Title

Trophic Interactions Between Birds and Aquatic Prey at North Campus Open Space

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Introduction

Trophic interactions control energy and nutrient movement through ecosystems. By documenting interactions between trophic levels we gain insights on consumer foraging patterns and the needs of species present in the ecosystem. In aquatic ecosystems, birds function as important connectors in trophic networks, consuming aquatic prey and linking aquatic and terrestrial food webs. As a large-scale restoration project, North Campus Open Space (NCOS) aims to reestablish native ecosystems and the flora and fauna within them. Evaluating trophic interactions within this system provides insight into whether restoration efforts have been successful at supporting native communities. At NCOS, bird species consume a large range of aquatic prey taxa, including fish, amphibians, crayfish, and invertebrates. The goal of this project was to summarize potential trophic links between bird species observed at NCOS and their aquatic prey taxa and to represent these relationships as an ecological network.

Methods

Trophic links were compiled for focal bird species and aquatic invertebrate taxa identified from prior monitoring efforts at NCOS and Devereux Slough (see Tables 3 and 4 in Appendix). We studied two groupings of bird species: birds that feed on aquatic invertebrates, primarily including ducks and shorebirds, and piscivorous birds, including both wading and diving species. These groupings were used to organize the trophic networks; however, some species utilize multiple foraging strategies and are therefore included in both networks. Bird data consisted of monthly surveys conducted at NCOS between 2017 and 2025. Aquatic prey data included quarterly aquatic invertebrate sampling at Devereux Slough since 2018, along with annual fish seining surveys (Senesac, 2022; Senesac et al., 2020). The most abundant invertebrate taxa were used to represent available prey resources (Table 2), with additional prey

categories for piscivorous birds including large fish, small fish, crayfish (*Procambarus clarkii*), and amphibians (Table 1). Information on avian diets was compiled from published literature, primarily using the Cornell Lab of Ornithology's Birds of the World (Billerman et al., 2026), but also other sources (Pospichal & Marshall, 1954; Wetmore, 1924). Two bipartite trophic networks were constructed using RStudio packages bipartite and rphylopic (v2.23, Dormann & Gruber, 2008; v1.6.0, Gearty & Jones, 2023). The food webs showcase connections between existing food resources and bird species observed (see Figures 1 and 2). Bird species and aquatic invertebrate taxa are shown as distinct node groups and documented feeding relationships represented as binary connections between them. This approach provides insight into trophic structure and the connectivity between bird consumers and aquatic prey within the system.

Table 1. Prey categories and associated species from NCOS used to compile additional trophic links between piscivorous birds and potential prey.

Vertebrate Network Prey Categories	Species at NCOS
Large Fish 12-30 cm	Mississippi silverside (*Menidia audens*)
	Topsmelt (*Atherinops affinis*)
	Longjaw mudsucker (*Gillichthys mirabilis*)
	Pacific staghorn sculpin (*Leptocottus armatus*)
Small Fish <12 cm	Mosquitofish (*Gambusia affinis*)
	Tidewater Goby (*Eucyclogobius newberryi*)
	California killifish (*Fundulus parvipinnis*)
	Arrow goby (*Clevelandia ios*)
Crayfish	Red swamp crayfish (*Procambarus clarkii*)
Amphibians	Pacific Chorus Frog (*Pseudacris regilla*)

Table 2. Invertebrate prey taxa compiled for bird-invertebrate interactions and their habitat characteristics (Benbow, 2009; Cooper et al., 2009; Courtney & Merritt, 2009; Havel, 2009; Martens & Horne, 2009; Traunspurger, 2009; Wallace, 2009; Williamson & Reid, 2009).

Invertebrate Prey Categories	Common Name	Habitat Type
Copepoda	Copepods	Open water / water column
Cladocera	Water Fleas	Open water / shallow water
Ostracoda	Ostracods; seed shrimp	Sediment / mudflat / benthic
Corixidae	Water boatmen	Shallow water / aquatic vegetation
Chironomidae	Midges	Mudflat / sediment / benthic
Ephydridae	Shore flies, brine flies	Mudflat / shore / shallow water
Ceratopogonidae	Sand flies, biting midges	Sediment / shore / shallow water
Nematoda	Nematodes	Sediment / mudflat
Oligochaeta	Earthworms	Sediment / mudflat / detritus

Results

Two bipartite trophic networks illustrate feeding interactions between bird species observed at NCOS and their respective aquatic prey taxa. These networks represent potential trophic interactions based on documented species diets, but not all linkages necessarily reflect interactions directly observed at NCOS. Figure 1 presents the network of 34 focal bird species and their associated aquatic invertebrate prey, documenting 96 trophic links. Figure 2 depicts 48 trophic relationships between piscivorous bird species and four broad aquatic prey categories: large fish, small fish, crayfish (*Procambarus clarkii*), and amphibians.

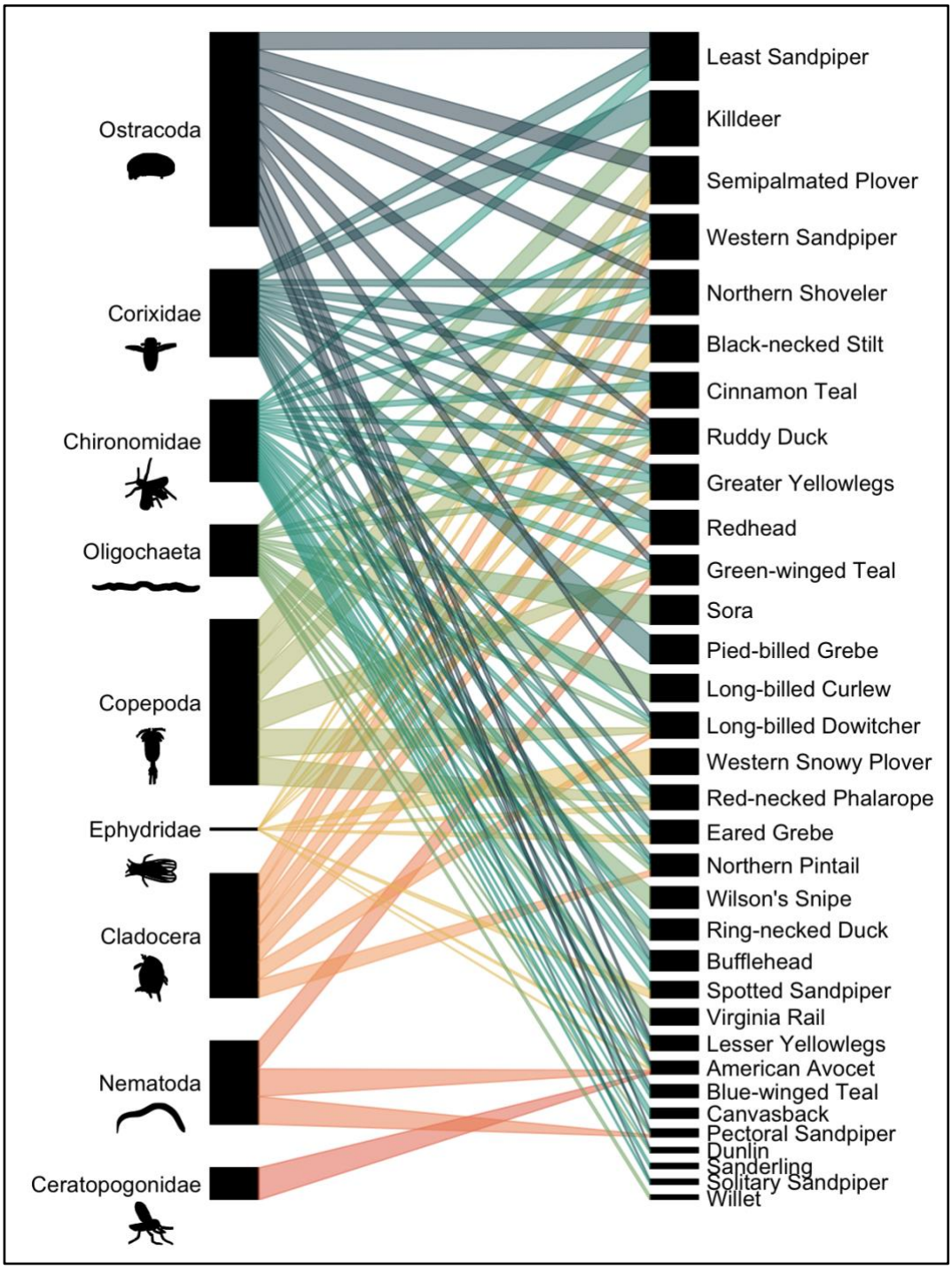

Figure 1. Bipartite trophic network illustrating potential feeding relationships between focal bird species (right) and aquatic invertebrate taxa (left) at North Campus Open Space (NCOS). Node sizes of both prey and predators are scaled according to the log-transformed abundances of each species at NCOS.

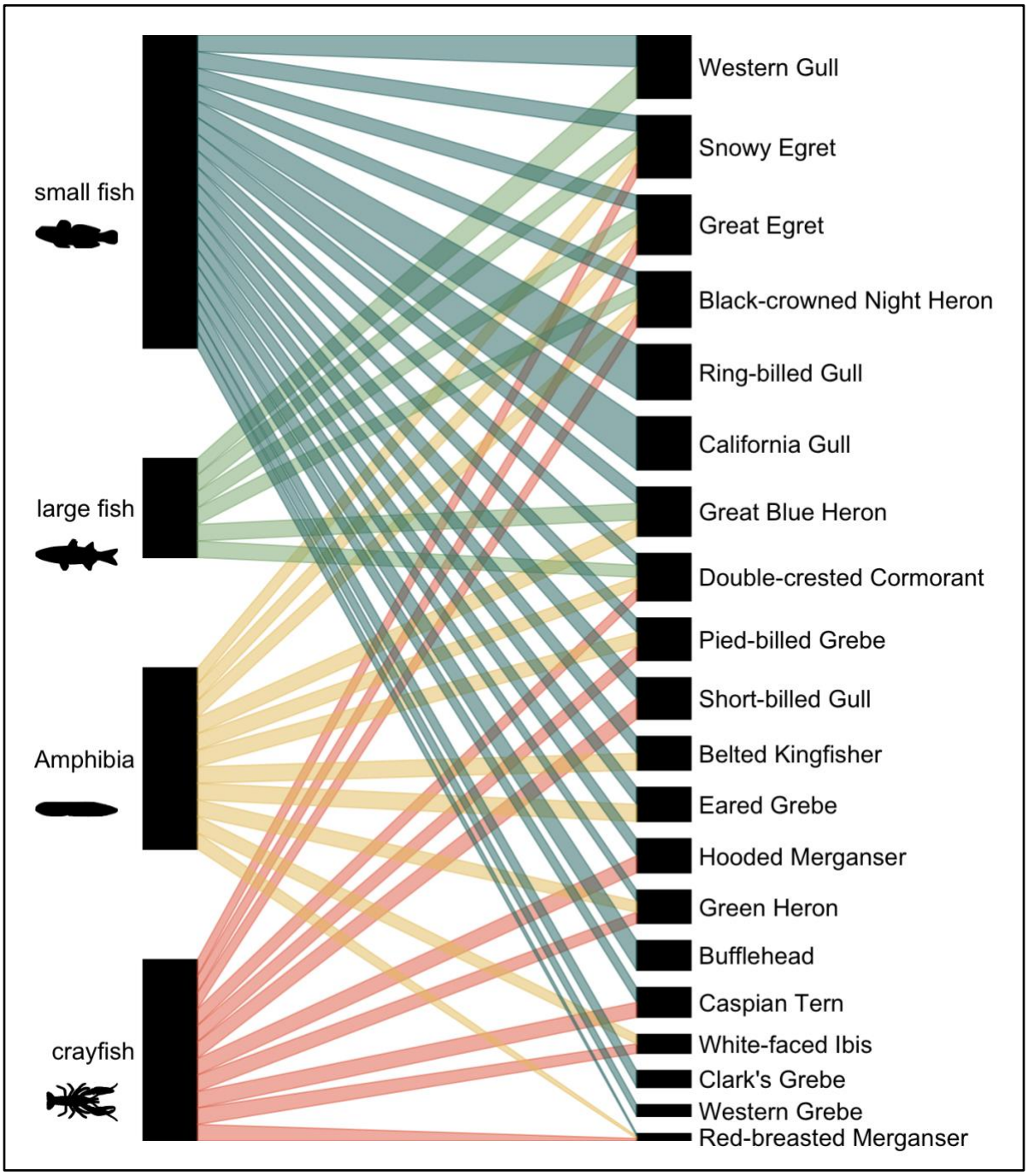

Figure 2. Bipartite trophic network showing feeding relationships between selected bird species and broad categories of aquatic prey at NCOS. Bird node size reflects log-transformed abundance; prey node size reflects number of linkages.

The aquatic invertebrate network (Figure 1) displayed numerous interactions between invertebrates and avian predators. Chironomidae (midges) exhibited the greatest number of connections with 23 connections, making up 24% of total links. Corixidae (water boatmen), Oligochaeta (earthworms), and Ephydridae (shore flies, brine flies) also exhibited many connections. Taxa such as Ceratopogonidae (sand flies, biting midges) and Nematoda (nematodes) exhibited fewer documented links, with Ceratopogonidae showing only a single linkage. Overall, most birds were connected to multiple invertebrate taxa.

The larger prey network (Figure 2) demonstrates patterns between piscivorous and wading birds and their aquatic prey. Small fish were the most highly utilized prey category in this network with 19 connections, and 40% of total links. They were documented being consumed by all focal bird species except for the White-faced Ibis. Amphibians and crayfish (*Procambarus clarkii*) were also linked to many birds; however, larger fish had fewer documented trophic associations.

Discussion

The compiled trophic networks provide insight into the potential structure of avian-aquatic food web interactions at NCOS. The large amounts of connectivity seen in both networks suggests that there is considerable overlap in prey use among bird species. Several prey taxa, including groups like Chironomidae and small fish, which are highly connected to many bird species, likely function as important resources for avian species found at NCOS. The structure of the networks also suggests variation in the types of prey consumed depending on the species of bird. Some birds showed numerous to different prey taxa, indicating generalist feeding strategies, whereas others displayed fewer links, suggesting more specialization. These differences may influence competition and niche overlap among bird species.

Despite these insights, it is important to recognize the limitations of this project. The documented links between predator and prey species represent potential feeding interactions rather than interactions directly observed at NCOS. Because bird diets can vary geographically, seasonally, and based on prey availability, some interactions included in these networks may not be occurring at NCOS. Conversely, many diets are not well-documented, so there may be additional linkages occurring at NCOS that have not yet been reported in the literature. Additionally, the low taxonomic resolution of the sampling data and literature sources may have

affected the patterns observed in this study. More detailed taxonomic identification could result in different observed trends. In the current bipartite network representation, feeding frequency, prey biomass, and the relative importance of prey in bird diets are not captured. As a result, the networks illustrate potential feeding interactions but do not show quantitative data within the ecosystem. Even so, these networks provide a useful framework for understanding potential food webs at NCOS and offer a visual representation of the connections often seen between avian predators and their prey.

Future work could build on these findings by gathering additional data, such as field observations and diet sampling, to validate which interactions are actually occurring at NCOS. Another possibility would be to expand the study area to include additional bird and prey species to further show patterns of resource use in various habitats throughout NCOS. Future studies could also incorporate life-stage transitions of aquatic insects, as many aquatic taxa emerge as terrestrial adults and become prey for a different group of birds. For example, adult flies emerging from aquatic habitats may be consumed by insectivorous birds, creating trophic linkages that were not captured in this study. Together these steps would improve our understanding of avian-aquatic food web dynamics and provide a stronger foundation for managing and conserving these species and their habitats.

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Appendix

Table 3. Summary of invertebrate-bird trophic interactions compiled from a literature review. The table presents links between bird species and their invertebrate prey.

bird_species	invert_taxon
Least Sandpiper	Ostracoda
Least Sandpiper	Corixidae
Least Sandpiper	Chironomidae
Killdeer	Oligochaeta
Killdeer	Corixidae
Semipalmated Plover	Copepoda
Semipalmated Plover	Ephydridae
Semipalmated Plover	Ostracoda
Western Sandpiper	Chironomidae
Western Sandpiper	Ephydridae
Western Sandpiper	Copepoda
Western Sandpiper	Ostracoda
Western Sandpiper	Oligochaeta
Western Sandpiper	Cladocera
Northern Shoveler	Cladocera
Northern Shoveler	Chironomidae
Northern Shoveler	Corixidae
Northern Shoveler	Ostracoda
Northern Shoveler	Copepoda
Black-necked Stilt	Ephydridae
Black-necked Stilt	Corixidae

Cinnamon Teal	Chironomidae
Cinnamon Teal	Cladocera
Cinnamon Teal	Corixidae
Cinnamon Teal	Ephydridae
Ruddy Duck	Chironomidae
Ruddy Duck	Cladocera
Ruddy Duck	Ostracoda
Ruddy Duck	Oligochaeta
Ruddy Duck	Corixidae
Ruddy Duck	Ephydridae
Greater Yellowlegs	Corixidae
Greater Yellowlegs	Oligochaeta
Greater Yellowlegs	Chironomidae
Greater Yellowlegs	Ephydridae
Redhead	Chironomidae
Redhead	Corixidae
Redhead	Cladocera
Green-winged Teal	Chironomidae
Green-winged Teal	Ostracoda
Green-winged Teal	Nematoda
Green-winged Teal	Copepoda
Sora	Oligochaeta
Pied-billed Grebe	Corixidae
Long-billed Curlew	Oligochaeta
Long-billed Dowitcher	Chironomidae

Long-billed Dowitcher	Ostracoda
Long-billed Dowitcher	Copepoda
Long-billed Dowitcher	Oligochaeta
Long-billed Dowitcher	Cladocera
Western Snowy Plover	Ephydridae
Red-necked Phalarope	Ephydridae
Red-necked Phalarope	Chironomidae
Red-necked Phalarope	Copepoda
Red-necked Phalarope	Corixidae
Eared Grebe	Ephydridae
Eared Grebe	Corixidae
Eared Grebe	Chironomidae
Northern Pintail	Chironomidae
Northern Pintail	Oligochaeta
Northern Pintail	Corixidae
Northern Pintail	Cladocera
Wilson's Snipe	Oligochaeta
Ring-necked Duck	Oligochaeta
Ring-necked Duck	Chironomidae
Bufflehead	Chironomidae
Bufflehead	Corixidae
Spotted Sandpiper	Chironomidae
Spotted Sandpiper	Ephydridae
Virginia Rail	Oligochaeta
Lesser Yellowlegs	Chironomidae

Lesser Yellowlegs	Corixidae
Lesser Yellowlegs	Ostracoda
Lesser Yellowlegs	Ephydridae
American Avocet	Ephydridae
American Avocet	Corixidae
American Avocet	Chironomidae
American Avocet	Ceratopogonidae
American Avocet	Ostracoda
American Avocet	Oligochaeta
American Avocet	Nematoda
Blue-winged Teal	Chironomidae
Blue-winged Teal	Corixidae
Canvasback	Chironomidae
Pectoral Sandpiper	Chironomidae
Pectoral Sandpiper	Nematoda
Pectoral Sandpiper	Ostracoda
Pectoral Sandpiper	Oligochaeta
Dunlin	Chironomidae
Dunlin	Oligochaeta
Dunlin	Ostracoda
Sanderling	Chironomidae
Solitary Sandpiper	Chironomidae
Solitary Sandpiper	Corixidae
Willet	Oligochaeta

Table 4. Summary of larger aquatic prey-bird trophic interactions compiled from a literature review. The table presents links between bird species and their larger prey.

bird_species	prey_taxon
Western Gull	small fish
Western Gull	large fish
Snowy Egret	small fish
Snowy Egret	large fish
Snowy Egret	Amphibia
Snowy Egret	Procambarus clarkii
Great Egret	Procambarus clarkii
Great Egret	large fish
Great Egret	small fish
Great Egret	Amphibia
Black-crowned Night Heron	small fish
Black-crowned Night Heron	Procambarus clarkii
Black-crowned Night Heron	large fish
Black-crowned Night Heron	Amphibia
Ring-billed Gull	small fish
California Gull	small fish
Great Blue Heron	small fish
Great Blue Heron	large fish
Great Blue Heron	Amphibia
Double-crested Cormorant	small fish
Double-crested Cormorant	large fish
Double-crested Cormorant	Amphibia

Double-crested Cormorant	Procambarus clarkii
Pied-billed Grebe	small fish
Pied-billed Grebe	Amphibia
Pied-billed Grebe	Procambarus clarkii
Short-billed Gull	small fish
Short-billed Gull	Procambarus clarkii
Belted Kingfisher	small fish
Belted Kingfisher	Amphibia
Eared Grebe	small fish
Eared Grebe	Amphibia
Hooded Merganser	Procambarus clarkii
Hooded Merganser	small fish
Green Heron	small fish
Green Heron	Amphibia
Green Heron	Procambarus clarkii
Bufflehead	small fish
Caspian Tern	small fish
Caspian Tern	Procambarus clarkii
White-faced Ibis	Amphibia
White-faced Ibis	Procambarus clarkii
Clark's Grebe	small fish
Western Grebe	small fish
Red-breasted Merganser	small fish
Red-breasted Merganser	Procambarus clarkii
Red-breasted Merganser	Amphibia