Supplementary Online Materials for

‘Conservation in heavily urbanized biodiverse regions requires urgent management action and attention to governance’

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Appendix S1: Conservation relevance of the study area

Estuaries are amongst the most at risk ecosystems due to a long history of human settlement, ongoing development, and new threats posed by climate change. Host to the busiest port in Canada, home to half of British Columbia's rapidly expanding urban population, and particularly vulnerable to sea-level rise, the Fraser River estuary is no exception. The Fraser River estuary is of great cultural importance to Coast Salish First Nations communities, who have lived in and found both spiritual and physical nourishment from its natural resources for more than 10,000 years. This estuary provides natural goods including commercially and recreationally valuable salmon populations, freshwater for industry and domestic use, and dams on some tributaries provide hydroelectric power, while services include water filtration, nutrient cycling, flood mitigation, storm protection, and outstanding aesthetic values to the lives of its 3 million residents and the >10.3 million tourists that visit the Vancouver area annually. Being a delta estuary, the region is highly fertile and produces one quarter of British Columbia's agricultural income on less than 2% of the land base.

Alongside its rich economic and cultural importance, the Fraser River estuary supports a wealth of biodiversity playing a crucial role in a complex food web that links fish, birds and marine mammals spanning the Pacific Ocean. Historically, the Fraser River had some of the largest salmon runs in the world, however annual returns have been declining for decades. Despite this, each year over 2 billion juvenile salmon spend weeks to months in the estuary before embarking on their ocean migration. The estuary also provides crucial rearing grounds to over 300 species of invertebrates and over 80 species of fish and shellfish. The estuary is part of the Pacific Flyway, is a Western Hemisphere Shorebird Reserve Network site, and a globally recognized Ramsar stopover habitat for migratory shorebirds. The Fraser stopover connects bird species from at least three continents and boasts the highest concentrations of migratory birds in Canada – with up to 1.4 million birds utilizing the Fraser River estuary at peak season. In 2017, Birdlife International designated the Fraser River estuary as an Important Bird and Biodiversity Area (IBA) in danger. Endangered southern resident killer whales also frequent the estuary's plume, where they rely on Chinook salmon (*Oncorhynchus tshawytscha*) populations and a relatively noise- and pollution-free habitat.

As with many of the world's major estuaries, the Fraser River estuary's wealth of biodiversity is under siege both from economic and societal uses and from environmental change. Over 70% of the floodplain habitat has been permanently altered by dykes and jetties, filling, and development - leaving only ~5% of remaining habitat classified as wetland. With further plans for significant industrial and urban development currently under review, and pollution from urban, industrial and agricultural runoff, industrial scale dredging, hundreds of kilometres of diking, exploitation of fish stocks, alteration of banks, agricultural intensification, and climate change, the need for a costed portfolio of management strategies that will deliver long-term ecological resilience to this highly contested region is urgent. To date, no overarching conservation management plan has been developed for the species of conservation concern and no governance structure exists to bring together the more than 64 municipal, First Nations, provincial, and federal government authorities that manage and use the Lower Fraser's valuable resources.

Appendix S2: **Species Inclusion Criteria**

We included species in our analysis if they met at least one of the following five criteria:

1. British Columbia List Status of Red or Blue, or a listing with the Committee on the Status of Endangered Wildlife in Canada (available at https://www.canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife.html).
2. Canadian Species at Risk Act (available at http://laws-lois.justice.gc.ca/eng/acts/S-15.3/index.html).
3. Conservation Framework Priority between 1-3 (available at https://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/species-ecosystems-at-risk/setting-priorities/conservation-framework-results).
4. Priority Species in Bird Conservation Region 5 (available at https://www.canada.ca/en/environment-climate-change/services/migratory-bird-conservation/publications/strategy-region-5-pacific-rainforest/chapter-6.html).
5. Species deemed to be of "economic and/or cultural importance" after expert consultation. This included all Pacific salmon species and the pink fawn lily (muthqiu), a plant of great cultural importance to the Musqueam Indian Band from which they derive their name (Table S1).

In addition to the above, species must also meet at least one of our spatial criteria:

1. A sufficient permanent or seasonal population in the study area. For example, plants must have more than four mapped known locations in the study area. Bird species were included if they had e-bird sightings in our study area of >2%, whereas birds listed as vagrant were not included.
2. The study area contained critically important habitat for the species.

In total, these criteria resulted in the selection of 102 species of conservation concern (Table S1) that were then amalgamated into 13 threat groups were included in our study (as detailed in main manuscript).

Appendix S3: Management Strategies

We developed a set of potential management strategies and associated actions to abate the threats to the species of conservation concern in the Fraser River estuary, in conjunction with ecological experts and available literature. Partnership with First Nations should be integral to the prioritization and implementation of management strategies. The ten individual management strategies, their goals, the species groups they are of relevance to, and the detailed management steps involved in implementing the strategy are as follows:

S1. Public Land Management

Management Goal: Protect, restore, and connect habitats necessary to maintain persistence of identified species.

Relevant Species Groups: All except seabirds

1. Campaign to protect, manage, and restore parks/green space and other protected area designations for wildlife values.
2. Update park policy objectives at a municipal and provincial level recognizing the dual purpose of urban parks to maintain habitat for wildlife as well as recreational/educational opportunities.
3. Create a new Ministry of Environment and Climate Change Strategy position dedicated to ensuring parks are protected from encroachment, roads, and fragmentation, maintaining integrity of protected area system and ensuring parks continue to provide important refuge for wildlife.
4. Evaluate wildlife values within the study area parks/green spaces and make recommendations across protected areas.
5. Create a Fraser Estuary Land Endowment Trust to purchase private land of high conservation value and establish conservation easements, and then restore these lands as necessary. Goal would be a large endowment with interest funding conservation purchases with priorities for:
    a. Riparian zones.
    b. Greater protection for Burns Bog (3,000 ha undeveloped peat bog located in Delta).
    c. Potentially protecting Agricultural Land Reserve lands (from Provincial Agricultural Land Commission available at https://www.alc.gov.bc.ca/alc/content/alr-maps).
    d. Purchase of conservation easements.

S2. Private Land Management

Management Goal: Manage, restore, and connect private land (urban and rural) necessary to maintain persistence of identified species.

Relevant Species Groups: All except seabirds

1. Political campaign to amend Agricultural Land Reserve legislation to incorporate riparian objectives.
2. Reinstate provincial funding for Environmental Farm Plan (available at https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/programs/environmental-farm-plan).
3. Legislation amendment to Agricultural Land Reserve Act to implement riparian objectives within the Agricultural Land Reserve. Existing policy needs to be grandfathered until land is sold or crop focus changes (i.e. from soybeans to blueberries). Once land is sold, new riparian regulations will apply.
4. Enforcement of Agricultural Land Reserve policy within the Agricultural Land Commission (to prevent conversion to urban or industrial land use), enforce and guide implementation of existing regulation for co-ordination between other agencies such Ministry of Environment and Climate Change Strategy, Fisheries and Oceans Canada, and municipalities.
5. Expand Salmon Safe Program (salmonsafe.org) - Salmon safety for agriculture industry: Implement salmon-safe certification standards for farms. Requires broad roll-out and clarification, including demonstrated benefits.

6. Establish a Stewardship Fund - provide property tax incentives to landowners who manage their property for conservation including trees, riparian zones, hedgerows, and natural habitat.
7. Include cash for services on farmland: this would be undertaken through the province or Environmental NGOs and includes establishing or protecting riparian zones by paying farmers directly for the lost production (since there are limits to the value of tax credits, and farmers can access many tax credits already. Cash payments can be more valuable and avoid perverse incentives).
8. Double the effort of the Delta Farmland & Wildlife Trust (deltafarmland.ca) and expand existing stewardship programs that contribute to agricultural soil fertility and wildlife habitat availability, while mitigating conflict between wildlife and farming operations.

S3. Green Infrastructure
Management Goal: Restore and maintain healthy hydrological cycles and implement habitat friendly flood management practices.

Relevant Species Groups: All

1. Create a strategic working group to champion and fully implement Integrated Storm Water Management Plan (ISWMP) initiatives as they address, improve and/or restore water quantity, water quality, and habitat. This includes reducing sediment entry to creeks (e.g. riparian planting, storm water retrofits), greater onsite infiltration of run-off, and reducing untreated raw sewage entry to water systems via upgraded infrastructure and green infrastructure, and ensure adequate waste-water management including municipal wastewater treatment. Outputs from the Storm Water Interagency Liaison Group will also be considered here.
2. Create new wetland ecosystems in strategic drainage areas to increase habitat area and reduce contaminant loads in the river.
3. Create plans and facilitate the implementation of green infrastructure alternatives for flood management via a Green Infrastructure Working Group (this incorporates multiple goals such as working with municipalities and First Nations to build green infrastructure projects that will act as habitat, strategic planning for habitat retreat, and working with dyke management to improve best practices around vegetation management).
4. Plan and build pilot flagship project for Green Infrastructure (e.g., creation of marsh and beach in front of an existing dyke to curtail rising waters on west side of Boundary Bay).
5. Review of the impacts of each floodgate and pump station to determine problem sites and areas for prioritization of upgrades and management interventions.
6. Upgrade problematic pumps to “fish-friendly”, heavy cast iron gates to be replaced with side-mounted aluminum gates which open more readily.
7. Whenever possible, chain open light floodgates during low flood risk periods.

S4. Problematic Species Management
Management Goal: Remove and control invasive overabundant species.

Relevant Species Groups*: All except bats, seabirds, and marine mammals*

1. Campaign for municipal bylaws / provincial legislation to make it illegal for nurseries and horticultural organizations to sell identified invasive plant species.
2. Remove invasive English cordgrass (i.e., spartina) via herbicide application and/or mechanical removal wherever possible. Removal should take place as quickly as possible and be continuous throughout the time-period.
3. Overabundant species management - where overabundant native species are negatively impacting native plant and bird populations, conduct site-specific population surveys and develop plans for population control. This could potnetially be achieved through:

    a. Hunting of Canada and snow geese – ensuring municipalities keep designated areas open to hunting.
    b. Culling Canada Geese during annual molt.
    c. Create alternative forage crop fields (e.g., Westham Island) to deter overabundant species from predating on natural marsh wetlands (contributing to loss of wetlands and salmonid impacts).
4. Feral cat monitoring and research and control/cull experiment.
5. Dog disturbance control and research at key sites (to be identified), with a focus on Brant geese that would recommend seasonal no go areas and/or dog restrictions.

S5. Transportation Regulation
Management Goal: Reduce the risk to species of transport related impacts.

Relevant Species Groups: All

1. Map high risk areas of biodiversity and cultural importance so that deployment can arrive quickly in the case of oil spills.
2. Increase contracted removal of derelict vessels with pollution risk through targeted assessment, policing, and removal.
3. Identify areas from Metro/municipal biodiversity strategies where Minister of Transportation should exercise power under *BC Transportation Act*, s.8(2)© to protect species.
4. Consideration of biodiversity in other planning processes. Consultation with regional biodiversity experts on implications of the Gateway Strategy for species (since 2006 and going forward).
5. Noise reduction: Collaborate with BC Ferries who are currently measuring noise and developing mitigation plans.
6. Disturbance: Properly monitor and reinforce marine mammal disturbance measures (e.g., double the minimum vessel distance to 200 m for southern resident killer whales).

S6. Fisheries Regulation
Management Goal: Reduce illegal fishing and bycatch.

Relevant Species Groups*: All except raptors, bats, coastal sand, grassland, and forest species*

1. Identify the extent of the problem of illegal fishing in terms of violations of regulations as they relate to time and area, species, size/slot limits, hooks, net size, mesh size (all species not just fin fish).
2. Additional personnel for enforcing fisheries regulations across all fisheries (First Nations, commercial, recreational):
    a. Implement and fund Aboriginal Fisheries Guardian Watchmen program (designated as a fishery officer within section 5 of the *Fisheries Act*) within the planning area to work with Fisheries Officers.
    b. Catch & release of sturgeon.
    c. Better monitoring and compliance of fin fish and shellfish fisheries.
3. Implement and fund additional personnel for catch monitoring.
4. Implement gear modifications to reduce bycatch including migratory birds.
5. Improve stock identification.
6. Improve monitoring of juvenile escapement.

S7. Pollution Control
Management Goal: Reduce pollutant loads in the study area.

Relevant Species Groups: All

1. Implement best practices for wood treatment (i.e., ban creosote use on pilings) in the study area.
2. Remove legacy creosote pilings and docks from priority sites (important habitat areas).

3. Implement ban on copper (and other harmful materials) in brake pads in study region.
4. Revise and implement guidelines to reduce the use of nutrient and pesticide loading.
5. Develop and implement a Metro Vancouver regional scale urban pesticide reduction program for urban landowners.
6. Identification of and action plan to restore legacy industrial seeps.
7. Campaign to revise legislation to create transparent registry for all additives in pesticide mixtures for the forestry, agricultural, urban, and transport industry.
8. Provincial inventory on pesticides sold and information on where they are being used.

S8. Population Augmentation
Management Goal: Increase species abundance to viable population sizes.

Relevant Species Groups: All except marine mammals, anadromous fishes, and seabirds.

1. Mitigate sources of collision mortality that may have detrimental impacts on bats and birds - add markings to windows, consider bird collisions when designing new infrastructure and transmission lines.
2. Install bat houses on private property.

S9. Aquatic Disease Control
Management Goal: Works towards removing potentially hazardous open net-pen salmon farms upstream from our study area; Understand then mitigate the potential risks of eelgrass and starfish wasting disease.

Relevant Species Groups: Anadromous fishes, marine mammals, seabirds, freshwater, saltwater, and wetland species (resident and migrant)

1. Research into disease causing pathogens the may impact Fraser River salmon, and the role of fish farms in pathogen transfer (e.g., Heart and Skeletal Muscle Inflammation and PiscineRio Virus).
2. Advocate for wild salmon by removing promotion of salmon aquaculture from Fisheries and Oceans Canada mandate.
3. Understand the risk and potential management interventions for eelgrass and starfish wasting disease.

S10. Aquatic Habitat Restoration
Management Goal: Restore and connect habitats necessary to maintain persistence of identified species.

Relevant Species Groups*: All except coastal sand, grassland, and forest species*
1. McDonald Slough Dike Connectivity project located on the Northern shore of Sea Island on the North Arm of the Fraser River (this site is representative of similar potential project sites).
2. Revise best management practices for dredging and log booming to include traditional ecological knowledge and best available science, and enforcement of these regulations.
3. Creation, restoration, and improvement of freshwater tributary streams, including riparian habitats. Improve stream habitat complexity (woody debris) and clearly define environmental flow needs, which establish and maintain adequate base flow in important habitat for all seasons, utilizing best information from BC Hydro water use plans and reviews.
4. Investigation and restoration of traditional cultural ecological systems, including restoration of clam gardens and other systems.
5. Large scale marsh restoration project (example >20 hectares).

In addition to the ten individual management strategies detailed above, we also evaluated three combinations of strategies because experts felt that the synergistic nature of these strategies meant that the benefit of the combined strategies held the potential to be greater than the benefits of their individual parts. The three combinations of strategies considered were:

S11. (S1) Public Land Management, (S2) Private Land Management, and (S8) Population Augmentation
Relevant Species Groups: All

S12. (S3) Green Infrastructure, (S7) Pollution Control, and (S10) Aquatic Habitat Restoration

Relevant Species Groups: All
S13. (S6) Fisheries Regulation, (S9) Aquatic Disease Control, and (S10) Aquatic Habitat Restoration
Relevant Species Groups: All except coastal sand, grassland, and forest species

S14. We then considered all ten management strategies combined.

Relevant Species Groups: All
Finally, in order to assess the benefits of preventing major future industrial threats, a scenario involving the implementation of a moratorium on all major future industrial development in the study region was assessed.

S15. Halting Future Major Industrial Development
Management Goal: Same as strategy title

Relevant Species Groups: All
Major future developments in the study region include: the TransMountain Pipeline, a new container terminal (*Roberts Bank Terminal 2), "*threatening internationally-significant migratory birds, salmon and endangered orcas. *The WesPac Tilbury Marine Jetty Project* – A Terminal to export LNG from Tilbury Island 21 kilometres up the Fraser. This will bring LNG carriers in the Fraser River for the first time in history threatening public health and safety and the survival of the Fraser River Ecosystem. *Direct Transfer Coal Facility at Fraser Surrey Docks* – plans to ship up to 9 million metric tonnes of American thermal coal through B.C. …*Vancouver Airport Fuel Delivery Project* – plans to bring supertankers up the Fraser River in order to import offshore jet fuel for the airport. *George Massey Tunnel Replacement Project* [Delta-Richmond Bridge] - The B.C. Government plans to build a very high bridge near the estuary to facilitate supertankers and Aframax freighters carrying jet fuel and LNG in the Fraser River" - Boundary Bay Conservation Committee (available at https://www.againstportexpansion.org/uploads/images/file_view/Fraser_River_Estuary_and_Mega_Projects_April_22_2016_A.pdf)

Appendix S4: **Co-Governance strategy – Fraser River Estuary Act**

Currently, there is no overarching, coordinated management of the Fraser River estuary. In 1985, the Fraser River Estuary Management Program was established. It served as an intergovernmental program responsible for coordinating environmental management review and interagency communications for projects and developments in the Fraser River estuary. After 28 years of operation it was disbanded in 2013. Since then, the role of coordinating project reviews was assumed by the Vancouver Fraser Port Authority. This was intended as a temporary measure, however, no appropriate governance structure has been developed with a mandate to protect the species of conservation concern and bring together the more than 64 municipal, First Nations, provincial, and federal governments and agencies that manage the Lower Fraser River's resources and activities that have an impact on ecosystems in the Lower Fraser River.

Review of the Fraser River Estuary Management Program (1985-2013)

We conducted an online survey (13 respondents) to review previous management of the study region by the Fraser River Estuary Management Program (FREMP) and held a 1-day workshop with twelve experts in estuarine governance, in which we facilitated a group discussion to outline a high-level co-governance strategy for the region. The following is a summary of our FREMP review and a blueprint for more effective governance in the Fraser River estuary.

FREMP Achievements:

1. Greater balance of healthy ecosystems and development opportunities
2. Savings in both time and resources
3. Habitat coding and classification: delineation of red, yellow, and green zones was useful in understanding areas at risk
4. In the mid-1990s a strong management committee with senior agency representatives
5. The majority of respondents did agree that FREMP was moderately effective in achieving its vision of a living working river, however, no respondents deemed it to be 'very effective'

FREMP Failures:

1. Prioritization of industry and development: 100% of respondents reported there was some level of clash of mandates between agencies.
2. The Vancouver Fraser Port Authority and industry were deemed to have had too much influence
3. No legislation to ensure program funding persisted through time – long-term consistent funding was identified as a major obstacle, with one respondent reporting that the: "biggest issue was lack of consistent core funding for the Program, and secretariat support for consistent and long term monitoring to provide intelligence about what was working and was not"
4. First Nations were not among the FREMP partners, which included the Province of BC, Government of Canada, Metro Vancouver, and the Vancouver Fraser Port Authority.
5. Gradual "watering down" of commitment by partners because there was no shared mandate, just coordination of individual agency mandates.
    a. Agencies no longer saw the value added in the delivery of the individual agency mandates through FREMP relative to delivery of their individual mandates (e.g. the partnership was no longer greater than the sum of its parts)
6. Insufficient direction from senior management committee
    a. No collective overview vision of how estuary should function (physical processes) and how that could guide conservation organizations
7. Lack of adequate habitat protection and restoration
    a. Habitat banking program inadequate with no overall net gain in functioning habitat

b. Failed to notice that brackish marshes have receded from 1989 to 2011

Below is an outline of a potential co-governance structure for the study region that was created by participants in the survey and workshop. Co-governance does not necessarily require a legislated framework, but participants in our survey and facilitated workshop saw legislation as a way to make long term political and funding commitments more likely, and thus to provide long-term benefits to species of conservation concern in the study region. This conceptual model does not address the recognition of Indigenous law or sovereignty, or reform of existing Canadian laws, which would both be necessary in practice. It simply assumes coordination of policy, research and monitoring across different orders of government, sustained funding, and communications. Its purpose is not to define an ideal governance structure for the region, but rather to provide a proxy to estimate how improved coordination, funding and communications might improve outcomes related to management strategies for species of conservation concern.

Outline for a Fraser River Estuary Act
Establish a Fraser River Estuary Federal-Provincial Act for the long-term protection of species and ecosystems of conservation concern. See the "Great Lakes Water Quality Agreement" (available at https://www.canada.ca/en/environment-climate-change/services/great-lakes-protection/2012-water-quality-agreement/appendix.html) for an example of what such legislation could look like.

The resulting governance structure supported by this act would have the following attributes:

1. Representation - Clear enunciation of the roles of partners and advisory committees.
2. The core partners would be:
    a. First Nations and appropriate federal, provincial, and municipal governmental agencies.
    b. An advisory committee consisting of NGOs, scientists and members of the public.

Vision

1. Develop a clear vision for the program and clarity around how it would be integrated with other agency programs.
2. Provide a common rationale and goals behind conserving species and ecosystems. For example, the 2006 'A Living, Working River' report (available at http://www.dfo-mpo.gc.ca/library/349044.pdf) was widely accepted by all FREMP partners

Programs & Responsibilities
Mandate to developing coordinated procedures for:

1. Project review.
2. Area designation and habitat mapping.
3. Management of policies and guidelines.
4. Standardized open-access databases.
5. Managing species recovery plans in conjunction with partners.
6. Collaborating and knowledge sharing across partners and advisory committees.

Funding

1. Enabling legislation to ensure that funding for a management program would not be subject to changes in government.
2. Prepare an annual business plan for the program, including measurable results leveraged with industry and public actions.
3. .

Data Sharing

1. Establish an integrated research and monitoring sharing hub to follow on and build upon the Community Mapping Network (cmnbc.ca).
2. Manage data to ensure long-term and open-access.

Communications and Outreach

1. Establish pathways to involve public engagement.
2. Ensure datasets are widely disseminated.
3. Reporting: highlight publicly the achievements of the co-governance authority regarding species recovery.

As well, participants noted the following considerations in relation to staff that would support the program:

1. Committed involvement from high-level governmental employees and representatives.
2. Appropriate staff dedicated to program activities including experienced field staff.
3. Cultivate long-term staff and members to establish dependability and trust among partners and to make for a more effective long-term partnership.
4. Strong political, management, and policy commitment to the program.

Appendix S5: **A Closer Look at Species Groups from Tiger Beetles to Killer Whales**

Species groups benefited from management to different degrees. The Coastal Sand species group was predicted to experience the least benefit from management compared to all other groups (Fig. 2, 50% persistence probability at baseline, 57% persistence probability with management, species: Audouin's night-stalking tiger beetle, and Silky beach pea). The Marine Mammal group, which contains one species, the southern resident killer whale, only reached a 51% probability of persistence when all strategies were undertaken (without co-governance, Fig. 2). However, when co-governance is included, fewer strategies were needed to yield the same probability of persistence for this species (either a combination of Aquatic Habitat Restoration, Green Infrastructure, and Pollution Control, or a combination of Aquatic Habitat Restoration, Fisheries Regulation, and Disease Control, Dataset S3). The largest benefit seen in any species group was found in Anadromous Fishes, with an increased probability of persistence of 21% when undertaking all strategies plus co-governance (45% under baseline to 66%, Fig. 2).

Appendix S6: Uncertainty Analysis

We find a substantial range between individual experts' benefits estimates of the probability of persistence of species groups in our study region (Fig. S5). The lower estimates of individual expert predictions for the 'best guess' baseline scenario show that no species groups would have a 50% probability of persistence, whereas the higher end of individual estimates indicate that all groups reach this threshold. This wide uncertainty is found across our management strategies and scenarios of best guess, optimistic, and pessimistic scenarios (Fig. S5).

When taking the average estimate from all individual experts in order to calculate the species persistence probabilities, there is substantial differences between best guess, optimistic and pessimistic scenarios. Under the optimistic, most likely, and pessimistic scenarios, the average probability of persistence when undertaking all management strategies across all species groups is 44%, 60%, and 74% respectively (Dataset S3). In a pessimistic (lower bound) scenario, the only way in which a species group could reach a 50% persistence threshold is when undertaking all management strategies, and even then, only two species groups reach this threshold (Fig. S6, Landbirds, n = 3, and Wetland Residents, n = 16). On the other hand, in the optimistic scenario, all species reach a 50% probability of persistence without implementation of our identified management strategies (i.e. baseline scenario, Fig. S6). When implementing Public Land Management and Fisheries Regulation at a total cost of $161M, 11 of 13 species groups reach a 70% threshold of persistence (Fig. S6, one species group, Anadromous Fishes, reaches this threshold under baseline). When implementing all management strategies, Marine Mammal and Grassland species groups both achieve a 68% probability of persistence (Dataset S3). By combining all management and co-governance four species groups reach an 80% probability of persistence threshold (Dataset S3, Landbirds, n = 3; Freshwater = 11; Anadromous Fishes = 12; and Wetland Resident species, n = 16). The implementation of co-governance was the only way in which two of these species groups reach an 80% probability of persistence (Freshwater & Wetland Residents, Dataset S3).

The largest change in cost-effectiveness rank is under an optimistic scenario, where Public Land Management moves from the 12^{th} ranked strategy to the 10^{th} (out of 14 strategies, Table S3). Green Infrastructure is the only strategy that improves its rank in both optimistic and pessimistic scenarios (from 10^{th} to 9^{th} position). The cost-effectiveness rank of strategies remains the same with and without co-governance except for Fisheries Regulation and Public Land Management (the 11^{th} and 12^{th} ranked strategies, respectively), which switch rank position under implementation of co-governance.

Appendix S7: **Acknowledgements**

Our participatory approach requires the input and collaboration from a broad group of professionals. We are particularly grateful to the many ecological experts who shared their expertise on species of conservation concern and strategy design, cost, feasibility, and benefits, specifically we would like to thank: Aidan Neill (Lower Fraser Fisheries Alliance), Aimee Mitchell (Athene Ecological), Amanda Rodewald (University of British Columbia), Andrea MacLeod (Vancouver Fraser Port Authority), Andrew Robinson (Environment and Climate Change Canada), Anna Mathewson (City of Surrey), Brent Gurd (BC Ministry of Forests, Lands and Natural Resources), Brian Clark (Ministry of Environment), Brian Riddell (Pacific Salmon Foundation), Carrie Holt (Fisheries and Oceans Canada), Cecilia Wong (Environment and Climate Change Canada), Charlotte Olson (Vancouver Fraser Port Authority), Christianne Wilhelmson (Georgia Strait Alliance), Cynthia Durance (Precision Identification), Dan Buffett (Ducks Unlimited Canada), Deborah Carlson (West Coast Environmental Law), Dianne Ramage (Pacific Salmon Foundation), Elsie Krebs (Environment and Climate Change Canada), Erin Stoddard (BC Ministry of Forests, Lands, and Natural Resource Operations), Gary Williams (GL Williams and Associates), Ivy Whitehorne (Environment and Climate Change Canada), Janson Wong (Lower Fraser Fisheries Alliance), Jeanne Hughes (Lower Fraser Fisheries Alliance), Jill Campbell (Musqueam Indian Band), Kathleen Moore (Environment and Climate Change Canada), Ken Ashley (British Columbia Institute of Technology), Ken Brock (Environment and Climate Change Canada), Laura Sparrow (Musqueam Indian Band), Lindsey Ogston (Tsleil-Waututh Nation), Marcin Pachcinski (Vancouver Fraser Port Authority), Marian Adair (The Nature Trust of British Columbia), Matt Pitcairn (Richmond Chamber of Commerce), Megan Lievesley (BC Conservation Foundation), Mike Brotherston (City of Delta), Oliver Brandes (University of Victoria), Peter Arcese (University of British Columbia), Peter Ross (Vancouver Aquarium), Robert Elner (Simon Fraser University), Rob Butler (Retired Environment and Climate Change Canada), Rob Knight (Ministry of Environment & Community Mapping Network), Ross Dixon (Raincoast Conservation Foundation), Sarah North (Northwest Hydraulic Consultants), Scott Hinch (University of British Columbia), Steven Stark (Tsawwassen First Nation), Thomas Doniol-Valcroze (Fisheries and Oceans Canada), Trevor Andrews (Vancouver Fraser Port Authority), ZoAnn Morten (Pacific Stream Keepers Federation).

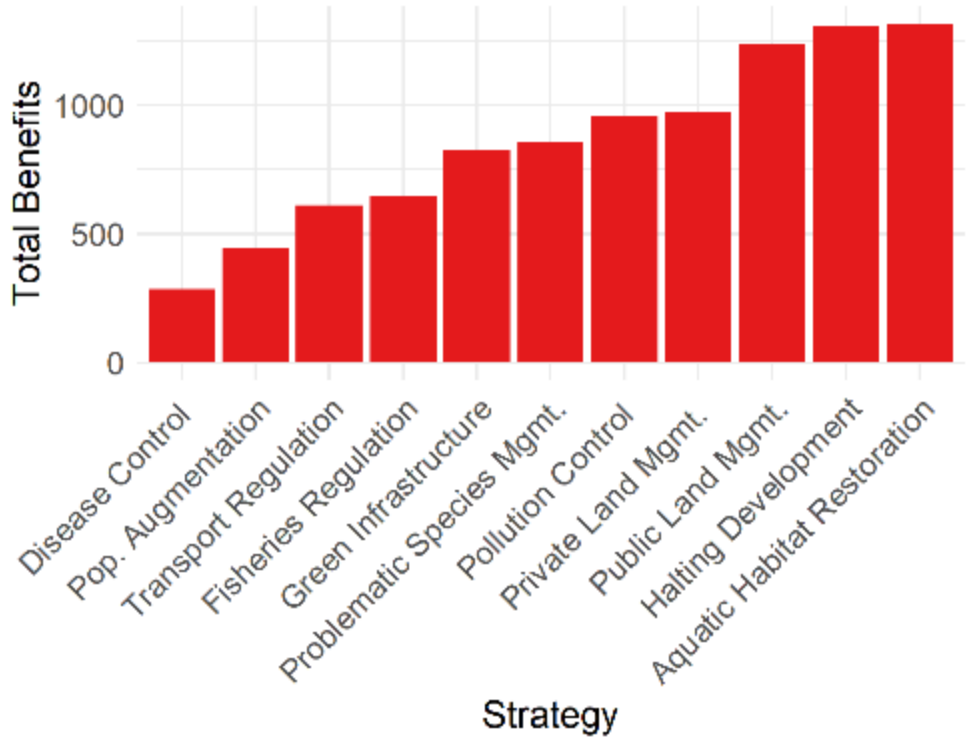
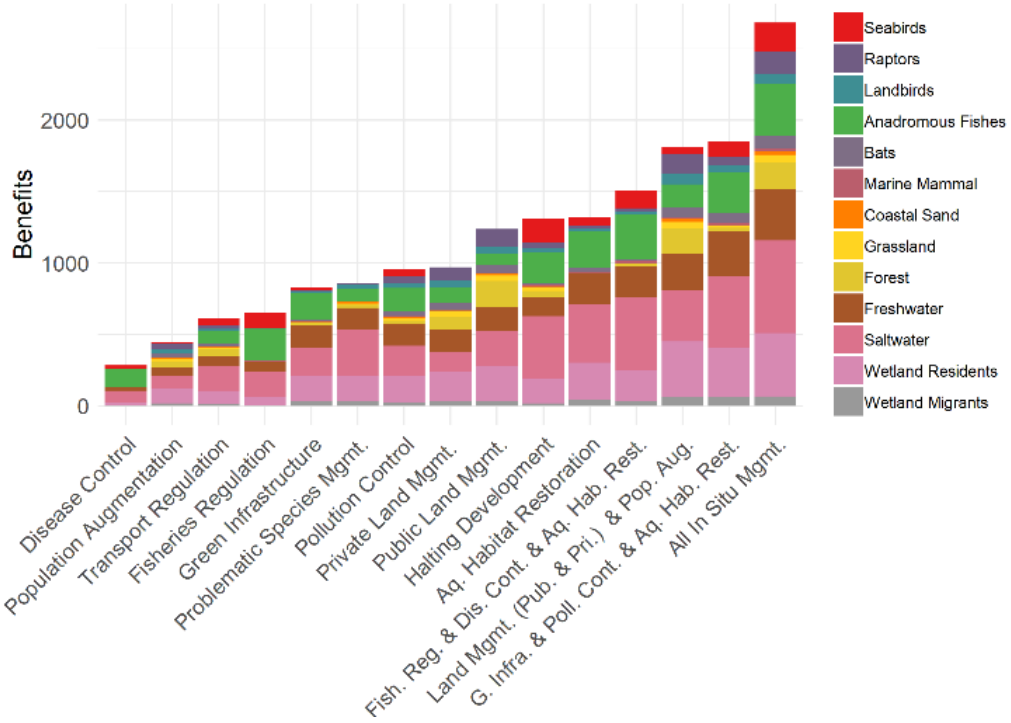


Figure S1. Total benefits for each management strategy and an additional scenario whereby proposed major industrial development within the study area is halted – 'Halting Development'. Benefits are calculated as the sum of the improvement in probability of persistence in 25 years for each species group under each management strategy.

(a)



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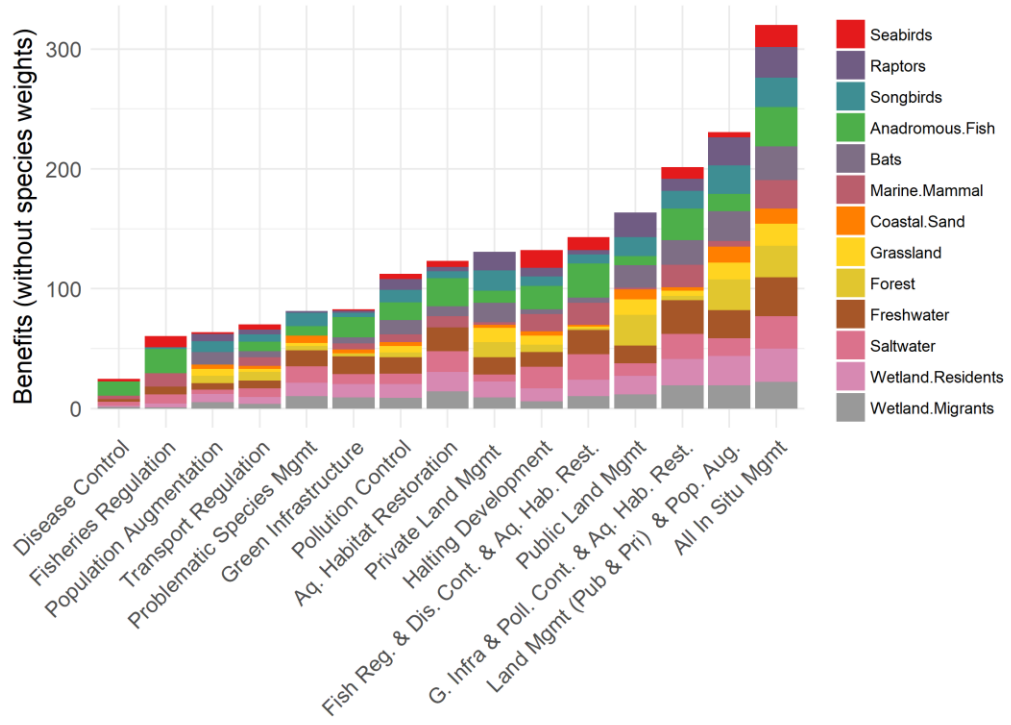

Figure S2. Benefits breakdown by species group and strategy in terms of improvement in probability of persistence from baseline. Estimates given by strategy and species groups. **(a)** benefits estimates are weighted by the number of species in each group, **(b)** benefits estimates are not weighted by the number of species in a group. 'All In Situ Mgmt.' represents the implementation of all ten management strategies.

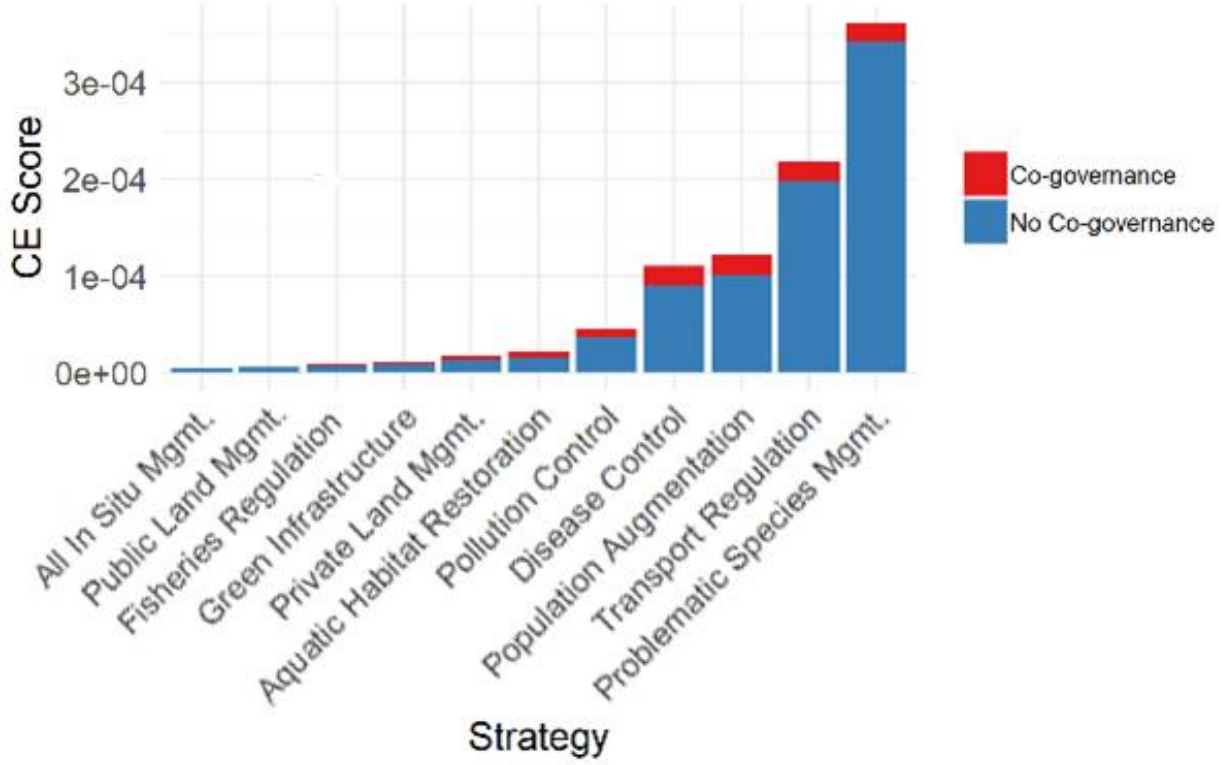

Figure S3. Cost-effectiveness of each management strategy (given by a strategy's: total benefits * feasibility / cost), with and without a co-governance structure in place. 'All In Situ Mgmt.' represents the implementation of all ten management strategies.

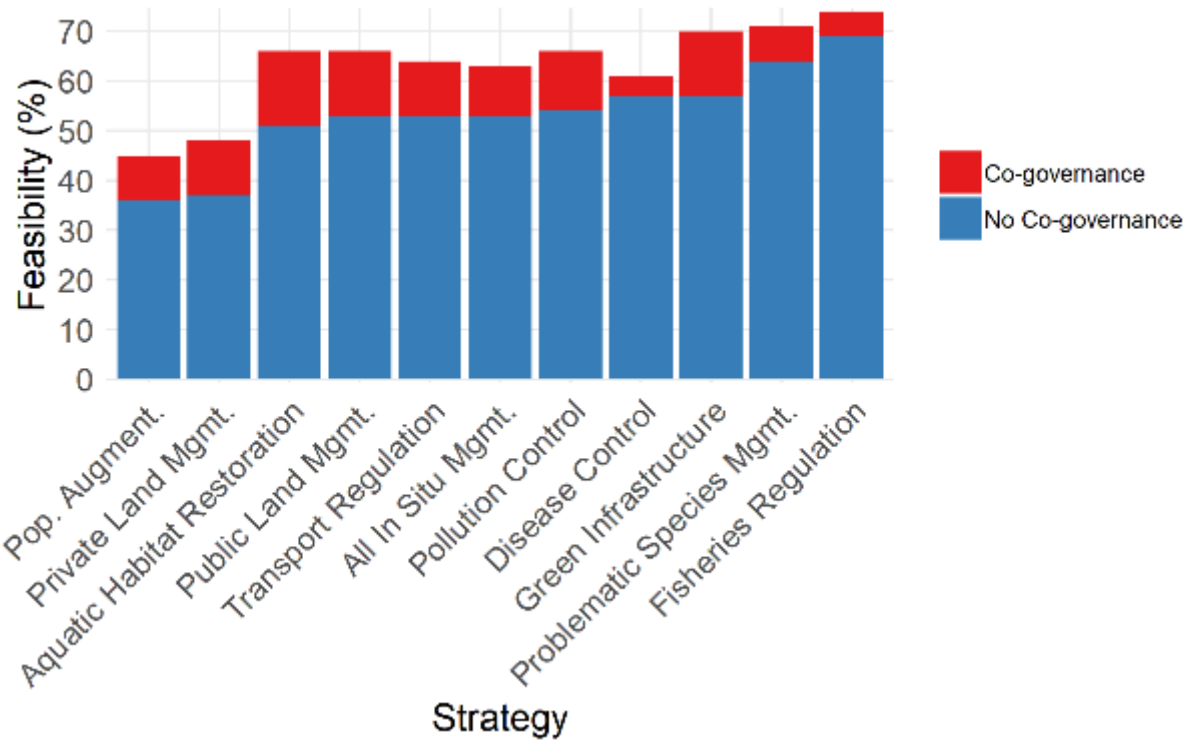

Figure S4. Average feasibility of each management strategy with and without a co-governance structure in place.

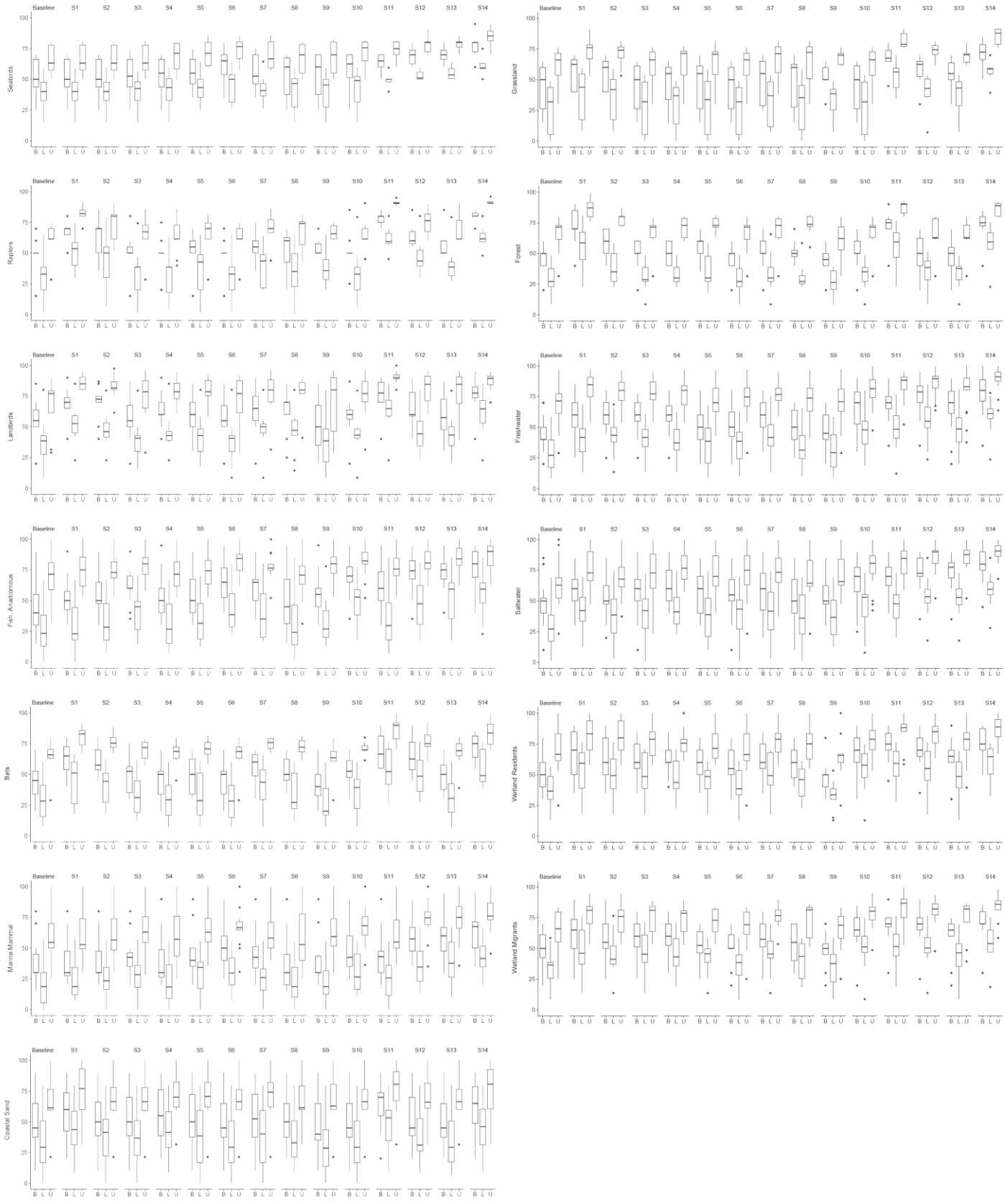
Baseline
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
S14
B L U
Seabirds
Grassland
Raptors
Forest
Landbirds
Freshwater
Fish, Anadromous
Saltwater
Bats
Wetland Residents
Marine Mammal
Wetland Migrants
Coastal Sand

Figure S5. Box plots illustrating the experts' final best-guess, upper and lower bound estimates of the probability of persistence for each species group for each strategy within the next 25 years, B = best guess, L = lower bound estimate, U = upper bound estimate. Strategy key: S1 = Public Land Management; S2 = Private Land Management; S3 = Green Infrastructure; S4 = Problematic Species Management; S5 = Transportation Regulation; S6 = Fisheries Regulation; S7 = Pollution Control; S8 = Population Augmentation; S9 = Aquatic Disease Control; S10 = Aquatic Habitat Restoration; S11 = combination of S1, S2, and S8; S12 = S3 + S7 + S10; S13 = S6 + S9 + S10; S14 = All Strategies

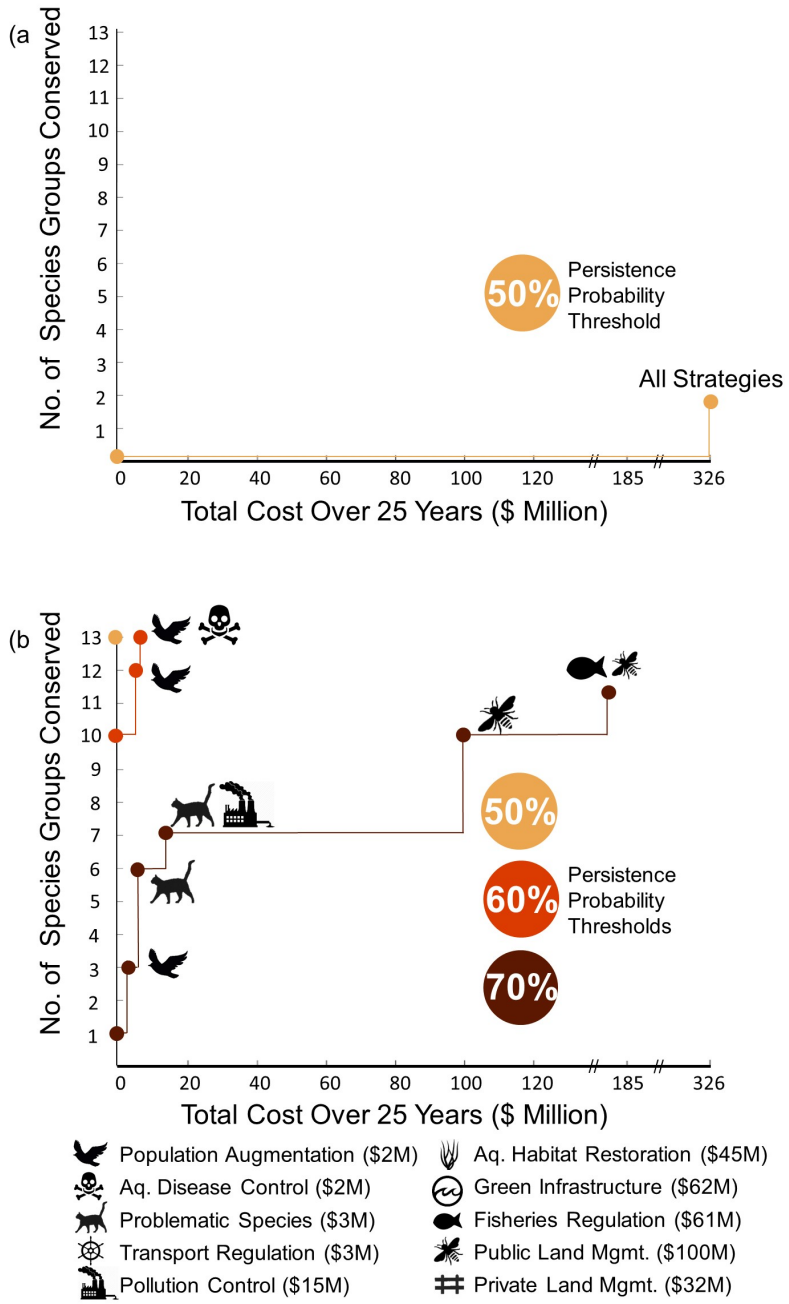

Figure S6. Persistence probabilities under (a) pessimistic and (b) optimistic scenarios for different levels of investment in complementary sets of management strategies. Data points crossing the y-axis (zero cost) represent the number of species groups reaching persistence thresholds under a baseline scenario of no additional management. The 'All Strategies' investment scenario includes all ten management strategies.

Table S1. Species list (n=102) for the Fraser River Estuary Priority Threat Management assessment, categorized by their species group. Within each group, species are sorted alphabetically by Family and then by common name.

Species Group	Family	Common Name	Species Name
Anadromous Fishes (n=12)	Acipenseridae	Green sturgeon	*Acipenser medirostris*
		White sturgeon (Lower Fraser River population)	*Acipense transmontanus* pop. 4
	Osmeridae	Eulachon (Fraser River population)	*Thaleichthys pacificus*
	Petromyzontidae	Pacific lamprey	*Lampetra tridentata*
	Salmonidae	Chinook salmon	*Oncorhynchus tshawytscha*
		Chum salmon	*Oncorhynchus keta*
		Coho salmon	*Oncorhynchus kisutch*
		Cutthroat trout (anadromous)	*Oncorhynchus clarkii*
		Dolly Varden char	*Salvelinus malma*
		Pink salmon	*Oncorhynchus gorbuscha*
		Sockeye salmon	*Oncorhynchus nerka*
		Steelhead trout*	*Oncorhynchus mykiss*
Bats (n=3)	Vespertilionidae	Hoary bat	*Lasiurus cinereus*
		Little brown myotis	*Myotis lucifugus*
		Townsend's big-eared bat	*Corynorhinus townsendii*
Coastal Sand (n=2)	Cicindelidae	Audouin's night-stalking tiger beetle	*Omus audouini*
	Fabaceae	Silky beach pea	*Lathyrus littoralis*
Forest (n=7)	Columbidae	Band-tailed pigeon	*Patagioenas fasciata*
	Liliaceae	Pink fawn lily	*Erythronium Revolutum*
	Lycaenidae	Johnson's hairstreak	*Callophrys johnsoni*
	Polygyridae	Oregon forestsnail	*Allogona townsendiana*
		Pygmy oregonian	*Cryptomastix germana*
	Sematophyllaceae	Roell's brotherella	*Brotherella roellii*
	Valloniidae	Western flat-whorl	*Planogyra clappi*
Freshwater (n=11)	Alismataceae	Wapato	*Sagittaria latifolia*
	Catostomidae	Salish sucker	*Catostomus* sp. 4
	Cyperaceae	Green-fruited sedge	*Carex interrupta*
	Cyprinidae	Nooksack dace	*Rhinichthys cataractae*
	Fabaceae	Streambank lupine	*Lupinus rivularis*
	Libellulidae	Autumn meadowhawk	*Sympetrum vicinum*
	Petromyzontidae	Western brook lamprey	*Lampetra richardsoni*
	Salmonidae	Bull trout	*Salvelinus confluentus* - coastal lineage
		Cutthroat trout (resident)	*Oncorhynchus clarkii*
	Soricidae	Pacific water shrew	*Sorex bendirii*
	Talpidae	American shrew mole	*Neurotrichus gibbsii*
Grassland (n=3)	Apidae	Western bumble bee	*Bombus occidentalis*
	Hirundinidae	Barn swallow	*Hirundo rustica*
	Nymphalidae	Monarch	*Danaus plexippus*

Marine Mammal (n=1)	Delphinidae	Orca (northeast pacific southern resident population)	*Orcinus orca* pop. 5
Raptors (n=6)	Accipitridae	Northern harrier	*Circus cyaneus*
		Rough-legged hawk	*Buteo lagopus*
	Falconidae	Peregrine falcon, anatum subspecies	*Falco peregrinus anatum*
	Strigidae	Short-eared owl	*Asio flammeus*
		Western screech-owl, kennicottii subspecies	*Megascops kennicottii kennicottii*
	Tytonidae	Barn owl	*Tyto alba*
Saltwater (n=24)	Ammodytidae	Pacific sand lance	*Ammodytes hexapterus*
	Anatidae	Brant goose	*Branta bernicla*
	Anatidae	American wigeon	*Anas americana*
	Cancridae	Dungeness crab	*Metacarcinus magister*
	Charadriidae	American golden-plover	*Pluvialis dominica*
		Black-bellied plover	*Pluvialis squatarola*
	Clupeidae	Pacific herring	*Clupea pallasii*
	Osmeridae	Longfin smelt	*Spirinchus thaleichthys*
		Olympia oyster	*Ostrea lurida*
		Pygmy longfin smelt	*Spirinchus thaleichthys*
		Surf smelt	*Hypomesus pretiosus*
	Scolopacidae	Black turnstone	*Arenaria melanocephala*
		Dunlin	*Calidris alpina*
		Red knot	*Calidris canutus*
		Red-necked phalarope	*Phalaropus lobatus*
		Rock sandpiper	*Calidris ptilocnemis*
		Ruddy turnstone	*Arenaria interpres*
		Sanderling	*Calidris alba*
		Short-billed dowitcher	*Limnodromus griseus*
		Surfbird	*Aphriza virgata*
		Wandering tattler	*Heteroscelus incanus*
		Western sandpiper	*Calidris mauri*
		Whimbrel	*Numenius phaeopus*
	Veneridae	Butter clams	*Saxidomus gigantea*
Seabirds (n=11)	Anatidae	Greater scaup	*Aythya marila*
		Harlequin duck	*Histrionicus histrionicus*
		Lesser scaup	*Aythya affinis*
		Long-tailed duck	*Clangula hyemalis*
		Surf scoter	*Melanitta perspicillata*
		White-winged scoter	*Melanitta fusca*
	Gaviidae	Common loon	*Gavia immer*
	Laridae	Caspian tern	*Hydroprogne caspia*
	Phalacrocoracidae	Double-crested cormorant	*Phalacrocorax auritus*
		Pelagic cormorant	*Phalacrocorax pelagicus*

	Podicipedidae	Western grebe	*Aechmophorus occidentalis*
Landbirds (n=3)	Trochilidae	Rufous hummingbird	*Selasphorus rufus*
	Tyrannidae	Olive-sided flycatcher	*Contopus cooperi*
		Willow flycatcher	*Empidonax traillii*
Wetland Migrants (n=3)	Anatidae	Green-winged teal	*Anas crecca*
	Hirundinidae	Purple martin	*Progne subis*
	Scolopacidae	Wilson's phalarope	*Phalaropus tricolor*
Wetland Residents (n=16)	Anatidae	Northern pintail	*Anas acuta*
	Ardeidae	American bittern	*Botaurus lentiginosus*
		Great blue heron, fannini subspecies	*Ardea herodias herodias*
	Asteraceae	Joe pye-weed	*Eutrochium maculatum* var. *bruneri*
		Vancouver island beggarticks	*Bidens amplissima*
	Bufonidae	Western toad	*Anaxyrus boreas*
	Callitrichaceae	Two-edged water-starwort	*Callitriche heterophylla* var. *heterophylla*
	Emydidae	Painted turtle - pacific coast population	*Chrysemys picta* pop. 1
	Hesperiidae	Dun skipper	*Euphyes vestris*
	Juncaceae	Pointed rush	*Juncus oxymeris*
	Poaceae	Slender-spiked mannagrass	*Glyceria leptostachya*
	Scrophulariaceae	False-pimpernel	*Lindernia dubia* var. *dubia*
	Malvaceae	Henderson's checker-mallow	*Sidalcea hendersonii*
	Ranidae	Northern red-legged frog	*Rana aurora*
	Scrophulariaceae	Pink water speedwell	*Veronica catenata*
	Soricidae	Olympic shrew	*Sorex rohweri*

- Rainbow trout (genetically identical non-anadromous form) also included but not listed separately as they are designated as the same species - *Oncorhynchus mykiss*

Table S2 Number of experts who provided estimates for each species group and management strategy. S0 = Baseline (full strategy key given in Table S3 legend)

Species Group	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Bats	8	8	8	8	8	8	8	8	7	7	8	8	8	8	8
Coastal Sand	8	8	8	8	8	8	8	8	7	7	8	8	8	8	8
Raptors	9	9	9	9	9	9	9	9	8	6	9	7	7	7	7
Anadromous Fishes	15	15	15	15	15	15	15	15	14	14	15	14	15	15	15
Forest	9	9	9	9	9	9	9	9	8	6	9	7	7	7	7
Grassland	8	8	8	8	8	8	8	8	7	5	8	6	6	6	6
Marine Mammal	13	11	11	12	10	13	13	12	9	11	12	11	12	12	12
Pelagic Seabirds	8	8	8	8	8	8	8	8	7	7	8	6	6	6	6
Freshwater	19	19	19	19	19	19	19	19	18	18	19	17	18	18	18
Saltwater	19	19	19	19	19	19	19	19	18	16	19	15	16	16	16
Landbirds	10	10	10	10	10	10	10	10	9	7	10	8	8	8	8
Wetland Migrants	10	10	10	10	10	10	10	10	9	8	10	8	9	9	9
Wetland Residents	13	13	13	13	13	13	13	13	12	9	13	10	11	11	11

Table S3 Strategy cost-effectiveness rank in terms of optimistic and pessimistic scenarios cost range. High cost refers to maximum cost estimates for Fisheries Regulation and Green Infrastructure - no changes in rank were found for low cost estimates. Numbers in brackets indicate change in rank. For example, S3 (Green Infrastructure) is the only strategy that improves its rank in both optimistic and pessimistic scenarios. Strategy key: S1 = Public Land Management; S2 = Private Land Management; S3 = Green Infrastructure; S4 = Problematic Species Management; S5 = Transportation Regulation; S6 = Fisheries Regulation; S7 = Pollution Control; S8 = Population Augmentation; S9 = Aquatic Disease Control; S10 = Aquatic Habitat Restoration; S11 = combination of S1, S2, and S8; S12 = S3 + S7 + S10; S13 = S6 + S9 + S10; S14 = All Strategies

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Optimistic	10 (+2)	7	9(+1)	1	2	12	5	3	4	6	13	11(-2)	8	14
Best Guess	12	7	10	1	2	11	5	3	4	6	13	9	8	14
Pessimistic	12	7	9(+1)	1	2	11	5	3	4	6	13	10(-1)	8	14
High Cost	11(+1)	7	10	1	2	13 (-2)	5	3	4	6	12(+1)	9	8	14

Dataset S1. Species threat database

Dataset S2. Full costings and feasibility spreadsheet for each management strategy

Dataset S3. Species probability of persistence