Identifying Conservation Priority Estuaries in British Columbia with a Graph-based Measure of Landscape Connectivity

by

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B.E.S., University of Waterloo, 2003

RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF RESOURCE MANAGEMENT

In the School of
Resource and Environmental Management

Report No. 407

SIMON FRASER UNIVERSITY

Summer 2006

APPROVAL

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Degree:	**Master of Resource Management**
Title of Research Project:	**Identifying Conservation Priority Estuaries in British Columbia with a Graph-based Measure of Landscape Connectivity**
Project No.:	**407**

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ABSTRACT

Predicting and ranking ecologically important estuaries supports estuary conservation efforts in British Columbia. Connectivity, an indicator of ecological importance, is not a component of rankings created to date by conservationists. I used graph theory to describe estuarine connectivity for three migratory birds: Dusky Canada Geese, Western Sandpipers, and White-winged Scoters and ranked estuaries based on their maintenance of connectivity. I developed seven metrics that quantified the importance of each estuary for connectivity at local and coastal scales. I computed the metrics and ranked estuaries separately for each species. Rankings were spatially proximal across species and indicated connectivity hot spots, i.e., collections of high-ranking estuaries within a restricted geographic area. Empirical observations of the focal species at connectivity hot spots verify that the graph model and connectivity metrics can predict important estuarine stopovers. These connectivity rankings are useful for prioritizing estuaries for conservation and for guiding future research.

Keywords: Estuaries -- British Columbia, Landscape Connectivity, Landscape Ecology, Nature Conservation, Estuarine Reserves

ACKNOWLEDGEMENTS

I wish to express my gratitude to the following people for their contributions to my research project:

Kris Rothley - This research project would not be the same without your expertise, insight, and dedication! Thank you for always being available to discuss connectivity, graph theory, and ArcView.

Dan Esler -Thank you for ensuring the biological foundations of this research. I am grateful for your thought-provoking questions and editorial comments.

Dan Buffett - You provided the estuary and elevation data that made this research possible! Thank you for your continued interest in my research and unceasing encouragement.

Pat Wong -Thank you for providing the wind data.

Ducks Unlimited Canada - Thank you for supporting my research financially.

Greg Harrold - My rock. Thank you for your knowledge of programming and never-ending support.

Christina Kereki - Thank you for chairing my defence and for being a part of so many of my REM experiences.

REM Staff - Laurence, Bev, Iris, and Sarah, thank you for everything you have done to make my time at REM such a fulfilling experience.

AWEL - Thank you fellow lab mates for being part of my REM experience and for supporting me through my research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

Cluster	A group of nodes, where each node is linked to at least one other node by at least one edge. A single node is also be a cluster when not connected to other nodes. A landscape with a single cluster is synonymous with a connected landscape.
Correlation Length	The average distance a migrant could fly within a cluster before it reached a barrier. Correlation length quantifies the average size of clusters in the landscape and indicates the degree of connectivity in the landscape.
Edge	A component of the graph that represents a pathway connecting two estuaries. Each edge has a cost assigned to it that corresponds to the effective distance of travelling along the edge.
Effective Distance	The cumulative cost of cells in the resistance surface (in cost units representing time or energy) that describes the least-cost pathway between two estuaries. The effective distance is used to set the effective distance thresholds.
Connectivity	Refers to "functional landscape connectivity," the degree that a landscape facilitates or impedes movement between habitat patches for a given species.
Graph Model	A spatially explicit model used to depict connectivity of estuaries in coastal British Columbia for a given species. Estuaries are represented as nodes and the linear, least-cost pathways that facilitate movement between the estuaries as edges.
Matrix	The landscape features between estuaries that correspond to costs of migrating between estuaries and either hinder or help movement.
Node	A component of the graph model, the node is a point located at the estuary's centroid and represents the spatial location of an estuary.
Resistance Surface	A grid representing the landscape between estuaries, where each cell in the grid has a cost value that either facilitates or impedes movement. The resistance surface determines the location of edges and the effective distance of each edge.
Threshold Distance	The maximum effective distance a migrant is capable of moving.

ESTUARY CONSERVATION IN BRITISH COLUMBIA

Although estuaries in British Columbia cover less than 3% of the shoreline, 80% of species inhabiting the coast use estuaries (National Round Table on the Environment and the Economy [NRTEE], 2004). Millions of shorebirds and waterfowl use estuaries as stopovers during migration to rest and re-fuel, as estuaries are extremely productive habitats (Monaco, Lowery, & Emmett, 1992; Nowlan & Jefferies, 1996). Because estuaries are discrete and uncommon habitats, they behave like stepping-stones and allow migrants to hopscotch between stopovers en route to their destinations. Humans also use estuaries, which can lead to competition with wildlife for estuarine resources. The relatively small amount of estuary land protected by federal or provincial legislation (Ryder, 2003) highlights the conflicting demands placed on estuaries and the need for more protection of estuarine habitats, as demands from industry or urban development often constrain habitat protection. To preserve estuaries and the important role they play for migratory birds in coastal British Columbia, conservation groups are working to secure estuarine habitats. Because available time, money, and personnel often limit conservation efforts, groups strive to magnify their effectiveness by protecting the most ecologically important estuaries. Therefore, correct assessment and identification of ecologically important estuaries is critical.

The Pacific Estuary Conservation Program is a leading group working on estuary conservation in British Columbia. The Pacific Estuary Conservation Program is a partnership of government and non-government agencies that protects estuarine habitats in British Columbia by acquiring land, preserving Crown Land, and developing or promoting land stewardship by private landowners (NRTEE, 2004). The program also performs land acquisition activities for the Pacific Coast Joint Venture in Canada, which falls under the auspices of the North American Waterfowl Management Plan (Peck, 1999). The Pacific Estuary Conservation Program attempts to magnify its effectiveness by focusing on top priority estuaries and using the best scientific knowledge available to prioritize the estuaries receiving conservation attention (NRTEE, 2004).

The Pacific Estuary Conservation Program created a dataset on 442 estuaries in British Columbia for use in conservation planning and resource assessment (Pacific Estuary Conservation Program [PECP], 2004). The dataset contains local characteristics of each estuary, such as location and shape, physical characteristics, and biological conditions that guide the assessment and identification of ecologically important estuaries from the landscape perspective. Ryder et al. (unpublished) used the estuary dataset to develop a method for prioritizing estuaries for conservation based upon the estuaries' biological and physical attributes. The method combined the dataset with biophysical indicators to rank the estuaries in terms of "Biophysical Importance" and hence conservation priority.

While the estuary dataset is extensive and subsequent rankings of Biophysical Importance are useful for directing conservation, this approach does not consider the effects that landscape structure and functionality have on an organism's ability to access the biophysically important estuaries. I added another variable to compare estuaries: functional landscape connectivity or the degree to which a landscape facilitates or impedes movement among resource patches (Taylor, Fahrig, Henein, & Merriam, 1993). Using the estuary dataset, I analyzed connectivity among the estuaries in British Columbia for one shorebird species and two waterfowl species that use estuaries as stopovers. The connectivity analysis examines how an estuary's spatial location and the habitat it contains combine to determine the estuary's relative value as a stopover for migratory birds. The purpose of my study was to augment the procedures used to rank estuaries in British Columbia for conservation priority.

OBJECTIVES

For this study, I examined landscape connectivity among 442 estuaries in British Columbia. I chose three focal species for the analysis: White-winged Scoter (*Melanitta fusca*), Western Sandpiper (*Calidris mauri*), and Dusky Canada Goose (*Branta canadensis occidentalis* Baird). I selected these species because they use estuarine habitat as migratory stopovers and because they have different habitat preferences within estuaries, and therefore, are representative of different guilds of birds. The aim of the connectivity analysis was to rank the estuaries for each species to predict the important estuaries that provide connectivity to the migrants, and therefore, maintain a connected chain of estuarine stopovers. I combined the estuary rankings for the individual species into an aggregate rank that allowed general prioritization of estuaries for conservation.

I used graph theory to model connectivity among the estuaries and developed seven connectivity metrics to score the value of each estuary as a stopover. I based the metrics on connectivity attributes that I assumed contribute to the importance of an estuary as a stopover. The objectives of the connectivity analysis were to:

1. Predict the estuaries that are important stopovers for each focal species by combining the seven metrics into an Overall Species Importance score
2. Predict the estuaries that are important stopovers for all three focal species by summing Overall Species Importance scores into Aggregate Importance scores
3. Determine the influence of individual connectivity metrics on the Overall Species Importance and Aggregate Importance scores
4. Assess the robustness of the predictions for Overall Species Importance and Aggregate Importance
5. Evaluate the resemblance of Aggregate Importance rankings to the rankings for Biophysical Importance

Historically, efforts to conserve migratory shorebirds and waterfowl have neglected the effect that landscape composition and habitat pattern have on the abundance and distribution of a species. Instead, management activity aimed to counter the chronic causes of population decline, for example, by limiting hunting and protecting or restoring breeding habitat. Over time, a growing knowledge of shorebird and waterfowl ecology was integrated with landscape level processes, such as migration, to inform management decisions from a broader perspective (Erwin, 2002). Shorebird and waterfowl managers increasingly recognized the need for a landscape approach to fulfil the goal of meeting birds' needs during all stages of the annual cycle (Melinchuk, 1995).

My study incorporated a landscape approach to identify high priority estuary habitat and to aid in shorebird and waterfowl conservation in British Columbia. The study was the first to investigate landscape connectivity for estuaries in British Columbia and was unique because it combined knowledge of shorebird and waterfowl migration with connectivity, a key element of the landscape approach to conserving migratory bird populations, but one often neglected. The inclusion of connectivity is necessary for the long-term stability of migratory bird populations because protection of unconnected habitat may not contribute to conservation goals (Soulé & Terborgh, 1999).

BACKGROUND

Shorebird and Waterfowl Migration in Coastal British Columbia

Each year, millions of waterfowl (order *Anseriformes*) and shorebirds (order *Charadriiformes*) pass through coastal British Columbia during their spring migration to northern breeding sites. From the perspective of a migrant, the coastline of British Columbia is a leading line that provides the bird with a north-south migration corridor, navigation cues, and stopover habitats (Berthold, 1993). While these migrants are capable of crossing ecological barriers (i.e., the Pacific Ocean or coastal mountains), such flights are rare because the optimal fat load for an energy-efficient migration excludes barrier crossing as an option (Alerstam, 2001; Berthold, 1993; Iverson, Warnock, Butler, Bishop, & Warnock, 1996). Instead, birds have evolved migration strategies to maximize energy conservation; for example, migrants fly primarily when tailwinds are favourable (Alerstam, 2001; Butler, Williams, Warnock, & Bishop, 1997), or fly so as to minimize fat loads and time spent migrating (Hendenstrom & Weber, 1999), or to optimize predator avoidance and resting/re-fuelling (Ydenberg et al., 2002). Individuals balance the costs and benefits of different migration strategies to arrive in optimal condition by choosing routes that get them to their destinations safely and at appropriate times (Berthold, 1993).

A number of environmental conditions, such as weather, tides, and prey availability, can influence the condition of an individual, and therefore, its migration strategy. Both the physical landscape and the individual's condition are influential determinants in stopover choice (Farmer & Wiens, 1998; Ydenberg et al., 2002). As a result, an individual may use the flyway differently during successive migrations by exploiting different flight paths and stopovers (Iverson et al., 1996). In addition, mortality risk influences the use of stopover sites; where a migrant chooses to stopover can be a trade-off between its fat reserves, the quality of a site, and the perceived danger in the landscape (Lank & Ydenberg, 2003).

The success of both shorebird and waterfowl migration depends heavily on the availability of stopovers along the route (Iverson et al., 1996; Senner, 1999). Stopovers are essential links in a chain of resting and re-fuelling points distributed along the migration route. Stopovers are particularly essential for shorebirds because the evolution of their migratory strategies has led to a dependence on a specific sequence of sites (Myers et al., 1987). Both waterfowl and shorebirds use information they have amassed during past migrations to make stopover decisions based on the dynamic circumstances of their current migration (Piersma & Lindstrom, 2004).

Although some traditional stopovers are well documented (Warnock, Takekawa, & Bishop, 2004), the migrants also use less-popular stopovers to complete their migrations (Iverson et al., 1996). The use of these less-popular stopovers can result from a bird deciding to trade-off the higher predation risk at a smaller, less-popular stopover in exchange for increased forage (Ydenberg et al., 2002). The birds may also use the less-popular stopovers due to density effects; because traditional stopovers quickly fill up, latecomers may choose to stopover at less-popular and less-crowded sites. Unexpected obstacles, such as strong headwinds encountered during flight that cause the migrants to seek emergency stopovers, are another likely explanation for the use of the less-popular stopovers. Emergency stopovers are locations along a migration route that an individual uses infrequently when the cost of flight is too expensive (Piersma & Lindstrom, 2004).

Estuaries in British Columbia make excellent stopovers for migrants because the estuaries are extremely productive and offer a range of habitats that can support different shorebird and waterfowl species (Dawe, Buechert, & Trethewey, 1995). Habitats may include open water, rocky inter-tidal beaches, mudflats, tidal sloughs, and brackish, saline, and freshwater marshes. The estuaries in British Columbia are particularly valuable stopovers for the migrants because the rugged terrain of British Columbia provides few other options for stopovers for waterbirds. Estuaries comprise less than 3% of the shoreline of British Columbia (NRTEE, 2004) due to the mountainous topography and relatively small number of rivers flowing into the Pacific Ocean (Emmett et al., 2000; Senner, 1999).

Regardless of an estuary's size, the limited availability of stopovers makes each estuary a potentially valuable stopover within an otherwise inhospitable landscape and emphasizes the need to conserve estuaries in British Columbia (Emmett et al., 2000). Furthermore, although not used by thousands or millions of individuals each year like traditional sites, a less-popular stopover may be just as important to a migrant because it can determine an individual's survival during unfavourable conditions regardless of the migration strategy adopted. As Farmer and Wiens (1998) discovered for returning shorebirds on the Great Plains, when high quality stopovers connect habitat, the migrants can employ multiple tactics to improve their chances of arriving in optimal breeding condition. The range of migration strategies and the importance of less-popular stopovers highlight the merit of maintaining a connected chain of estuarine stopovers in British Columbia.

Landscape Connectivity and Reserve Design

A connected landscape facilitates the movement of an organism between resource patches (Taylor et al., 1993). For the shorebirds and waterfowl migrating through coastal British Columbia, estuarine stopovers facilitate movement by connecting the landscape and making migration feasible. Landscape connectivity comes in two varieties: structural and functional. Structural connectivity analyzes a landscape's structure independent of an organism's movement capability (Tischendorf & Fahrig 2000b; With, Gardner, & Turner, 1997). Functional connectivity combines landscape structure and an organism's movement capability by explicitly considering the organism's behavioural response to landscape elements (Tischendorf & Fahrig 2000b). Because functional landscape connectivity (hereafter referred to as connectivity) is a product of both landscape structure and the movement characteristics of an organism, connectivity is a species-specific characteristic of the landscape (D'Eon, Glenn, Parfitt, & Fortin, 2002; Haig, Mehlman, & Oring, 1998; Knappen, Scheffer, & Harms, 1992; Uezu, Metzger, & Vielliard, 2005).

Connectivity is an important element in reserve design because human alteration of the landscape results in increasingly fragmented habitat (Noss, 1987). Fragmentation reduces connectivity -- it creates edge habitat that increases both the number of habitat boundaries encountered by a dispersing organism and the perimeter to area ratio of habitat patches (see Tischendorf, 1997). According to Hunter et al. (2003), connectivity is essential because it allows for the movement of individuals and the continuation of ecological processes. Therefore, the spatial location and context of habitat should be considered in conservation planning because the location of protected habitat, relative to other habitat patches, can be critical to the long-term persistence of a species (Briers, 2002). For migrating animals, connectivity is a critical element of the landscape, as it influences the availability of the resources that the migrants' require for a successful migration. A conservation plan designed to perpetuate the connectivity of estuaries in British Columbia is a powerful tool for conserving migratory shorebirds and waterfowl because it allows the migrants to exploit estuarine stopovers while minimizing their energetic costs.

Perpetuating the connectivity of estuarine stopovers for migratory birds requires not only a consideration of the pattern and size of estuaries (i.e., structural connectivity), but also calls for an examination of the matrix -- the area of unsuitable habitat between estuaries (Ricketts, 2001). If conservation planners ignore the matrix, even a well-planned endeavour can produce an island of refuge in a sea of uncrossable habitat, with devastating consequences for conservation (Dunning, Danielson, & Pulliam, 1992; Soulé & Terborgh, 1999; Taylor et al., 1993). The matrix matters when conserving habitat to perpetuate migratory birds because the migrants have complex interactions with the migratory landscape (Warnock et al., 2004). For example, the physical barriers of British Columbia, such as the numerous mountain ranges and open ocean, funnel migrants into corridors that are typically convoluted and seldom the shortest path (Bruderer, 1997; Gustafson & Gardner, 1996). Nevertheless, the migrants may choose to follow the corridors, even though they are capable of crossing barriers, through decisions related to costs and benefits of different routes, for example, differences in mortality risk (Alerstam, 2001). In British Columbia, the matrix between estuaries influences where the waterfowl and shorebirds fly, and therefore, dictates in part the estuaries that function as important stopovers and deserve protection.

Measuring Landscape Connectivity

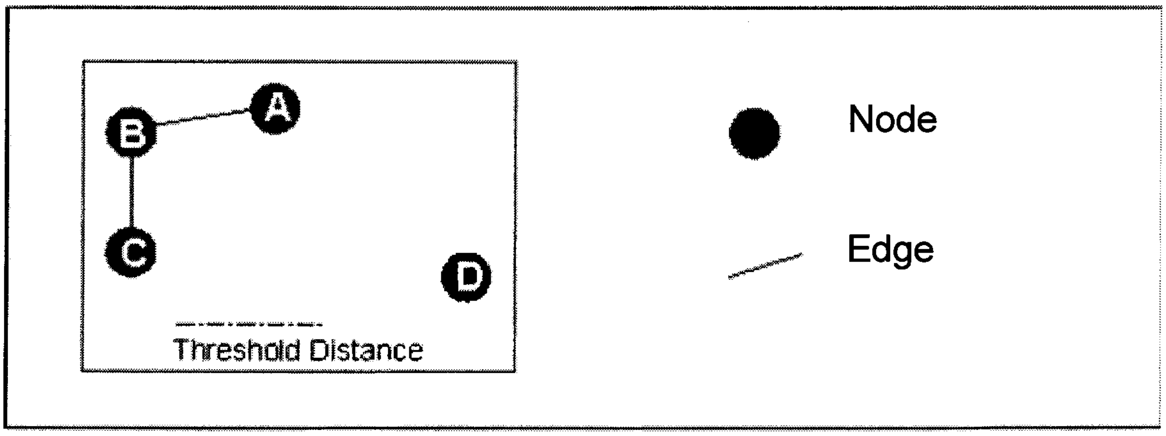
One can examine connectivity empirically, although this is technically challenging, particularly for organisms that migrate over great distances, or by simulations based on various metrics (D'Eon et al., 2002; Dunning, Borgella, Clements, & Meffe, 1995; Goodwin & Fahrig, 2002; Tischendorf & Fahrig, 2000). In the case of metrics, no one best measure exists; generally, connectivity metrics fall into three broad classes that range in detail and data requirements, as described by Calabrese and Fagan (2004). First, structural metrics typically require the least detail and data for analysis because they rely solely on the physical attributes of a landscape. Second, potential metrics combine a landscape's physical attributes with information about the species' movement capability, thereby increasing the detail and data required for the examination. Third, actual metrics are empirical observations of movements by individuals; however, they are also the most difficult to obtain.

Corry and Naussauer (2005) cautioned against using landscape pattern indices, such as structural metrics or potential metrics, to characterize landscapes because there is a lack of evidence that landscape pattern indices imply ecological processes. Furthermore, landscape pattern indices are sensitive to scale, spatial resolution, data resolution, landscape representation accuracy, and land cover classification and aggregation (Corry & Naussauer, 2005). Nevertheless, a lack of evidence does not necessarily imply that landscape pattern indices are unable to predict ecological processes, at least at a coarse scale, or that their applicability be postponed until empirical evidence is forthcoming. Currently, we are unable to comprehend bird migration without information on the birds' behavioural responses to a landscape's structure and function (Farmer & Wiens, 1998). At present, given the logistical difficulty of observing a migrating bird's response to landscape structure, landscape pattern indices in combination with landscape models are the best tool available for combining the movement capability of a species with its theoretical migration strategy in an attempt to understand how the landscape influences migration.

The ideal potential metric for a landscape scale analysis, given the trade-off between resolution and required data, is the graph model (Calabrese & Fagan, 2004).

The graph model is a spatially-explicit depiction of the landscape where habitat patches are discrete landscape elements represented as nodes and the linear pathways that facilitate movement between habitat patches are represented as edges (see Figure 1) (Keitt, Urban, & Milne, 1997; Rothley & Rae, 2005; Urban & Keitt, 2001). Graphs are useful for providing structural insight into reserve design (Zhang and Wang, in press) or for enhancing the understanding of species' functional connectivity among habitat patches (Bunn, Urban, & Keitt, 2000; O'Brien, Manseau, Fall, & Fortin, in press).

Figure 1: The landscape graph of a hypothetical landscape and a hypothetical species.



Node D is not connected to nodes A, B, or C by an edge because the distance separating node D from nodes A, B, or C is greater than the threshold distance.

In the graph, an edge connects two nodes when the distance between the nodes is below a theoretical distance that the species is capable of travelling (i.e., threshold distance); above this distance the nodes are too far apart to be connected by an edge. In its basic form, the graph model measures structural connectivity: the arrangement of nodes and the distance between the nodes determine the degree of connectedness in the landscape. The graph model can include the behaviour (i.e., functional connectivity) by making the threshold distance between nodes a function of the matrix over which an organism moves to access distant nodes. A resistance surface, a theoretical friction parameter that reflects a landscape's heterogeneity and either facilitates (less friction) or impedes (high friction) movement (Nikolakaki, 2004), is one method for incorporating movement behaviour into the graph model. With enough knowledge of a species, it is possible to predict the resistance of landscape features to the specie's movement capability (Knappen et al., 1992).

The resistance surface is a grid, where the value assigned to each cell in the grid is the cost-distance (for example, cost in energy or time) of the landscape feature that the cell represents. The cost-distance reflects the relative cost to an individual if it chose to cross the cell. If the graph is drawn over the resistance surface, so that the edges follow the least-cost pathways, the graph model can be used to quantify the relative importance of each habitat patch in maintaining connectivity in the landscape for a given species (Bunn et al., 2000; Jordan, Baldi, Orci, Racz, & Varga, 2003; Keitt et al., 1997; Urban & Keitt 2001). The straight-line distance modified to follow the least-cost pathway is the effective distance between two habitat patches (Adriaensen et al., 2003).

The graph model of a hypothetical landscape and species depicted in Figure 1 is in a disconnected phase because it consists of two clusters rather than a single cluster. A cluster is a group of connected nodes where each node has at least one edge below the threshold distance that connects it to at least one other node. The number of clusters in a graph is an indication of the degree of connectivity within a landscape for a species. In Figure 1, nodes A, B, and C form a cluster because both node A and node C link to node B via an edge that is below the threshold distance. Nodes A, B, and C form Cluster ABC even though the distance between node A and node C is greater than the threshold distance because the hypothetical species can access node A from node C by following the edge that connects node A to node B, and then following the edge that connects node B to node C. In contrast, the distance that separates node D from either node A, B, or C is greater than the threshold distance, and as a result, node D is itself Cluster D, the second cluster in the landscape. For the hypothetical species, the landscape is disconnected because the specie's movement capability (represented as the threshold distance) isolates node D. Given a higher threshold distance, an edge could link node D to Cluster ABC, and therefore, form the single cluster that indicates a connected landscape.

When measuring connectivity for birds, Euclidean (or straight line) distance appears useful; however, even flying organisms respond to landscape patterns and their routes are a function of the underlying matrix (Clergeau & Burel, 1997). For example, in the prairie pothole region, habitat use by migrating shorebirds was a reflection of landscape attributes and vegetation structure (Naugle, Johnson, Estey, & Higgins, 2001). Similarly, Farmer and Parent (1997) found variations in landscape pattern explained much of the variability in inter-wetland movements by shorebirds. Therefore, a measure of estuarine connectivity for shorebirds and waterfowl migrating through coastal British Columbia should include estuary location, as well as species-specific movement capability and indicators of habitat quality and the mortality risks in the landscape through which the birds are migrating (Calabrese & Fagan, 2004; Clergeau & Burel, 1997; Goodwin & Fahrig, 2002; Naugle et al., 2001).

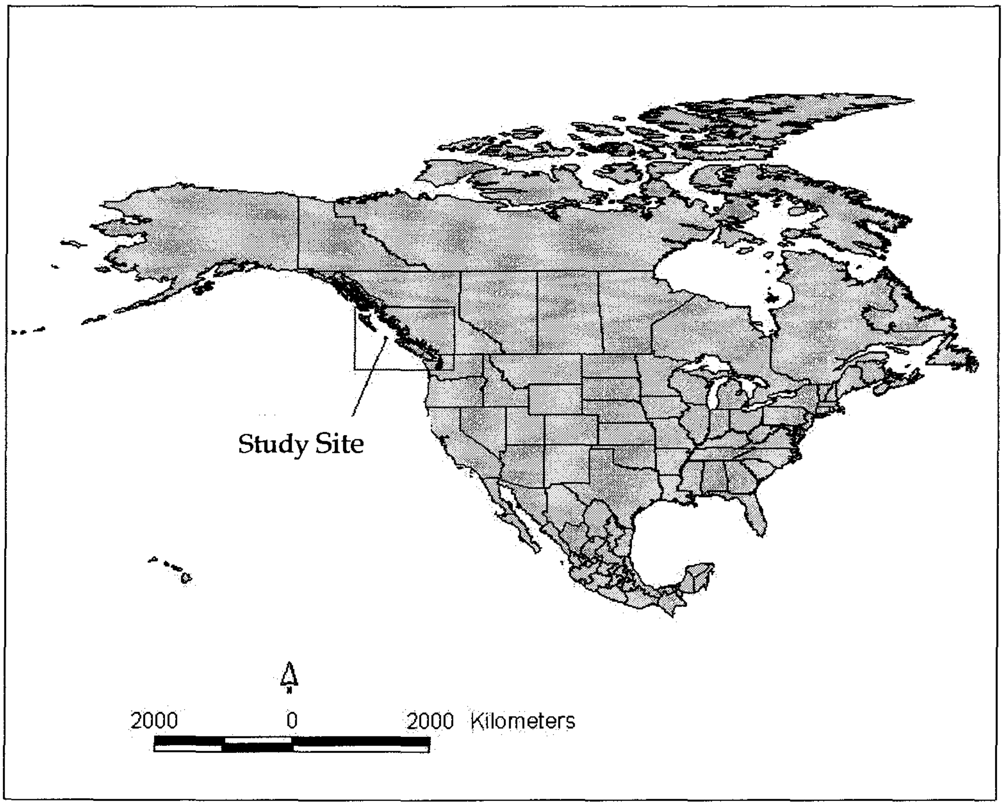
METHODS OF THE CONNECTIVITY ANALYSIS

Estuaries in British Columbia

Coastal British Columbia extends from 48.20°N - 123.44°W to 55.94°N - 130°W and consists of Vancouver Island, the mainland coast, the Queen Charlotte Islands, and numerous, smaller nearshore islands (Figure 2). The Biogeoclimatic Ecosystem Classification System for British Columbia identifies two zones in this area: Coastal Douglas-fir and Coastal Western Hemlock (Meidinger & Pojar, 1991). The Coastal Western Hemlock zone is the prominent zone in coastal British Columbia and occurs from low to mid elevations along the entire coastline, with mean annual temperature from 5.2°C to 10.5°C and mean annual precipitation from 1000 mm to 4400 mm. The Coastal Douglas-fir zone lies within the rain shadow of the mountains on Vancouver Island up to 150 m, where mean annual temperature ranges from 9.2°C to 10.5°C and mean annual precipitation ranges from 647 mm to 1263 mm.

Due to the mountainous coastline, many small rivers flow directly into the Pacific Ocean. Consequently, estuaries in British Columbia are typically small (<100 km^2 surface area), drowned river valleys with low freshwater inflows (Emmett et al., 2000). Nevertheless, the estuaries are extremely productive and important to coastal wildlife. High productivity and flat terrain also make the estuaries in British Columbia attractive to human settlement, which creates conditions for conflicts between wildlife and human values (Fox & Nowlan, 1978). Because urbanization, forestry, agriculture, aquaculture, and tourism/recreation often occur in estuarine habitat, estuaries are among the most threatened habitats in British Columbia (Ryder, 2003).

Figure 2: **The location of coastal British Columbia within North America (box identifies study site).**



Map Data Source: ESRI Data & Maps. Copyright 1999.

Focal Species

The focal species I selected for connectivity analysis represented a range of the habitat preferences and flight capabilities of shorebird and waterfowl species that migrate through coastal British Columbia during spring migration. Using a cross-section of the habitats typically occurring in an estuary, I chose focal species to represent three of the primary estuarine habitats that migrating waterfowl and shorebirds use. Moving from marine to fresh water, the habitats were subtidal, intertidal, and backshore marsh. Representing waterfowl that use subtidal habitat, I chose White-winged Scoters (*Melanitta fusca*). To represent the shorebirds that use intertidal habitat, I chose Western Sandpipers (*Calidris mauri*). Lastly, Dusky Canada Geese (*Branta canadensis occidentalis* Baird) represented waterfowl species that use marshy estuarine habitats. In addition to differing habitat preferences, I also chose these species because of their differing flight capabilities during migration because movement capabilities, in conjunction with habitat features, determine landscape connectivity for a species (Taylor et al., 1993). In addition, the British Columbia Steering Committee for the Pacific Coast Joint Venture listed each species as a Species of Conservation Importance (Pacific Coast Joint Venture, 2005). For the analysis, I examined the focal species' spring migrations and considered only the portion of the migration that passes through coastal British Columbia en route to breeding locations farther north.

White-winged Scoters

The White-winged Scoter is a sea duck and, like many sea ducks, information on the life history of White-winged Scoters is minimal; fortunately, some knowledge exists on general habitat preferences and movement patterns of the scoters in coastal British Columbia. In winter, White-winged Scoters prefer to inhabit estuaries and large bays from Alaska to Southern California (Rosenberg & Petrula, 1998; Sea Duck Joint Venture, 2003) where they dive for molluscs and crustaceans in littoral zones with mud, silt, or sand substrates (Booth & Rueggeberg, 1989; Brown & Fredrickson, 1997; Rosenberg & Petrula, 1998). In coastal British Columbia, White-winged Scoters tend to concentrate along the east coast of the Queen Charlotte Islands, in Big Bay (near Prince Rupert), and in the Strait of Georgia (Campbell, Dawe, McTaggart-Cowan, Cooper, Kaiser, & McNall, 1990c). Beginning in March and continuing through to May, White-winged Scoters move northward and fly inland to breeding locations in the boreal forest (Brown & Fredrickson, 1997). The birds typically begin their spring migration by flying along the coast, stopping at estuaries and other coastal habitats before making the overland flight to breeding sites (Sea Duck Joint Venture, 2003).

Western Sandpipers

More knowledge exists for the Western Sandpipers' spring migration relative to the White-winged Scoter. Western Sandpipers migrate to their breeding range in north-western Alaska from wintering sites at tidal sloughs and open mudflats along the Pacific coast of the Americas between Washington, U.S.A. and Peru (Warnock & Takekawa, 1995; Wilson, 1994). The spring migration of Western Sandpipers coincides with the spring migration of migratory races of Peregrine Falcon (*Falco peregrinus*) (Lank, Butler, Ireland, & Ydenberg, 2003; Ydenberg, Butler, Lank, Smith, & Ireland, 2004). To reduce risk of predation by Peregrines, the sandpipers migrate with low fat stores to facilitate the fast take-offs and high manoeuvrability needed to escape attacking Peregrines (Lima, 1993). However, this requires the sandpipers to make short flights, stop frequently to re-fuel, and shorten the time spent at individual stopovers (Ydenberg et al., 2004). Ultimately, an individual's choice of stopover can be a trade-off between safety and food abundance (Pomeroy, submitted).

Depending on weather conditions, Western Sandpipers can use traditional or less-popular stopover sites. Traditional stopovers in coastal British Columbia during the spring migration are the intertidal deltas of the Fraser River and Boundary Bay in the Lower Mainland, and Long Beach, Chesterman Beach, and Tofino Inlet on the West Coast of Vancouver Island (Campbell et al., 1990b). In a study by Iverson et al. (1996), some radio-tagged individuals were missed at traditional stopovers en route, but located later, which suggests that undetected birds used smaller, less-popular stopovers. A potential cause for the use of less-popular stopovers may be unfavourable wind conditions encountered while in flight. Favourable tailwinds in the upper atmosphere greatly influence Western Sandpiper migrations by increasing an individual's speed and decreasing the time and energy required to fly between stopovers (Butler et al., 1997). During spring migration through British Columbia, tailwinds from the southeast are optimal; therefore, a headwind or side wind can force a migrant to land at a less-popular stopover.

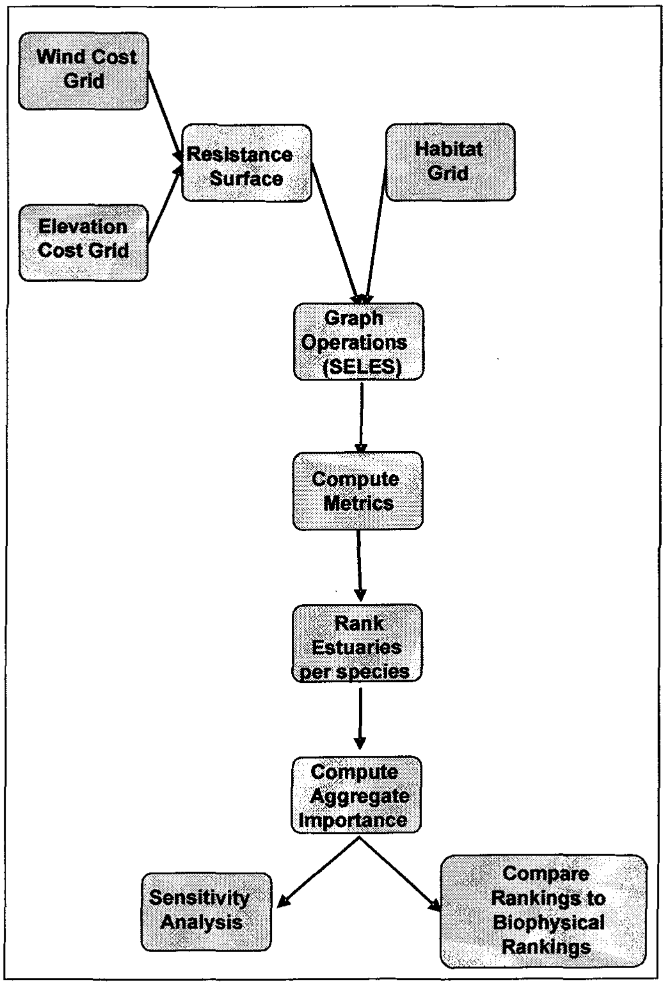
Dusky Canada Geese

The Dusky Canada Goose is a race of Canada Goose that nests along the Gulf of Alaska and migrates down the Pacific coast of North America to winter in the Lower Columbia Valley, WA, and the Willamette River Valley, OR (Mowbray, Ely, Sedinger, & Trost, 2002). Though available knowledge on the routes and stopovers used by the geese during the spring migration is lacking, the migration strategy may be similar to that used during fall migration, in which the geese fly offshore and make few stopovers (Hansen, 1962). In support of a similar strategy for spring migration, Bromley and Jarvis (1993) found lipid reserves in the geese peak prior to departure from wintering areas, which suggests the geese may be building energy stores for subsequent use as migration fuel, perhaps because few appropriate stopovers are available en route. One known stopover area in coastal British Columbia that Dusky Canada Geese visit during fall migration is the Queen Charlotte Islands (Bromley & Rothe, 2003). At a stopover, preferred habitats are likely saltwater marshes and freshwater meadows found at riverine and estuarine sites (Hawkings, 1982).

Measuring Functional Landscape Connectivity

The connectivity analysis was composed of many steps. Figure 3 provides a visual outline of the steps in the connectivity analysis. In this sections that follow I explain each step in detail.

Figure 3: Flowchart of the steps necessary to complete the connectivity analysis.



Graph Theory as a Framework to Measure Connectivity

For the three focal species, graph theory was an applicable measure of estuarine connectivity because estuaries in British Columbia exist as isolated and discrete stopovers. I used graph theory to analyze estuarine connectivity for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese because the theory could model the species' responses to the matrix. For the analysis, equal-sized nodes represented the estuaries, and for a range of pre-set distances that represented the total effective distance the migrants were capable of flying (i.e., effective threshold distances), edges were drawn to connect the nodes. As a result, at each threshold distance, the estuaries resided in clusters. A cluster was a group of connected nodes, where each node has an edge linking it to at least one other node. Each cluster had a centroid that was used to determine the cluster's radius, which indicated the size of the cluster (Radius of Gyration, in distance units). The number of nodes contained in the clusters and the size of clusters increased, as the threshold distance increased, until all nodes were connected as a single, large cluster. At each threshold distance, the degree of connectedness in the landscape was defined as correlation length, i.e., the average size of all clusters present in the landscape, or, the average distance an individual migrants was capable of flying before it reached a barrier (Keitt et al., 1997). Correlation length was calculated as:

$$C_d = \frac{\sum_{i=1}^{m} n_i R_i}{\sum_{i=1}^{m} n_i} \quad , \qquad (1)$$

where m is the number of clusters in the landscape, n_i is the number of nodes in the i^{th} cluster, and R_i, is the Radius of Gyration that measures the size of the i^{th} cluster in the graph:

$$R_i = \frac{1}{n}\sum_{j=1}^{n_i}\sqrt{\left(x_j - \bar{X}_i\right)^2 * \left(y_j - \bar{Y}_i\right)^2} \quad , \qquad (2)$$

where $\overline{X}_i$ and $\overline{Y}_i$ are the mean x and y coordinates in cluster *i*, x_j and y_i are the coordinates of the j^{th} cell in cluster *i*, and *n* is the number of nodes in the cluster (Keitt et al., 1997). If correlation length was small, the estuaries resided in multiple, disconnected clusters; a migrating bird would be unable to access all of the available estuaries.

Using the correlation length that resulted from increasing threshold distances, I predicted the relative importance of an estuary as a stepping-stone for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese. Stepping-stone estuaries, because of their location in the surrounding landscape, are crucial for maintaining connectivity and, if lost, can cause a single, connected graph to disintegrate into clusters. The graph model quantified the relative importance of each node, which I used as one of my connectivity metrics to predict the location of stepping-stone estuaries (Bunn et al., 2000; Jordan et al., 2003; Keitt et al., 1997; Urban & Keitt, 2001). I found the stepping-stones by removing each node from the graph at each threshold distance and observing the change in correlation length. A normalized importance index, I_{dk}, identified the stepping-stones for a given threshold distance as:

$$I_{dk} = \frac{C_d - C_{dk}}{C_d} \, , \qquad (3)$$

where C_{dk} is the correlation length after node *k* is removed (Keitt et al., 1997).

For the connectivity analysis, I used SELES (Spatially Explicit Landscape Event Simulator) v 3.1 because it employs spatial graphs to set up and run an analysis of landscape connectivity (Fall & Fall, 2001). SELES follows three steps when analyzing connectivity:

1. **Graph Extraction** – draw edges that follow the least-cost pathways to link all pairs of nodes. The cost attributed to each edge is the effective distance of moving between the pair of nodes. Given a choice between extracting the minimum planar graph, where edges are not allowed to cross, or the complete graph, where edges are allowed to cross, I extracted the complete graph, as I intended to measure connectivity given all the possible routes and did not intend to identify movement corridors.

2. Graph Analysis – remove all edges with a cost above the threshold distance (i.e., effective distance threshold) and calculate correlation length. Repeat for a range of threshold distances that reflect the effective distance a migrant could fly. This phase determined the effective distance that a species had to fly to join all estuaries in a single, connected graph.

3. Patch Importance - iteratively remove each node from the graph for threshold distance *d* and calculate the normalized importance index. This phase predicted the stepping-stone estuaries based on the estuaries' locations in the graph.

Connectivity Metrics

I developed six connectivity metrics, in addition to patch importance, that respond to different attributes of the landscape to quantify and rank each estuary for its role in perpetuating connectivity in coastal British Columbia. The landscape attributes pertain to the connectivity value of estuaries, in terms of spatial location and habitat area. The first four metrics measured connectivity at a local scale by examining the spatial relationships of adjacent estuaries. Although local connectivity may seem irrelevant for migratory species, if well-connected, desirable estuaries reside within a low effective distance, the migrants may perceive the well-connected, desirable estuaries as a single stopover. Consequently, a migrant may exploit the various estuaries in the conglomerated stopover during a single stopover event, which may increase the value of the estuaries, as the conglomerated stopover allows the birds to access a range of sites. Farmer and Parent (1997) observed that during the spring migration of Pectoral Sandpipers (*Calidris melanotos*), the sandpipers perceived multiple stopover sites as a single stopover when the distance between stopovers was minimal. In the event that White-winged Scoters, Western Sandpipers, and Dusky Canada Geese also perceive estuaries separated by a minimal effective distance as a single stopover, I developed four metrics to quantify the local connectivity importance of estuaries. However, the focal species may not perceive multiple estuaries as a single stopover, which would make the local metrics more appropriate to other species/movements. As part of the analysis, I examined the similarity of locally important estuaries to coastally important estuaries.

The relative importance of an estuary at the local scale depended on the effective distance separating an estuary from it closest neighbours, as well as the amount of desirable habitat within the estuary and its neighbours. For these metrics, I assumed that adjacent estuaries influenced an estuary's likelihood to be a locally important estuary more than distant estuaries, as the effective distance separating an estuary from its adjacent neighbours would be lowest (Dunning et al., 1992). Adjacent estuaries are estuaries connected to the estuary of interest by edges that are below the effective distance threshold. For each subsequent increase in threshold distance, I reduced the influence of the additional estuaries by assigning weights that reduced the additional estuaries' influences.

The last three metrics, including patch importance, measured connectivity at the coastal scale. Here I assumed that attractiveness of an estuary depended on the migrant's ability to use the estuary as a stepping-stone to reach other estuaries. The first metric in this group considered the energetic costs and motivation of migration and scored estuaries based on their lateral distance from the primary coastline. For this metric I assumed that migrants would avoid expending the fuel or time to stopover at estuaries that required movements in a direction other than the preferred migration direction, i.e., to fly to an estuary at the head of an inlet. The remaining two metrics measured connectivity at the coastal scale following the patch importance step in SELES. Below I describe the physical characteristics that I assumed influenced the attractiveness of an estuary as a stopover and explain the subsequent metrics designed to quantify these characteristics.

Local Connectivity Metrics

1. Area of Habitat The presence of habitat at an estuary provides migrants with the opportunity to re-fuel, and therefore, contributes to increased connectivity. I assumed the amount of appropriate habitat available in an estuary had a positive relation to the attractiveness of that estuary for migrating birds. *Habitat Area* is the area (m^2) of habitat preferred by White-winged Scoters, Western Sandpipers, or Dusky Canada Geese (shallow subtidal, intertidal, and marsh habitats, respectively). For Western Sandpipers, the size of an estuary's intertidal delta influences how the birds perceive danger from raptors, and may affect stopover decisions (Lank & Ydenberg, 2003; Schmaljohann & Dierschke 2005; Ydenberg et al., 2004). I assumed estuaries with large intertidal deltas are safer and therefore more attractive stopovers. To account for the dangerous area within 150 m of shoreline vegetation (Pomeroy, submitted), I subtracted the risky area from the area of intertidal delta.

2. Lots of Neighbours An isolated estuary can be less attractive than one with many neighbours because proximity of other estuaries can influence a migrant's use of a particular estuary (Graham, 2001). I assumed the presence of lots of neighbouring estuaries enhanced local attractiveness because more estuaries were available, and therefore, the migrants might perceive the neighbouring estuaries as a single stopover. *Number of Neighbours* is the number of neighbours per estuary, as a function of effective distance (Jordan et al., 2003).

3. Many Close Neighbours Moving among estuaries is easier when the estuaries exist in a cluster that has many neighbours all located within a minimal effective distance. I assumed an estuary with many close neighbours contributed to connectivity because it permitted a migrant to move between estuaries during a stopover event while incurring the least cost. The *Transversibility* of an estuary is the sum of the effective distance of each neighbour weighted by its relative distance from the estuary, which is a function of effective distance.

4. Area of Habitat in Neighbours If an estuary has many close neighbours but little habitat within those neighbours, then the attractiveness of the estuary diminishes because its neighbours cannot support the migrant. I assumed that estuaries with the largest total Habitat Area within the shortest effective distance threshold were key estuaries for local connectivity. *Neighbourhood Habitat* is the total area of habitat in neighbouring estuaries over the total number of neighbours and is a function of effective distance.

Coastal Connectivity Metrics

5. Ease of Access An attractive estuarine stopover will not cost the migrants too much time or energy to access. I assumed that the migrants would not choose to diverge from their northwest orientation to stopover at an estuary at the head of inlet and that such estuaries would be unattractive stopovers. *Accessibility* is an estuary's distance (m) from the primary shoreline, i.e., the distance from the northwest trajectory along the general coastline that a migrant would have to detour in order to visit an estuary at the head of an inlet.

6. Contributes to Connectivity An estuary is particularly important when it functions as a stepping-stone. I assumed that estuaries with the greatest negative normalized importance index were stepping-stone estuaries because their removal caused the graph to fragment into clusters. *Connectivity Maintenance* (i.e., patch importance) is the mean normalized importance index that results from the removal of an estuary from the graph and quantifies an estuary's contribution to connectivity.

7. Per Area Contribution to Connectivity An estuary that is a stepping-stone, and that contains the habitat a migrant would use to rest or re-fuel is an attractive stopover. I assumed that the greater the extent of habitat at a stepping-stone, the more attractive that estuary, and the more it contributed to connectivity. *Critical Stepping-stone* is the change in correlation length per m^2 that would result if the estuary were lost.

In total, habitat size occurs in three of the metrics, but its weight on the rankings for overall connectivity importance is essentially equal to the other landscape attributes. Any additional weight habitat size might have received from Critical Stepping-stone was nullified by Neighbourhood Habitat because the size of habitat an estuary contained was attributed as a benefit to another estuary, thereby cancelling any double weighting from Critical Stepping-stone. In contrast, an estuary's contribution to connectivity received double weighting relative to the other landscape attributes because it factored into Connectivity Maintenance and Critical Stepping-stone.

Assigning double weights to Connectivity Maintenance is a positive feature of this connectivity analysis because migration would be exceedingly difficult without a connected network of stopovers.

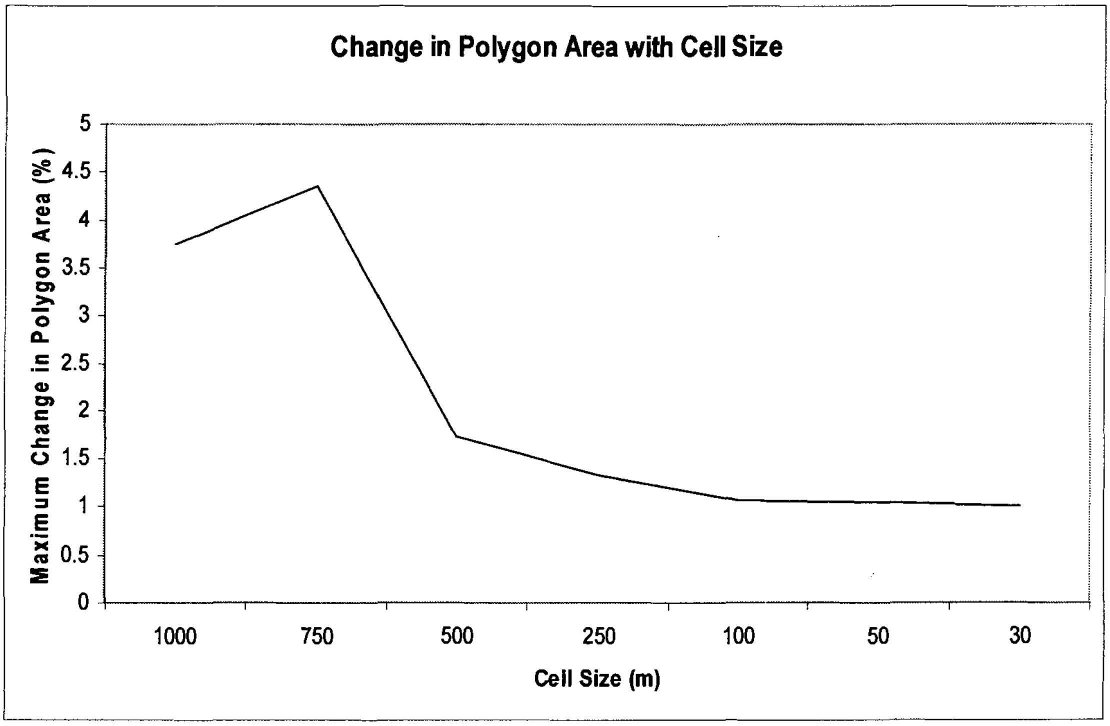
Data Description

To run the connectivity analysis in SELES, two raster images are required: one represented the location of the estuaries and the other represented the matrix. I based the estuary grid on a dataset compiled by the Pacific Estuary Conservation Program and created a resistance surface to represent the matrix. The resistance surface was a grid, where each cell in the grid had a value, in cost units that corresponded to the cost-distance to the migrant if it flew across the cell. Cost-distance could refer to lost energy or time, and the higher the value, the more resistant the cell to the migrants' movements. To create the resistance surface, I chose two predominant attributes in coastal British Columbia, wind and elevation, that I believed either impeded or facilitated the migration of the focal species. For the connectivity analysis, I assumed elevation and wind affected all three focal species equally. I created a separate cost grid for wind and another cost grid for elevation. I added the two cost grids together to create the resistance surface that mimicked the large-scale processes in the matrix that can influence the least-cost pathways available to the migrants, and as a result, the locations of important estuarine stopovers. SELES extracted the graph, as dictated by the resistance surface, by drawing edges to connect the estuaries that followed the least-cost pathways.

Habitat Grid

The Pacific Estuary Conservation Program (2004) compiled a dataset that described 442 estuaries along the coast of British Columbia. The dataset contains point, line, and polygon information on the local attributes for each estuary: location and shape, physical characteristics (area, ecoregion, and shoreline type), biological conditions (nearshore vegetation, herring spawn, mussel beds, and waterfowl use), protection status, and stewardship (local tenure of the estuary and of the surrounding lands). For the connectivity analysis, I was interested in the location of each estuary, as the spatial location of nodes within the landscape is a key component of connectivity. From the estuary dataset, I created the habitat grid. Within this grid, I reduced each estuary to a single node, from which I generated a binary raster, where a cell containing a node has a value of one and every other cell a value of zero. To find the optimal grid resolution, I chose a section of the coastline with many islands represented as polygons. I then ran multiple raster conversions with different resolutions and recorded the percent change in the area of each polygon at each cell size. I chose a resolution of 500 m, as the change in polygon area at a cell size of 500 m approached 1%, yet remained a manageable file size (Figure 4).

Figure 4: The maximum change in the area of a polygon following conversion from vector to grid.



Elevation Cost Grid

Migrating waterfowl and shorebirds can adopt flight paths that correspond to topography (Bruderer, 1997). The focal species chosen for the connectivity analysis tend to avoid higher elevations while passing through coastal British Columbia. For example, White-winged Scoters migrate over open water until they turn inland to reach breeding locations (Campbell et al., 1990c). Western Sandpipers follow a route that skirts the Pacific coast in order to exploit scattered, but highly productive, coastal stopovers (Wilson, 1994). Dusky Canada Geese, like the Western Sandpipers, adopt a primarily coastal route (Campbell et al., 1990). To incorporate the effect of elevation on migration, I programmed SELES to adhere to least-cost pathways and draw edges at sea level by creating an elevation cost grid where the higher the elevation, the higher the cost of moving across a cell. To create the elevation cost grid, I converted vector elevation data (contour lines at 20 m) to a 500 m grid using the Contour Gridder extension for ArcView 3.2 (Stuckens, 2002). I then mosaicked the grids with the ArcView 3.2 extension Grid Tools v 1.3 (Jenness, 2005). To ease computation, I reclassified the grid from elevation values to cost values between zero and 50 cost units.

Wind Cost Grid

Wind is an important factor in migration strategies, as it directly influences behaviour, such as flight speed, orientation, and decisions regarding timing of departure and routes taken (Berthold, 1993). Migrants prefer to fly with a tailwind that allows the birds to reduce relative flight speed, but maintain a quick ground speed and preferential compass bearing (Berthold, 1993). Wind can specifically affect the migration of the focal species by instigating a response in the migrants to headwinds and tailwinds. White-winged Scoters follow the coastline and fly just above the water in headwinds to save time and energy (Brown & Fredrickson, 1997). For Western Sandpipers, dominant wind patterns determine the use of stopovers, and, in the presence of headwinds, can dictate the use of emergency stopovers (Piersma & Lindstrom, 2004). In general, Canada Geese time their migrations to coincide with weather systems to exploit tailwinds (Mowbray et al., 2002).

Because the focal species funnel through coastal British Columbia before diverging to breeding areas in the north, I assumed that wind coming from the southeast (135°), thereby blowing to the northwest (315°) and paralleling the coastline, was the ideal tailwind to facilitate migration. Because the focal species funnel through coastal British Columbia before diverging to breeding areas in the north, I assumed wind coming from the southeast and blowing to the northwest was the ideal tailwind to facilitate migration. The farther from 135°, the less the wind facilitated flight and the greater the cost to the migrants if they flew. The initial wind data, provided by Environment Canada, was an hourly log of the wind direction (°) and speed (km/h) for April 2005 recorded at 18 weather stations in coastal British Columbia. I chose to use wind data from April because each focal species moves through coastal British Columbia during April (Campbell et al., 1990, 1990b, 1990c; Wilson, 1994). Using these wind records, I created three wind cost grids: one baseline scenario, as well as a best and a worst-case wind scenario. The last two scenarios tested the robustness of the graph model's predictions to the values that formed the cost grid for the baseline wind scenario.

For the initial connectivity analysis with the baseline scenario, I selected the maximum wind speed and corresponding direction from each station (Table 1). I chose the maximum wind speed because it generated a cost grid that maintained the disparity in wind conditions along the coastline. In contrast, the average wind speed and minimum wind speed resulted in a smoothed cost grid that diminished the dynamic nature of wind conditions in coastal British Columbia. I then calculated V, the velocity of a migrant given the maximum wind speed and direction relative to 315°, using

$$V = \left[\sin\left(d_i + 315\right)\right] * s_i , \qquad (3)$$

where d_i was the direction (°) of the maximum wind speed at weather station i and s_i was the maximum wind speed (km/h) at weather station i. Next, I used a linear transformation to rescale V to cost-distance values between zero and 50 cost units, where zero was the lowest cost and the highest velocity, representing wind coming from the southeast and blowing quickly to the northwest. Using the cost-distance value for each weather station, I interpolated the baseline wind cost grid using the spline (regularized, number of points = 4, and weight = 0.1) interpolation method in ArcView 3.2. I used the spline method because it had the lowest mean absolute error from a collection of interpolated surfaces that I generated from multiple interpolation methods (see Kurtzman & Kadmon 1999). I then added the baseline wind cost grid to the elevation cost grid to produce the resistance surface.

Table 1: **For each weather station, the maximum wind speed and corresponding direction. Velocity was calculated from speed and direction, and then rescaled to cost-distance, which was used to interpolate the wind cost grid.**

Station	Speed (km/h)	Direction (°)	Velocity (°/km/h)	Cost (cost unit)
Rose Spit	93	140	92.66	4
Cathedral Point	74	60	19.06	40
Bonilla Island	91	140	90.67	5
Prince Rupert	44	170	36.08	32
Port Hardy	41	100	33.55	33
Fanny Island	50	300	-48.27	50
Tofino	46	120	44.42	28
Race Rock Campbell Scientific	63	270	-44.46	50
Vancouver International Airport	39	90	27.54	36
South Moresby	79	129	78.40	11
South Hecate Strait	75	148	72.99	14
West Dixon Entrance	67	124	66.06	17
North Hecate Strait	82	128	81.81	9
East Dellwood	69	140	69.22	15
South Brooks	72	135	71.64	14
Halibut Bank	53	103	44.54	28
West Moresby	82	114	76.25	12
Sentry Shoal	62	135	61.56	19

Ranking Estuaries for Connectivity Importance

The purpose of ranking estuaries for connectivity importance was threefold. First, I wanted to predict which estuaries were the important because they maintained a connected chain of estuarine stopovers for each focal species. Second, I wanted to predict which estuaries, because of their spatial location and the habitats contained within, were the estuarine stopovers used by all three focal species. Third, I wanted to predict where the hot spots for connectivity were located. Connectivity hot spots were distinct geographic areas that supported a collection of top ranking estuaries, and therefore, multiple estuarine stopovers. Identifying connectivity hot spots can provide insight into estuary conservation by directing attention to collections of estuaries that can support a large number of migrants (Brown, Mehlman, & Stevens, 1995).

Connectivity Importance per Species

My first objective was to identify and map which estuaries were important stopovers for each focal species. Because I assumed the presence of species-appropriate habitat determined the availability of an estuary as a potential stopover, I limited the available estuaries to those that contained the specie's preferred habitat type. As a result, no focal species had access to all 442 estuaries. I excluded these unavailable estuaries from the connectivity analysis by increasing the effective distance of each edge that linked an unavailable estuary into a cost too extreme to be accessible. For the estuaries available to each of the focal species, I computed the seven metrics, and then added the rankings of the seven metrics for each estuary into a total estuary score. I ranked the totals of all the available estuaries to produce an Overall Species Importance score that I used to discern which estuaries were the most important stopovers for each species. I then mapped the top 15 ranking estuaries for the Overall Species Importance of each focal species to discern if any connectivity hot spots were present.

I estimated each metric from a combination of GIS spatial analysis, information in the estuary dataset, and connectivity statistics produced by SELES. First, I quantified Habitat Area using the estuary dataset by determining the amounts of habitat type preferred by the focal species that each estuary contained . Second, I determined Accessibility by measuring how far a migrant would have to detour from its northwest trajectory to access an estuary. To do so, I modelled the northwest trajectory as a 1 km buffer of the coastline that I modified to close off inlets and bays. I used the Nearest Features v 3.8a extension for ArcView 3.2 (Jenness, 2004) to measure the distance of each estuary from the 1 km buffer. Third, I used Python v 2.4.2 (Python Software Foundation, 2005) to catalogue Number of Neighbours, Transversibility, and Neighbourhood Habitat. Fourth, outputs from SELES's graph analysis and patch importance phases provided the statistics to determine Connectivity Maintenance and Critical Stepping-stone.

Because Number of Neighbours, Transversibility, and Neighbourhood Habitat are all a function of effective distance, I first had to identify the effective distance thresholds that I would used to calculate these metrics. I did so using the statistical output from SELES's graph analysis phase for the minimum planar graph. I used the minimum planar graph because (1) it was computationally easier to work with and (2) it included the minimum length of edges necessary to connect the graph, therefore, giving an indication of the effective distance thresholds present in the complete graph. To find the effective distance thresholds, I determined the total number of neighbours for each node, as well as the total cost of all of the edges. For each node, I then plotted the total number of neighbours against the total cost of edges (Figure 5), from which I determined the lowest total cost of edges for each number of neighbours. I rounded-up the lowest total cost of edges that permitted an additional neighbour to identify the effective distance thresholds (Table 2).

Figure 5: **The total number of neighbours for each estuary plotted against the total cost of the edges that linked the estuary to its neighbours, as determined by the minimum planar graph.**

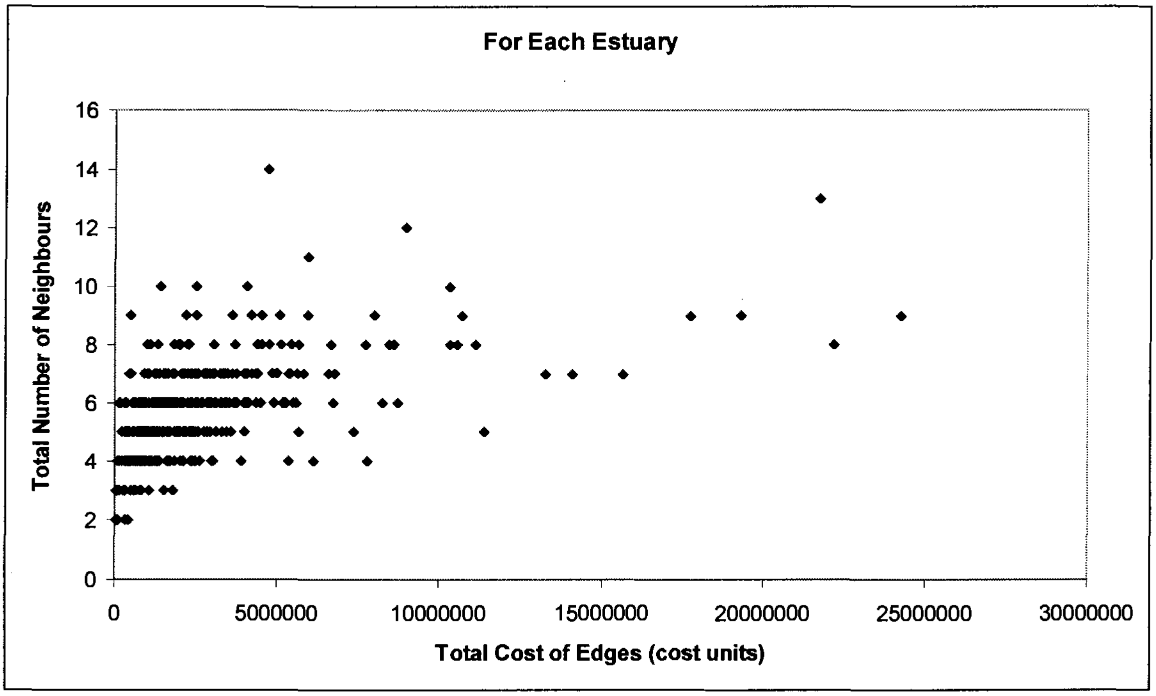


Table 2: **The lowest total cost of edges that permitted an additional neighbour rounded-up to an effective distance threshold that was used for the connectivity analysis.**

Lowest total cost of edges that permitted an additional neighbour (cost units)	Effective distance threshold (cost units)
62386	63000
82760	83000
92362	93000
144522	145000
222322	223000
471077	472000
519209	520000
1015490	1100000
1421241	1422000
4728598	4729000
5969266	5970000
8971620	8980000
21761905	21770000

The first effective distance threshold was within the migratory flight range of each focal species. Assuming 1 cost unit is roughly equivalent to 1 m (i.e., the units of cost are similar to the distance units in the resistance surface), the minimum effective distance threshold of 63,000 cost units is roughly equivalent to 63,000 m. Because the resolution of the cost surface is 500 m, a cost distance of 63,000 cost units would then equal approximately 31,500 m, which is below the average flight range of each focal species. For Western Sandpipers, Senner (1979) records the mean spring flight at 600 km/day and Butler et al. (1996) observed a mean spring flight speed of 422 km/day. The longest observed flight of a Western Sandpipers was approximately 1,800 km (Butler et al., 1997). For Dusky Canada Geese, Bromley and Jarvis (1993) noted that the migratory route is roughly 2,600 km and the migratory period averaged 11 days, therefore, the geese fly on average 236 km/day. Due to limited published sources, I calculated the migratory flight range of White-winged Scoters using Flight 1.16 (Pennycuick, 2006). I based the parameters for the calculation on data collected from scoters in the field, as well as assumptions stemming from known values for Harlequin Duck (*Histrionicus histrionicus*). The estimated distance a male could fly before he was out of fuel was 736 km and the estimated distance a female could fly before she was out of fuel was 1056 km. However, during migrations White-winged Scoters would likely fly shorter distances.

Coastal vs. Local Connectivity

Presumably, for migrating White-winged Scoters, Western Sandpipers and Dusky Canada Geese coastal connectivity is more pertinent than local connectivity. Therefore, migrants may view the connectedness of estuaries in close proximity to one another differently from the connectedness of estuaries dispersed across the landscape. If the preceding statement is true, the importance of an estuary on the coastal scale could be dissimilar to the local importance of the same estuary. To determine if the coastally important estuaries are also locally important, I ranked the estuaries according to the local connectivity metrics and according to the coastal connectivity metrics. I compared the rankings of the local metrics with the rankings of the coastal metrics using Spearman's Rank Correlation to discern if the coastal and local metrics made similar predictions of estuary importance. Furthermore, the correlation between the two rankings would indicate the relevance of either coastal connectivity or local connectivity to conservation planning indented to conserve estuarine stopovers for migratory birds.

Connectivity Importance across Species

Connectivity is species-specific, but how different is the connectivity of estuarine stopovers for Dusky Canada Geese, Western Sandpipers, and White-winged Scoters? I attempted to answer this question by examining the correlation length at various threshold distances to determine the effective distance at which estuaries became a single cluster for each species. Correlation length was a measure of overall estuarine connectivity in the landscape for a given threshold distance and had units of distance that represent the average distance a migrant could fly within a cluster before it reached a barrier (Keitt et al., 1997). A disconnected landscape consists of many clusters, whereas a connected landscape consists of a single cluster that represents a migrant's ability to access all available estuaries. To migrate through the matrix, a bird did not require a single cluster -- only enough estuaries to permit the bird to hopscotch between stopovers. Regardless, the average size of clusters was a useful statistic to compare the degree of estuarine connectivity for each species.

As my second objective, I wanted to compare Overall Species Importance across species to determine which of the 442 estuaries were important for all three species and if collections of these estuaries occurred as connectivity hot spots. To do so, I summed the Overall Species Importance rankings of all species for each of the 442 estuaries into an Aggregate Importance score; however, not all estuaries were available to all three species. If an estuary was not available to a particular focal species, it received an Overall Species Importance score of 2856, which was 408 (the poorest rank assigned to any estuary) multiplied by seven (the number of metrics), so that all 442 estuary were given an Overall Species Importance score for each species. I then summed the three species' Overall Species Importance ranks to determine the Aggregate Importance score and ranked the estuaries for their relative importance in maintaining connectivity for all three species. Next, I computed Spearman's R to compare the individual specie's Overall Species Importance rankings to the Aggregate Importance rankings in order to distinguish if one species had a stronger relationship to Aggregate Importance than the other species. Lastly, I mapped the top 15 ranked estuaries for Aggregate Importance to discern if any connectivity hot spots were evident.

The third objective in my study was to examine the influence of individual metrics on the ranking of estuaries for connectivity importance. If one or several metrics explained a large portion of the importance score, then those metrics could guide further connectivity analyses or conservation research. I examined the degree that each metric influenced the Overall Species Importance ranks for each focal species and for the degree that each metric influenced the Aggregate Importance score using Spearman's R to determine the strength and direction of the correlations. I also removed each metric and re-calculated Overall Species Importance based on six metrics, and then compared the rankings of the re-calculated Overall Species Importance to the initial Overall Species Importance using Spearman's R to determine the weight of the individual metrics on Overall Species Importance.

Sensitivity Analysis

For my fourth objective, I performed a sensitivity analysis to evaluate the robustness of the results to values in the resistance surface because the graph model can be extremely sensitive to small changes in the resistance surface (Gardner & Gustafson 2004). Elevation was a static feature over the period of the connectivity analysis; wind however, was highly dynamic. To test the robustness of the results, I replaced the baseline wind scenario with either the best or the worst wind cost grid, added that grid to the elevation cost grid, and re-ran the connectivity analysis. To determine what wind speed and direction to use for the best and worst wind scenarios, I first computed the wind cost for all daylight hours at each weather station and averaged the costs across all stations into a single wind cost for each day in April 2005. I then selected the day with the lowest wind cost and the day with the highest wind cost as the best and worst days, respectively. The least-costly wind conditions occurs on April 14 -- the best day for migration, and the most-costly wind conditions occurs on April 4 -- the worst day for migration.

As the second step, I selected the hourly wind record to use for the interpolations of the best and worst scenarios by assuming that the migrants would still fly, but would choose the optimal wind conditions during the day to do so. Therefore, I took the maximum wind speed, and corresponding direction, for each weather station on April 14 to represent the strongest tailwinds present on that day. Next, I took the minimum wind speed, and corresponding direction, for each weather station on April 4 to represent the weakest headwinds present on that day. For the best and worst day, I then calculated and re-scaled the velocity to cost values, added the new wind cost grid to the elevation cost grid, repeated the connectivity analysis, and re-calculated the connectivity metrics. Finally, I performed a Spearman Rank Correlation to determine the strength of the relationship between the important estuaries as ranked by the baseline wind scenario and as ranked by the best or worst wind scenarios. I only considered the Dusky Canada Goose for the sensitivity analysis because the species had the fewest available estuaries, and consequently, might be the most susceptible to changes in the wind cost grid.

Connectivity Importance in Relation to Biophysical Importance

My last objective was to contrast the resemblance of the results obtained in my connectivity analysis to an existing assessment of the biophysical value of estuaries in British Columbia. In a biophysical assessment of British Columbian estuaries for conservation prioritization, Ryder et al. (unpublished) used five parameters to score biophysical importance for the 442 estuaries. The parameters were estuary size, habitat rarity, species rarity, waterbird density, and amount of herring spawn. For each estuary, the parameter scores were tallied into an Overall Rank, as well as a Biophysical Importance score out of 100. The intention of both Overall Rank and Biophysical Importance was to assist in conservation planning by prioritizing estuaries for conservation attention (Ryder et al., unpublished).

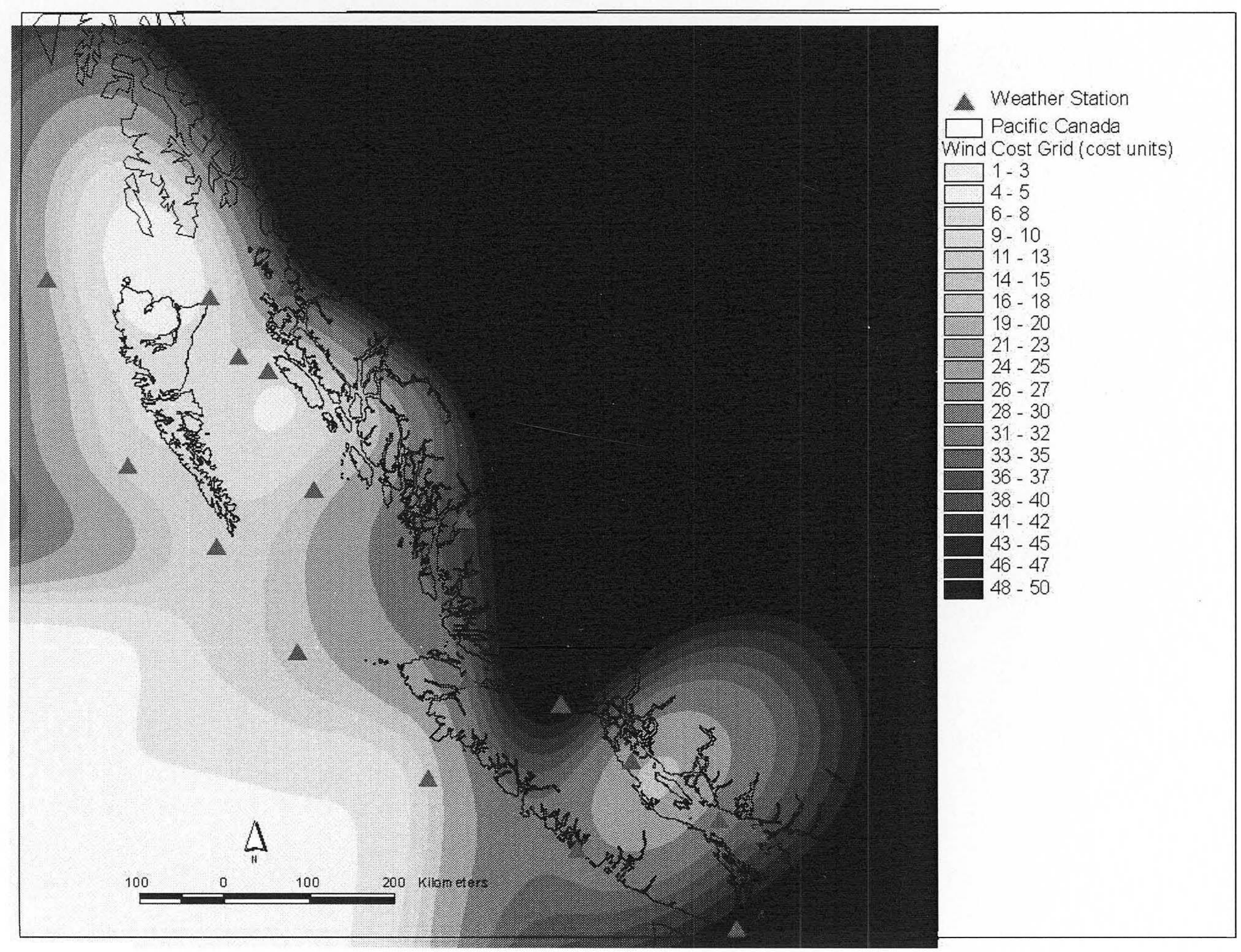
I used the Biophysical Importance scores to rank the estuaries from one to 442 in order to match the ranking system for Aggregate Importance. I then compared the Biophysical Importance rankings with the Aggregate Importance rankings using Spearman's R to determine how similar the ranking were. If the rankings had a strong positive correlation, then estuary conservation based upon the biophysical importance would indirectly sustain estuarine connectivity. If the rankings had a weak positive correlation, then estuary conservation based upon the biophysical importance would be inadvertently exercising selective connectivity maintenance by maintaining connectivity for some estuaries, but not others. If the rankings had a negative correlation, then estuary conservation based upon biophysical importance would not be leading towards maintenance of estuarine connectivity. However, I expected a positive correlation, as habitat influenced both Aggregate Importance and Biophysical Importance.

RESULTS OF THE CONNECTIVITY ANALYSIS

Cost Grids and Resistance Surface

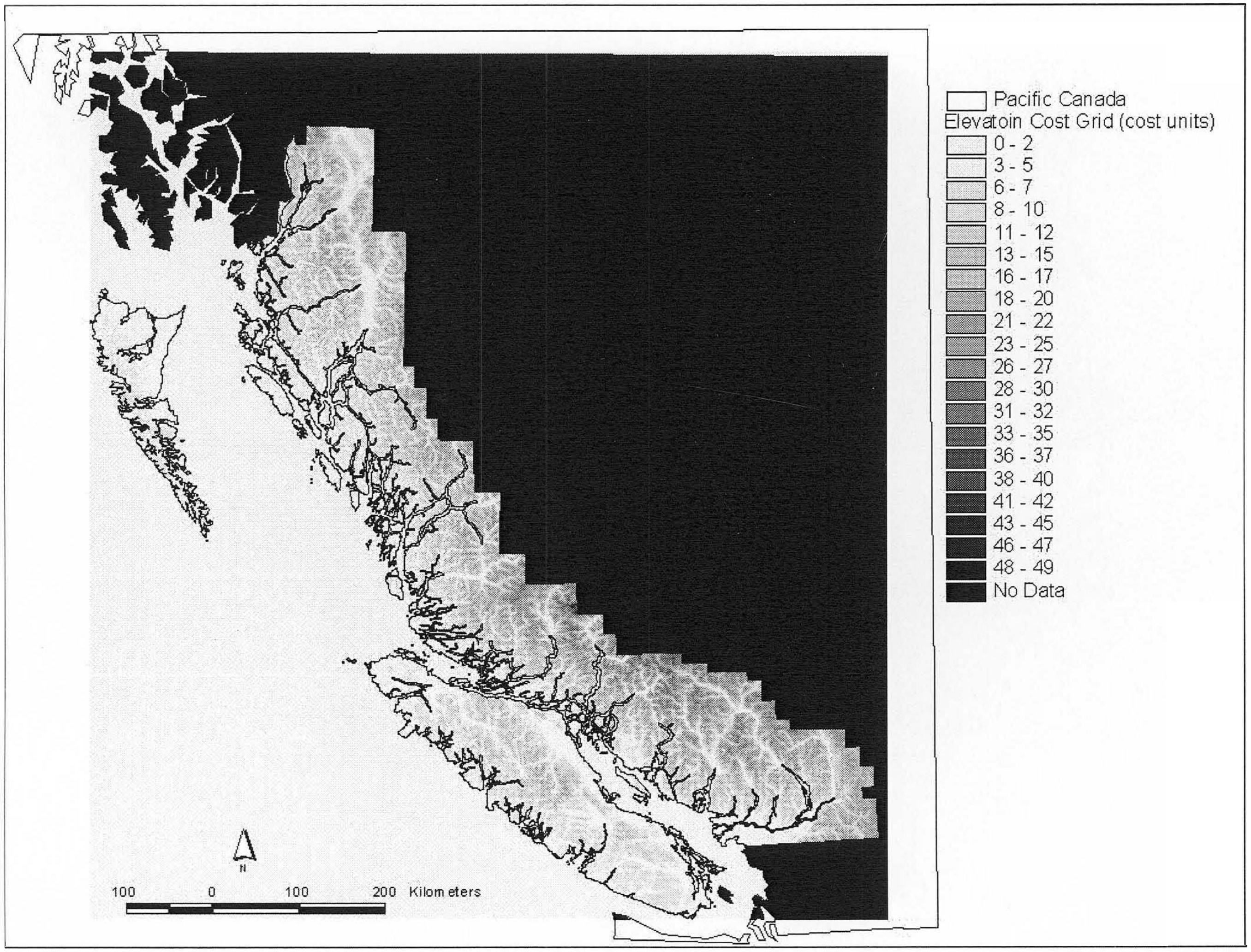
I modelled the matrix by combining the baseline wind cost grid (Figure 6) with the elevation cost grid (Figure 7) to create the resistance surface (Figure 8). The resistance surface then dictated the placement of the least-cost pathways and the effective distance of the edges. In the connectivity analysis, the resistance surface was a representation of the cost incurred by the migrants when they flew through the landscape that separated estuarine stopovers. I assumed that all focal species incurred equal costs when flying through this matrix (i.e., the effective cost was equal for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese).

Figure 6: Wind cost grid for baseline wind scenario.



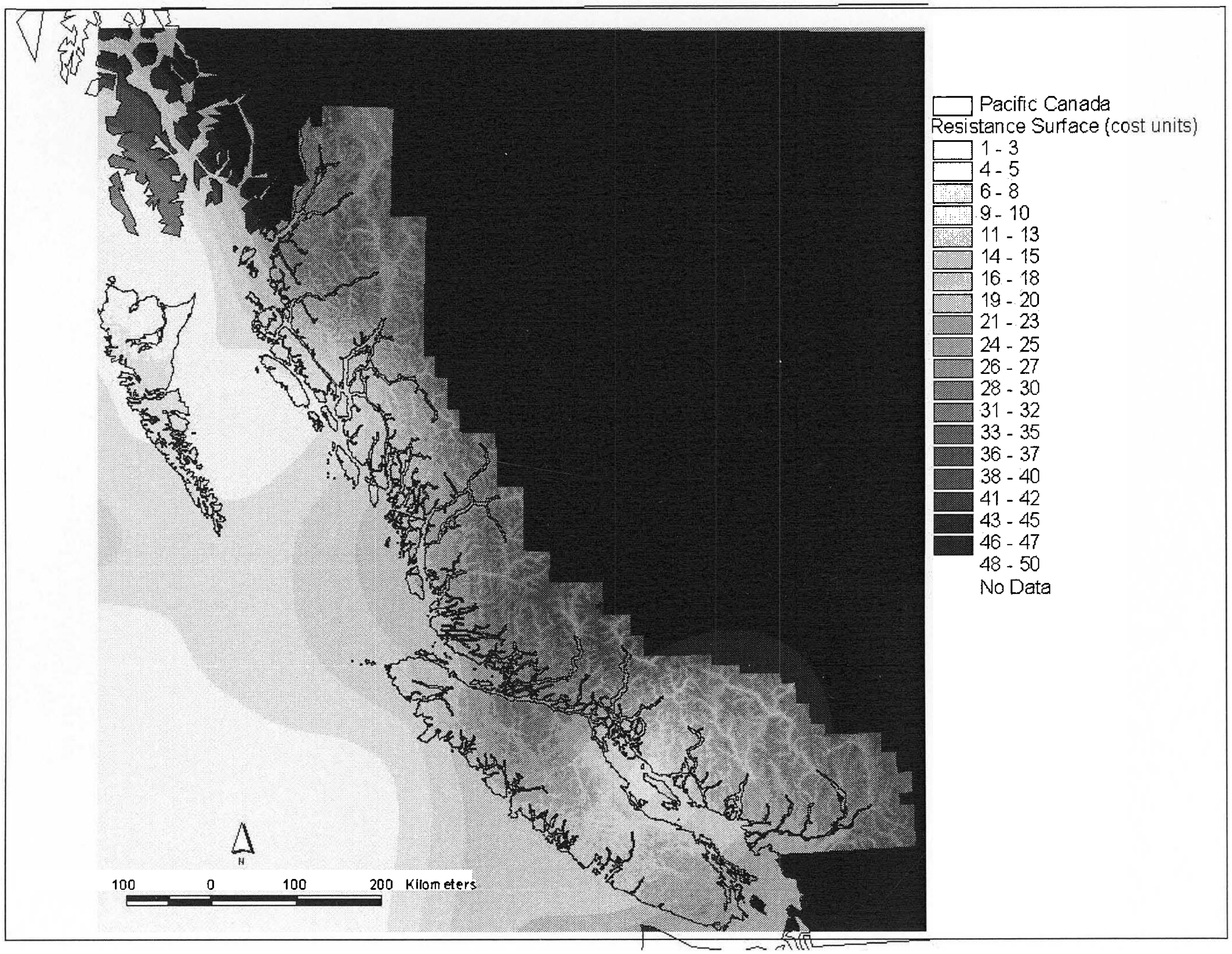
The triangles are the 18 weather stations used to interpolate the grid.

Figure 7: Elevation cost grid.



Cells with "No Data" are outside of the Study Area (i.e., interior British Columbia, Alaska, and Washington).

Figure 8: **Resistance surface (baseline wind cost grid + elevation cost grid).**

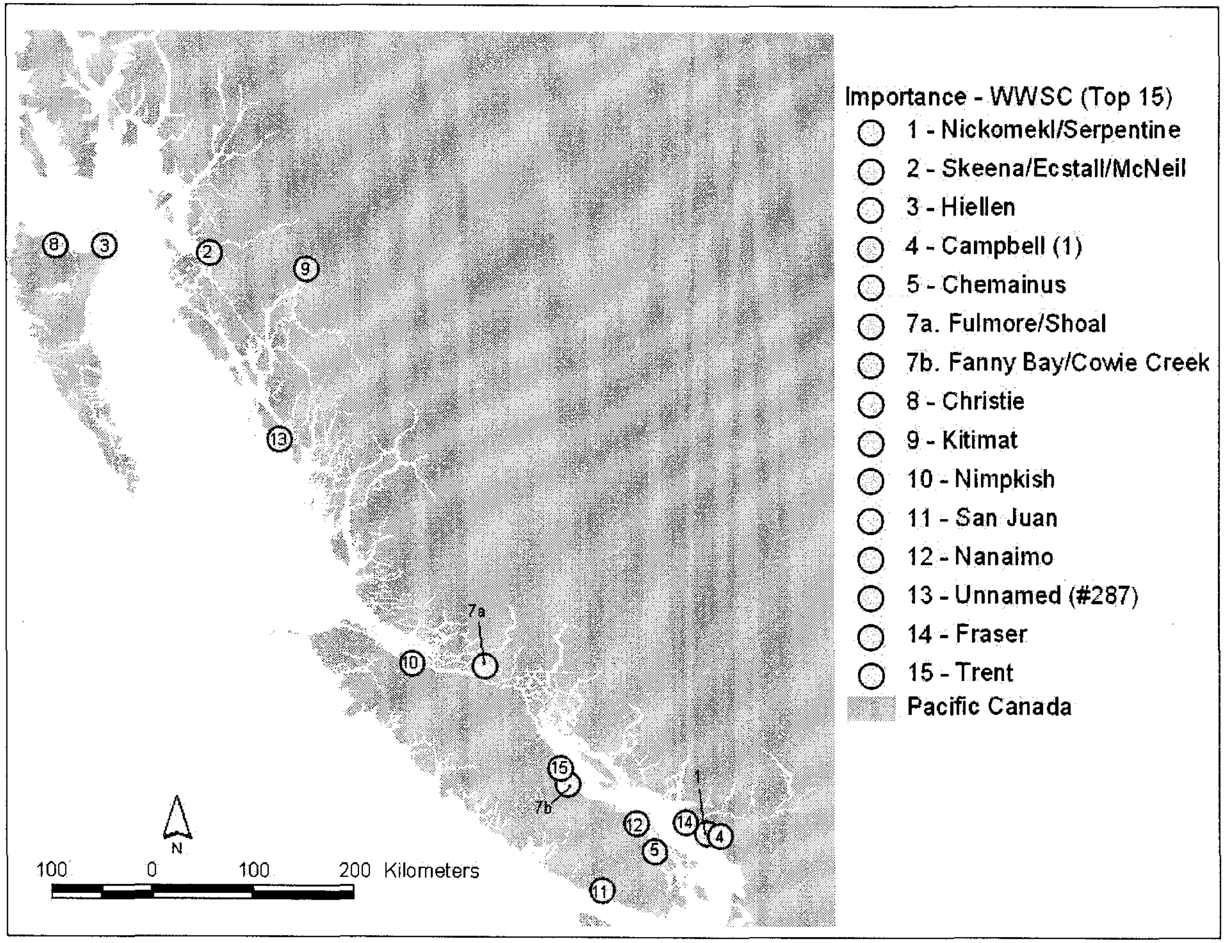


Connectivity Maintenance per Species

White-winged Scoters

Among the 442 estuaries in British Columbia, 333 were available to migrating White-winged Scoters. The top ranking estuary for Overall Species Importance was the Nickomekl/Serpentine River Complex, located at the southern extent of metropolitan Vancouver, British Columbia. This estuary was indicated to be an important stopover at both the coastal and local scale for White-winged Scoters because it ranked within the top 15 for metrics that quantified coastal connectivity (Accessibility and Connectivity Maintenance) and local connectivity (Habitat Area, Number of Neighbours, and Transversibility). In general, the important estuarine stopovers for White-winged Scoters were dispersed along the coastline (Figure 9). The areas predicted to be connectivity hot spots for White-winged Scoters during spring migrations were the Lower Mainland, eastern Vancouver Island, and northern Hecate Strait. These areas were predicted to be connectivity hot spots because they harboured collections of high-ranking estuaries.

Figure 9: The 15 most important estuaries for White-winged Scoters, as ranked by Overall Species Importance.

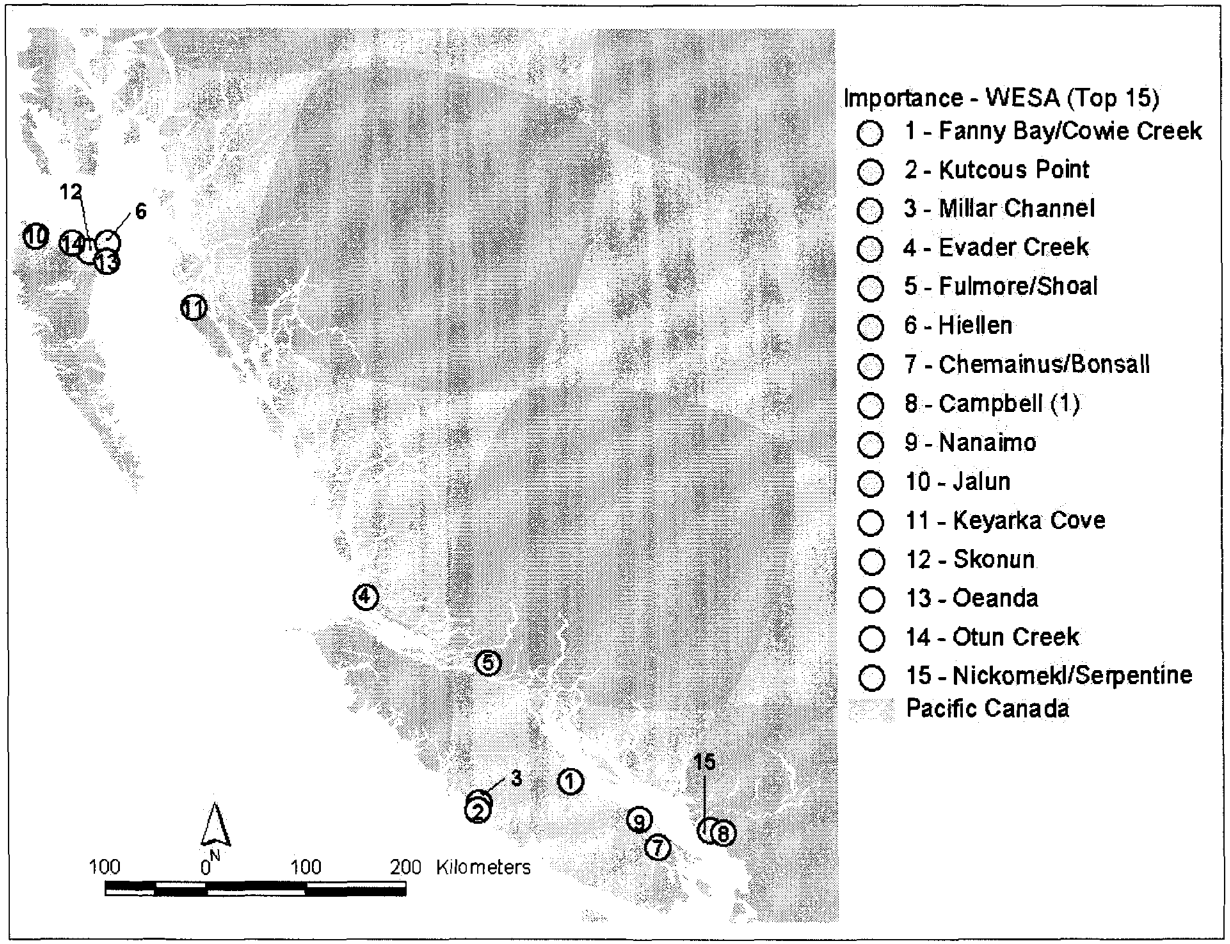


The estuaries ranked 14, 1, and 4 form the connectivity hot spot in the Lower Mainland. The estuaries ranked 15, 7b, 12, and 5 form the connectivity hot spot on eastern Vancouver Island. The estuaries ranked 8, 3, and 2 are the connectivity hot spot in Hecate Strait.

Western Sandpipers

In total, 408 estuaries were available to migrating Western Sandpipers. The highest-ranking estuary for Overall Species Importance was Fanny Bay/Cowie Creek, located on eastern Vancouver Island off the Strait of Georgia. The estuary ranked first for Connectivity Maintenance, although it ranked poorly for both Number of Neighbours and Transversibility (407th and 329th, respectively) and received a moderate rank for Habitat Area (71st). The estuary also ranked first for coastal connectivity, but 220th for local connectivity. The rankings predicted that although the Fanny Bay/Cowie Creek estuary lacked close neighbours and a large area of intertidal delta, its location in the graph established it as a critical stepping-stone for Western Sandpipers. Generally, the top 15 estuaries for Overall Species Importance showed two noteworthy trends (Figure 10). First, the estuaries predicted to maintain connectivity for Western Sandpipers were located in either the southern or the northern portion of coastal British Columbia, but absent from the central portion. Second, both the northern coast of the Queen Charlotte Islands and the Strait of Georgia contained collections of important estuaries and were predicted to be hot spots for connectivity.

Figure 10: **The 15 most important estuaries for Western Sandpipers, as ranked by Overall Species Importance.**

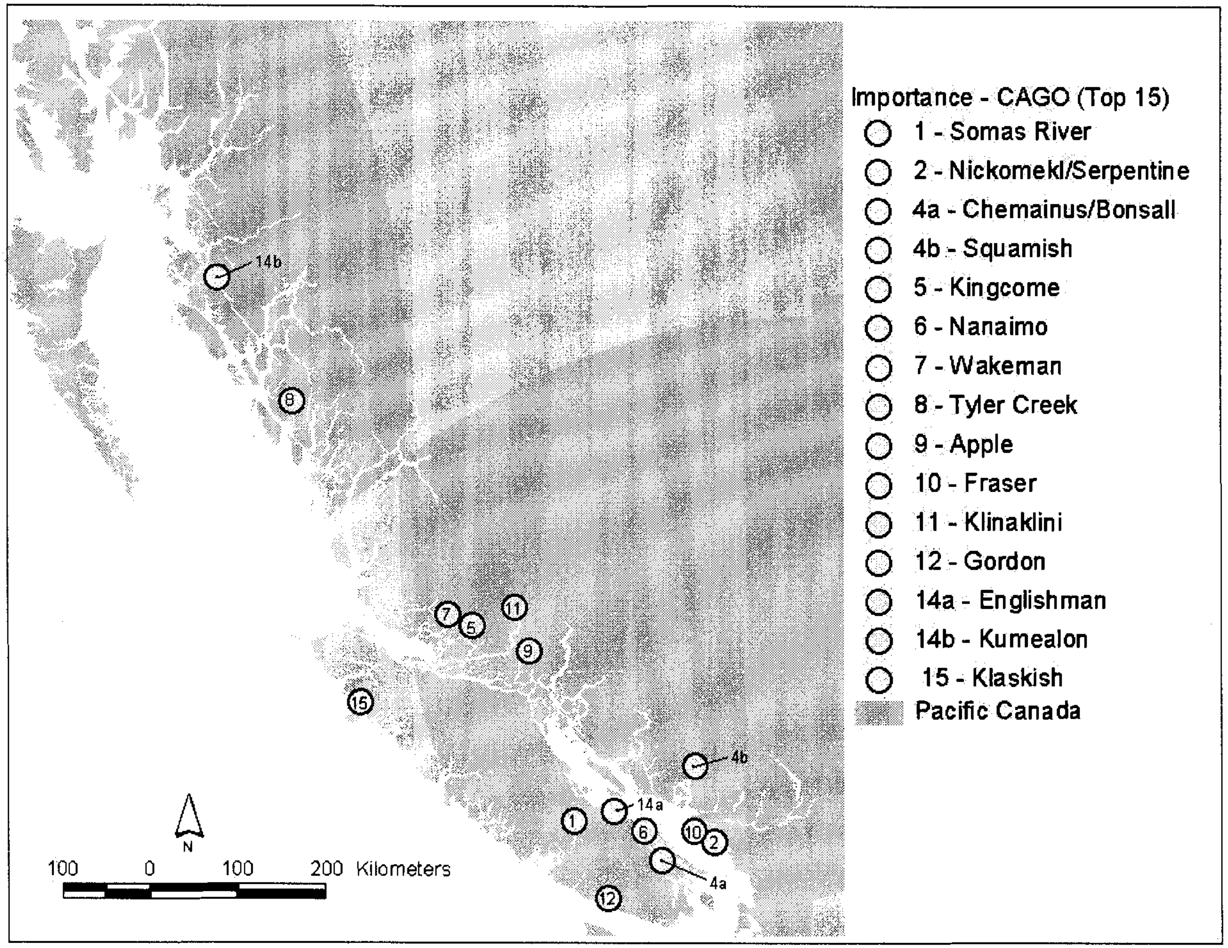


The estuaries ranked 10, 14, 12, 6, and 13 are the connectivity hot spot on the north coast of the Queen Charlotte Islands. The estuaries ranked 1, 9, 7, 15, and, 8 form the connectivity hot spot in the Strait of Georgia.

Dusky Canada Geese

For a migrating Dusky Canada Geese, 123 estuaries were available as stopovers. The highest ranked estuary for Overall Species Importance was the Somas River, located at Port Alberni, British Columbia, at the head of the Alberni Inlet. Due to the estuary's position -- within the top 12 for Habitat Area, Number of Neighbours, Transversibility, Connectivity Maintenance, and Critical Stepping-stone -- both habitat within the estuary and distance to its neighbours explain much of the Overall Species Importance of the Somas River estuary. Furthermore, the Somas River estuary was predicted to be equally important as a local and coastal stopover, as it ranked 17th for both coastal connectivity and local connectivity. Three notable features about the distribution of important estuaries for Dusky Canada Geese were evident in the estuaries that ranked in the top 15 (Figure 11). First, the Queen Charlotte Islands lacked an estuary predicted to be in the top 15 most important stopovers. Second, with the exception of two estuaries along the northern coast, all of the top 15 estuaries were located in the southern portion of coastal British Columbia on either Vancouver Island or the mainland. Third, the southern end of the Georgia Strait, particularly along eastern Vancouver Island, was predicted to be an essential area for maintaining connectivity among the estuarine stopovers available to migrating Dusky Canada Geese during spring migration because six of the top 15 estuaries occurred in this area. Likewise, the mainland coast east of northern Vancouver Island was predicted to be a connectivity hot spot.

Figure 11: The 15 most important estuaries for Dusky Canada Geese, as ranked by Overall Species Importance.



The connectivity hot spot located in the Strait of Georgia is formed by estuaries ranked 14a, 6, 4a, 2, 10, and 4b. Estuaries ranked 7, 5, 11, and 9 form the hot spot on the mainland coast east of northern Vancouver Island.

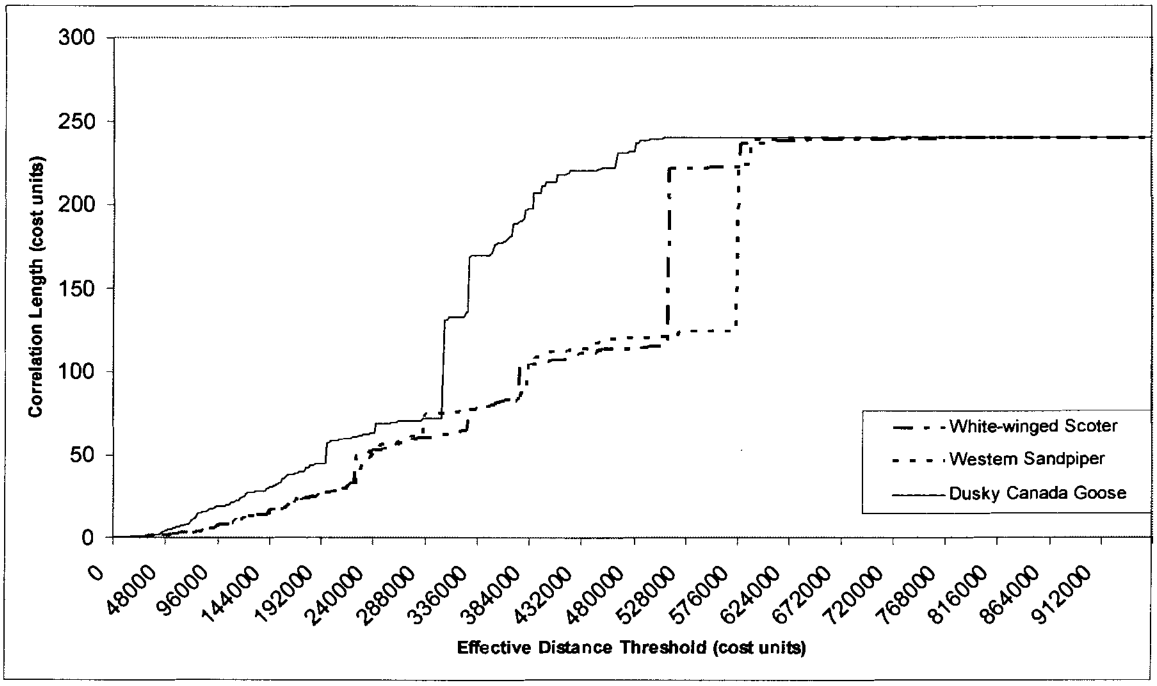
Coastal vs. Local Importance

The connectivity analysis predicted that White-winged Scoters, Western Sandpipers, and Dusky Canada Geese viewed local connectivity differently than coastal connectivity. Estuaries that were important at the coastal scale were not important for the focal species at the local scale, as a weak negative correlation was present between the metrics quantifying coastal connectivity and the metrics quantifying local connectivity: for White-winged Scoters Rs = -0.30, n = 333; for Western Sandpipers Rs = -0.37, n = 408, for Dusky Canada Geese Rs = -0.26, n = 123 (all correlations were significant at $p < 0.01$). Consequently, efforts to conserve estuarine habitat based on local connectivity will not translate directly into maintenance of coastal connectivity for the three focal species. Furthermore, coastal metrics are likely the most relevant for conservation planning to conserve estuaries in British Columbia for migrating White-winged Scoters, Western Sandpipers, and Dusky Canada Geese. The local metrics may be better suited for non-migratory movements and may benefit the management of species that have similar habitat needs as the focal species, but that either winter or breed at estuaries in British Columbia instead of using the estuaries as stopovers.

Connectivity Importance across Species

For White-winged Scoters, Western Sandpipers, and Dusky Canada Geese, the estuaries became a single, connected cluster at different effective distance thresholds (Figure 12). A single cluster occurred when the correlation length equalled 240 cost units, which meant that all estuaries were connected and accessible to the species because the average distance a migrant could fly within a cluster before reaching a barrier (i.e., 240 cost units) was greater than the average distance between estuaries. A correlation length below 240 cost units represented a disconnected landscape; the species would reach a barrier before it could access all available estuaries. The Dusky Canada Goose was the first species for which all of the available estuaries formed a single cluster. The next species that acquired a single cluster was the Western Sandpiper, followed by the White-winged Scoter.

Figure 12: Degree of estuarine connectivity for the three focal species, as a function of effective distance threshold.

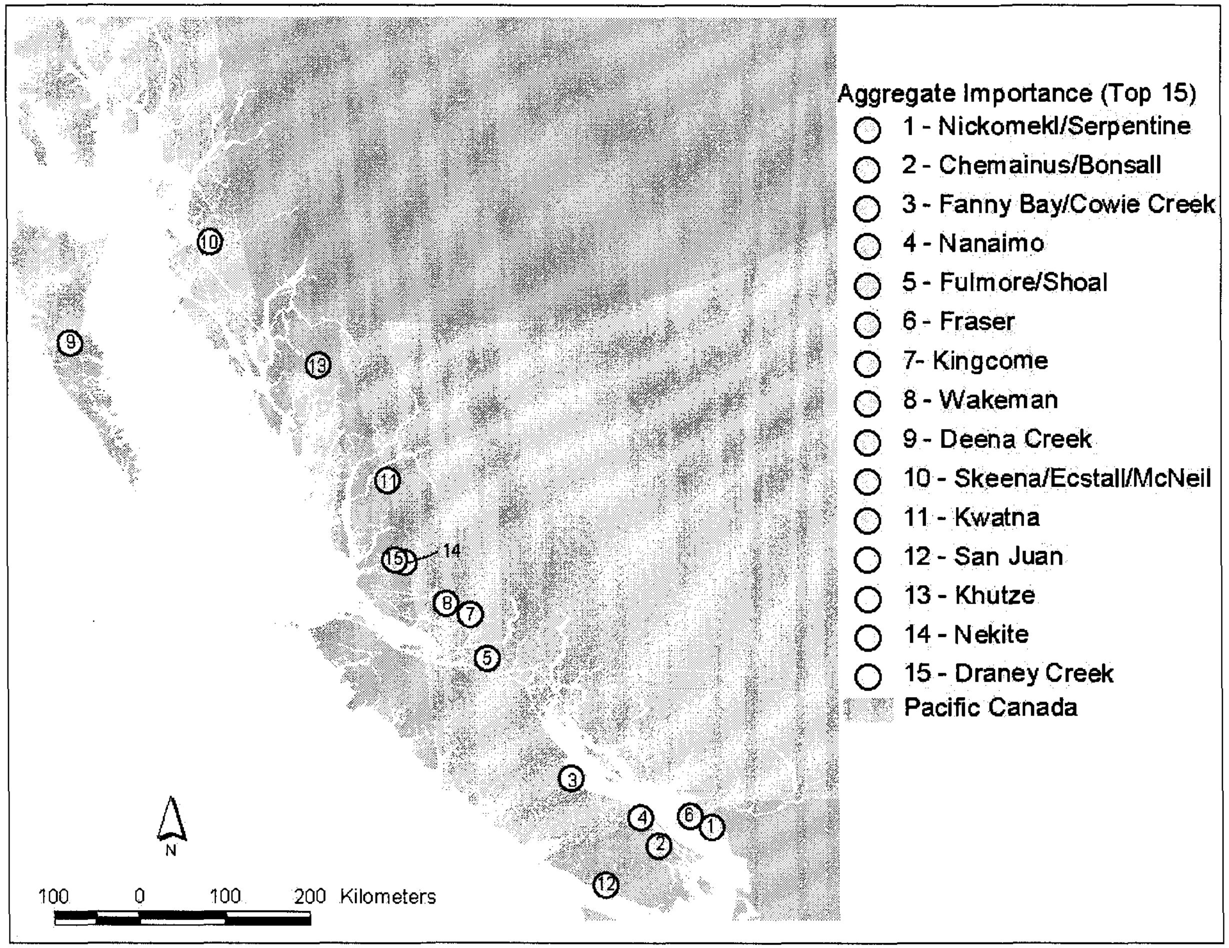


As an example for interpreting the graph: for a White-winged Scoter with a flight capability of 513,600 cost units, the correlation length was 221 cost units. (i.e., for a scoter that could fly 513,600 cost units, the average distance the scoter could fly within a cluster before it reached a barrier was 221 cost units).

A possible explanation for the differences in the effective distance thresholds necessary to attain a single cluster is the number of direct links in a graph. A direct link occurred when the edge connecting two nodes did not connect to any additional node. In contrast, an indirect link made use of at least one stepping-stone to connect two nodes. The number of direct links per effective distance threshold was highest for White-winged Scoters (9 direct links/threshold increment), followed by Western Sandpipers (7 direct links/threshold increment) and Dusky Canada Geese (5 direct links/threshold increment). A higher number of direct links implied that fewer estuaries were accessible in a single flight, and therefore, that more flights of increasing distances were necessary to access all of the available estuaries. In addition, the low number of estuaries available to the Dusky Canada Goose may explain why the goose attained a connected graph before the White-winged Scoter or Western Sandpiper, as fewer edges were required to connect the available nodes. Although the Western Sandpiper had more available estuaries than the White-winged Scoter, the additional nodes may have provided more stepping-stones, which resulted in fewer direct links than the White-winged Scoter, and may explain why the Western Sandpiper attained a single cluster before the White-winged Scoter.

The estuary that scored the highest for Aggregate Importance was the Nickomekl/Serpentine River Complex, which ranked first and second for the Overall Species Importance for White-winged Scoters and Dusky Canada Geese, respectively. The rankings for Aggregate Importance revealed that western Vancouver Island was not an important area for maintaining connectivity during spring migration, that is, the area did not support estuaries that all three focal species might use (Figure 13). In contrast, the connectivity metrics predicted both the Strait of Georgia and the mainland coast east of northern Vancouver Island to be connectivity hot spots. Surprisingly, the majority of the estuaries located on the mainland that were predicted to be in the top 15 were far from open water at the head of inlets even though ease of access was a factor in determining relative importance. Evidently, these estuaries were predicted to be of sufficient connectivity value that migrants would be willing to incur the added cost of reaching these estuaries.

Figure 13: Top 15 ranking estuaries for Aggregate Importance.



The estuaries ranked 3, 4, 6, 1 and 2 form the connectivity hot spot in the Strait of Georgia. The estuaries ranked 15, 14, 8, 7, and 5 form the connectivity hot spot on the mainland east of northern Vancouver Island.

Each focal species was related to Aggregate Importance to varying degrees. The strongest relationships between the rankings of Overall Species Importance and Aggregate Importance belonged to White-winged Scoters (Rs = 0.71) and Western Sandpipers (Rs = 0.68), followed by Dusky Canada Geese (Rs = 0.07) (for all correlations n = 442 and $p < 0.01$). The scoter and sandpiper exerted the greatest influence on Aggregate Importance because the variances in the rankings were more similar to one another than to the substantially higher variance in the Dusky Canada Goose's rankings. Because Dusky Canada Geese had fewer available estuaries, the estuaries that were available were ranked 1st - 123rd, with every other estuary ranked 442nd (i.e., not important). Consequently, the Dusky Canada Goose had a larger variance in its rankings than the Western Sandpiper or White-winged Scoter, and therefore, exerted minimal effect on the rankings for Aggregate Importance.

The relationships between the rankings for each metric and the rankings for Overall Species Importance showed three noteworthy trends. First, the connectivity metric with the strongest positive correlation to the Overall Species Importance of Dusky Canada Geese and White-winged Scoters was Number of Neighbours (Rs = 0.70, n= 123, $p < 0.01$ for Dusky Canada Geese and Rs = 0.62, n = 333, $p < 0.01$ for White-winged Scoters) (Table 3). In contrast, Connectivity Maintenance had the strongest positive correlation to the Overall Species Importance of Western Sandpipers (Rs = 0.52, n = 408, $p < 0.01$). Second, Neighbourhood Habitat had a negative correlation to Overall Species Importance for all three focal species (Rs = -0.60, n = 123 for Dusky Canada Geese, Rs = -0.60, n = 333 for White-winged Scoters, and Rs = -0.18, n = 408 for Western Sandpipers, for all correlations $p < 0.01$). Third, Connectivity Maintenance showed a strong positive correlation with Overall Species Importance for Dusky Canada Geese (Rs = 0.51, n = 123, $p < 0.01$) and Western Sandpiper (Rs = 0.53, n = 408, $p < 0.01$), but a weak positive correlation with Overall Species Importance for White-winged Scoters (Rs = 0.46, n = 333, $p < 0.01$). Critical Stepping-stone exhibited correlations similar to Connectivity Maintenance. Testing for the presence and strength of correlations between the rankings for individual metrics and the rankings for Overall Species Importance suggested that Connectivity Maintenance and Critical Stepping-stone were consistently positively correlated to Overall Species Importance for all three focal species. Evidently, the coastal metrics that identify stepping-stone estuaries maintain a consistent influence on Overall Species Importance.

Table 3: Correlation of each connectivity metrics to the Overall Species Importance score and Aggregate Importance score

Metric	Overall Dusky Canada Geese (Rs)	Overall Western Sandpipers (Rs)	Overall White-winged Scoters (Rs)	Aggregate Importance (Rs)
Habitat Area	0.56	0.27	0.46	0.60
Number of Neighbours	0.70	0.20	0.62	0.56
Transversibility	0.51	0.41	0.41	0.53
Neighbourhood Habitat	-0.60	-0.18	-0.60	0.35
Accessibility	-0.08	0.27	0.34	0.94
Connectivity Maintenance	0.51	0.53	0.46	0.37
Critical Stepping-stone	0.51	0.49	0.46	0.34

Some of the metrics also exhibited a strong positive correlation with Aggregate Importance (Table 3). The metrics with a strong positive correlation to Aggregate Importance were Accessibility (Rs = 0.94), Habitat Area (Rs = 0.60), Number of Neighbours (Rs = 0.56), and Transversibility (Rs = 0.53) (for all correlations n = 442 and $p < 0.01$). The strongest correlation between the rankings was for Accessibility, although it did correlate weakly with the Overall Species Importance for the focal species. In addition, Neighbourhood Habitat, which maintained a negative correlation under Overall Species Importance, showed a weak positive correlation to Aggregate Importance (Rs = 0.35). Testing for the presence and strength of correlations between the rankings for individual metrics and Aggregate Importance suggested that an estuary's contribution to connectivity depended primarily on the distance to open water, the amount of habitat it contained, the number of neighbours it had, and the effective distance separating it from its neighbours. An estuary's value as a stepping-stone did not influence Aggregate Importance to the degree that it did for Overall Species Importance.

Upon iteratively removing each metrics and observing changes to the rankings for Overall Species Importance, no metric had a disproportionately strong affect on Overall Species Importance. I determined these affects by removing each metric and re-calculating Overall Species Importance based on six metrics, then comparing the rankings of the re-calculated Overall Species Importance to the initial Overall Species Importance (Table 4). For Dusky Canada Geese, the relationship between the six-metrics-calculation and the initial calculation ranged from Rs = 0.86 to Rs = 0.95 ($n = 123$, $p < 0.01$). Rs ranged from 0.84 to 0.89 for Western Sandpipers ($n = 408$, $p < 0.01$) and from 0.86 to 0.94 for White-winged Scoters ($n = 333$, $p < 0.01$). Among all species, the metric that upon its removal resulted in the strongest positive correlation to the initial Overall Species Importance was Neighbourhood Habitat (Rs = 0.95, $n = 123$ for Dusky Canada Geese, Rs = 0.89, $n = 408$ for Western Sandpipers, and Rs = 0.95, $n = 333$ for White-winged Scoters, all correlations significant at $p < 0.01$), suggesting that Neighbourhood Habitat was the least important contributor to Overall Species Importance. Nevertheless, omission of any one metric from the connectivity analysis would have a minimal affect on the Overall Species Importance rankings and the identification of important estuaries or connectivity hot spots.

Table 4: **The strength of the effect of each connectivity metric on the Overall Species Importance for each focal species, where Rs is the correlation between rankings from the six-metric and seven-metric calculations of Overall Species Importance**

Metric	Dusky Canada Geese (Rs)	Western Sandpipers (Rs)	White-winged Scoter (Rs)
Accessibility	0.89	0.86	0.89
Habitat Area	0.85	0.87	0.88
Number of Neighbours	0.90	0.88	0.89
Transversibility	0.90	0.85	0.87
Neighbourhood Habitat	0.95	0.90	0.95
Connectivity Maintenance	0.91	0.85	0.87
Critical Stepping-stone	0.90	0.85	0.88

Sensitivity Analysis

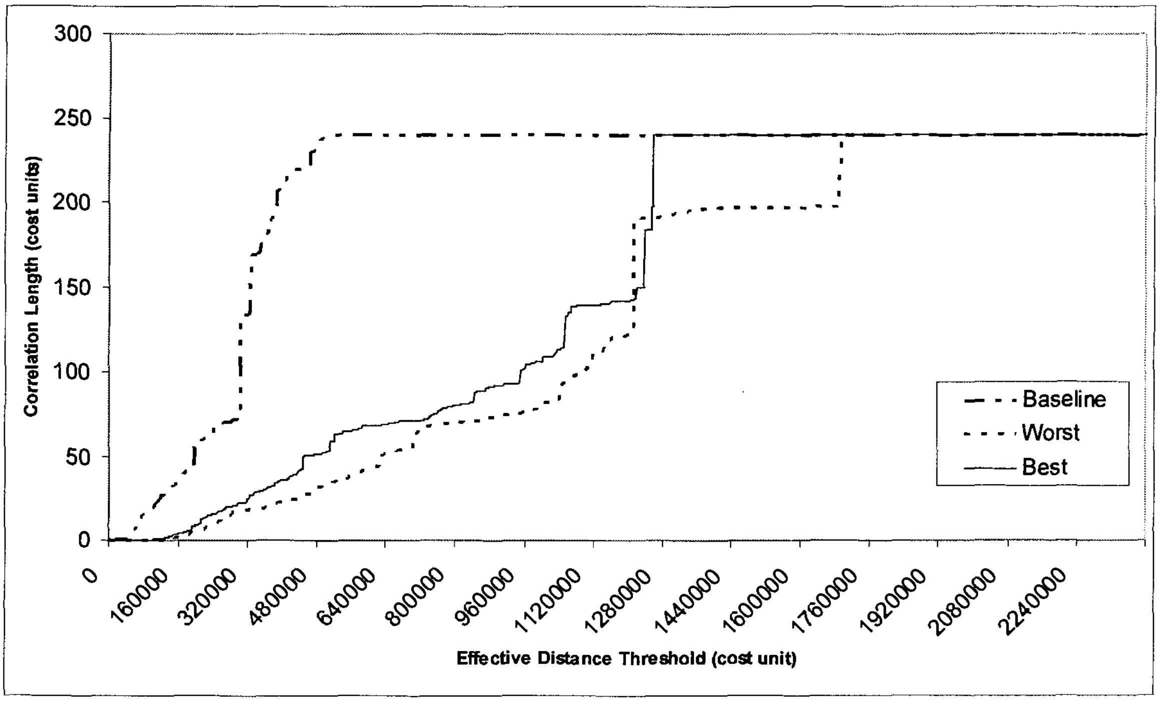
The values used to interpolate the best wind scenario cost grid and the worst wind scenario cost grid resulted in costlier resistance surfaces than the baseline wind scenario. The best wind scenario averaged a higher wind cost than the baseline wind scenario because the wind speeds selected were slower than the speeds selected for the baseline scenario (Table 5). In addition, wind direction averaged closer to the optimal tailwind (of 135°) in the baseline wind scenario than in the best wind scenario. The worst wind scenario averaged lower in both wind speed and direction than the baseline and best wind scenarios, and as a result had the highest average wind cost of the wind scenarios.

Table 5: The wind cost values of the weather station that were used to interpolate the baseline wind cost grid, best scenario wind cost grid, and worst scenario wind cost grid.

Station	Wind Cost for Baseline Scenario (cost units)	Wind Cost for Best Scenario (cost units)	Wind Cost for Worst Scenario (cost units)
Rose Spit	4	35	49
Cathedral Point	40	29	49
Bonilla Island	5	42	49
Prince Rupert	32	33	50
Port Hardy	33	34	38
Fanny Island	50	30	44
Tofino	28	33	50
Race Rock Campbell Scientific	50	31	46
Vancouver International Airport	36	32	44
South Moresby	11	50	49
South Hecate Strait	14	50	50
West Dixon Entrance	17	32	43
North Hecate Strait	9	34	33
East Dellwood	15	33	50
South Brooks	14	40	50
Halibut Bank	28	42	42
West Moresby	12	44	50
Sentry Shoal	19	39	50
Average Wind Cost	*23.2*	*36.8*	*46.4*

Furthermore, under both the best and worst days for migration, the threshold distances necessary to obtain a single cluster were substantially larger than under the baseline wind scenario (Figure 14). A single cluster means that the birds can access all available estuaries because the average distance a migrant would fly within the cluster before it reached a barrier is greater the distance required to reach a neighbouring estuary. Under the best wind conditions, a single cluster formed at 1,257,600 cost units, a lower threshold distance than the worst wind conditions (1,691,200), but approximately 3 times greater than the baseline. The fact that the best wind scenario and worst wind scenario were more similar to one another than to the baseline wind scenario suggested that the best and worst wind scenarios might be closer to reality than the baseline scenario.

Figure 14: Degree of estuarine connectivity for the Dusky Canada Goose, as a function of threshold distance, given the baseline, worst, and best wind scenarios.



Regardless of the dissimilarities between the best, worst, and baseline wind scenarios, the rankings for Overall Species Importance under both the best and worst wind scenarios maintained strong positive correlations to rankings for Overall Species Importance under the baseline wind conditions (Rs = 0.82 and Rs = 0.83 for the worst and best days, respectively, n = 123, $p < 0.01$). Consequently, the values used to construct the wind cost grid did not have a significant effect on the estuaries' relative importance as links in the chain of estuarine stopovers. As a result, the predictions of relative importance were robust to the cost values in the resistance surface.

The individual metrics maintained strong correlations to their rankings for the baseline wind scenario and their rankings for the best and worst wind scenarios. Of the local metrics, Number of Neighbours (Rs = 0.77 for the worst wind scenario and Rs = 0.76 for the best wind scenario) and Transversibility (Rs = 0.65 for the worst wind scenario and Rs = 0.68 for the best wind scenario) exhibited the greatest response to the affect of wind because they employed effective distance to determine the number of neighbouring estuaries. The wind cost grid set the effective distance between estuaries, and consequently, the number of estuaries within a neighbourhood. The results from the sensitivity analysis illustrated that favourable wind conditions enlarged the amount of accessible habitat and that unfavourable wind conditions reduced the amount of accessible habitat.

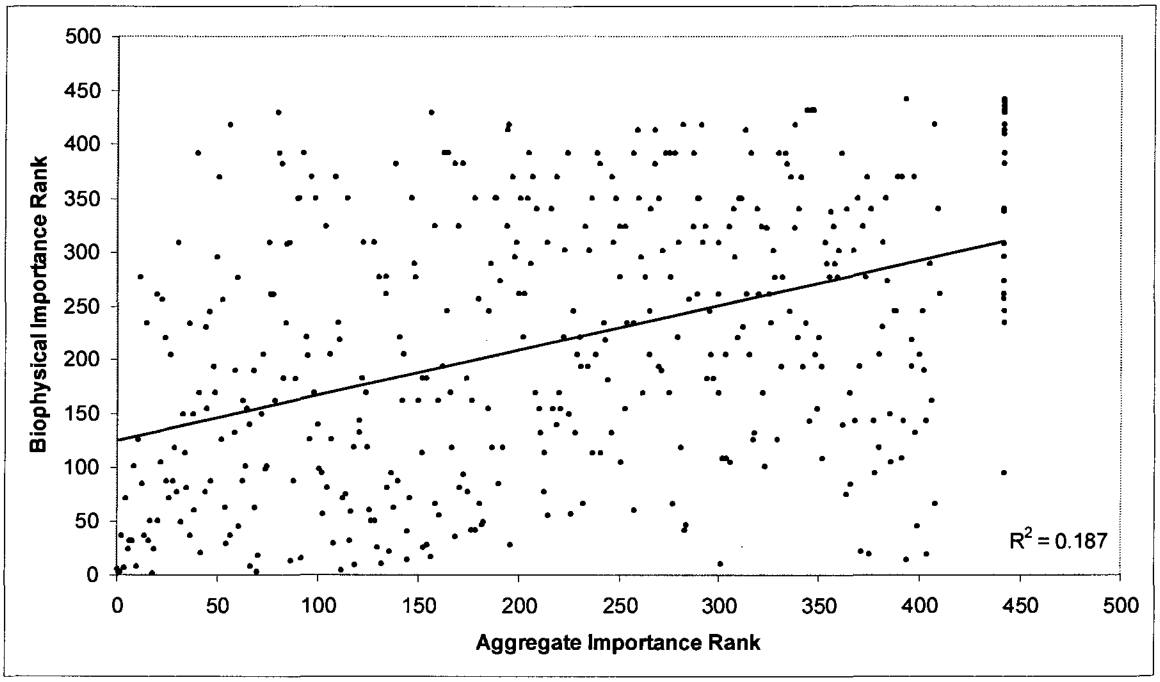
The coastal metrics showed a weaker response to the values used to interpolate the wind cost grid than the local metrics. Of the coastal metrics, those least affected by wind conditions were Connectivity Maintenance (Rs = 0.96 for the worst wind scenario and Rs = 0.98 for the best wind scenario) and Critical Stepping-stone (Rs = 0.94 for the worst wind scenario and Rs = 0.99 for the best wind scenario). The graph model and connectivity metrics predicted that wind conditions have a minimum effect on an estuary's importance for maintaining connectivity, particularly at the coastal scale.

Connectivity Importance in Relation to Biophysical Importance

The rankings for Biophysical Importance were dissimilar from the rankings for Aggregate Importance. Estuary conservation based upon the biophysical rankings would unintentionally preserve the connectivity value of some estuaries, but not others. The estuaries predicted to be essential for maintaining connectivity were not necessarily the estuaries that possessed the greatest amount or diversity of biophysical phenomena.

In fact, the rankings for Aggregate Importance diverged from the rankings for Biophysical Importance, as the correlation between the rankings was positive, but weak (Rs = 0.43, n = 442, $p < 0.01$). The greatest divergence between the ranks was 386 points for the Denad Creek estuary, which ranked 18th for Aggregate Importance, but 404th for Biophysical Importance. The top ranking estuary according to Biophysical Importance was the Kitimat River, which ranked 64th for Aggregate Importance. Figure 15 illustrates the degree of similarity in the two rankings. The large amount of scatter around the trend line ($R^2 = 0.187$, n = 442, p = 0.01) illustrates the variability between the two ranking schemes and supports the consideration of connectivity when deciding where to focus conservation resources, as biophysical factors alone do not explain why some estuaries are more valuable to migrants than others. A better understanding of the value of particular estuaries as stopovers calls for the consideration of both connectivity and biophysical factors.

Figure 15: Degree of similarity between the estuaries for connectivity ranking (Aggregate Importance) and biophysical ranking (Biophysical Importance).



DISCUSSION

Estuary rankings varied among White-winged Scoters, Western Sandpipers, and Dusky Canada Geese, and single clusters formed at different effective distance thresholds for each species. These results confirmed that connectivity is a species-specific phenomenon of the landscape (Haig et al., 1998). Nevertheless, the three focal species predicted similar connectivity hot spots: the mainland east of both the Queen Charlotte Strait and the Port Harvey Johnstone Strait (Hot spot 1) and the Strait of Georgia (Hot spot 2). In Hot spot 1, White-winged Scoters had two of their top 15 most important estuaries, Western Sandpipers also had two, and the Dusky Canada Geese had four. In Hot spot 2, White-winged Scoters had seven of their top 15 most important estuaries, Western Sandpipers had four, and Dusky Canada Geese had six.

The seven connectivity metrics also ranked the estuaries differently. For example, for Western Sandpipers, the Fraser River estuary ranked first for Number of Neighbours, but 408th for Connectivity Maintenance. The rankings of variables in the landscape for connectivity value varied with the metric applied because the connectivity metrics responded to different aspects of the landscape (Goodwin & Fahrig, 2002). Despite their differences, no one metric exerted a substantially stronger influence on the Overall Species Importance or Aggregate Importance than the other metrics, although Neighbourhood Habitat had the least influence. Furthermore, the estuaries that ranked as important for local connectivity were not important for coastal connectivity, as each focal species showed a negative correlation between the rankings of local metrics and the rankings of coastal metrics. For migrating birds, maintaining coastal connectivity is likely more relevant than maintaining local connectivity.

A comparison of the connectivity ranking scheme with the purely biophysical ranking scheme demonstrated that connectivity importance was not synonymous with biophysical importance. Basing conservation plans to protect estuarine habitat on biophysical information alone is not enough to effectively protect British Columbian estuaries for migratory birds. The difference in the two schemes is a warning that conservation efforts that ignore connectivity may be unable to preserve the long-term persistence of species (Briers, 2002; Cabeza, 2003). The differences also re-enforced a petition by Amezaga, Santamaria, & Green (2002) that the protected areas intended to conserve waterfowl should be designed to accommodate waterfowl movements. The same can be said for shorebirds.

Unexpected Findings

Based upon my predictions of the outputs of the connectivity analysis, the actual results showed some unanticipated outcomes. The predominant unexpected finding was the order that the species attained a single cluster. The results showed that the species with the lowest number of available estuaries, the Dusky Canada Goose, attained a single cluster at the lowest effective distance threshold. I had predicted that Dusky Canada Geese would have the most difficulty forming a single cluster because they had the fewest available estuaries. A possible explanation of why Dusky Canada Geese formed a single cluster before the other species is that, by having fewer estuaries to connect, the connected graph required fewer edges. In contrast, White-winged Scoters and Western Sandpipers each had a higher number of available estuaries, and each required a higher number of edges to connect all the available estuaries. Between White-winged Scoters and Western Sandpipers, the Western Sandpiper attained a single cluster at a lower effective distance than the White-winged Scoters, despite White-winged Scoters having fewer available estuaries. In this case, the estuaries may have become a single cluster for Western Sandpipers at a lower effective distance because more estuaries were available, and having more estuaries that are available increased the likelihood for stepping-stones to link distant estuaries along indirect links. Regardless of the order in which the estuaries became a single cluster for the different species, the amount of habitat available in the landscape was a key factor in determining the degree of connectedness among the estuarine stopovers.

Surprisingly, to access the majority of estuaries located on the mainland at Hot spot 1 the migrants would have to diverge from their northwest trajectory to visit the sites. This result was unexpected because Accessibility was a factor in determining an estuary's relative importance. Evidently, the predicted connectivity value for these mainland estuaries was greater than the costs incurred by the birds when they attempted to reach the estuaries. The importance of the estuaries in this connectivity hot spot suggests that the spatial pattern of available estuarine habitats dictated the relative importance of estuarine stopovers rather than the ease of access.

Another unexpected finding of the connectivity analysis was the predicted unimportance of the Fraser River estuary as a stopover for Western Sandpipers. The Fraser River estuary is in fact a major stopover for the Sandpipers during their spring migration because of the disproportionately large size of the estuary compared with other estuaries in British Columbia (Butler et al., 1996, 1997). In the connectivity analysis, the Fraser River estuary ranked as 38th most important for the Western Sandpipers. Two factors may explain why the Fraser River Estuary earned a lower rank than expected. First, the amount of habitat an estuary contained was only one of seven metrics and did not have a greater weight than the other metrics on the rankings for Overall Species Importance and Aggregate Importance. Therefore, habitat size could exert only a moderate amount of variation in the rankings. Although the amount of habitat did factor into Critical Stepping-stone, Neighbourhood Habitat nullified any additional weighting that area of habitat might have gained because Neighbourhood Habitat attributed the habitat value of the Fraser River estuary to other nearby estuaries.

Second, the scale of the connectivity analysis did not include the Western Sandpiper's entire migration route. If the study area were to extend beyond coastal British Columbia and encompass the Pacific Flyway from Peru to Alaska, the Fraser River estuary may receive a higher importance ranking for Western Sandpipers than it did for the current analysis. In contrast to Western Sandpipers, the scale of the connectivity analysis was better suited to Dusky Canada Geese and White-winged Scoters, and as a result, the predictions of relative estuary importance for the two species may be more accurate. Dusky Canada Geese begin their spring migration just south of the Canadian border in Washington and Oregon (Bromley & Jarvis, 1993). Likewise, White-winged Scoters begin their spring migration from wintering sites between Alaska and southern California (Sea Duck Joint Venture, 2003).

Validity of Methods and Results

Modelling Estuarine Connectivity in British Columbia as a Graph

In my connectivity analysis, I reduced a dynamic system into a simplified graph model to test the effects of wind and elevation on the migrants' stopover decisions. I did not intend to identify unequivocally the most important estuaries or to predict the corridors the migrants follow, but to blend the existing knowledge on shorebird and waterfowl migration with concepts of landscape ecology to identify the relative importance of estuaries in British Columbia as stopovers for migrating birds. I chose to measure estuarine connectivity as a graph because graph operations rely on a grid-based, spatially explicit model that prompts a strong response in a simulated organism to its landscape (Gardner & Gustafson, 2004; Tischendorf, 1997). I was therefore able to include the migrants assumed behavioural response to the matrix by drawing edges that followed least-cost pathways. As a result, I could predict the relative importance of individual estuaries through iterative node removal and subsequent connectivity statistics.

I also chose graph theory to model estuarine connectivity because of its wide range of applicability to connectivity problems and the realism that it can bring to addressing those problems. The graph model is a general model -- it is applicable to a range of landscapes and species, as well as to conservation decision-making (Conroy, n.d.). For example, the model can predict the degree of connectivity among habitat patches for any mobile species (Bunn et al., 2000; Jordan et al., 2003; O'Brien et al., 2006) and can provide insight into reserve design (Rothley & Rae, 2005; Zhang & Wang, 2006). The graph model also provides realism when the resistance surface contains fundamental parameters of the study system. For my connectivity analysis, the fundamental elements were the influence of wind and elevation on the migrants' decisions to use a particular estuarine stopover.

Furthermore, the graph model is applicable to species with movements that cover large spatial scales, such as migratory movements by birds, mammals, or fish, because distance thresholds are flexible. For example, a graph model could predict the relative importance of oases in a desert to migrating passerines or the relative importance of marine protected areas in the Pacific Ocean to migrating Gray whales. In either case, the distance thresholds are adjustable and could approximate the movement capability of the passerines or the whales. A graph model can also provide insight into movements that occur on large spatial scales, but are not part of life cycles. For example, the model can aid in predicting the spread of diseases or invasive species by identifying populations or locations at greatest risk.

Do the Results Verify the Model?

Due to the rugged topography and isolation of many of British Columbia's estuaries, monitoring the use of estuaries by migrating shorebirds and waterfowl is challenging. Consequently, verifying the results of the connectivity analysis is difficult, particularly when the migrants do not necessarily use the same estuaries in subsequent years. The purpose of the connectivity analysis was to predict which estuaries were the important stopovers that maintained connectivity, even though the migrants might not use these estuaries each year. For this reason, verifying the model would require years of observations at an estuary, as observations from a single year are a snapshot of usage and even a year's worth of observations will have inconsistencies due to changing conditions while recording observations. Consequently, a single year of observation may underestimate an estuary's value as a stopover.

Nonetheless, annual observations at a small sample of easily accessible estuaries show consistent use by migrants, and when compared with the results of the connectivity analysis, indicate that the graph model and connectivity metrics accurately predicted important estuarine stopovers. For example, observations of White-winged Scoters along the east coast of the Queen Charlotte Islands, near Prince Rupert, and in the Strait of Georgia corroborate the model's identification of these areas as connectivity hot spots for White-winged Scoters (Campbell et al., 1990c). Furthermore, the model's prediction of estuaries on western Vancouver Island and the Lower Mainland as important stopovers for Western Sandpipers is in line with observations of the species at the Lower Mainland, and at Long Beach, Chesterman Beach, and Tofino Inlet on the West Coast of Vancouver Island (Campbell et al., 1990b). Unfortunately, the Dusky

Canada Geese is a rare species and consistent annual observations of the geese staging in coastal British Columbia during the spring migration are rare.

Additional evidence that the graph model and connectivity metrics can predict important estuarine stopovers is the model's prediction that the Lower Mainland is a connectivity hot spot. In reality, estuarine habitats in the Lower Mainland see substantial use by migratory shorebirds and waterfowl and the area is a well-known traditional stopover. The primary estuarine habitats visited by these migrants are the Fraser River Delta and Boundary Bay, which is a large intertidal delta that joins the estuaries of the Nickomekl and Serpentine Rivers. The migrants stage at these estuaries each year because extensive marshes and mudflats provide many opportunities for resting and re-fuelling (Butler & Campbell, 1987). The connectivity analysis predicted both sites as important stopovers: the Nickomekl/Serpentine River Complex ranked in the top 15 for Overall Species Importance for all three focal species and the Fraser River ranked in the top 15 for Overall Species Importance for both the White-winged Scoters and the Dusky Canada Geese. The Fraser River Delta did not rank in the top 15 for Western Sandpipers because the estuary performed poorly in Neighbourhood Habitat, Connectivity Maintenance, and Critical Stepping-stone . Again, the scale of the connectivity analysis failed to accommodate the continental scale of the Western Sandpiper's migration.

Tailoring the Model to Address Specific Management Concerns

The graph model I used to measure estuarine connectivity incorporated species-specific information to predict the estuaries that were most important stopovers for three focal species capable of flying long distances. By modifying the species-specific information, the model can likewise predict the important estuarine stopovers of other migratory birds or the important stepping-stone habitat patches of other taxonomic groups or non-migratory movements. Here I discuss how the model can address specific management concerns regarding estuary conservation, as well as other species and habitats.

Depending on the circumstance and management concerns for estuaries in British Columbia, some metrics are more applicable to identifying estuaries for conservation priority than other metrics. The main asset of the method I used to analyze connectivity is its ability to quantify connectivity for any number of connectivity metrics; the suite of metrics chosen can be tailored to specific species and conservation needs. Selecting a suite of metrics to address a management concern can guide decisions because different measures of connectivity may suggest different conservation actions (Jordan et al., 2003).

First, consider how the coastal metrics can assist managers looking to conserve estuary habitat across British Columbia for migratory birds. If the managers wish to preserve the small stepping-stones, they might consider Connectivity Importance. If protecting large areas of habitat is also a concern, then Critical Stepping-stone is useful as well. Alternatively, perhaps protecting large amounts of habitat is the goal. If so, Habitat Area is the metric of choice. Second, consider how the local metrics can benefit conservation decisions at the smaller, regional scale for species that exploit more than one estuary during wintering or breeding periods, or even during a single stopover event. The preferred metrics would be Transversibility and Neighbourhood Habitat because habitat patches with nearby and large neighbours have a greater exchange of individuals (Gustafson & Gardner, 1996).

The model is not necessarily limited to the seven connectivity metrics. Other metrics that are more appropriate to the management concern could be substituted for one of the seven or added to the set. Currently, no one metric has a disproportionately strong weighting on Overall Species Importance. As such, dropping, adding, or substituting metrics can adapt the connectivity analysis to a management concern without giving a metric unwarranted weight over the results. However, assigning a particular metric a higher or lower weighting is easy to do when determining Overall Species Importance or Aggregate Importance.

The graph model and connectivity metrics are also applicable to other migrating terrestrial and aquatic species, and with some tweaking, to wildlife movements other than migration. By changing the preferred habitat type, the movement capability, and the cost values in the resistance surface, the model can accommodate the specific information of another species and quantify the connectivity of the landscape for that species.

Importance of the Connectivity Analysis

When studying far-ranging species, such as migratory birds, a landscape approach can illuminate particular patterns and lend understanding to trends in a population that a more localized approach could misinterpret. For this reason, the landscape scale is relevant when studying environmental parameters that control populations (Clergeau & Burel, 1997). Landscape ecology, which examines how landscape physiognomy affects the movement of energy and individuals, provides an ideal framework to investigate the functional landscape connectivity of estuaries in British Columbia for migratory birds. By employing concepts from landscape ecology, I was able to predict how the movement behaviour of each focal species and the landscape structure of coastal British Columbia interacted to influence estuarine connectivity and the location of important stopovers.

In general, knowing the location of the habitat patches that maintain connectivity can aid conservation plans that use reserves to protect habitat. A key function of reserves is to perpetuate the long-term stability of species (Cabeza & Moilanen, 2001). Ecologists increasingly recognize that connectivity is an important concept to consider when designing reserves (Hunter et al. 2003). Unfortunately, in practice, reserve designers often omit any serious thought of connectivity or of the spatial distribution of species (Cabeza, 2003). This omission can lead to the effective loss of habitat, where the effective distance separating the patch is beyond the movement capability of the species. Given the relationship between habitat loss and connectivity, reserve designers should not only work to conserve as much habitat in the landscape as possible, but also focus on identifying and protecting the important habitat patches that maintain connectivity. These important patches may be the smallest patches in the landscape, but due to their location, provide the link between distant habitat patches that would otherwise be effectively isolated.

Certain, well-used estuaries, such as the Fraser River estuary, provide traditional stopovers for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese. In their own right, these traditional stopovers deserve conservation attention; however, unpredictable environmental conditions, such heavy precipitation, sudden changes in wind direction, or heavy siltation in a river due to mass wasting upstream, can render traditional stopovers as either inaccessible or unfavourable. In such conditions, birds must find alternate stopovers, and some estuaries fulfil the role of alternate stopover better than other estuaries. My connectivity analysis lends understanding to both the landscape parameters and the habitat parameters that combine to make certain estuaries more important. The results of my connectivity analysis could therefore be useful as supplementary information to aid in the prioritization of estuaries for conservation; continue protecting and restoring habitat at the well-used estuaries, but also partition resources into protecting habitat at the important estuaries that provide alternate stopovers.

Another option to enhance the degree of connectivity among habitat patches is to protect movement corridors. Corridors, however, may not be appropriate for estuary conservation when the goal is to support shorebird or waterfowl migration. The intention of corridors as a conservation strategy is to link formally contiguous habitat that has since become fragmented (Noss, 1987). Estuaries, however, have always been isolated and fragmented because they occur sporadically where rivers meet the ocean. Moreover, no one corridor could provide the link between two estuaries because the route a migrant follows changes from year to year due to dynamic environmental factors and the individual's condition (Farmer & Wiens, 1998; Ydenberg et al., 2002). Given the already disjointed distribution of estuaries and the high mobility of migratory birds, corridors are a less-effective option to sustain connectivity than protecting habitats at the estuaries that maintain connectivity.

Protection of habitat at the estuaries that maintain connectivity for migratory shorebirds and waterfowl should not be delayed. To date, estuarine habitat loss and degradation has been extensive because estuaries provide valuable resources for humans, for example, resources related to log storage, port facilities, fisheries, and agriculture (Emmett et al., 2000). Knowing the location of important stopovers will enhance the efficacy of estuary conservation and counter the loss and degradation of estuarine habitats. With an increase in available knowledge, decision-makers can partition resources to protect the estuaries with the greatest ecological value.

LIMITATIONS OF CURRENT STUDY AND OPPORTUNITIES FOR FURTHER RESEARCH

Limitations to the Connectivity Analysis

As with any modelling exercise, the outputs of my connectivity analysis are a reflection of the assumptions and initial data that went into constructing the model. In my connectivity analysis, several assumptions simplified the relationship between landscape structure and the use of estuaries by migrating birds. The assumptions pertain to the accuracy of the estuary dataset, the accuracy of the species' flight capabilities, and the omission of habitat parameters that may influence a migrant's decisions to stopover at an estuary. Each assumption reduced the realism in the connectivity analysis.

Concerning the accuracy of the estuary dataset, I assumed the estuaries were mapped correctly. In reality, neither air photo interpretation nor ground-truthing were conducted to confirm that the estuary dataset was accurate because the purpose of the dataset, "to identify and map estuaries at the landscape level of British Columbia for use in conservation planning and resource assessment" (PECP, unpublished, p. 2), does not require the extremely fine detail that air photo interpretation and ground-truthing could provide. Consequently, any errors in the delineation of an estuary's boundary, or the delineation of habitats within the estuary, were present in the connectivity analysis. Inaccuracies in boundary delineation could result in errors in the estuary rankings, particularly in the metrics that used area of habitat to score the importance of an estuary (i.e., Habitat Area, Neighbourhood Habitat, and Critical Stepping-stone). Boundary delineation had a minimal affect on the remaining connectivity metrics because they used an estuary's spatial location, rather than size, to determine relative importance. Furthermore, by reducing each estuary to a node I removed any area-weighted affects on Number of Neighbours, Transversibility, and Connectivity Maintenance. For these metrics, the location of the estuary, not the size of the estuary was the basis for calculating the metrics and ranking the estuaries.

Regarding the species' equal flight capabilities; I made two assumptions that restricted the level of species-specific detail in the analysis. First, I assumed White-winged Scoters, Western Sandpipers, and Dusky Canada Geese all perceived elevation and wind resistance equally. In reality, the species have distinct characteristics and physiology that influence how they perceive and respond to the landscape (Belisle, 2005; Taylor et al., 1993). Because I used one resistance surface for all three species, the number of estuaries that contained the species' preferred habitat, rather than each specie's response to wind and elevation, distinguished the degree of estuarine connectivity for each species. For the second assumption, White-winged Scoters, Western Sandpipers, and Dusky Canada Geese were able to move in any direction to reach an estuary. This assumption allowed for edges in the graph to be drawn in any direction, rather than in the northwest direction that expedited the migrants' journeys to northern breeding ranges. If I had restricted the direction of the edges to move from southeast to northwest, the edges could have followed costlier pathways that could have delayed the formation of the single clusters, and changed the order of the estuaries in the rankings. Although edges could follow any least-cost pathway in the connectivity analysis, I did simulate the northward direction of the migrants' flight by assigning lower cost values to cells in the wind cost grid that represented wind blowing from the southeast.

Furthermore, because the graph could draw edges in any direction, I did not assign a cost penalty to an edge that diverged from the migrants' northwest bearing to access estuaries at the head of inlets. This lack of a penalty might explain why Accessibility had the strength of correlations that it did with Overall Species Importance and Aggregate Importance and why Hot spot 1 consisted of relatively inaccessible estuaries at the head of inlets. To reach the estuaries in Hot spot 1 the migrants would have to diverge from their northwest trajectory.

The last group of assumptions pertain to the habitat factors that influence a migrant's stopover decisions. Two factors that influence stopover decisions that I did not account for are predation risk and habitat quality. In the connectivity analysis, predation risk was only a factor for Western Sandpipers. I simulated predation by Peregrine Falcons on Western Sandpipers by removing the area of predation risk near shoreline vegetation from the total area of intertidal delta available at an estuary. I did not address predation by raptors on either White-winged Scoters or Dusky Canada Geese because predatory attacks by raptors likely occur with greater frequency on nestlings and juveniles than on migratory adults. However, the threat of predation may be a significant determinant in the timing of migration and the routes chosen by the migrants and incorporating predation risk into the connectivity analysis could increase the realism in the model and improve its predictive capability.

I also did not account for differences in the quality of available estuaries. I used the presence and size of the focal species' preferred habitats as a proxy for the quality of an estuary and assumed that the larger the area of habitat, the greater an estuary's quality as a stopover. In reality, many factors coalesce to affect an estuary's quality, and quality may be better explained by an estuary's aspect, exposure, and productivity, the sediment loads in a river, the remaining shoreline vegetation, or the presence and type of industry. Considering other factors that can influence a migrant's stopover decisions will enhance the accuracy of identifying emergency stopovers and connectivity hot spots.

Opportunities for Further Research

I examined estuarine connectivity for migratory shorebirds and waterfowl because it is an element of effective conservation. If included in conservation planning, connectivity can increase the potential for a species' long-term stability (Van Teeffelen, Cabeza, & Moilanen, 2006). Although the connectivity analysis was a first pass at measuring estuarine connectivity in coastal British Columbia, the results suggested that the model has predictive ability and that further research is necessary to both improve the analysis and validate the rankings. Here I discuss how further research could benefit an analysis of estuarine connectivity.

Improving the Existing Connectivity Analysis

One opportunity to expand the current analysis is to enlarge the study area to encompass the entire geographic range of a focal species during their migrations. The study area would then vary with each species, but the analysis would have more realism. If the connectivity analysis encompassed the entire landscape that a species passed through during migration, the relative importance of estuaries could shift because the scale of the landscape influences the results of the connectivity analysis (Tischendorf & Fahrig, 2000b).

Considering other migrations or other species that occur in coastal British Columbia could likewise improve the analysis. Currently, the results of the connectivity analysis illustrate the importance of estuaries as stopovers during spring migration for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese. Using the same focal species, the same analysis could quantify estuary importance during fall migration and the results compared with the results from the current connectivity analysis to determine if the estuaries that are important during spring migration are also important during fall. Alternatively, by concentrating on the spring migration period, one could investigate estuarine connectivity for additional shorebird or waterfowl species and incorporate the rankings for those species' Overall Species Importance into Aggregate Importance. Doing so could identify additional estuaries that are important stopovers or substantiate the existing rankings.

A further option to improve the connectivity analysis is to include additional parameters that can influence a migrant's stopover decisions. To include such parameters, the analysis could be re-run with adjustments to either the cost of reaching an estuary or the characteristics that determine quality. Regarding cost, the edges that connect estuaries that either lack or contain a resource below a threshold could be effectively isolated by assigning costs that are too expensive for the migrants. Regarding ideal habitat, the calculations for Habitat Area, Neighbourhood Area, or Critical Stepping-stone could be modified to account for factors that determine an estuary's quality. For example, the percentage of remaining vegetation multiplied by the extent of backshore marsh then divided by a categorical scale for human activity. Introducing other factors that may explain an estuary's quality as a stopover could lend more realism in the identification of emergency stopovers.

Finally, applying a graph model to measure functional landscape connectivity is one of many possible approaches to analyzing connectivity. The ideal connectivity index is empirical observation, which could also validate the results of the current analysis, but empirical evidence is difficult to collect for highly mobile species, such as migratory shorebirds and waterfowl. In lieu of empirical evidence, other potential metrics could measure estuarine connectivity in British Columbia and the results compared with those from the connectivity analysis using a graph model.

Validating the Existing Connectivity Analysis

If the results of the estuary rankings are to aid in estuary conservation, validation of the rankings is necessary. Surveying estuaries could determine whether the focal species predicted by the model to stopover at an estuary do, in fact, stopover and that the number of individuals at any one estuary corresponds to the relative importance of that estuary as a stopover. Unfortunately, a comprehensive evaluation of the results would require substantially more data than currently exists. Furthermore, surveying the abundance of migrants at all 442 estuaries is infeasible. As an alternative, a random sample of estuaries could be chosen and aerial surveys flown to estimate the number of species/individuals at an estuary. A regression analysis could then determine if a relationship exists between the number of birds counted in an estuary and the ranking of the estuary. Another design is stratified sampling to compare the use of estuaries predicted to be important with estuaries predicted to be less important.

A further option for validating the results is the British Columbia Coastal Waterbird Survey (BCCWS). The BCCWS is a survey conducted by volunteers along the shorelines of British Columbia in urbanized areas to monitor coastal waterbird populations and distributions (Badzinski, Cannings, Smith, & Komaromi, 2005). The benefit of using the BCCWS as a tool to validate the connectivity analysis is the multiple years of data. The BCCWS began in 1999/2000 and has since recorded waterbird observations from September to April in every subsequent year. Observations for April are the most pertinent for evaluating the results of this connectivity analysis. Moreover, because the most intensive surveying occurs in the Strait of Georgia, validation is possible primarily for estuaries in the Strait.

Unfortunately, the BCCWS could not validate the model for Western Sandpipers because surveyors do not count shorebirds. However, even validating estuary use for White-winged Scoters or Dusky Canada Geese is a challenge. First, estuaries are not a habitat category listed on the survey sheets (Badzinski et al., 2005); therefore, observations must be cross-referenced with map coordinates to retrieve the observations that occurred within estuaries. Second, the survey is not appropriate for Dusky Canada Geese because it does not distinguish the Dusky from other races of Canada Goose. Moreover, surveyors record observation of birds that are on the water, and therefore, would misrepresent the abundance of Canada Geese because the geese spend more time grazing on land than out on the water where they would be visible to surveyors.

Although the BCCWS is limited in its spatial extent and does not sample for all three focal species, it is still a useful source of information and could assist in validating the model. Recalling that the focal species chosen for the connectivity analysis represent the range of habitat preferences and flight capabilities of the shorebirds and waterfowl species that migrate through coastal British Columbia, the BCCWS can provide observations of waterbird species represented in the connectivity analysis by the focal species and therefore, empirical data to assist in validating the model. The presence and numbers of the waterbirds represented by either White-winged Scoters or Dusky Canada Geese can provide insight into migratory waterfowls' use of estuarine habitats by comparing the number of birds observed at an estuary to the estuary's importance as a stopover.

MANAGEMENT IMPLICATIONS

Habitat loss and degradation is the foremost hindrance to healthy populations of migratory birds in North America (Melinchuk, 1995). The stress of migration, combined with a lack of suitable stopovers, can severely affect the long-term stability of a population. In coastal British Columbia, the loss and degradation of both traditional and less-popular estuaries compounds the difficulty of migration for shorebirds and waterfowl. Unfortunately, estuary management, like wetland management, has a history of preserving the well-used, traditional sites and managing those sites as isolated units (Amezaga et al., 2002; Emmett et al., 2000). As a result, most wetland conservation in the past focussed on large, single sites along migration pathways and failed to consider the importance of smaller sites or the ability of birds to access the protected wetlands (Haig et al., 1998). Recently, management objectives and conservation goals evolved from a site-specific approach into a landscape perspective that is useful for guiding conservation efforts at the broader landscape scale, as well as the localized scale (Hunter et al., 2003). Currently, the Pacific Estuary Conservation Program (PECP), a partnership between government and non-government agencies that protects estuary habitat, is the leading entity for estuary conservation in British Columbia (NRTEE, 2004).

The PECP strives to amplify the effectiveness of its conservation projects by using the best scientific knowledge available to identify the top-priority estuaries, and then focussing the attention of partners on protecting habitat in the top-priority sites (NRTEE, 2004). However, the functional landscape connectivity of estuaries in coastal British Columbia is an element of successful conservation that the PECP has yet to examine fully. Estuarine connectivity deserves exploration because it is a crucial element in successful conservation planning because, when faced with uncertainty about a species, maintaining habitat connectivity is a prudent choice (Noss, 1987). I believe the consideration of estuarine connectivity will further expand the knowledge available to the PECP and amplify the effectiveness of estuary conservation.

From my connectivity analysis that predicted that estuaries were important stopovers for migrating birds, I was able to identify and rank the estuaries that are important stopovers for migrating shorebirds and waterfowl. These stopovers increased estuarine connectivity by decreasing the effective distance between estuaries that would otherwise be too far apart and effectively isolated (Goodwin & Fahrig, 2002). Because estuaries in British Columbia are naturally isolated, focusing conservation on important estuaries is a reasonable option for preserving the migration of species that use estuaries as stopovers (Baum et al., 2004). I provide the following recommendations as means to incorporate connectivity into conservation planning to protect estuarine habitat in British Columbia:

1. Incorporate connectivity into conservation decision-making

The PECP bases its decisions on the best available scientific information to compare estuaries, set priorities, and develop conservation plans (NRTEE, 2004). Accurately comparing estuaries in order to set priorities requires correctly identifying the ecologically important estuaries. Connectivity is a critical variable for comparing estuaries and I agree with Briers (2002) that, although connectivity is a costly phenomena to consider when deciding where to take conservation action, it is critical for the sustainability of species. For this reason, connectivity should factor into decisions regarding the efficient and effective use of conservation resources. I further stress the importance of connectivity as an effective means of setting conservation priorities because human activities in the estuaries of British Columbia is causing habitat loss and degradation (Fox & Nowlan, 1978).

My connectivity analysis presents four examples of how connectivity can guide the conservation and management of estuarine resources in British Columbia. First, if the conservation goal is to protect estuarine habitat for an umbrella or keystone species, a connectivity analysis could identify the estuaries that are important stopovers for the species. Second, depending on the management concerns for a species, a subset of connectivity metrics can detect the estuaries that fulfil the specific needs of that species and contribute to its persistence. Third, if the conservation goal is to protect estuarine habitat to benefit as many migratory bird species as possible, then several connectivity analyses that are tailored to the differing habitat requirements of the species could be combined into an aggregate score to identify the important estuarine stopovers that maintain connectivity for multiple species. Fourth, depending on the scale of the conservation effort, connectivity metrics are available to rank the importance of estuaries at either the coastal or the local scale that may be applicable to the species of interest or the PECP partner's area of influence.

2. Use each focal species as a surrogate species for a habitat guild

Since its inception, waterbird management and conservation has evolved from the single species approach into one that integrates space, time, landscape functionality, and land management objectives (Erwin, 2002). Today, the intention of conservation is often to sustain ecological process, thereby maintaining habitat for species, and hopefully, the species' persistence. Nonetheless, under the guise of flagships, indicators, umbrellas, or keystones, single species remain useful surrogates to guide conservation planning. The three focal species chosen for the connectivity analysis could likewise be single species that guide conservation planning regarding estuaries in British Columbia by being the surrogates for migrating shorebird and waterfowl species that share similar habitat guilds.

I chose White-winged Scoters, Western Sandpipers, and Dusky Canada Geese as the focal species for the connectivity analysis because the species represent a range of estuarine habitats used by migrating waterfowl and shorebirds. Therefore, each focal species is akin to a surrogate for other shorebird or waterfowl species that prefer similar habitats and possess similar flight capabilities. Consequently, the estuaries that ranked high for the Overall Species Importance for White-winged Scoters, Western Sandpipers, and Dusky Canada Geese would also be important estuaries for other migrants.

White-winged Scoters could be the surrogates for the waterbirds that prefer submerged intertidal delta with mud or sand substrates. Waterfowl sharing a similar habitat guild to White-winged Scoters are Bufflehead (*Bucephala albeola*), Long-tailed Duck (*Clangula hyemalis*), and Surf Scoter (*Melanitta perspicillata*). Western Sandpipers could be the surrogate for the intertidal delta habitat guild. The closest species to the Western Sandpipers sharing this guild is the Dunlin (*Calidris alpina*), followed by

Semipalmated Plover (*Charadrius semipalmatus*) and Short-billed Dowitcher (*Limnodromus griseus*), but some species of dabbling ducks could also be encompassed by Western Sandpipers, for example, American Widgeon (*Anas americana)* and Green-winged Teal (*Anas crecca*). These dabbling ducks do not share the same flight capabilities as the Western Sandpipers, but would benefit from protection of intertidal deltas. Lastly, Dusky Canada Geese can be the surrogate for waterbirds that prefer backshore or intertidal marsh, such as Northern Pintail (*Anas acuta*), Snow Goose (*Chen caerulescens*), and Trumpeter Swan (*Cygnus buccinator*).

3. Concentrate conservation efforts within the connectivity hot spots

I performed a connectivity analysis on multiple species to find the areas in coastal British Columbia that support a cluster of important estuarine stopovers that could be the focus of conservation attention. My analysis highlighted two prominent hot spots for connectivity that contain estuaries that are important stopovers for all three focal species, as well as other species sharing similar habitat requirements. The connectivity hot spots are the mainland east of the Queen Charlotte Strait and Port Harvey Johnstone Strait (Hot spot 1) and the Strait of Georgia (Hot spot 2); together the two hot spots boast nine of the top 15 ranking estuaries for Aggregate Importance.

Both hot spots occur in the southern portion of the study area where rivers that are comparatively large for coastal British Columbia meet marine waters, but the two hot spots vary in their level of human occupation. Compared to the Strait of Georgia, with the highest population density of British Columbians in the province, Hot spot 1 is a relatively inaccessible area for humans and supports small, scattered settlements. The high-ranking estuaries that make this location a hot spot reside at the head of inlets. The inaccessibility of these estuaries and the low human population surrounding them help to reduce the range of demands that humans place on these estuaries. Protecting habitat in the estuaries in Hot spot 1 could be a conservation priority because the estuaries are in near pristine condition due to the limited human activity. Conservation in this hot spot is likely to be successful because of the reduced competition from humans for estuarine resources.

Hot spot 2 has already received attention as a critical area for migrating and wintering waterfowl and shorebirds (Vermeer, Butler, & Morgan, 1994). The large estuaries in this hot spot that are popular among waterfowl and shorebirds are the Fraser River, Squamish River, Campbell River, and Cowichan River (Butler & Campbell 1987; Dawe et al., 1995). Unfortunately, these estuaries also coincide with locations of urban settlement and agriculture. Due to development, the Strait of Georgia contains the most threatened estuaries in British Columbia. As of 2003, less than 4% of estuarine habitat in the Strait of Georgia was protected under either Federal or Provincial legislation (Ryder, 2003). To date, the PECP has been active in Hot spot 2, with habitat already conserved in the Cowichan River, Fraser River, and Nanaimo River estuaries, among others (Peck, 1999). The fact that the Strait of Georgia is a connectivity hot spot supports ongoing efforts to conserve estuaries in Hot spot 2.

4. Apply connectivity to international agreements and ventures

Just as shorebirds and waterfowl cross national borders, so too do efforts to conserve the birds and their habitats. If conservation efforts are international, then incorporating estuary connectivity into conservation decisions should cross international borders as well. International agreements and efforts to conserve estuarine habitat, such as the Pacific Coast Joint Venture, should strive to apply connectivity to conservation decision-making because a connected landscape allows the migrants to exploit higher quality stopovers while minimizing energetic costs (Farmer & Parent, 1997). The PECP is the land acquisition arm of the Pacific Coast Joint Venture, whose purpose is to ensure both the long-term maintenance of habitat values and the natural ecological processes in coastal wetland ecosystems for bird conservation (Pacific Coast Joint Venture, 2006). The venture works in coastal areas from California to Alaska, the geographic extent of the spring migrations for White-winged Scoters and Dusky Canada Geese, and some populations of Western Sandpipers.

Expanding the current study area to the coastal area covered by the Pacific Coast Joint Venture would improve the predictability of the graph model and connectivity metrics, particularly for Western Sandpipers, by enhancing the realism of the model. Before applying connectivity to international agreements, estuary connectivity should be examined at the international scale. The first step is to expand the study area for the connectivity analysis to include estuaries from California to Alaska. The second step is to gather the necessary data to expand the wind cost grid and elevation cost grid. The third step would be to conduct the connectivity analysis and rank the estuaries to determine where the international connectivity hot spots reside. If partners of the Pacific Coast Joint Venture then focus conservation planning on the international connectivity hot spots, the effectiveness of conservation can improve, and in turn, the long-term maintenance of estuarine habitat and the species they support would be enhanced.

5. Strive to better understand the role of estuary connectivity for migratory birds

I propose ongoing research aimed at understanding shorebird and waterfowl movements and the use of estuaries as stopovers because a wider breadth of understanding will improve the scientific information available, and in turn, the effectiveness of conservation efforts. Ideally, the research will be empirical, though I realize that when deciding how to use monetary resources, taking concrete action can be preferable to research. In lieu of empirical observations, additional migratory shorebirds and waterfowl could be the subjects of similar connectivity analyses, particularly when the conservation goal is to preserve diversity (Gustafson & Gardner, 1996).

CONCLUSION

Using graph theory, connectivity metrics, and habitat area to analyze estuarine connectivity in British Columbia, I was able to predict the relative importance of estuaries as stopovers during spring migration for one shorebird species and two waterfowl species. Although the individual rank for the estuaries varied with each of the focal species, the model repeatedly predicted individual estuaries as important stopovers, or groups of estuaries as connectivity hot spots. The estuaries predicted to be important stopovers at the local scale were not important at the coastal scale. The connectivity attributes that determined the relative importance of the estuaries were distance to open water, amount of habitat, amount of habitat in neighbours, and ability to link distant estuaries. The method used to predict the estuaries' relative importance as stopovers was robust to changes in the resistance surface. The connectivity rankings were weakly correlated with the indices used to rank estuaries for their biophysical characteristics. The difference in the rankings highlights the merit of connectivity when deciding where to focus conservation resources, as biophysical factors alone do not explain why some estuaries are more valuable than others as stopovers for the migrants.

Furthermore, by predicting the locations of the important estuarine stopover and connectivity hot spots, the rankings that resulted from the connectivity analysis augment the biophysical indices used to rank estuaries in British Columbia for conservation priority. Knowing where the important staging areas and connectivity hot spots are located can enhance conservation decision-making by directing efforts to the estuaries that maintain a connected chain of stopovers for a range of waterfowl and shorebird species. Conservation efforts targeting estuaries that maintain connectivity are necessary to protect important estuarine stopovers and counteract the effects of human activities in the estuaries that are important to migratory birds. Given the present decline in estuarine habitat in British Columbia, using conservation resources effectively is paramount to the long-term persistence of estuarine habitats and the species that rely on them.

APPENDICES

APPENDIX 1: RANK OF EACH ESTUARY AVAILABLE TO WHITE-WINGED SCOTERS

- Estuary number
Overall - Overall Species Importance
A – Habitat Area
B – Number of Neighbours
C – Transversibility
D – Neighbourhood Area
E – Accessibility
F – Connectivity Maintenance
G – Critical Stepping-stone

Estuary Name	#	Overall	A	B	C	D	E	F	G
Nickomekl/Serpentine River Complex	218	1	2	3	5	329	1	14	169
Skeena/Ecstall/McNeil River Complex	35	2	4	2	2	332	163	3	148
Hiellen River	181	3	15	33	64	327	42	60	156
Campbell River (1)	361	4	13	11	66	252	57	155	168
Chemainus River/Bonsall Creek Complex	13	5	7	160	262	248	11	2	78
Fanny Bay/Cowie Creek	1	7	60	331	332	41	18	1	4
Fulmore/Shoal Creek Complex	392	7	20	23	78	194	83	209	180
Christie River	179	8	49	127	146	275	9	56	129
Kitimat River	25	9	6	4	4	331	331	4	112
Nimpkish River	71	10	23	21	48	328	25	195	178
San Juan River	136	11	78	37	46	322	67	137	149
Nanaimo River	15	12	5	95	253	298	49	7	137
Unnamed	287	13	271	102	88	184	80	88	34
Fraser River	391	14	1	1	1	333	7	333	177
Trent River	6	15	31	300	278	125	39	5	79
Phillips River	396	16	44	44	130	158	124	182	179
Kumdis Creek	193	17	26	64	136	311	143	38	147
Deena Creek	174	18	54	97	91	307	118	74	132
Bilston Creek	147	19	96	109	68	294	55	130	128
Kutcous Point	340	20	168	120	168	132	36	142	120
Takush River	362	21	113	73	125	173	103	152	151
Malksope River	104	23	81	18	6	326	81	194	189
Khutze River	298	23	67	16	62	245	280	95	130
Coates Creek	160	25	143	91	85	274	75	120	111
Skonun River	180	25	32	157	237	241	35	53	144
Quaal River/Kitkiata Creek Complex	234	26	9	8	55	330	285	51	162
Big Qualicum River	74	27	57	57	65	314	24	199	186

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Cow Bay	341	28	76	194	113	55	58	211	198
Tsable River	36	29	37	7	9	312	6	321	217
Seal Inlet	165	30	119	80	83	308	88	116	119
Wakeman River	374	31	38	101	70	81	237	207	183
Oeanda River	182	32	158	163	166	237	37	64	93
Kingcome River	380	33	28	29	89	166	259	177	175
Otard Creek	159	35	193	151	95	246	51	99	89
Otun Creek	199	35	33	155	310	228	30	29	139
Logan Creek	142	37	224	200	111	200	15	100	75
Kwatna River	336	37	27	84	86	116	272	170	170
Quatse River/Boyden Creek Complex	3	38	59	324	323	85	69	6	62
Kilbella/Chuckwalla River Complex	357	39	30	19	92	244	229	148	167
Carmanah Creek	144	40	235	188	107	210	22	107	64
Kildala River	296	41	29	12	54	266	329	92	152
Cluxewe River	4	42	47	316	318	97	41	8	109
Kaouk River	127	43	75	82	72	317	113	132	146
Millar Channel	339	44	252	162	190	108	3	141	84
Black Creek	34	46	51	10	11	305	19	319	228
Stanley Creek	178	46	36	126	173	280	110	73	145
Nimmo Bay	373	47	84	56	120	183	175	163	164
Lagins Creek	173	48	101	127	104	271	144	84	116
Tsulquate River	81	50	90	25	10	323	54	237	214
Neekas Creek	306	50	215	74	102	168	199	112	83
Tyler Creek	266	51	103	46	84	318	224	66	113
Draney Creek	360	52	83	54	115	165	228	154	157
James Bay	280	53	151	49	75	243	260	86	98
Salmon River	33	54	35	6	8	315	59	324	216
Walbran Creek	143	55	225	211	133	189	20	111	77
Klinaklini River	390	56	10	9	63	226	291	192	176
Mussel River	299	57	140	40	73	220	290	98	107
Nekite River	359	58	46	48	119	179	255	157	165

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Naden River/Davidson Creek Complex	177	59	11	91	220	306	114	65	163
Yuquot Point	338	60	270	164	191	107	33	140	68
Security Cove	175	61	144	135	148	259	94	93	104
Unnamed	167	62	170	118	109	264	102	114	101
Gudal Creek	171	63	248	205	147	195	52	80	52
Oyster River	75	68	71	17	15	302	16	314	245
Schmidt Creek	114	68	309	216	117	152	5	146	35
Muir Creek	135	68	273	177	100	199	47	128	56
Mosquito Bay	305	68	277	107	114	144	185	108	45
Pye Creek	343	68	234	161	175	109	53	145	103
Taleomey River	323	70	41	14	67	273	309	125	153
Nass/Ksi'Hlginx/Burton/Iknouck/Chambers/ Kincolith River Complex	431	70	3	5	3	313	171	313	174
Tankeeah River	303	71	327	150	126	129	136	106	11
Tartu Inlet	166	73	146	200	178	205	86	78	99
Khutzeymateen River	205	73	21	83	218	286	231	10	143
Kitlope/Tsaytis River Complex	256	75	12	42	165	174	321	113	166
Wannock/Nicknaqueet River Complex	358	75	66	134	105	70	242	191	185
Skowquiltz River	317	76	74	20	77	255	316	121	136
Chambers Creek	206	77	69	138	276	233	158	11	115
Mackenzie Cove	190	78	205	190	215	212	74	44	61
Ououkinsh/Unnamed River Complex	85	80	104	38	38	320	100	201	203
Bottleneck Inlet	301	80	216	63	93	192	249	110	81
Clyak River	355	81	80	67	138	160	252	153	158
Gordon River	137	83	169	152	96	249	78	144	121
Keecha Creek	272	83	329	192	155	131	128	72	2
Adam River	78	84	82	26	18	303	23	311	249
Lignite Creek	176	85	40	195	282	208	96	54	138
Kloiya River	200	86	172	184	229	209	129	22	71
Kiltuish River	251	87	94	47	97	321	295	50	114
Toquart River	28	88	61	12	13	297	71	325	240
Lois River	410	89	132	210	121	66	31	228	232
Waukwaas Creek	79	90	56	31	49	325	107	246	207
Cullite Creek	141	91	245	254	219	140	13	94	57
Yakoun River	197	92	14	106	277	277	165	30	155

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Kokish River	72	93	125	41	17	316	45	242	239
Bazett Island Area	342	94	305	183	201	106	64	139	33
Flat Creek	186	97	186	229	239	157	112	40	70
Goat River	259	97	167	62	79	299	276	63	87
Arnoup Creek	265	97	187	67	81	293	254	69	82
Hird Point	282	99	321	148	108	153	218	79	12
Falls River	295	99	137	43	69	253	327	102	108
Maggie River	29	101	107	33	29	247	8	331	285
Riley Creek	169	101	171	220	202	180	108	71	88
Scow Bay	261	102	195	78	80	283	273	59	73
Hart Creek	228	103	108	293	329	50	4	135	126
Bloomfield Lake	269	104	290	123	103	177	250	81	22
Conuma River	107	105	112	36	7	319	187	190	196
Milton River	356	106	156	113	149	134	220	149	127
Kauwinch River	87	107	97	102	76	285	116	186	188
Tasu Creek	187	108	249	238	235	146	104	39	40
Mountain Creek	170	110	250	212	145	185	127	85	50
Kakweiken River	381	110	77	176	101	40	226	229	205
Viner Sound	377	111	131	115	144	142	198	166	160
Jermaine Point Area	310	112	315	185	207	103	119	115	14
Zeballos River	130	113	111	76	61	310	159	172	172
Camper Creek	140	114	286	264	223	136	27	96	30
Shushartie River	46	116	117	81	71	287	44	236	227
Dass Creek	184	116	200	212	204	163	178	43	63
Kshwan River	209	117	43	98	256	282	243	21	124
Mill Stream	98	118	155	141	110	256	62	173	173
Mathieson Channel	281	120	307	140	106	161	263	77	17
Shade Island area	364	120	333	256	200	68	46	161	7
Bonanza Creek	212	123	160	142	268	223	193	17	74
Captain Cove	221	123	139	234	288	138	153	35	90
Bella Coola/Necleetsconnay River Complex	328	123	39	15	87	270	324	171	171
Koprino River	56	124	53	113	123	289	84	223	194
Mamin Creek	192	125	130	199	240	191	196	28	96
Ensheshese River	203	126	227	191	263	186	150	19	47
Aaltanhash River	262	127	257	112	90	250	278	61	38

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Franklin River	389	129	45	157	112	47	287	240	199
Stafford River	393	129	105	108	169	122	219	180	184
Toon River	201	130	87	159	249	238	227	18	110
Kemano/Wahoo River Complex	258	131	52	117	242	148	320	76	134
Homathko/Teaquahan River Complex	401	132	18	125	153	58	289	260	187
Tsitika River	73	133	138	175	129	224	28	189	208
Atleo River	93	134	209	84	57	281	56	185	220
Power River	84	137	165	61	47	301	92	204	223
Kashutl River	88	137	129	38	12	309	139	232	234
Stawamus River	273	137	287	122	124	198	246	91	25
Kromann/Moore Cove Creek Complex	219	138	55	228	312	61	200	97	141
Escalante River	65	140	177	52	22	242	10	301	296
Seymour River (2)	368	140	128	72	170	175	264	151	140
Keyarka Cove	225	142	244	250	299	135	98	32	44
Apple River	394	142	91	116	135	113	221	217	209
Tahsish River	126	143	68	28	36	324	161	267	222
Keogh River	80	144	201	78	51	284	29	212	252
Sydney River	62	145	123	29	16	261	109	299	275
Triumph River	249	146	188	100	140	276	292	46	72
Lynn Creek	207	147	314	230	287	151	115	9	9
Cascade Creek	213	148	184	178	290	204	188	16	60
McClinton/Unnamed Creek Complex	196	149	114	247	317	137	173	31	102
Hathaway Creek	51	151	85	27	23	265	147	322	256
Kewquodie Creek	54	151	118	60	60	304	123	235	225
Ickna Creek	322	152	62	174	182	88	307	158	161
Klekane River	260	153	124	87	188	296	274	58	106
Goodspeed River	50	154	109	24	14	268	146	302	272
Easy Inlet	86	155	192	133	82	235	101	183	210
Unnamed	94	158	274	217	128	162	2	174	181
Marmot River	217	158	174	127	244	240	262	24	67
Ahta River	376	158	115	197	122	44	239	210	211
Roderick Cove	302	159	330	188	177	100	241	101	3
Seymour River (1)	208	161	323	235	292	150	125	12	5
Kooryet Creek	227	161	263	274	306	86	133	48	32
Stagoo Creek	214	162	121	219	314	171	201	23	97

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Courtenay River	16	163	8	90	232	295	61	282	182
Datlamen Creek	191	165	322	253	241	123	168	36	8
Keswar Inlet	223	165	301	315	313	7	89	103	23
Unnamed	224	166	247	232	298	149	167	26	37
Nahmint River	30	168	98	32	26	254	145	330	273
Artlish River	89	168	100	33	20	300	152	295	258
Scott Cove	378	169	258	169	174	117	160	164	118
Crab River	247	170	251	143	159	225	298	45	41
Waump Creek	365	171	208	109	193	139	248	150	117
Kowesas River	254	172	63	207	246	95	314	105	135
Unnamed	168	173	264	284	274	120	106	82	43
Dala River	297	174	48	186	226	96	330	134	154
Unnamed	83	175	230	172	99	196	79	181	219
Unnamed	257	176	306	149	116	206	322	62	16
Marble River	31	177	64	91	131	272	157	253	213
Oih Creek	210	178	178	192	315	190	235	13	59
Sooke River	17	179	72	132	164	229	66	290	235
Braverman Creek	183	180	228	282	291	114	179	41	54
Nordstrom Cove	58	181	223	65	28	213	50	300	311
Pa-aat River	241	182	212	258	297	69	208	83	66
Kirby Creek	134	185	300	313	333	78	43	104	24
Bish Creek	231	185	136	130	231	251	328	27	92
Koeye River	350	185	127	276	192	31	73	248	248
Songhees Creek	82	186	265	146	74	214	26	197	277
Wathlsto Creek	230	187	226	123	194	236	332	34	55
Squamish River	24	188	88	21	19	269	247	306	251
Mahatta Creek	57	189	189	77	41	211	60	323	306
Walt Creek	215	191	255	261	326	128	190	20	28
Carter River	284	191	149	204	293	105	268	89	100
Nascall River	320	192	285	147	195	121	300	122	39
Capilano River	26	195	210	65	31	207	76	312	309
Wanokana Creek	53	195	89	136	141	262	174	208	200
Sucwoa River	109	195	197	196	143	203	186	160	125
Unnamed	270	196	283	302	284	33	132	129	48
Naka Creek	115	197	280	289	322	104	21	138	58

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mooyah River	66	199	176	69	40	218	95	315	301
Kitsault/Illiance River Complex	428	199	22	171	198	83	267	276	197
Price Cove	255	200	238	144	186	227	317	52	51
Unnamed	172	202	162	88	118	278	117	215	238
Noeick River	324	202	50	215	157	74	311	218	191
Sarita River	23	203	86	139	206	222	82	258	224
Coleman Creek	102	205	259	104	52	258	137	179	229
Georgie River	216	205	232	263	308	127	214	25	49
Unnamed	237	206	308	179	199	176	302	42	13
Ain River	195	208	183	285	319	99	232	33	69
Gilford Creek	379	208	281	202	172	89	111	175	190
Pike Creek	238	209	291	156	205	197	304	49	20
Somas River	22	210	34	104	171	260	184	266	204
Canoona River	263	211	331	187	160	188	270	87	1
Youghpan Creek	52	212	148	75	59	290	156	243	254
Hot Springs Creek	321	213	328	164	181	119	301	123	10
Frederick Arm	397	214	207	206	179	77	134	193	231
Effingham River	99	215	199	236	213	164	121	162	133
Kiskosh Creek	235	216	194	252	286	80	277	67	76
Powell River	409	217	237	249	151	46	40	225	288
Clesklagh Creek	49	219	175	50	25	231	151	309	298
Hans Point	211	219	239	239	327	145	238	15	36
Heydon Creek	395	220	214	243	137	25	130	220	271
Ice River	63	221	206	69	37	215	99	307	308
Kainet Creek	279	222	126	254	252	75	281	133	123
Unnamed	236	223	326	182	216	169	299	47	6
Swallop Creek	315	224	293	166	203	112	326	118	29
Espinosa Creek	129	225	157	71	53	291	142	261	274
Rainbow Creek	370	226	282	172	187	115	251	159	86
Kleeptee Creek	69	227	198	59	30	234	135	297	302
Unnamed	77	229	294	121	58	232	17	222	313
Mamquam River	274	229	241	221	295	124	253	70	53
Burman River	91	230	133	51	27	279	191	293	284
Quatlena River	346	231	70	243	185	63	236	251	212
Cous Creek	37	233	147	45	21	239	211	308	290

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Tsimtack Lake	246	233	279	268	305	87	240	55	27
Little Zeballos River	90	234	166	57	32	267	154	294	292
Cowichan River	14	235	17	203	316	182	63	289	195
Klootchlimmis Creek	55	238	92	207	228	202	149	196	192
Wathl Creek	229	238	142	212	281	170	333	37	91
Vancouver River/High Creek Complex	414	238	154	226	127	57	225	231	246
Canton Creek	108	239	164	240	236	159	183	156	131
Glenlion River	32	240	256	95	34	178	68	318	321
Unnamed	244	242	299	167	210	216	294	68	18
Belowe Creek	245	242	218	273	270	65	257	109	80
Kennedy River	113	243	240	169	98	201	97	200	269
Tlupana/Nesook River Complex	110	244	161	53	24	292	177	281	287
Quatam River	404	245	173	236	134	39	204	233	257
Hesquiat River	64	248	236	94	42	193	72	327	315
Barrie Creek	253	248	302	154	189	230	310	75	19
Nooseseck River	326	248	296	180	225	110	313	124	31
Cayaghis Creek	117	249	145	54	45	288	192	277	279
Mud Bay/Rosewall /Waterloo Creek Complex	11	252	42	299	275	98	48	305	215
Evelyn Creek	243	252	254	265	285	82	297	57	42
Clayton Falls Creek	327	252	284	168	217	118	323	126	46
Orford River	403	253	150	181	180	94	258	202	218
MacNair Creek	354	254	229	246	176	43	166	188	236
Brim River/Owyacumish Creek Complex	252	255	217	251	280	73	312	90	65
Tom Browne Creek	384	256	65	278	224	49	182	270	221
Amor de Cosmos Creek	76	257	260	232	156	156	38	187	262
Coeur d'Alene Creek	41	258	221	137	94	221	91	250	293
Kwinamass River	432	259	25	280	254	64	176	304	206
Silverado Creek	67	260	246	99	43	257	122	244	300
Tzoonie River	417	261	163	222	161	76	217	227	247
Paril River	248	262	202	286	279	52	293	119	94
Skwawka River	411	263	152	209	152	84	271	221	237
Brem River	405	264	182	230	139	54	256	219	250
Lucky Creek	39	265	275	131	50	147	77	329	323
Colquitz River	97	266	266	111	39	219	70	310	320
Sliammon Creek	408	267	106	321	330	14	12	291	263

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Brittain River	413	268	191	227	154	62	222	224	259
Jacklah River	92	269	219	241	211	155	207	165	142
China Creek	101	270	269	224	150	167	212	169	150
Indian River	427	271	99	262	221	37	215	265	243
Marvinas Bay	337	272	211	296	209	24	87	239	280
Nootum River	348	273	95	291	222	51	203	257	233
Unnamed	116	274	320	152	56	187	34	273	331
Little Qualicum River	5	276	58	320	301	92	14	328	242
Hevenor Lagoon	294	276	304	287	311	56	244	127	26
Cypre River	18	277	73	247	307	141	85	280	226
Tofino Creek	27	278	253	89	35	181	170	317	318
McNab Creek	423	279	135	266	214	48	180	255	267
Unnamed	250	280	317	310	289	23	296	117	15
Lull Creek	382	282	220	267	183	13	169	234	283
Oona River	434	282	93	288	255	32	172	285	244
Foch Lagoon	232	284	134	303	328	42	305	136	122
Toba/Tahumming River Complex	406	284	16	258	261	72	284	286	193
Unnamed	325	285	332	217	238	93	303	167	21
Cornwall Inlet	264	286	242	306	304	38	245	143	95
Goldstream River	440	287	110	318	266	17	105	292	270
Bear River [2]	441	288	24	271	247	79	269	287	202
Kwalate River	383	289	268	197	184	90	234	178	230
Houston River	68	290	295	119	33	172	155	284	324
Macktush Creek	38	291	190	144	132	217	189	249	278
Weewanie Creek	239	292	196	311	325	28	308	131	105
Jump Across Creek	316	293	267	272	259	53	325	147	85
Englishman River	2	294	79	332	331	36	32	332	268
Blind Creek	385	295	278	223	197	71	195	184	266
Earle Creek	416	296	262	277	158	29	148	241	307
Moyeha River	95	297	159	243	248	154	126	247	265
Gold River	111	298	222	86	44	263	223	296	310
Lard Creek	278	299	181	301	324	34	282	168	159
Taaltz Creek	371	300	272	269	167	19	230	206	291
Donahue Creek	430	302	203	297	243	15	140	269	295
Gilttoyees River	437	302	19	275	258	91	315	303	201

Estuary Name	#	Overall	A	B	C	D	E	F	G
Bulson Creek	20	303	122	258	294	133	141	264	260
Unnamed	40	304	231	291	271	102	93	216	276
Tsowwin River	43	305	204	270	251	130	164	213	253
Moh Creek	398	306	289	242	196	67	213	198	299
McCurdy Creek	70	307	292	224	142	143	205	203	304
Snug Basin	42	308	261	290	265	101	90	214	294
Bedwell Creek	19	309	141	257	267	126	162	283	282
Furry Creek	425	310	213	294	233	20	202	262	297
Southgate River	400	311	120	308	272	22	286	272	261
Tranquil River	21	312	179	279	296	111	138	263	289
Gorge Waters/Craigflower Creek	12	313	180	325	309	60	65	316	303
Asseek River	442	314	102	312	269	30	306	288	255
Bear River [1]	399	315	297	280	163	12	275	226	314
Rainy River	422	316	312	305	227	18	131	252	326
Huaskin Lake	367	317	319	319	234	9	120	254	329
Stakawus Creek	412	318	303	283	162	26	266	230	316
Poison Cove Creek	300	319	233	304	273	27	288	205	264
Sim River	387	320	153	314	264	16	283	279	286
Nusash Creek	319	321	316	298	230	21	318	176	241
Sechelt Creek	420	322	298	295	208	35	206	245	319
Leiner River	8	323	116	328	321	59	194	320	281
Lime Creek	429	324	243	307	250	11	265	268	312
Restoration Bay	345	325	313	309	212	8	261	238	325
Mackenzie Lake	372	326	288	329	300	3	181	271	322
Long Lake	363	327	325	322	245	5	210	259	332
Tahsis River	7	329	185	330	320	45	197	326	305
Doc Creek	347	329	324	322	257	10	209	256	330
Grand Creek	426	330	311	317	260	2	216	275	328
Charles Creek	375	331	276	327	302	4	233	274	317
Wahkash Creek	388	332	310	326	283	6	279	278	327
Jesse River	436	333	318	333	303	1	319	298	333

APPENDIX 2: RANK OF EACH ESTUARY AVAILABLE TO WESTERN SANDPIPERS

- Estuary number
Overall - Overall Species Importance
A – Habitat Area
B – Number of Neighbours
C – Transversibility
D – Neighbourhood Area
E – Accessibility
F – Connectivity Maintenance
G – Critical Stepping-stone

Estuary Name	#	Overall	A	B	C	D	E	F	G
Fanny Bay/Cowie Creek	1	1	71	407	329	40	26	1	17
Kutcous Point	340	2	200	149	23	151	48	184	145
Millar Channel	339	3	306	194	5	133	4	183	80
Evader Creek	366	4	46	137	58	92	102	250	225
Fulmore/Shoal Creek Complex	392	5	22	24	28	219	134	256	235
Hiellen River	181	6	16	41	105	402	62	76	224
Chemainus River/Bonsall Creek Complex	13	7	7	221	293	354	15	2	74
Campbell River (1)	361	8	13	11	75	319	92	221	247
Nanaimo River	15	9	5	125	248	351	77	6	181
Jalun River	156	10	102	298	107	186	35	98	175
Keyarka Cove	225	11	296	297	4	160	154	35	56
Skonun River	180	12	34	211	184	259	47	58	210
Oeanda River	182	13	189	213	94	264	49	72	124
Otun Creek	199	14	35	207	253	247	40	29	199
Nickomekl/Serpentine River Complex	218	15	2	5	356	406	2	9	238
Takush River	362	16	138	82	9	196	160	197	237
Trent River	6	17	33	373	312	134	53	5	113
Cow Bay	341	18	90	239	55	59	93	270	218
Yuquot Point	338	19	326	199	76	131	43	182	71
Bilston Creek	147	20	115	140	62	344	90	125	170
Kwatna River	336	21	29	100	7	127	345	219	220
Cheewhat River	145	22	158	100	68	357	59	161	152
Naden River/Davidson Creek Complex	177	23	11	127	101	367	173	60	232
Lois River	410	24	159	252	8	77	41	283	255
Kshwan River	209	25	49	127	63	326	311	22	179
Restless Bight	148	26	309	215	79	241	16	146	72
Theodosia River	407	27	60	172	10	101	201	294	241

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Carmanah Creek	144	28	286	226	89	240	30	132	91
Kingcome River	380	29	30	34	38	197	329	223	244
Quatse River/Boyden Creek Complex	3	30	70	398	323	91	114	7	96
Deena Creek	174	31	63	116	118	364	177	82	200
Wakeman River	374	32	40	125	31	89	305	259	272
Cluxewe River	4	34	53	393	354	103	56	8	158
Shade Island area	364	34	408	281	54	99	71	209	3
Logan Creek	142	36	268	244	113	223	22	127	129
Tlell River	198	36	54	151	328	308	76	25	184
Kdelmashan Creek	285	37	322	293	136	108	100	90	82
Fraser River	391	38	1	1	66	408	9	408	239
Flat Creek	186	39	223	277	132	177	171	46	109
Woodcock Islands Area	289	40	390	328	121	86	82	117	15
Oyster Bay	353	43	351	242	36	109	152	198	52
Kilbella/Chuckwalla River Complex	357	43	32	22	86	278	296	203	223
Nekite River	359	43	52	58	50	201	324	205	250
Head of Kootenay Inlet	188	44	156	296	213	172	125	40	142
Chambers Creek	206	45	81	187	231	249	221	14	166
Lombard Point	288	46	377	323	128	93	97	113	25
Stannard Creek	291	48	226	63	123	393	81	118	155
Seymour River (2)	368	48	153	79	16	200	335	199	177
Mamin Creek	192	49	155	248	122	206	262	32	136
Kakweiken River	381	50	91	222	15	48	292	276	221
Tartu Inlet	166	51	176	238	149	230	137	87	151
Hosu Cove	161	52	342	273	120	191	104	104	43
Mace Creek	163	54	217	141	85	313	165	141	119
Mackenzie Cove	190	54	244	232	211	235	120	49	90
East Creek	120	55	163	159	77	324	101	178	180
Clyak River	355	56	94	85	12	199	320	196	277
Ickna Creek	322	57	73	220	6	110	380	201	196
Unnamed	167	58	202	144	100	312	159	142	128

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Christie River	179	59	56	165	362	323	12	75	195
Cullite Creek	141	61	297	307	205	162	20	115	84
Gudal Creek	171	61	301	241	172	220	84	86	86
Loss Creek	138	63	327	382	134	128	17	126	77
Weeteeam Bay Area	286	63	161	242	320	125	94	101	148
Sombrio Creek	139	64	280	121	140	302	58	170	122
Yeo Lake	304	65	353	120	70	232	259	129	33
Wannock/Nicknaqueet River Complex	358	66	78	177	40	96	310	243	253
McClinton/Unnamed Creek Complex	196	68	139	304	190	148	237	36	144
Bazett Island Area	342	68	373	209	157	136	109	180	34
Camper Creek	140	69	349	311	137	159	37	119	88
Coates Creek	160	71	173	112	146	352	122	154	143
Kingkown Inlet	226	71	167	301	292	111	146	67	118
Milton River	356	72	187	133	87	165	286	193	153
Dass Creek	184	74	239	259	93	203	242	47	123
Draney Creek	360	74	98	66	104	207	295	200	236
Marvinas Bay	337	75	252	361	13	31	138	291	121
Stanley Creek	178	77	38	170	92	341	169	138	261
Sliammon Creek	408	77	128	397	2	24	19	357	282
Carter River	284	78	179	240	103	124	340	94	133
Stafford River	393	79	127	129	14	166	285	226	271
Waump Creek	365	80	247	119	20	173	316	194	150
Khutze River	298	81	79	18	74	380	353	139	178
Tasu Creek	187	82	302	284	199	170	161	44	63
Tsable River	36	83	39	7	110	379	8	390	291
Neekas Creek	306	84	258	75	111	276	265	135	106
Khutzeymateen River	205	85	23	103	243	334	299	12	214
Kildala River	296	87	31	12	81	374	402	103	227
Dean River	313	87	47	15	64	327	405	157	215
Cohoe Creek	369	88	209	367	71	30	78	313	171
Georgetown Creek	204	89	15	61	396	391	142	16	219
Taleomey River	323	90	43	14	106	329	382	159	211
Naka Creek	115	92	337	355	116	121	29	176	112
Heydon Creek	395	92	255	290	42	29	191	275	164
Skeena/Ecstall/McNeil River Complex	35	93	4	2	405	407	226	3	201

Estuary Name	#	Overall	A	B	C	D	E	F	G
Muir Creek	135	95	330	216	176	233	72	165	65
Mountain Creek	170	95	304	252	142	208	188	95	68
Cascade Creek	213	96	221	219	227	237	252	17	89
Pye Creek	343	97	285	191	34	132	85	191	345
San Juan River	136	99	92	43	266	392	112	171	188
Ensheshese River	203	99	275	233	238	218	213	21	66
Gordon River	137	100	201	201	125	284	127	188	141
Phillips River	396	101	50	57	252	224	183	227	275
Skowquiltz River	317	103	88	23	39	372	389	155	204
Apple River	394	103	107	145	26	138	287	267	300
Keecha Creek	272	104	404	202	168	228	189	77	5
Hankin Point	222	105	298	376	353	16	69	114	48
Gilford Creek	379	107	341	229	46	120	170	255	114
Franklin River	389	107	51	214	67	54	360	298	231
Lignite Creek	176	108	42	247	352	222	151	59	203
Toon River	201	109	103	210	240	255	293	19	159
Waterfall Inlet	352	110	403	383	29	8	144	302	11
Amos Creek	151	113	278	262	311	202	18	111	100
Lynn Creek	207	113	383	265	254	183	174	10	13
Mussel River	299	113	170	42	117	331	363	122	137
Hart Creek	228	115	132	359	390	63	6	172	161
Frederick Arm	397	115	246	246	82	102	195	236	176
Billy Creek	220	117	75	184	388	286	157	31	163
Nimmo Bay	373	117	99	65	141	213	239	231	296
Kumdis Creek	193	118	28	84	350	369	206	42	208
Kootenay Inlet	189	119	251	236	297	225	126	54	99
Unnamed	270	120	346	364	124	46	193	166	51
Bonanza Creek	212	122	191	191	281	248	257	18	107
Kimsquit/Hoam Creek Complex	312	122	85	19	65	377	403	151	193
Zeballos River	130	124	136	87	88	373	222	174	217
Bottleneck Inlet	301	124	260	68	131	287	317	136	98
Klinaklini River	390	125	10	9	174	258	364	232	252
Aaltanhash River	262	126	312	117	73	307	351	65	75
Quatlena River	346	127	83	303	41	69	304	304	197

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Big Qualicum River	74	129	68	71	250	378	32	246	259
Noeick River	324	130	57	265	48	80	384	269	202
Moneses Lake	122	131	283	230	206	231	52	173	131
Kitlope/Tsaytis River Complex	256	132	12	48	276	214	394	137	230
Kloiya River	200	134	206	228	340	221	190	23	108
James Bay	280	134	181	51	119	400	330	105	130
Koeye River	350	135	152	339	59	51	119	305	292
Jordan River	133	136	338	307	242	161	45	149	79
Lull Creek	382	137	264	320	47	14	233	289	156
Yakoun River	197	138	14	131	370	325	229	33	222
Dunn Point Area	333	139	401	354	27	34	258	239	12
Kwatleo Creek	60	141	48	206	212	283	86	242	249
Walbran Creek	143	141	272	252	331	216	28	124	103
MacNair Creek	354	142	277	291	22	62	230	238	207
Braverman Creek	183	143	276	340	219	129	243	43	78
Black Creek	34	145	59	10	178	361	27	388	307
Betteridge Inlet Area	292	145	340	363	165	45	186	190	41
Beresford Creek	154	146	97	159	376	333	66	112	190
Hana Koot Creek	155	147	126	181	383	304	70	108	162
Unnamed	287	148	328	103	307	328	131	92	46
Viner Sound	377	149	157	139	44	164	264	240	328
Blind Creek	385	150	335	260	25	97	261	228	132
Kromann/Moore Cove Creek Complex	219	152	64	286	367	74	266	116	167
Swallop Creek	315	152	358	181	69	140	399	153	40
Kingfisher Creek	121	154	121	35	216	394	51	207	317
Sialun Creek	153	154	45	271	357	322	25	109	212
Nascall River	320	155	348	168	95	158	373	156	44
Tankeeah River	303	156	400	145	255	209	197	128	9
Stagoo Creek	214	158	146	263	326	193	267	24	125
Jermaine Point Area	310	158	384	205	260	130	178	145	42
Salmon River	33	160	37	6	145	381	96	391	289
Ingram Creek	276	160	356	121	130	297	328	83	30
Tsulquate River	81	161	106	28	150	398	89	292	284
Haines Creek	157	162	182	333	342	152	88	97	154
Nimpkish River	71	163	25	27	361	403	33	254	246

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Nooseseck River	326	164	363	204	52	149	386	160	37
Powell River	409	165	289	293	11	60	55	281	365
Schmidt Creek	114	166	378	244	300	192	7	187	49
Quartcha Creek	307	168	205	302	51	78	338	192	192
Ahta River	376	168	140	237	45	55	307	263	311
Bloomfield Lake	269	170	355	135	108	330	318	85	28
Snass Lake	283	170	391	141	97	318	297	99	16
Mercer Lake	164	171	303	274	301	189	130	93	70
Empetrum Lake	123	172	269	203	225	257	61	177	169
Keswar Inlet	223	174	368	387	314	11	140	121	21
Hird Point	282	174	393	151	164	267	284	84	19
Maggie River	29	176	130	40	152	272	11	405	354
Arnoup Creek	265	176	224	73	202	363	322	70	110
Scow Bay	261	177	234	80	185	356	346	63	101
Pachena River	132	179	129	216	180	273	95	150	323
Clayton Falls Creek	327	179	347	197	60	153	396	163	50
Quaal River/Kitkiata Creek Complex	234	180	9	8	306	404	358	56	226
Battle Bay	125	182	271	137	345	293	5	179	138
Tyler Creek	266	182	124	53	268	396	290	69	168
Hansen/Rasmus/Fisherman River Complex	45	183	19	96	229	388	103	284	251
Kowesas River	254	184	74	256	246	104	387	131	173
Unnamed	332	185	387	349	49	38	294	233	22
Kitimat River	25	186	6	3	404	405	406	4	147
Stranby River	48	189	108	56	175	375	60	310	294
Oyster River	75	189	84	20	198	359	23	380	314
Cave Creek	158	189	360	271	385	190	34	106	32
Kakushdish Harbour Area	334	190	339	330	156	50	228	218	58
Ououkinsh/Unnamed River Complex	85	191	125	45	127	387	156	262	278
Hevenor Lagoon	294	192	372	348	91	73	312	164	26
Clanninick Creek	106	193	114	37	249	385	1	377	229
Toba/Tahumming River Complex	406	194	17	326	19	81	357	351	243
Otard Creek	159	196	232	195	366	281	83	123	116
Seymour River (1)	208	196	395	264	349	184	184	13	7
Captain Cove	221	197	169	284	395	181	216	41	111
Mamquam River	274	198	293	249	241	154	321	74	67

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Security Cove	175	199	174	178	360	298	149	107	134
Tsitika River	73	200	168	218	220	252	38	235	276
Goat River	259	201	199	73	239	366	349	68	115
Lard Creek	278	202	218	366	96	43	355	215	117
Riley Creek	169	203	204	267	359	198	167	78	140
Keith River	103	205	122	47	196	371	54	361	263
Macjack River	150	205	82	305	394	275	63	110	185
Kooryet Creek	227	206	318	331	374	115	194	53	31
Wanokana Creek	53	208	105	178	72	295	238	260	270
Unnamed	325	208	407	223	61	137	376	213	1
Lagins Creek	173	209	120	170	346	316	207	89	172
Stawamus River	273	210	350	133	159	332	314	102	35
San Josef River	44	211	67	17	189	340	105	399	313
Pa-aat River	241	212	253	318	338	79	274	88	83
Seal Inlet	165	214	144	93	392	368	139	144	157
Marmot River	217	214	210	162	347	266	333	27	92
Unnamed	224	215	300	269	381	182	231	28	47
Tahsish River	126	216	80	30	90	397	224	328	290
Ada Cove	349	218	344	379	133	17	198	307	62
Brittain River	413	218	230	276	30	84	288	278	254
Jump Across Creek	316	219	323	324	83	66	398	189	59
Malksope River	104	220	95	21	223	401	132	253	319
Easy Inlet	86	221	231	172	115	261	158	229	279
Lipsett Creek	149	222	249	145	375	289	99	162	127
Youghpan Creek	52	224	178	87	1	345	219	293	325
Oih Creek	210	224	214	231	380	215	303	11	94
Kokish River	72	225	150	46	194	384	67	296	312
Shushartie River	46	226	142	95	210	342	65	290	306
Quatam River	404	227	208	288	57	49	270	295	287
Kainet Creek	279	228	151	317	186	95	354	169	183
Ain River	195	230	220	345	335	118	300	34	104
Nusash Creek	319	230	385	362	43	28	391	224	23
Kiltuish River	251	231	112	51	289	395	368	55	189
Unnamed	168	232	319	341	322	139	163	120	57
Nasparti River	124	234	134	55	265	376	128	322	182
Roderick Cove	302	234	405	190	261	163	309	130	4
Courtenay River	16	237	8	118	267	350	106	359	257

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Power River	84	237	197	67	147	365	145	251	293
Cornwall Inlet	264	237	294	371	173	53	313	185	76
Hathaway Creek	51	238	100	30	98	300	210	396	332
Georgie River	216	239	282	314	358	147	280	26	60
Datlamen Creek	191	241	394	298	344	155	232	39	10
Belowe Creek	245	241	262	332	237	76	326	134	105
Kaouk River	127	242	89	99	310	382	172	208	213
Songhees Creek	82	243	320	176	78	250	36	257	357
Unnamed	116	244	392	168	263	229	44	345	36
Tzoonie River	417	245	194	268	32	87	283	280	335
Adam River	78	246	96	29	230	360	31	401	333
Falls River	295	247	166	48	102	390	400	148	228
Walt Creek	215	248	310	310	402	150	254	20	38
Spiller Inlet	277	249	399	155	203	303	323	96	6
Toquart River	28	250	72	12	218	353	116	397	318
Sydney River	62	252	148	30	129	301	168	369	344
Scott Cove	378	252	313	197	21	142	223	212	381
Kewquodie Creek	54	253	143	75	138	362	182	288	303
Mill Stream	98	256	186	186	251	292	107	222	248
Evelyn Creek	243	256	308	316	279	112	370	62	45
Brim River/Owyacumish Creek Complex	252	256	261	309	274	82	385	100	81
Triumph River	249	257	225	110	295	346	365	51	102
Unnamed	250	258	386	376	170	35	369	147	14
Vancouver River/High Creek Complex	414	259	185	275	35	75	291	287	352
Nahwitti River	47	260	228	289	163	168	68	266	320
Escalante River	65	262	213	60	204	274	14	374	366
Bolivar Islet	351	262	109	346	244	71	187	314	234
Weewanie Creek	239	263	235	381	215	32	381	168	95
Unnamed	94	264	331	249	262	188	3	220	256
Kiskosh Creek	235	265	233	311	343	107	350	73	93
Homathko/Teaquahan River Complex	401	266	20	172	317	65	362	330	245
Cowichan River	14	267	18	251	299	194	108	375	267
Conuma River	107	268	137	38	114	389	251	245	340
Coleman Creek	102	269	314	113	135	315	199	234	206
Marble River	31	271	76	114	191	321	220	312	283
McKay Cove	105	271	259	166	224	262	74	211	321
Tsimtack Lake	246	272	336	319	336	119	308	61	39

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Hans Point	211	273	291	282	401	171	306	15	53
Unnamed	83	275	279	211	139	239	129	230	295
Mosquito Bay	305	275	334	107	400	245	249	133	54
Beano Creek	131	276	256	107	80	320	73	321	368
Bish Creek	231	277	165	161	327	296	401	30	146
Brem River	405	279	219	280	153	68	325	277	205
Skwawka River	411	279	183	252	33	94	344	272	349
Denad Creek	59	280	131	279	275	185	147	244	269
Koprino River	56	281	62	141	318	337	135	274	264
Sarita River	23	283	101	181	257	251	133	318	297
Klekane River	260	283	149	97	351	370	347	64	160
Gorge Waters/Craigflower Creek	12	284	216	400	3	61	110	383	371
Poison Cove Creek	300	285	284	369	155	37	361	252	87
Atleo River	93	286	248	91	226	339	91	247	310
Sucwoa River	109	287	236	234	232	226	250	204	174
Unnamed	77	288	361	131	99	277	24	279	387
Kauwinch River	87	289	116	124	179	355	175	309	301
Dala River	297	290	55	235	379	123	404	167	198
Kitsault/Illiance River Complex	428	291	24	225	305	88	339	340	242
Pike Creek	238	292	357	166	269	282	377	52	61
Mud Bay/Rosewall /Waterloo Creek Complex	11	293	44	369	302	135	75	355	285
Unnamed	237	294	376	199	324	227	375	45	20
Mathieson Channel	281	295	375	150	334	270	334	81	24
Barrie Creek	253	296	370	163	256	291	383	79	27
Campbell River (2)	9	297	66	389	303	106	13	386	308
Wathl Creek	229	298	172	257	384	195	408	38	120
Waukwaas Creek	79	299	65	33	233	399	164	379	302
Nahmint River	30	300	117	35	181	288	208	404	343
Kwalate River	383	301	324	226	245	122	302	225	135
Wathlsto Creek	230	302	273	148	364	279	407	37	73
Canoona River	263	304	406	188	285	268	342	91	2
Roscoe Creek	309	304	196	69	407	285	343	143	139
Unnamed	172	305	193	103	378	335	176	273	126
Keogh River	80	306	240	87	288	343	39	265	324
Goodspeed River	50	307	133	26	201	314	209	366	339
Sooke River	17	308	86	180	309	244	111	353	309
Effingham River	99	310	238	287	313	180	180	210	187

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Klaskish River	118	310	207	100	283	338	121	186	360
Kleeptee Creek	69	312	237	70	84	265	196	373	372
Price Cove	255	312	290	163	348	280	390	57	69
Tlupana/Nesook River Complex	110	314	192	62	228	348	241	337	194
Bella Coola/Necleetsconnay River Complex	328	314	41	16	382	317	397	216	233
Unnamed	257	315	374	156	286	299	395	66	29
Ice River	63	316	245	82	112	256	155	378	379
Irony Creek	119	317	257	92	193	311	57	324	375
Western Lake Chain	275	318	270	351	321	70	332	181	85
Cypre River	18	320	87	306	280	157	136	344	304
Kirby Creek	134	320	367	385	143	114	64	140	401
Englishman River	2	322	93	408	296	36	42	406	336
Nass/Ksi'Hlginx/Burton/Iknouck/Chambers /Kincolith River Complex	431	322	3	4	371	383	235	381	240
Unnamed	236	323	398	191	339	260	372	50	8
Tom Browne Creek	384	324	77	347	284	72	246	333	260
Crab River	247	325	305	156	386	290	371	48	64
Nootum River	348	327	113	357	294	58	269	319	216
Taaltz Creek	371	327	329	313	17	26	298	258	385
Cayaghis Creek	117	328	175	64	271	349	256	347	165
Mooyah River	66	330	212	81	177	243	150	392	373
Artlish River	89	330	119	39	200	358	215	367	330
Earle Creek	416	331	317	336	37	42	211	297	389
Sim River	387	332	184	388	151	20	356	342	191
Klootchlimmis Creek	55	333	110	258	333	211	212	248	266
Nanoose/Bonell Creek Complex	10	335	58	384	308	113	87	384	305
Nordstrom Cove	58	335	267	77	235	238	79	360	383
Kashutl River	88	336	154	44	171	386	202	343	341
Village Bay	402	337	369	336	109	21	117	285	405
Mahatta Creek	57	338	227	87	217	236	98	398	380
Capilano River	26	339	250	77	192	234	123	389	384
Clesklagh Creek	49	340	211	53	166	263	214	376	367
Grant Bay	61	341	287	114	208	210	46	395	391
Little Qualicum River	5	342	69	395	355	98	21	400	316
Indian River	427	343	118	322	290	41	281	327	280
Paril River	248	344	241	344	398	64	366	152	97
Kwinamass River	432	345	27	349	341	85	240	356	268

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Squamish River	24	347	104	25	222	309	315	372	322
Amor de Cosmos Creek	76	347	315	277	273	179	50	237	338
Canton Creek	108	348	195	293	282	176	247	202	286
Jacklah River	92	349	263	291	258	174	273	214	209
Foch Lagoon	232	350	162	374	397	52	378	175	149
Unnamed	244	351	366	185	373	271	367	71	55
Espinosa Creek	129	352	188	86	187	347	205	329	348
Coeur d'Alene Creek	41	353	265	172	195	254	143	308	363
Orford River	403	354	180	224	325	105	327	249	298
Glenlion River	32	355	311	103	182	204	113	403	399
Hesquiat River	64	356	288	109	207	217	118	387	390
Silverado Creek	67	357	299	111	154	306	181	301	370
Doc Creek	347	358	396	396	315	10	275	316	18
Somas River	22	360	36	136	403	294	248	336	274
Unnamed	40	360	281	356	209	116	148	271	346
Bulson Creek	20	361	147	321	259	145	204	326	331
Macktush Creek	38	362	229	188	169	242	253	306	347
Snug Basin	42	363	316	352	183	117	141	268	362
Rainbow Creek	370	364	345	196	148	143	319	206	393
Lucky Creek	39	365	332	154	162	175	124	402	402
Little Zeballos River	90	367	198	71	234	305	217	364	364
Moyeha River	95	367	190	300	272	169	185	303	334
McNab Creek	423	368	164	324	365	57	244	317	288
Oona River	434	369	111	360	389	39	236	349	281
Kennedy River	113	370	292	207	287	246	153	195	388
Bear River [1]	399	372	364	335	18	25	348	282	403
Donahue Creek	430	372	242	365	319	15	203	332	299
Moh Creek	398	373	354	282	160	90	279	241	376
Mackenzie Lake	372	374	352	402	56	4	245	335	394
Charles Creek	375	375	333	401	24	5	301	339	386
Burman River	91	376	160	58	270	336	255	363	353
Whitly Point	433	377	203	380	332	18	166	346	356
Southgate River	400	379	145	378	298	23	359	334	265
Goldstream River	440	379	135	392	399	19	162	358	337
Colquitz River	97	381	321	123	214	253	115	382	398
Bear River [2]	441	381	26	336	406	83	341	352	262
Cous Creek	37	382	177	50	316	269	277	362	358

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Hot Springs Creek	321	383	402	158	158	156	374	158	406
Gilttoyees River	437	384	21	343	337	100	388	370	258
Tofino Creek	27	385	307	97	188	212	234	394	397
Bedwell Creek	19	386	171	314	291	141	225	348	351
Tranquil River	21	387	215	342	278	126	200	325	359
Huaskin Lake	367	388	389	391	167	9	179	315	400
Long Lake	363	389	397	394	53	6	276	320	407
McCurdy Creek	70	390	359	260	144	178	271	261	382
Tsowwin River	43	391	243	328	330	144	227	264	327
Restoration Bay	345	392	382	372	126	13	331	299	342
Furry Creek	425	393	254	357	377	22	268	323	273
China Creek	101	394	325	269	236	187	278	217	369
Stakawus Creek	412	395	371	333	161	44	337	286	355
Unnamed	439	396	343	405	391	2	10	371	378
Gold River	111	397	266	93	221	310	289	368	374
Mohun Creek	96	398	274	327	304	146	80	407	396
Sechelt Creek	420	399	365	353	247	47	272	300	361
Leiner River	8	400	141	403	372	67	260	385	350
Grand Creek	426	401	380	389	197	3	282	338	395
Asseek River	442	402	123	386	408	33	379	354	329
Houston River	68	403	362	130	368	205	218	350	404
Rainy River	422	404	381	368	369	27	192	311	408
Lime Creek	429	405	295	374	393	12	336	331	326
Wahkash Creek	388	406	379	399	277	7	352	341	315
Tahsis River	7	407	222	404	363	56	263	393	377
Jesse River	436	408	388	406	387	1	392	365	392

APPENDIX 3: RANK OF EACH ESTUARY AVAILABLE TO DUSKY CANADA GEESE

- Estuary number
Overall - Overall Species Importance
A – Habitat Area
B – Number of Neighbours
C – Transversibility
D – Neighbourhood Area
E – Accessibility
F – Connectivity Maintenance
G – Critical Stepping-stone

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Somas River	22	1	8	13	21	117	60	4	39
Nickomekl/Serpentine River Complex	218	2	3	28	77	102	1	6	57
Chemainus River/Bonsall Creek Complex	13	4	9	66	100	82	6	2	10
Squamish River	24	4	12	4	4	120	80	5	50
Kingcome River	380	5	4	7	8	65	84	66	65
Nanaimo River	15	6	7	44	91	95	16	7	52
Wakeman River	374	7	18	14	22	43	75	72	70
Tyler Creek	266	8	26	16	27	116	71	17	48
Apple River	394	9	20	17	33	46	70	69	69
Fraser River	391	10	1	1	1	123	4	123	75
Klinaklini River	390	11	2	5	6	73	104	73	66
Gordon River	137	12	43	36	26	107	31	41	46
Englishman River	2	14	21	110	120	66	13	1	3
Kumealon Creek	240	14	38	25	36	112	73	13	37
Klaskish River	118	15	59	27	16	110	30	56	49
Khutze River	298	17	14	8	13	111	94	48	62
Draney Creek	360	17	27	20	40	68	72	60	63
Fanny Bay/Cowie Creek	1	19	93	123	123	1	8	3	1
Salmon River	33	19	11	3	3	121	19	119	76
Cowichan River	14	20	13	58	102	75	25	26	55
Theodosia River	407	21	29	47	35	33	48	85	78
Nass/Ksi'Hlginx/Burton/Iknouck/Chambers/ Kincolith River Complex	431	22	10	23	51	49	55	95	73
Mountain Creek	170	23	64	64	47	87	46	24	27
Kiltuish River	251	24	30	19	32	115	106	16	42
San Juan River	136	25	96	59	38	78	26	45	21
East Creek	120	26	71	50	37	94	21	52	40

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Schmidt Creek	114	27	98	71	45	71	2	55	24
Zeballos River	130	28	63	41	24	103	50	47	41
Seymour River (2)	368	29	33	26	46	67	86	58	58
Ickna Creek	322	30	23	34	50	41	110	57	61
Adam River	78	31	31	10	9	114	11	110	92
Dass Creek	184	32	53	66	67	92	58	12	30
Nekite River	359	33	34	32	52	60	81	61	59
Kitsault/Illiance River Complex	428	34	6	20	49	51	87	98	72
Ahta River	376	35	36	53	34	29	76	79	77
Unnamed	257	37	44	24	31	113	117	21	36
Dunn Point Area	333	37	40	68	48	23	62	71	74
Bella Coola/Necleetsconnay River Complex	328	38	16	11	25	108	119	49	60
Hird Point	282	39	105	56	42	80	68	25	14
Roscoe Creek	309	40	67	29	44	90	90	39	33
Deena Creek	174	42	102	85	74	56	42	20	15
Mamin Creek	192	42	58	75	87	74	64	10	26
Hansen/Rasmus/Fisherman River Complex	45	44	25	43	55	101	22	78	71
Kimsquit/Hoam Creek Complex	312	44	46	18	28	97	122	40	44
Tsable River	36	46	52	12	10	104	3	114	103
Goodspeed River	50	46	24	6	5	119	49	111	84
Kingkown Inlet	226	48	73	89	106	54	37	18	23
Yeo Lake	304	48	115	69	53	53	63	38	9
Kildala River	296	49	54	22	30	109	121	31	34
Kitimat River	25	50	5	2	2	122	123	81	68
Kowesas River	254	51	15	32	71	85	113	36	56
Kaouk River	127	53	100	81	61	61	41	46	19
James Bay	280	53	95	45	41	96	85	30	17
Stagoo Creek	214	55	42	61	114	88	66	9	31
Milton River	356	55	80	52	58	48	69	59	45
Kokish River	72	56	72	30	11	105	14	84	96
Cayaghis Creek	117	58	28	9	7	118	61	103	87
Kdelmashan Creek	285	58	107	101	115	30	20	28	12
Quaal River/Kitkiata Creek Complex	234	59	77	48	57	100	99	14	20
Atleo River	93	60	87	42	18	98	18	68	85
Georgetown Creek	204	62	118	99	113	40	35	8	6

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Kitlope/Tsaytis River Complex	256	62	17	38	73	84	116	37	54
Naka Creek	115	63	75	90	101	55	10	51	38
Keswar Inlet	223	65	108	118	116	6	33	33	11
Roderick Cove	302	65	117	79	64	45	77	35	8
Mooyah River	66	67	45	15	12	106	39	112	100
Mussel River	299	67	92	40	39	99	103	34	22
Kiskosh Creek	235	69	62	82	96	50	93	19	28
Nooseseck River	326	69	55	35	62	81	112	42	43
Effingham River	99	70	61	73	69	72	43	62	53
Stawamus River	273	71	119	80	63	58	79	29	7
Kainet Creek	279	72	39	84	84	34	95	50	51
Homathko/Teaquahan River Complex	401	73	22	57	60	28	102	92	79
Kemano/Wahoo River Complex	258	74	56	70	94	57	115	22	32
Canoona River	263	76	121	86	68	52	89	27	4
Nimmo Bay	373	76	113	87	72	26	57	63	29
Kromann/Moore Cove Creek Complex	219	77	97	112	119	15	65	32	16
Triumph River	249	79	120	92	76	44	105	15	5
Barrie Creek	253	79	104	63	66	77	111	23	13
Orford River	403	80	65	65	65	27	83	74	81
Clayton Falls Creek	327	81	84	51	78	64	118	43	25
Bish Creek	231	82	82	60	85	89	120	11	18
Franklin River	389	83	47	76	54	20	101	87	86
San Josef River	44	84	79	39	17	83	23	118	113
Cornwall Inlet	264	85	69	100	104	22	78	54	47
Toquart River	28	86	81	31	14	91	28	116	114
Brem River	405	87	74	78	56	16	82	82	89
Skwawka River	411	88	66	74	59	25	91	83	88
Black Creek	34	91	106	55	20	63	9	113	121
Moyeha River	95	91	41	72	82	76	45	88	83
Kwatna River	336	91	89	91	75	12	92	64	64
Silverado Creek	67	92	99	49	19	86	44	86	110
Kleeptee Creek	69	93	83	37	15	93	47	109	111
Unnamed	325	94	123	106	93	21	107	44	2
Coeur d'Alene Creek	41	95	88	54	43	79	36	91	107
Tom Browne Creek	384	96	51	103	88	13	59	97	95

Estuary Name	**#**	**Overall**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Fulmore/Shoal Creek Complex	392	97	112	94	83	17	32	67	104
Tsowwin River	43	99	68	83	89	59	54	75	82
Nimpkish River	71	99	114	93	70	42	12	70	109
Quatlena River	346	101	70	98	80	9	74	89	98
Toba/Tahumming River Complex	406	101	19	88	95	32	98	106	80
Bedwell Creek	19	102	50	77	90	62	52	96	93
Nusash Creek	319	103	90	96	81	8	114	65	67
Skeena/Ecstall/McNeil River Complex	35	105	94	46	23	70	53	120	119
Tahsish River	126	105	103	62	29	69	51	93	118
Foch Lagoon	232	106	76	109	122	24	108	53	35
Little Qualicum River	5	107	32	114	112	47	7	121	97
Sechelt Creek	420	108	86	95	79	14	67	90	106
Courtenay River	16	109	57	97	118	39	24	104	101
Campbell River (2)	9	110	48	116	117	37	5	117	102
Bear River [2]	441	111	37	107	99	19	88	107	91
Nahwitti River	47	112	111	105	92	35	15	76	115
Nanoose/Bonell Creek Complex	10	114	60	117	103	36	17	115	105
Southgate River	400	114	49	103	97	11	100	99	94
Unnamed	40	115	91	102	107	38	38	80	99
Koeye River	350	116	110	115	86	4	29	94	120
Asseek River	442	117	35	108	98	18	109	108	90
Snug Basin	42	118	109	111	108	31	34	77	112
Quatse River/Boyden Creek Complex	3	119	85	122	121	7	27	122	116
Whitly Point	433	120	122	121	105	2	40	100	123
Green Lagoon	438	121	78	113	110	10	96	105	108
Oona River	434	122	116	120	109	5	56	101	122
Sim River	387	123	101	119	111	3	97	102	117

APPENDIX 4: RANK OF EACH ESTUARY FOR AGGREGATE CONNECTIVITY IMPORTANCE AND BIOPHYSICAL IMPORTANCE

Estuary Name	Estuary #	Aggregate Importance Rank	Biophysical Importance Rank
Fanny Bay/Cowie Creek	1	3	36
Englishman River	2	87	12
Quatse River/Boyden Creek Complex	3	21	50
Cluxewe River	4	135	80
Little Qualicum River	5	92	15
Trent River	6	119	9
Tahsis River	7	350	220
Leiner River	8	345	142
Campbell River (2)	9	140	87
Nanoose/Bonell Creek Complex	10	155	27
Mud Bay/Rosewall /Waterloo Creek Complex	11	284	46
Gorge Waters/Craigflower Creek	12	318	131
Chemainus River/Bonsall Creek Complex	13	2	2
Cowichan River	14	67	7
Nanaimo River	15	4	6
Courtenay River	16	70	3
Sooke River	17	270	193
Cypre River	18	301	10
Bedwell Creek	19	102	94
Bulson Creek	20	326	233
Tranquil River	21	335	245
Somas River	22	75	100
Sarita River	23	262	168
Squamish River	24	69	62
Kitimat River	25	18	1
Capilano River	26	289	260
Tofino Creek	27	325	260
Toquart River	28	55	29
Maggie River	29	196	27

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Nahmint River	30	257	233
Marble River	31	253	153
Glenlion River	32	304	108
Salmon River	33	26	70
Black Creek	34	39	59
Skeena/Ecstall/McNeil River Complex	35	10	7
Tsable River	36	16	31
Cous Creek	37	315	204
Macktush Creek	38	320	260
Lucky Creek	39	317	125
Unnamed	40	97	369
Coeur d'Alene Creek	41	90	350
Snug Basin	42	99	350
Tsowwin River	43	100	138
San Josef River	44	121	142
Hansen/Rasmus/Fisherman River Complex	45	116	31
Shushartie River	46	210	153
Nahwitti River	47	134	260
Stranby River	48	391	108
Clesklagh Creek	49	293	324
Goodspeed River	50	66	138
Hathaway Creek	51	226	56
Youghpan Creek	52	246	131
Wanokana Creek	53	237	112
Kewquodie Creek	54	234	193
Klootchlimmis Creek	55	294	181
Koprino River	56	232	65
Mahatta Creek	57	287	324
Nordstrom Cove	58	281	117
Denad Creek	59	404	18
Kwatleo Creek	60	375	18
Grant Bay	61	408	66
Sydney River	62	229	204

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Ice River	63	285	255
Hesquiat River	64	306	104
Escalante River	65	230	220
Mooyah River	66	78	260
Silverado Creek	67	91	350
Houston River	68	336	369
Kleeptee Creek	69	86	309
McCurdy Creek	70	333	391
Nimpkish River	71	30	76
Kokish River	72	48	193
Tsitika River	73	206	289
Big Qualicum River	74	157	16
Oyster River	75	183	48
Amor de Cosmos Creek	76	300	168
Unnamed	77	280	309
Adam River	78	45	153
Waukwaas Creek	79	228	131
Keogh River	80	251	104
Tsulquate River	81	171	80
Songhees Creek	82	246	369
Unnamed	83	253	324
Power River	84	219	138
Ououkinsh/Unnamed River Complex	85	190	84
Easy Inlet	86	223	301
Kauwinch River	87	231	193
Kashutl River	88	257	233
Artlish River	89	275	168
Little Zeballos River	90	309	220
Burman River	91	314	260
Jacklah River	92	310	350
Atleo River	93	59	189
Unnamed	94	241	112
Moyeha River	95	95	203

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Mohun Creek	96	410	260
Colquitz River	97	322	168
Mill Stream	98	221	153
Effingham River	99	77	260
Henderson Lake	100	442	412
China Creek	101	327	301
Coleman Creek	102	257	391
Keith River	103	396	217
Malksope River	104	179	41
McKay Cove	105	402	189
Clanninick Creek	106	394	14
Conuma River	107	220	168
Canton Creek	108	297	181
Sucwoa River	109	265	204
Tlupana/Nesook River Complex	110	292	309
Gold River	111	332	276
Megin River	112	442	255
Kennedy River	113	312	230
Schmidt Creek	114	36	233
Naka Creek	115	46	245
Unnamed	116	282	417
Cayaghis Creek	117	83	181
Klaskish River	118	127	50
Irony Creek	119	405	289
East Creek	120	108	29
Kingfisher Creek	121	380	204
Moneses Lake	122	373	276
Empetrum Lake	123	386	104
Nasparti River	124	399	45
Battle Bay	125	388	245
Tahsish River	126	63	87
Kaouk River	127	41	168
Kapoose Creek	128	442	94

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Espinosa Creek	129	296	204
Zeballos River	130	38	148
Beano Creek	131	403	142
Pachena River	132	387	245
Jordan River	133	374	369
Kirby Creek	134	278	391
Muir Creek	135	163	391
San Juan River	136	12	276
Gordon River	137	20	260
Loss Creek	138	364	339
Sombrio Creek	139	365	168
Camper Creek	140	165	391
Cullite Creek	141	158	324
Logan Creek	142	134	276
Walbran Creek	143	170	324
Carmanah Creek	144	131	276
Cheewhat River	145	353	309
Nitinat River	146	442	260
Bilston Creek	147	124	168
Restless Bight	148	354	289
Lipsett Creek	149	398	131
Macjack River	150	396	193
Amos Creek	151	370	193
Klanawa River	152	442	339
Sialun Creek	153	380	117
Beresford Creek	154	377	142
Hana Koot Creek	155	378	94
Jalun River	156	351	193
Haines Creek	157	382	309
Cave Creek	158	391	369
Otard Creek	159	175	76
Coates Creek	160	138	62
Hosu Cove	161	361	391

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Unnamed	162	442	337
Mace Creek	163	362	138
Mercer Lake	164	385	148
Seal Inlet	165	182	46
Tartu Inlet	166	146	70
Unnamed	167	147	350
Unnamed	168	239	391
Riley Creek	169	202	220
Mountain Creek	170	28	87
Gudal Creek	171	149	276
Unnamed	172	277	66
Lagins Creek	173	185	245
Deena Creek	174	9	100
Security Cove	175	187	117
Lignite Creek	176	169	35
Naden River/Davidson Creek Complex	177	132	10
Stanley Creek	178	145	13
Christie River	179	129	50
Skonun River	180	121	131
Hiellen River	181	111	217
Oeanda River	182	123	309
Braverman Creek	183	211	131
Dass Creek	184	25	87
Upper Victoria Lake Chain	185	442	417
Flat Creek	186	148	289
Tasu Creek	187	167	117
Head of Kootenay Inlet	188	358	289
Kootenay Inlet	189	372	324
Mackenzie Cove	190	152	112
Datlamen Creek	191	235	301
Mamin Creek	192	23	255
Kumdis Creek	193	145	40
Kumdis Slough	194	442	417

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Ain River	195	247	309
McClinton/Unnamed Creek Complex	196	174	181
Yakoun River	197	181	66
Tlell River	198	355	276
Otun Creek	199	126	59
Kloiya River	200	178	350
Toon River	201	185	153
Thulme River	202	442	409
Ensheshese River	203	180	255
Georgetown Creek	204	112	4
Khutzeymateen River	205	160	161
Chambers Creek	206	143	204
Lynn Creek	207	194	412
Seymour River (1)	208	214	309
Kshwan River	209	142	161
Oih Creek	210	238	204
Hans Point	211	263	276
Bonanza Creek	212	186	289
Cascade Creek	213	188	350
Stagoo Creek	214	50	295
Walt Creek	215	250	324
Georgie River	216	248	350
Marmot River	217	222	220
Nickomekl/Serpentine River Complex	218	1	5
Kromann/Moore Cove Creek Complex	219	49	168
Billy Creek	220	371	21
Captain Cove	221	203	260
Hankin Point	222	368	142
Keswar Inlet	223	51	369
Unnamed	224	227	245
Keyarka Cove	225	139	382
Kingkown Inlet	226	110	233
Kooryet Creek	227	219	369

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Hart Creek	228	177	41
Wathl Creek	229	283	41
Wathlsto Creek	230	271	189
Bish Creek	231	74	98
Foch Lagoon	232	94	220
Unnamed	233	442	382
Quaal River/Kitkiata Creek Complex	234	32	48
Kiskosh Creek	235	73	204
Unnamed	236	290	350
Unnamed	237	273	391
Pike Creek	238	275	391
Weewanie Creek	239	295	245
Kumealon Creek	240	324	322
Pa-aat River	241	236	350
Salter Lake	242	442	382
Evelyn Creek	243	266	339
Unnamed	244	300	309
Belowe Creek	245	260	350
Tsimtack Lake	246	268	412
Crab River	247	272	301
Paril River	248	305	324
Triumph River	249	60	276
Unnamed	250	291	417
Kiltuish River	251	44	230
Brim River/Owyacumish Creek Complex	252	270	350
Barrie Creek	253	81	391
Kowesas River	254	52	125
Price Cove	255	279	220
Kitlope/Tsaytis River Complex	256	37	36
Unnamed	257	72	148
Kemano/Wahoo River Complex	258	44	76
Goat River	259	201	350
Klekane River	260	244	180

Estuary Name	Estuary #	Aggregate Importance Rank	Biophysical Importance Rank
Scow Bay	261	198	295
Aaltanhash River	262	191	273
Canoona River	263	76	309
Cornwall Inlet	264	82	382
Arnoup Creek	265	194	324
Tyler Creek	266	24	220
Quigley Creek	267	442	233
Unnamed	268	442	417
Bloomfield Lake	269	197	369
Unnamed	270	207	369
Surf River	271	442	273
Keecha Creek	272	168	382
Stawamus River	273	53	255
Mamquam River	274	243	217
Western Lake Chain	275	406	161
Ingram Creek	276	381	230
Spiller Inlet	277	400	204
Lard Creek	278	289	350
Kainet Creek	279	68	189
James Bay	280	33	148
Mathieson Channel	281	240	382
Hird Point	282	40	391
Snass Lake	283	384	273
Carter River	284	200	260
Kdelmashan Creek	285	107	125
Weeteeam Bay Area	286	364	74
Unnamed	287	152	181
Lombard Point	288	359	276
Woodcock Islands Area	289	356	337
Kwakwa River	290	442	431
Stannard Creek	291	360	301
Betteridge Inlet Area	292	376	339
Banks Lakes	293	442	417

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Hevenor Lagoon	294	259	412
Falls River	295	213	76
Kildala River	296	17	50
Dala River	297	258	59
Khutze River	298	13	84
Mussel River	299	31	309
Poison Cove Creek	300	321	324
Bottleneck Inlet	301	172	382
Roderick Cove	302	56	417
Tankeeah River	303	177	161
Yeo Lake	304	109	369
Mosquito Bay	305	208	168
Neekas Creek	306	150	161
Quartcha Creek	307	383	350
Ellerslie Lagoon	308	442	295
Roscoe Creek	309	128	309
Jermaine Point Area	310	195	417
Unnamed	311	442	417
Kimsquit/Hoam Creek Complex	312	113	70
Dean River	313	366	84
Sutslem Creek	314	442	409
Swallop Creek	315	224	391
Jump Across Creek	316	287	391
Skowquiltz River	317	166	168
Nusash Creek	318	442	435
Nusash Creek	319	93	391
Nascall River	320	216	339
Hot Springs Creek	321	311	350
Ickna Creek	322	34	112
Taleomey River	323	161	54
Noeick River	324	213	112
Unnamed	325	80	428
Nooseseck River	326	59	131

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Clayton Falls Creek	327	65	153
Bella Coola/Necleetsconnay River Complex	328	61	44
Farquhar River	329	442	428
Link River	330	442	391
Four Lakes	331	442	435
Unnamed	332	389	369
Dunn Point Area	333	115	350
Kakushdish Harbour Area	334	392	142
Gibraltar Point	335	442	295
Kwatna River	336	11	125
Marvinas Bay	337	217	153
Yuquot Point	338	130	25
Millar Channel	339	118	117
Kutcous Point	340	117	58
Cow Bay	341	125	117
Bazett Island Area	342	162	193
Pye Creek	343	164	245
Holti Point	344	442	307
Restoration Bay	345	343	233
Quatlena River	346	64	100
Doc Creek	347	338	322
Nootum River	348	303	204
Ada Cove	349	397	369
Koeye River	350	63	161
Bolivar Islet	351	401	245
Waterfall Inlet	352	369	349
Oyster Bay	353	357	324
MacNair Creek	354	233	324
Clyak River	355	154	181
Milton River	356	27	204
Kilbella/Chuckwalla River Complex	357	136	21
Wannock/Nicknaqueet River Complex	358	153	25
Nekite River	359	14	36

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Draney Creek	360	15	233
Campbell River (1)	361	114	74
Takush River	362	122	181
Long Lake	363	344	431
Shade Island area	364	156	428
Waump Creek	365	189	350
Evader Creek	366	349	153
Huaskin Lake	367	338	417
Seymour River (2)	368	22	104
Cohoe Creek	369	367	301
Rainbow Creek	370	308	295
Taaltz Creek	371	316	391
Mackenzie Lake	372	341	369
Nimmo Bay	373	29	117
Wakeman River	374	8	31
Charles Creek	375	342	193
Ahta River	376	47	87
Viner Sound	377	192	117
Scott Cove	378	242	233
Gilford Creek	379	205	391
Kingcome River	380	7	31
Kakweiken River	381	159	66
Lull Creek	382	250	276
Kwalate River	383	300	260
Tom Browne Creek	384	88	87
Blind Creek	385	261	295
Ahnuhati River	386	442	244
Sim River	387	101	98
Wahkash Creek	388	352	108
Franklin River	389	42	20
Klinaklini River	390	19	23
Fraser River	391	6	24
Fulmore/Shoal Creek Complex	392	5	70

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Stafford River	393	173	93
Apple River	394	35	80
Heydon Creek	395	204	350
Phillips River	396	141	220
Frederick Arm	397	209	339
Moh Creek	398	330	391
Bear River [1]	399	331	193
Southgate River	400	103	56
Homathko/Teaquahan River Complex	401	57	36
Village Bay	402	407	417
Orford River	403	89	181
Quatam River	404	254	233
Brem River	405	84	233
Toba/Tahumming River Complex	406	79	161
Theodosia River	407	106	204
Sliammon Creek	408	215	54
Powell River	409	225	148
Lois River	410	137	94
Skwawka River	411	85	307
Stakawus Creek	412	339	220
Brittain River	413	268	382
Vancouver River/High Creek Complex	414	265	245
Treat Creek	415	442	438
Earle Creek	416	313	412
Tzoonie River	417	276	276
Gustafson Bay	418	442	409
Misery Creek	419	442	438
Sechelt Creek	420	104	324
Clowhom River	421	442	435
Rainy River	422	346	431
McNab Creek	423	319	339
Mill Creek	424	442	441
Furry Creek	425	334	382

Estuary Name	**Estuary #**	**Aggregate Importance Rank**	**Biophysical Importance Rank**
Grand Creek	426	347	431
Indian River	427	307	339
Kitsault/Illiance River Complex	428	71	17
Lime Creek	429	348	204
Donahue Creek	430	328	276
Nass/Ksi'Hlginx/Burton/Iknouck/Chambers /Kincolith River Complex	431	54	62
Kwinamass River	432	302	108
Whitly Point	433	199	309
Oona River	434	98	168
Kumowdah River	435	442	440
Jesse River	436	393	441
Gilttoyees River	437	329	125
Green Lagoon	438	340	339
Unnamed	439	409	339
Goldstream River	440	323	100
Bear River [2]	441	96	125
Asseek River	442	105	80

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