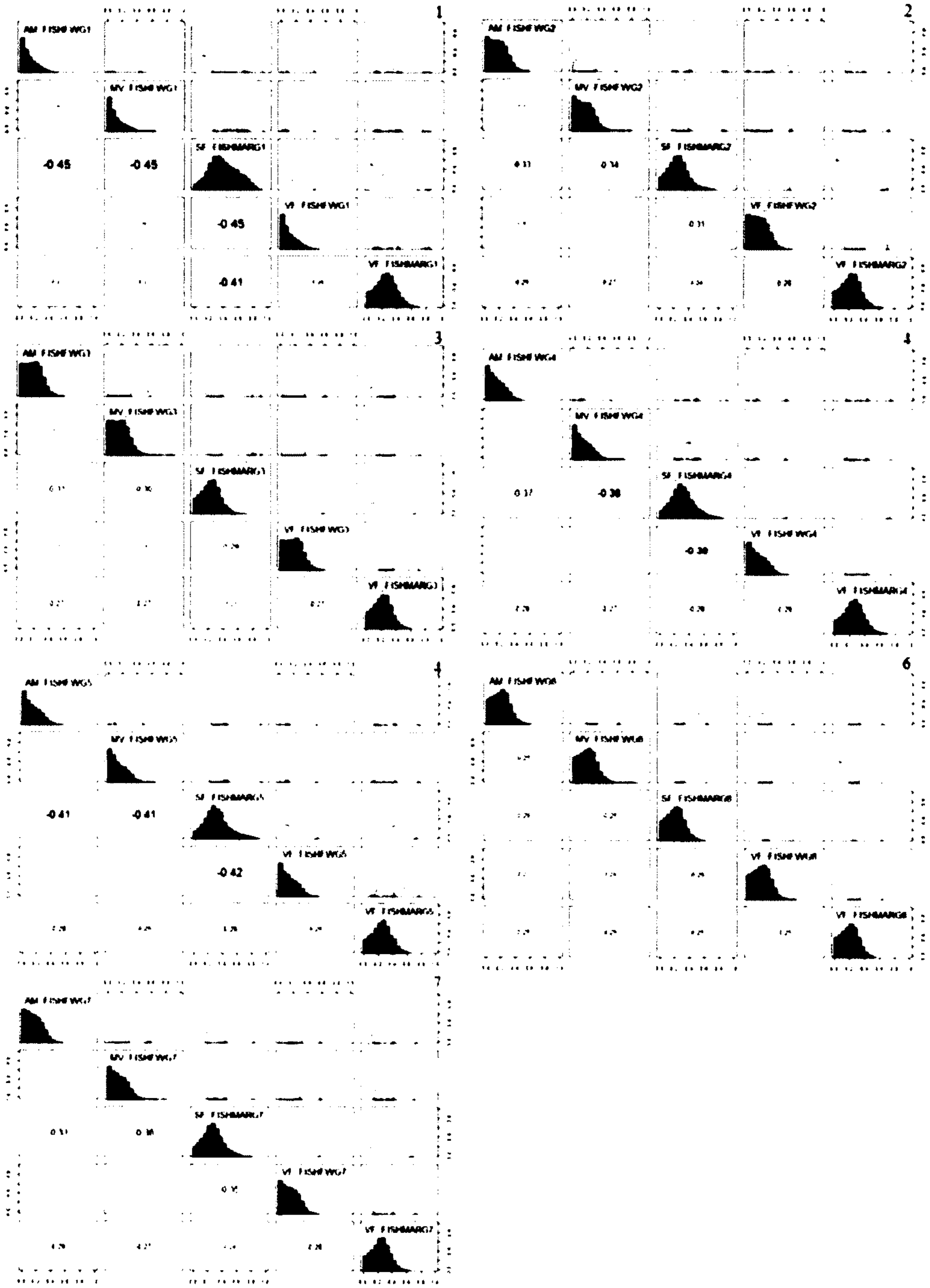
Between Veazie and Milford Dam (VF)

Above Milford Dam (AM)



APPENDIX D: OSPREY DIETARY PROPORTIONS

Figure D.1 Matrix plot of the posterior dietary proportions obtained from the osprey data from the lowest river section (South of Frankfort) by nest (n=7).

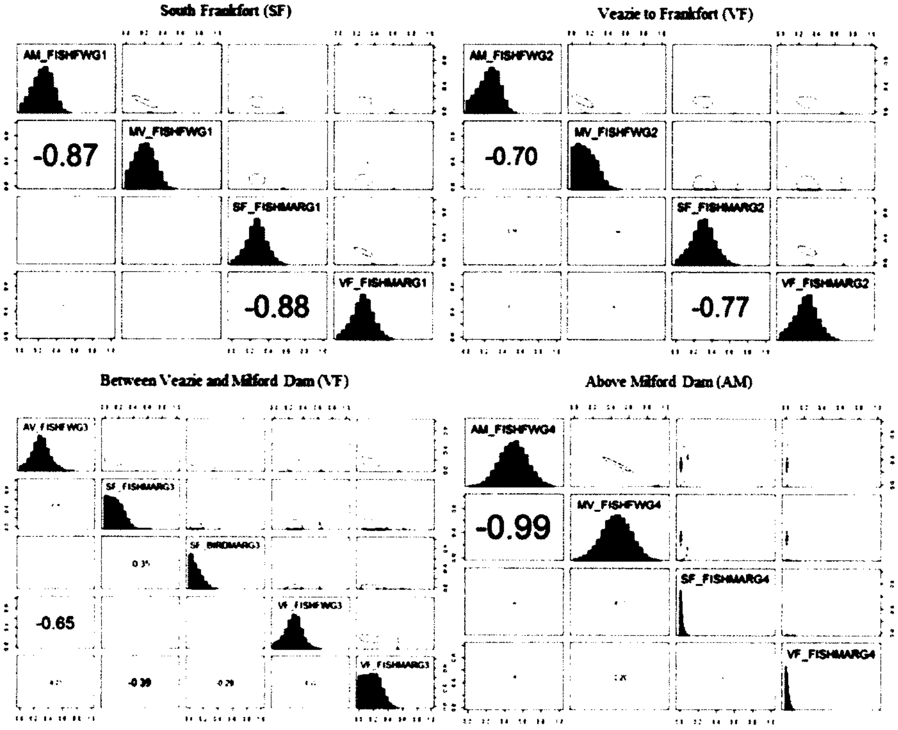


APPENDIX E: WITHIN NEST VARIATION COMPARISONS

Appendix E.1 There were no significant differences in within nest variation of $\delta^{13}C$ and $\delta^{15}N$ values (Wilcoxon sum rank test, *P* = 0.96, *P* = 0.63 respectively) between bald eagle and osprey below the Veazie Dam, however there was a marginally significant (*P* = 0.04) difference in $\delta^{34}S$. This difference in the within nest variation of $\delta^{34}S$ between eagle and osprey is due to $\delta^{34}S$ values in a single bald eagle nest (7.89, 11.08) resulting in a larger standard deviation (2 S.D. = 2.26).

APPENDIX F: BELTED KINGFISHER DIETARY PROPORTIONS

Figure F.1 Matrix plots of each Penobscot River section of the posterior dietary proportions obtained from the belted kingfisher data.



South Frankfort (SF)

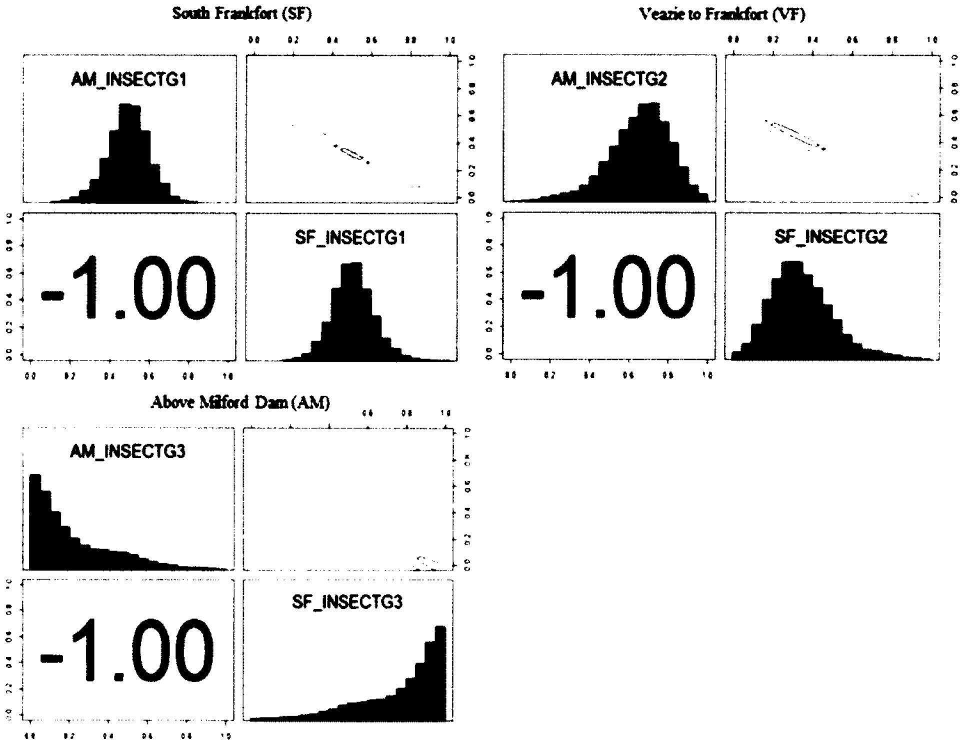
Veazie to Frankfort (VF)

Between Veazie and Milford Dam (VF)

Above Milford Dam (AM)

APPENDIX G: TREE SWALLOW DIETARY PROPORTIONS

Figure G.1 Matrix plots of three Penobscot River sections of the posterior dietary proportions obtained from the tree swallow data.



BIOGRAPHY OF THE AUTHOR

Erynn Call attended Michigan State University and graduated in 1998 with a Bachelor of Science degree in Wildlife Ecology and Management. She completed a Master of Science degree in Fisheries and Wildlife from the University of Missouri – Columbia in 2002. After receiving her degree she worked as an Avian Ecologist in the Everglades with the South Florida Water Management District and as a Wildlife Biologist in the Upper Peninsula with the Michigan Department of Natural Resources. Erynn is currently serving as the State Raptor Specialist for the Maine Department of Inland Fisheries and Wildlife, within the Wildlife Research and Assessment Section. She is a candidate for the Doctor of Philosophy degree in Wildlife Ecology from The University of Maine in May 2015.