Supplemental Materials

Appendix 1. Data Tables Referred to in the Book

Appendix 2. Estuaries and Other Water Bodies Mentioned in the Book and Appendix 1, with Geographic Information and Coordinates

Appendix 3. Estuary Primer: An Overview of Salmonids and Estuarine Ecosystems for Citizen Scientists

Appendix 4. Additional Literature Consulted

Appendix 5. Colour Photos Linked to Figures in the Book

Appendix 1

Data Tables Referred to in the Book

Note: References marked with an asterisk are listed in the References section of the main book. All other references are listed in Appendix 4.

Appendix Table 1.1. Salmonids known to utilize estuaries, with their geographic range (native, invaded) and conservation status as of August 2012 in selected international, national, and regional listings. Websites accessed for information on current conservation status (as of August 2012) are as follows:

CDC (BC). Conservation Data Centre, Ministry of Sustainable Resource Management, British Columbia. http://www.env.gov.bc.ca/cdc/.

COSEWIC. Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.gc.ca/eng/sct5/index_e.cfm.

EC Habitats Directive (Annex II). Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. http://jncc.defra.gov.uk/page-1374.

ESA. Endangered Species Act (US). http://www.nmfs.noaa.gov/pr/laws/esa/.

IUCN. International Union for Conservation of Nature (Red Listing category). http://www.iucnredlist.org/technical-documents/categories-and-criteria.

Japan. Nature Conservation Bureau, Ministry of the Environment (expands IUCN Red List model). http://www.stateofthesalmon.org/resources/endangered_listings/.

OSPAR Convention. The Convention for the Protection of the Marine Environment of the North-East Atlantic. http://www.ospar.org/.

Russia. Ministry of Nature of Russia, Commission for Rare and Endangered Animals, Plants, and Fungi (expands IUCN Red List model). http://www.stateofthesalmon.org/resources/endangered_listings/.

Species name (common name)	Geographic range of self-reproducing populations (from Fish Base and Groot and Margolis 1991)	Conservation status CDC (BC) / COSEWIC / ESA / EC Habitats Directive / IUCN / Japan / OSPAR / Russia
Hucho perryi (Sakhalin taimen)	Northwest Pacific: Hokkaido to Primorskii Krai, Russian Far East	IUCN. Critically Endangered. Japan. National: Endangered. Hokkaido Prefecture: Critically Endangered. Russia. National: Category 2 (decreasing in number).

Oncorhynchus clarkii (cutthroat trout)	North Pacific: Northern California to Prince William Sound, Alaska	IUCN. Not yet assessed. CDC (BC). Blue (special concern). ESA. Threatened.
Oncorhynchus gorbuscha (pink salmon)	North Pacific and Arctic: Korea to Chukotka, Russia; central California to Point Barrow, Alaska; Iceland, Norway, and northwest Arctic coast of Russia	IUCN. Not yet assessed.
Oncorhynchus keta (chum salmon)	North Pacific and Arctic: Korea to the Laptev Sea; Monterey, California, to Mackenzie River, Northwest Territories; Chile	ESA. Threatened: Columbia River, Washington-Oregon; Hood Canal, Washington summer run. IUCN. Not yet assessed.
Oncorhynchus kisutch (coho salmon)	North Pacific and Arctic: Korea to Chukotka, Russia; central California to Kotzebue Sound, Alaska. Introduced to Europe and South America (Chile).	COSEWIC. Endangered: Interior Fraser River, British Columbia, population. ESA. Endangered: Central California coast. Threatened: Lower Columbia River, Washington-Oregon, Oregon coast, Southern Oregon and Northern California coasts. IUCN. Not yet assessed.
Oncorhynchus masou ishikawae (amago)	Honshu Island, Japan	Nomenclature from Oohara and Okazaki 1996. Japan. National: Near Threatened (earlier nomenclature named subspecies *rhodurus* as near threatened). IUCN. Not yet assessed.
Oncorhynchus masou masou (masu)	Northwest Pacific: Korea to Kamchatka	Nomenclature from Oohara and Okazaki 1996. IUCN. Not yet assessed. Japan. National: Threatened. Russia. Khabarovsk Territory: Category 2 (decreasing in number). Northern Far East of Russia: Category 3 (rare).

Oncorhynchus mykiss (steelhead)	North Pacific: Southern California to Kamchatka; northwest and northeast Atlantic; Argentina	ESA. Endangered: Southern California. Threatened: Puget Sound, Central California coast, Snake River basin, Idaho; Upper Columbia River, Middle Columbia River, Lower Columbia River, Washington-Oregon, Upper Willamette River, Oregon, Northern California, South-Central California coast, California central valley. IUCN. Not yet assessed. Russia. National: Category 3 (rare). Northern Far East of Russia: Category 2 (decreasing in number). Khabarovsk Territory: Category 3 (decreasing in number).
Oncorhynchus nerka (sockeye salmon)	North Pacific and Arctic: Northern Japan to Chukotka, Russia; central California to Kotzebue Sound, Alaska	COSEWIC. Endangered: Cultus Lake, British Columbia, population; Sakinaw Lake, British Columbia, population. ESA. Endangered: Snake River. Threatened: Ozette Lake. IUCN. Least Concern. Japan. National: Extinct: ssp. *kawamurae.* Hokkaido Prefecture: Critically Endangered.
Oncorhynchus tshawytscha (Chinook salmon)	North Pacific and Arctic: Northern Japan to Chukotka, Russia; central California to Kotzebue Sound, Alaska; New Zealand; Chile, Argentina	COSEWIC. Threatened: Okanagan River, British Columbia, population. ESA. Endangered: Upper Columbia River spring run, Washington-Oregon; Sacramento River, California, winter run. Threatened: California coastal, Central Valley, California, spring run, Lower Columbia River Washington-Oregon, Puget Sound, Washington, Snake River, Idaho falls and spring/summer run, Upper Willamette River, Oregon. IUCN. Not yet assessed.

Salmo salar (Atlantic salmon)	Atlantic Ocean. North America: Connecticut to northern Québec; Europe: Portugal to Russia; Faroe Islands; Antarctic Ocean islands	COSEWIC. Extinct population: Lake Ontario (2010). Endangered populations: Anticosti Island, Québec; Eastern Cape Breton, Nova Scotia; Inner Bay of Fundy, Nova Scotia; Nova Scotia Southern Upland; Outer Bay of Fundy, Nova Scotia. EC Habitats Directive (Annex II). Special Area of Conservation (freshwater only). ESA. Endangered: Gulf of Maine Distinct Population Segment (DPS). IUCN. Lower Risk/Least Concern. OSPAR. List of Threatened and/or Declining Species, all locations where it occurs.
Salmo trutta (sea trout)	Atlantic Ocean: Europe (northwest coast); Caspian Sea; Black Sea; Sea of Azov. Successful invader of estuaries on all continents except Africa and Antarctica.	IUCN. Least Concern. **Notes on subspecies**: *Salmo trutta caspius*, Caspian salmon. IUCN. Least Concern. Considered endangered by local authorities (see Niksirat and Abdoli 2009*). *Salmo labrax,* Black Sea salmon. IUCN. Least Concern. Considered endangered by local authorities (e.g., Seyhan et al. 2009). European ecotype: Rare, IUCN. *Salmo trutta aralenis,* sea trout from the Aral Sea, considered extinct (Ermakhanov et al. 2012).
Salvelinus alpinus (Arctic char)	North Atlantic Ocean, Arctic Ocean	IUCN. Least Concern.
Salvelinus confluentus (bull trout)	Northeast Pacific Ocean	IUCN. Vulnerable. CDC (BC). Blue (special concern). ESA. Threatened (National).
Salvelinus fontinalis (brook trout)	Northwest Atlantic Ocean; Chile, Argentina	IUCN. Not yet assessed. Recovery programs for reduced populations of anadromous form are under way in United States (Eastern Brook Trout Joint Venture 2014*)

Salvelinus malma (Dolly Varden)	Northwest Pacific: Korea to Bering Sea; Arctic and Northeast Pacific: Alaska to Puget Sound	CDC (BC). Blue (special concern). COSEWIC. Special Concern: Western Arctic population. IUCN. Not yet assessed. Japan. National: Near Threatened: ssp. *kraschenninnikovi, miyabei.*
Salvelinus namaycush (lake trout)	Canadian Arctic Ocean	IUCN. Not yet assessed.
Salvelinus leucomaenis (White spotted char)	Northwest Pacific: Korea to Bering Sea	IUCN. Not yet assessed. Japan. National: Threatened local population: ssp. *imbrius, japonicus.*

Appendix Table 1.2. Fish communities in selected salmonid estuaries in the Northern and Southern Hemispheres. [1] = invasive species; n.a. = not available.

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
Northwest Pacific Ocean							
Bol'shaya River estuary, Russia	Riverine channel	Chum salmon, chinook salmon, coho salmon, pink salmon, steelhead, sockeye salmon, Dolly Varden, masu, White spotted char, starry flounder (*Platichthys stellatus*), flathead sculpin (*Megalocottus platycephalus platycephalus*), three- and nine-spine stickleback (*Gasterosteus aculeatus, Pungitius pungitius*), Arctic rainbow smelt (*Osmerus mordax dentex*)	31 species, >1,000 individuals	Beach seine, cast net, gillnet	Agonidae Ammodytidae Cottidae Clupeidae Gadidae Gasterosteidae Osmeridae Petromyzontidae Pleuronectidae Trichodontidae	None	Tokranov 1994*
Northeast Pacific Ocean							

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
Fraser River estuary, British Columbia	Riverine channel	Peamouth chub (*Mylocheilus caurinus*), starry flounder (*Platichthys stellatus*), three-spined stickleback (*Gasterosteus aculeatus*), longnose (*Rhinichthys falcatus*) and leopard dace (*R. cataractae*), Chinook salmon, largescale sucker (*Catostomus macrocheilus*), staghorn sculpin (*Leptocottus armatus*), northern squawfish (*Ptychocheilus oregonensis*), coho salmon, longfin smelt (*Spirinchus thaleichthys*), chum salmon, mountain whitefish (*Prosopium williamsoni*), rainbow trout, white sturgeon (*Acipenser transmontanus*), common carp (*Cyprinus carpio*),[1] brown bullhead (*Ictalurus nebulosus*),[1] black crappie (*Pomoxis nigromaculatus*),[1] pink salmon, sockeye salmon, Dolly Varden, cutthroat trout, eulachon (*Thaleichthys pacificus*), white greenling (*Hexagrammos stelleri*)	33 species, >1,000 individuals	Beach seine, gillnet	Acipenseridae Ammodytidae Clupeidae Coregonidae Cottidae Clupeidae Embiotocidae Gadidae Gasterosteidae Hexagrammidae Osmeridae Stichaeidae Pleuronectidae	Centrarchidae Cyprinidae Ictaluridae	Richardson et al. 2000*
Baltic Sea							

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
Neva River estuary, Russia	Primarily riverine channel	Atlantic salmon, sea trout, steelhead,[1] river lamprey (*Lampetra fluviatilis* L.), Atlantic vendace (*Coregonus albula* L.), whitefish (*Coregonus lavaratus* L.), Baltic vimba (*Vimba vimba* L.), eel (*Anguilla anguilla* L.), European smelt (*Osmerus eperlanus* L.), pike (*Esox lucius* L.), bream (*Abramis brama* L.), pike perch (*Sander lucioperca* L.), burbot (*Lota lota* L.), three-spined stickleback (*Gasterosteus aculeatus* L.) nine-spined stickleback (*Pungitius pungitius* L.), sterlet (*Acipenser ruthenus* L.),[1] Siberian sturgeon (*Acipenser baerii* Brandt),[1] four species[1] of whitefish: *Coregonus autumnalis migratorius* Georgi, *C. nasus* Pallas, *C. muksun*, *C. peled* Gmelin; catfish (*Catostomus rostratus* Tilesius),[1] carp (*Cyprinus carpio* L.),[1] Amur sleeper (*Perccottus glenii* Dyb),[1] flounder (*Pleuronectes flesus*), eelpout (*Zoarces viviparous*), burbot (*Lota lota*)	60 species	n.a.	Anguillidae Clupeidae Coregonidae Cottidae Cyprinidae Esocidae Gadidae Gasterosteidae Lotidae Osmeridae Percidae Petromyzontidae Pleuronectidae Zoarcidae	Acipenseridae Catostomidae Coregonidae Cyprinidae Odontobutidae Salmonidae	Telesh et al. 2008*

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
Northwest Atlantic							
Miramichi River estuary, New Brunswick	Primarily riverine channels	Atlantic salmon, brook trout, fundulids (*Fundulus diaphanous* and *F. heteroclitus*), sticklebacks (*Gasterosteus aculeatus, Apeltes quadracus,* and *Pungitius pungitius*), Atlantic silversides (*Menidia menidia*), white perch (*Morone americana*), golden shiner (*Notemigonus crysoleucas*)	47 species	Seining, trawling, trapnet	Ammodytidae Anguilidae Atherinopsidae Bothidae Catostomidae Clupeidae Cottidae Cyclopteridae Cyprinidae Cryptacanthodidae Fundulidae Gadidae Gasterosteidae Ictaluridae Labridae Moronidae Osmeridae Percidae Petromyzontidae Pholidae Pleuronectidae Rajidae Scombridae Stichaeidae Stromateidae Zoarcidae	None	Hanson and Courtenay 1995*
Arctic and Near Arctic							

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
Estuaries of the Kara and Livar-Yakha Rivers, Russia	n.a.	Arctic char, Atlantic salmon, pink salmon,[1] Siberian cisco (*Coregonus sardinella*), whitefish (*Coregonus* spp.), capelin (*Mallotus villosus*), Atlantic herring (*Clupea harengus*), Arctic rainbow smelt (*Osmerus modax dentex*), Arctic cod (*Boreogadus saida*), navaga (*Eleginus nawaga*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*), four-horned sculpin (*Myoxocephalus quadricornis*), lumpfish (*Cyclopterus lumpus*), Arctic flounder (*Liopsetta glacialis*), Arctic cisco (*Coregonus autumnalis*)	15 species	Mostly beach seines	Clupeidae Coregonidae Cottidae Cyclopteridae Gadidae Osmeridae	Salmonidae	Semushin and Novoselov 2009*
Southern Hemisphere							
Kakanui River estuary, New Zealand	Mud and sand flats, gravel	Sea trout,[1] steelhead,[1] Chinook salmon,[1] cockabullies (*Tripterygion nigripenne*) and common bullies (*Gobiomorphus cotidianus*), yellow-eyed mullet (*Aldrichetta forsteri*), giant bully (*Gobiomorphus gobioides*), common smelt (*Retropinna retropinna*), short-	20 species	Beach seines, fyke nets	Anguillidae Cheimarrichthyidae Clupeidae Eleotridae Galaxiidae Gempylidae Geotriidae Labridae Leptoscopidae Mugilidae	Salmonidae	Jellyman et al. 1997*

Region	Habitat type	Salmonids present and other species of note	Sample size	Sampling method and equipment	Native fish families found with salmonids	Invasive fish families	References
		finned eel (*Anguilla australis*), long-finned eel (*Anguilla dieffenbachii*), inanga (*Galaxias maculatus*), black flounder (*Rhombosolea retiaria*)			Pleuronectidae Retropinnidae Tripterygiidae		

Appendix Table 1.3. Selected equipment used for harvesting, sampling, or observing salmonids in estuaries around the world. F = fry, S = smolts, A = adult. Number of “+” under frequency indicates common to rarely used. “+” or “–“ under life stage indicates whether or not the technique is applicable.

Equipment	Frequency of use	Limitations	F	S	A	References or examples of deployment
Angling	++	Can be difficult to estimate population size	–	–	+	Hvidsten et al. 2000*
Baited traps	+	Work well in low-salinity areas	+	+	–	Johnson et al. 1992
Beach seine	+++++	Effective on gently sloping soft beach substrate	+	+	+	See Jaenicke et al. 1985 for deployment in pairs; Levings, McAllister, and Chang 1986;* see Tay District Salmon Fisheries Board 2014 for example of use in fishery for adults.
Block net	+	Useful for enumerating density in a specific habitat	+	+	+	Toft et al. 2007*
Bottom (benthic) trawling,including beam trawling	+	Not effective for salmonids unless water is very shallow	–	+	+	Lobry et al. 2008* Nicolas et al. 2010*
Cast net	+	Often used in estuaries of the Russian Far East	+	+	–	Tokranov 1994*
Dip nets	++	Depends on visual sightings of schools	+	–	–	Hiwatari et al. 2011*
Electrofishing	+	Effective only in fresh water	+	+	–	Friesen et al. 2007*
Fixed trap, bag, weir or “pound net”	++	Used in industrial fishing	–	–	+	Fixed and therefore cannot be used in distributional work; Elliott and Hemingway 2002
Fyke nets	++++	Most effective when used in a constrained area, e.g., tidal creeks, but can also be used to capture fish moving along a shoreline	+	+	+	Craig et al. 1985; Hanson and Courtenay 1995;* Levy and Northcote 1982*
Gillnets	+++	Effectiveness varies with mesh size	–	+	+	Fraser et al. 1982;* Levy and Levings 1978*

Equipment	Frequency of use	Limitations	F	S	A	References or examples of deployment
Inclined plane traps	+	Most effective when tides and river currents are strong enough to move fish over the trap screen	+	+	–	Bussanich et al. 2009
Pole seine	+++	Most effective when used in a constrained area, e.g., tidal creek	+	+	–	Maier and Simenstad 2009*
Portable beach with beach seine	+	Useful in very shallow water; consists of two plywood sheets hinged over a small shallow-draft boat	+	+	–	Macdonald 1984*
Purse seining	+++	Difficult to use in shallow water	+	+	–	Argue et al. 1986; Johnsen and Sims 1973; Levings 1982*
Push net	+	Used for juvenile Chinook salmon	+	+	–	Raquel 1996
Snorkel or scuba	+++	Effectiveness limited by turbidity and species identification problems	+	+	+	Haggarty 2001; Iwata and Komatsu 1984;* Macdonald et al. 1987;* Toft et al. 2007*
Sonar	+	Extensive calibration required	–	–	+	Gerasimov et al. 2004; Xie et al. 2005*
Stake net	+	Historically used in the Tay River estuary, Scotland	–	–	+	Tay District Salmon Fisheries Board 2014
Surface or mid water trawling	+++	Difficult to operate vessels in estuarine channels	+	+	–	Hvidsten et al. 1992; Levings 2004;* Magie et al. 2010
Video camera	+	Water clarity	–	+	–	Borgstrøm et al. 2010; Sonoma County Water Agency 2014

Appendix Table 1.4. Selected equipment or method used to tag, mark, or identify salmonids in estuaries. F = fry, S = smolts, A = adult. Number of “+” under frequency indicates common to rarely used. “+” or “–“ under life stage indicates whether or not the technique is applicable.

Equipment	Frequency of use	Limitations	F	S	A	References or examples of deployment
Hydroacoustic tags	+ +	Technology is steadily improving but limited for fry due to size; needs to be inserted in body cavity	–	+	+	Chittenden et al. 2008;* Harnish et al. 2012;* McMichael et al. 2010, 2013; Rechisky et al. 2012;* Solomon and Potter 1988*
PIT tags	++	Recent advances in technology have helped reduce salinity effects for detection; needs to be inserted in body cavity	–	+	+	Used to investigate cutthroat trout and Chinook salmon movements in an estuary (Hering et al. 2010;* Krentz 2007*)
Fin clips	++	May harm fish in some circumstances	+	+	+	Mason 1974
Floy tag, Carlin tag	+	Other types of dart or skin-inserted tags are also used	–	–	+	Smith and Smith 1997*
Dye marking	+ +	Works well in low-salinity areas	+	+	–	Levy et al. 1982*
Fluorescent grit spray	+	May harm fish in some circumstances	+	+	–	Levings et al. 1983

Appendix Table 1.5. Representative growth data (ranges) for juvenile or sea-run salmonids in estuaries (mm • d^{-1}). Where available, specific growth rate (SGR) data are also given. Method for growth estimation is indicated by superscripted numbers: 1 = marked or tagged fish; 2 = scales or otoliths; 3 = change in length over time; 4 = includes older age classes of repeat sea-run migrants.

Species	**Growth rate (mm • d^{-1}) or percent for SGR**	**Location**	**Comments**	**References**
Arctic char[1, 4]	1.03–1.49 SGR 1.4–1.5	Northern Norway, Svalbard	Includes coastal habitat; post-smolts and older fish	Finstad and Heggberget 1993; Gulseth and Nilssen 2001; Rikardsen et al. 2000*
Atlantic salmon[3, 2]	0.23–2.03	Newfoundland and Labrador; Russia; Québec	Parr, smolts	Cunjak 1992;* Kazakov 1994;* Power 1969*
Brook trout[1, 2, 4]	0.03–0.66 SGR 0.08–0.42	Rivers on Cape Cod, Massachusetts; Sainte Marguerite River estuary, Québec; Lac Guillaume-Delisle, Québec.	1 and 2 years old	Dutil and Power 1980; Mullan 1958; Morinville and Rasmussen 2003; Thériault and Dodson 2003
Bull trout[3, 4]	1.2	Puget Sound, Washington	Likely includes coastal habitat; post-smolts and older fish	Goetz et al. 2004
Chinook salmon[1, 2]	0.07–1.32	Oregon, California, British Columbia	Fry, pre-smolts	Healey 1991;* Reimers 1973;* MacFarlane 2010;* Volk et al. 2010*
Chum salmon[1]	0.84–1.13	Hokkaido, Japan	Hatchery fish, includes coastal habitat	Mayama 1985
Chum salmon[3]	0.5–1.0	British Columbia; Sakhalin Island, Russia	Fry	Healey 1980b;* Karpenko 2003*
Coho salmon[1]	0.25–0.44	British Columbia, Oregon	Fry	Atagi 1994; Miller and Sadro 2003*
Cutthroat trout[4]	0.45–28 SGR	Oregon	2- and 3-year-old fish	Zydlewski et al. 2009
	0.83–1.5	Oregon	1-4-year-old fish	Johnson 1982; Tomasson 1978

Species	**Growth rate (mm • d^{-1}) or percent for SGR**	**Location**	**Comments**	**References**
Dolly Varden[2]	0.5–2.4	Chukchi region, Russia	Northern form; post-smolts and older fish	Chereshnev et al. 1989; Gudkov 1995
Amago[3]	0.44	Honshu, Japan	Smolts	Kato 1991
Masu [3]	1.85	Hokkaido, Japan	Smolts	Kato 1991
Pink salmon[3]	1.33	Alaska	An outlier for pink salmon estuarine growth	Murphy et al. 1988*
Sea trout[2]	0.4–0.6	Ireland, Argentina, Norway, Netherlands	Includes coastal habitat	Fahy 1985; O'Neal and Stanford 2011* and references therein
Sockeye salmon[3]	0.44	British Columbia, Russia	Fry	Birtwell et al. 1987;* Bugaev and Karpenko 1984*
Steelhead[1]	0.43–0.78	California	Fry and parr	Hayes et al. 2008*
Sakhalin taimen[3, 4]	1.1–1.5	Sakhalin Island, Russia; Hokkaido, Japan	Post-smolts and older fish	Gritsenko et al. 1974;* Kawamula et al. 1983
Whitespotted char[1, 2, 4]	0.85–2.8	Hokkaido, Japan; north coast Okhotsk Sea, Russia	Includes coastal habitat; post-smolts and older fish	Gudkov 1992; Takami et al. 1996

Appendix Table 1.6. List of estuarine salmonids showing gradients in their physiological response to increased salinity as they move from the river to the estuary and ocean. + indicates species with kelts, sea-run migrants; Chinook salmon and masu are included as they may have malture male parr that may survive and breed again (Fleming 1998*).

Species	Distinct parr-smolt transformation?	Example of life history type or location of specialized form benefiting from estuary residence	Comments	Reference
Amago	Yes	Precocious male parr	Smolts enter the estuary in autumn when estuarine waters are cooler.	Nagahama et al. 1982; Ueda et al. 1983.
Arctic char+	Yes, but exceptions	Population in the Skibotn River estuary, Norway, overwinters in the estuary.	Strategy may enable the populations to avoid low-temperature issues related to salinity toxicity.	Jensen and Rikardsen 2008*
Atlantic salmon+	Yes, but exceptions	Parr: Western Arm Brook estuary, Newfoundland and Labrador; Severn River estuary, England; Frome River; England Smolts: Varzuga River estuary, Russia Smolts to adults: Koksoak River estuary, Québec; Nastapoka River estuary, Québec; Nabisipi River estuary, Québec; Freshwater River, Newfoundland and Labrador	Parr may move back into river for overwintering. Smolts at Nabisipi River and Koksoak River estuaries, Québec, were exceptionally large.	Birt et al. 1990; Claridge and Potter 1994;* Cunjak et al. 1989;* Kazakov 1994;* Lee and Power 1976; Morin 1991; Pinder et al. 2007; Robitaille et al. 1986*
Brook trout+	Yes, but exceptions	Small age 1+ in Petite Cascapédia River estuary, Québec; older fish in St-Jean River estuary, Québec	Found overwintering in upper estuary.	Castonguay et al. 1982; Curry et al. 2010*
Bull trout+	Yes	Possibly Hoh River, Washington	Data on osmoregulation of the	Brenkman and Corbett 2007

Species	Distinct parr-smolt transformation?	Example of life history type or location of specialized form benefiting from estuary residence	Comments	Reference
			anadromous form of bull trout could not be found but there is demonstrated estuarine use by the species (Hoh River, Washington).	
Chinook salmon+	Yes for river type and minijacks, but not for fry or subyearlings of ocean type life history found in many estuaries	Campbell River estuary, British Columbia; Nanaimo River estuary, British Columbia; Salmon River estuary, Oregon; Sacramento River estuary, California; Columbia River estuary, Washington-Oregon	The ability to rear in the estuary has been established for numerous populations and appears to be a resilient trait for coastal stocks; minijacks in Columbia River estuary are inferred from scale patterns; Bol'shaya River estuary, Russia.	Argue et al. 1979; Healey 1980a;* Hering et al. 2010;* Johnson et al 2012;* Levings et al. 1986;* Miller et al. 2010;* Roegner et al. 2012;* Lister and Walker 1966; Leman and Chebanova 2005*
Chum salmon	No	n.a.	Requires a variable period of adaptation to low-salinity water.	Iwata and Komatsu 1984;* Salo 1991; Uchida and Kaneko 1996
Coho salmon	Yes for many coho salmon populations, but not for fry of "nomad" or fall migration life history type found in several estuaries or spring migrating "pre-smolts"	Winchester Creek estuary, Oregon; Carnation Creek, British Columbia; Avacha River estuary, Russia; two estuaries in Washington	Fry may overwinter in upper estuary or stream or move to the ocean in the fall.	Miller and Sadro 2003;* Hoem Neher et al. 2013; Koski 2009;* Roni et al. 2012 ; Tschaplinski 1982;* Varnavsky et al. 1992*
Cutthroat trout+	Yes, but possible exceptions	n.a.	Some populations migrate to coastal habitats while others move further out in the ocean.	Trotter 1989; Zydlewski et al. 2009

Species	Distinct parr-smolt transformation?	Example of life history type or location of specialized form benefiting from estuary residence	Comments	Reference
Dolly Varden[+]	Yes, but exceptions	Southern form of Dolly Varden (e.g., Deer Track Creek, Alaska); northern form of Dolly Varden (e.g., several estuaries in Russia)	About 20% of smolts did not meet the seawater challenge and may have been still in the parr stage; "thousanders" rear in the estuary for 2–4 months before migrating to the river for overwintering and finally migrating to the ocean the next spring.	Johnson and Heifetz 1988; Pavlov and Savvaitova 2008*
Lake trout[+]	Yes	Estuary of a stream draining Nauyuk Lake, Nunavut	Now known to be an anadromous species that migrates to the estuary at very old age (13 years); this species has the potential to osmoregulate in 10–20 psu estuarine waters.	Hiroi and McCormick 2007; Swanson et al. 2010*
Masu [+]	Yes	Razdol'naya River estuary, Russia	Variation in size and age that juvenile males of various life history types use the estuary	Tsiger et al. 1994; Miyakoshi et al. 2001
Pink salmon	No	n.a.	Ability to excrete salt is attained at an early age without a distinct freshwater life history stage	Grant et al. 2009
Sea trout[+]	Yes, but exceptions	Populations in the Skibotn River estuary, Norway, and the Ponoi River estuary, Russia, overwinter in the estuary; parr from streams on Gotland, Sweden (Baltic Sea) rear in estuary.	Strategy may enable northern populations to avoid low-temperature issues related to salinity toxicity.	Elliott and Chamber 1996; Jensen and Rikardsen 2008;* Limburg et al. 2001; Lukin and Krylova 2010
Sockeye salmon	Yes for the lake rearing sockeye	Several estuaries in the Northeast and	The ability to rear in low-salinity water in	Birtwell et al. 1987;* Bugaev

Species	Distinct parr-smolt transformation?	Example of life history type or location of specialized form benefiting from estuary residence	Comments	Reference
	salmon, but not for fry of "sea type" life history type found in several estuaries.	Northwest Pacific.	the upper estuary has been established for several populations and appears to be a resilient trait for coastal stocks.	2004;* Bugaev and Karpenko 1984;* Wood et al. 2008*
Steelhead+	Yes, but exceptions	Klamath River estuary, California; Scott Creek estuary, California; and several estuaries in Russia	Parr migrate between the estuary and stream; "half-pounders" rear in the estuary for 2–4 months before migrating to the river for overwintering and finally migrating to the ocean the next spring.	S.A. Hayes et al. 2011b;* Hodge et al. 2014;* Kesner and Barnhart 1972; Savvaitova et al. 2005
Sakhalin taimen+	Yes	n.a.		Honda et al. 2010
White-spotted char+	Yes but exceptions	Several estuaries in Russia	"Thousanders" rear in the estuary for 2–4 months before migrating to the river for overwintering and finally migrating to the ocean the next spring.	Pavlov and Savvaitova 2008*

Appendix Table 1.7. Summary of industrial harvesting, recreational fishing, ocean ranching, and aquaculture for estuarine salmonids, with comments on present and past stock levels and ocean ranching/aquaculture practices.

Species	Harvest status/general stock assessment in estuaries	Ocean ranching and aquaculture in estuaries	References
Amago	Commercial and recreational fisheries are conducted, but the species is considered overexploited.	Ocean ranching: extensive hatchery/ocean ranching programs are a concern for the maintenance of wild populations.	Fisheries: Hamai et al. 1996; Kato 1991 Ocean ranching: Kato et al. 1982; Kawamura et al. 2012*
Arctic char	Targeted for commercial, subsistence and recreational fisheries in Arctic and subarctic estuaries in the Northern Hemisphere. Worldwide catch estimated at 3000 t in 1995.	Aquaculture: In 2008 about $1.7 \bullet 10^3$ were cultured on the Norwegian coast. Norway and Iceland cultured 800 and 300 t, respectively, in 1993. Ocean ranching: potential, but large variation in return rate.	Fisheries: Dempson et al. 2004; Johnson 1980; Johnson and Burns 1984; Maitland 1995; Roux et al. 2011 Aquaculture: Directorate of Fisheries 2009; Heasman and Black 1998; Sæther et al. 2013 Ocean ranching: Moksness 2008
Atlantic salmon	Commercial, subsistence, and recreational; abundance is very reduced and estuarine harvesting has been curtailed in many countries.	Ocean ranching: 96% are hatchery-reared (2009); in some areas, only ocean-ranched fish can be retained. Aquaculture: one of the most widespread cultured salmon in the world; the species is cultured in sea pens in coastal zones of Norway, Scotland, Ireland, Canada, United States, Chile, New Zealand, and Australia, but many operations are not within the estuary proper because of low growth rates in reduced salinities.	Fisheries: Elliott and Hemingway 2002;* Mills 2003; Pascual et al. 2009 Ocean ranching: Whoriskey 2009* Aquaculture: 1.4 M t produced worldwide in 2010 (Food and Agriculture Organization of the United Nations, 2014*)
Brook trout	Subsistence fisheries in subarctic northwest Atlantic estuaries, e.g.,	Aquaculture: extensive experimentation concluded that brook trout were not	Aquaculture: Naiman et al. 1987

Species	Harvest status/general stock assessment in estuaries	Ocean ranching and aquaculture in estuaries	References
	15,500 kg • y^{-1} in Koksoak River estuary, Québec in the 1970s. Estuarine brook trout recreational fisheries from Newfoundland and Labrador to Massachusetts.	suitable for marine or estuarine culturing. Ocean ranching: stocking of sea-run brook trout “salters” conducted In several states on the northeast coast of the United States and experimentally on Prince Edward Island, Canada. In some areas, only ocean-ranched fish can be retained.	Fisheries: Berkes and Freeman 2011 for subsistence fishery; Northern Québec Inuit Association 1976, in Power 1980 Recreational fishery: Prince Edward Island: Saunders and Smith 1964; Maine: Bonney 2009; Massachusetts: Saunders et al. 2006,* Eastern Brook trout Joint Venture 2014*
Bull trout	Bycatch in estuarine gillnet fisheries for other salmonids.	n.a.	Brenkman and Corbett 2005, 2007
Chinook salmon	Commercial, subsistence, and recreational; abundance is severely reduced, especially in southern part of the range.	Ocean ranching: extensive hatchery/ocean ranching programs all along the west coast of North America. In 1990, about 400 million passed through estuaries in that region. In some areas only ocean-ranched fish can be retained. Aquaculture: cultured in fjords and coastal zone in British Columbia, New Zealand, and Chile, but many operations are not within the estuary because of low growth rates in reduced salinities.	Fisheries: Department of Fisheries and Oceans 1995;* Fraser et al. 1982* Ocean ranching: Mahnken et al. 1998 Aquaculture: Correa and Gross 2008*
Chum salmon	Commercial, subsistence, and recreational.	Ocean ranching: extensive hatchery/ocean ranching programs along the west coast of North America and in Asia, especially Japan.	Fisheries: Department of Fisheries and Oceans 1995; Novomodny et al. 2004* Ocean ranching: Kaeriyama and Edpalina 2008;* Ruggerone and

Species	Harvest status/general stock assessment in estuaries	Ocean ranching and aquaculture in estuaries	References
			Nielsen 2004; Ruggerone and Connors 2015*
Coho salmon	Commercial, subsistence, and recreational; abundance is severely reduced especially in southern part of the range; bycatch with more abundant species such as chum salmon and pink salmon is an issue in some areas.	Ocean ranching: extensive hatchery/ocean ranching programs along the west coast of North America; in some areas only ocean-ranched fish can be retained. Aquaculture: cultured in fjords and coastal zone in British Columbia, New Zealand, and Chile, but many operations are not within the estuary because of low growth rates in reduced salinities.	Fisheries: Buchanan et al. 2002;* Fraser et al. 1982;* Sandercock 1991; Vincent-Lang et al. 1993* Ocean ranching: Mahnken et al. 1998 Aquaculture: Food and Agriculture Organization 2014;* Sasaki et al. 2002; Soto et al. 2001;* Pascual et al. 2009
Cutthroat trout	Bycatch in commercial fishing; targeted in recreational fisheries.	Ocean ranching: enhancement programs in British Columbia, Washington, and Oregon have hatchery programs for rearing and releasing smolts. In some areas only ocean-ranched fish can be retained.	Fisheries: Duffy and Beauchamp 2008;* Krentz 2007*
Dolly Varden	Subsistence and recreational fisheries; abundance very reduced in some regions of Northeast Pacific so recreational fishery is catch and release only.	n.a.	Fisheries: Andreev and Skopets 2003; British Columbia Ministry of Forests, Lands and Natural Resource Operations 2015;* Department of Fisheries and Oceans 2001; Stephenson 2003; Tiller 2013; Zolotukhin 2003a.
Lake trout	Likely subsistence and recreational fisheries in estuaries in Nunavut.	n.a.	n.a.
Masu	Commercial (mostly gillnet and traps) and recreational fisheries are conducted, but the species is considered overexploited.	Ocean ranching: extensive hatchery/ocean ranching, e.g., 10 M stocked in Japan during 2000 Aquaculture: some	Fisheries: Ando and Miyakoshi 2003; Zolotukhin 2003a Ocean ranching: Morita et al. 2006; Miyakoshi et

Species	Harvest status/general stock assessment in estuaries	Ocean ranching and aquaculture in estuaries	References
		experimental pen rearing in coastal waters.	al. 2001 Aquaculture: Ohta et al. 1988
Pink salmon	Commercial, subsistence, and recreational; this species is one of the most abundant in estuarine fisheries in the Northeast and Northwest Pacific.	Ocean ranching: extensive hatchery/ocean ranching programs along the west coast of North America and in Asia, especially Japan.	Fisheries: Pacific Salmon Commission 1999; Zolotukhin 2003b Ocean ranching: Ruggerone and Nielsen 2004; Ruggerone and Connor 2015*
Sakhalin taimen	Previously targeted; now overfished and bycatch in industrial fishing. Targeted in recreational fisheries, especially in Kamchatka estuaries.	n.a.	Fisheries: Edo et al. 2005; Fukushima et al. 2011*
Sea trout	Commercial fisheries were conducted historically, e.g., catches in Caspian Sea estuaries were 1,100 t in 1940, decreasing to 9 t by 1999. Recreational: sea trout are the target for sport fishers in many salmonid estuaries of the Northern and Southern Hemispheres.	Ocean ranching: hatchery/ocean ranching programs are conducted in European countries and some states in US on the northwest Atlantic; broodstock development using eggs from reconditioned kelts has also been tested. Aquaculture: the species has been considered for coastal net pen rearing in a number of European countries (and in the Caspian Sea), but this species is apparently not widely used for aquaculture.	Fisheries: Faschevsky 2004; Fisher and Vallance 2010; Harris and Milner 2006;* O'Neal and Stanford 2011;* Poole et al. 1994; Rikardsen et al. 2007;* Veinott et al. 2012 Ocean ranching: Mitchell 2003;* Ruzzante et al. 2004; Serrano et al. 2009 Aquaculture: Dorafshan et al. 2008; Quillet et al. 1992
Sockeye salmon	Commercial because of high value as food, sockeye salmon fisheries in estuaries are perhaps the most intensively managed salmonid fisheries in the world (mostly gillnets and traps).	Ocean ranching: limited hatchery/ocean ranching programs and some conservation hatcheries.	Fisheries: Burgner 1991; Hilborn et al. 2003; Berman et al 1997 Ocean ranching: Zaporozhets and Zaporozhets 2012*

Species	Harvest status/general stock assessment in estuaries	Ocean ranching and aquaculture in estuaries	References
	Recreational: throughout the estuary.		
Steelhead	Recreational fisheries for steelhead usually located upstream of estuaries; bycatch of steelhead in commercial fisheries for other species is a problem and techniques are being tested to prevent accidental catch.	Ocean ranching: extensive hatchery/ocean ranching in California, Oregon, Washington, and British Columbia (e.g., 15.4 M smolts released to Columbia River, Washington-Oregon in 2010). In some areas, only ocean-ranched fish can be retained. Aquaculture: the non-anadromous form (rainbow trout) is cultured in sea pens in coastal zones (Scotland, Ireland, Canada, United States, Chile, Denmark, New Zealand, Norway, Australia and other countries, but typically operations are not within the estuary because of low growth rates in reduced salinities.	Fisheries: Cox-Rogers 1994; Department of Fisheries and Oceans 2001* Aquaculture: Food and Agriculture Organization of the United Nations 2014;* Pedersen 2000; Porter 2000; Skilbrei 2002; Soto et al. 2001*
White spotted char	Commercial (mostly gillnet and traps) (e.g., annual commercial catch of 30 t at estuaries around the Sea of Okhotsk in 1992) and recreational fisheries are conducted but the species is considered overexploited; poaching reported as a problem.	n.a.	Fisheries: Gudkov 1992; Zolotukhin 2003a.

Appendix Table 1.8. Selected indicators of contaminants in the salmonid estuary (adapted from Sanchez and Porcher 2009*).

Biomarker (from Sanchez and Porcher 2009*)	Related function	Example of application to assess effects of exposure to contaminants in salmonids	References
Ethoxyresorufin-O-deethylase (EROD)	Detoxification enzyme	Dioxin from pulp mill effluent	Rogers et al. 1989
Acetylcholinesterase activity (AChE)	Indicator of reduced neural (brain) function	Pesticides	Laetz et al. 2009
Vitellogenin (VTG)	Indicator of egg development rate	Flame retardants	Boon et al. 2002
Metallothionein (MT)	Detoxification enzyme	Heavy metals	Dang et al. 2001
Amino-levulinic acid dehydratase (ALAD)	Enzyme for hemoglobin synthesis; reduced levels affect brain function	Heavy metals	Heier et al. 2009
DNA damage	Genetic damage to somatic (e.g., red blood cells) and germ (e.g., spermatocytes) cells.	Pesticides and heavy metals	Dhawan et al. 2009
Lysozyme activity	Immune response and skin mucus production to help shed disease organisms	Stress response to disease caused by various pollutants	Skinner et al. 2010
Macrophage aggregate	Immune response that stimulates growth of specific melanin-producing cells (sometimes melanin-producing cells sequester bacteria)	Stress response to various pollutants, but may not be specific	Agius and Roberts 2003

Appendix Table 1.9. General summary of seasonal occurrence of various life stages of salmonids in estuaries. n. a. = not applicable.

Season/ life stage	**Spawning**	**Alevin**	**Fry**	**Parr**	**Smolt or pre-smolt**	**Adult**
Spring	n.a.	If spawning grounds are a short distance above the estuary (especially noted for *Oncorhynchus* spp.)	Extensive use by chum and pink salmon; population-specific use by Chinook and coho salmon	Population-specific use by Atlantic salmon, Chinook salmon, and steelhead	Extensive use by all taxa	Extensive use by spring Chinook salmon, kelts from *Salmo, Salvelinus,* and *Hucho* spp.
Summer	n.a.	n.a.	Population-specific use by Chinook salmon	Population-specific use by Chinook and Atlantic salmon	Extensive use by all taxa	Population-specific use by all taxa
Autumn	Pink and chum salmon in British Columbia, Alaska, and Russia	n.a.	n.a.	Population-specific use by Chinook and Atlantic salmon	Population-specific use by Chinook and Atlantic salmon	Extensive use by all taxa
Winter	Incubation of pink and chum salmon eggs	n.a.	n.a.	n.a.	Population-specific use by Chinook salmon	Population-specific use by Chinook salmon, Arctic char, and Atlantic salmon

Appendix 2

Estuaries and Other Water Bodies Mentioned in the Book and Appendix 1, with Geographic Information and Coordinates

Name, geopolitical area, latitude, and longitude of estuaries and other water bodies mentioned in the book and appendices are shown below. Coordinates were found using Google Maps and itouchmap.com. An explanation of the various geopolitical units is given at the end of the list.

River/estuary	Location	Latitude	Longitude
Aberdeenshire Dee River estuary	Aberdeenshire, Scotland	N 57° 08′ 29″	W 002° 05′ 39″
Åbjora River system (the Å River)	Nordland, Norway	N 65° 01′ 29″	E 012° 45′ 58″
Adam River estuary	British Columbia, Canada	N 50° 27′ 58″	W 126° 17′ 10″
Akaroa Harbour	Canterbury District, New Zealand	S 43° 48′ 14″	E 172° 58′ 56″
Alouette River	British Columbia, Canada	N 49° 15′ 53″	W 122° 42′ 28″
Alsea River estuary	Oregon, United States	N 44° 25′ 21″	W 124° 04′ 51″
Altafjord	Finnmark County, Norway	N 70° 12′ 00″	E 023° 06′ 00″
Amu-Darya River estuary	Karakalpakstan, Uzbekistan	N 43° 40′ 00″	E 059° 01′ 00″
Amur River estuary	Khabarovsk Krai, Russia	N 52° 55′ 48″	E 141° 09′ 36″
Anapka River estuary	Kamchatka Krai, Russia	N 60° 10.5′ 00"	E 165° 03′ 00"
Aral Sea	Uzbekistan and Kazakhstan	N 45° 00′ 00"	E 60° 00′ 00″
Ashida River estuary	Hiroshima Prefecture, Japan	N 34° 26′ 16″	E 133° 24′ 03″
Aurland River estuary	Sogn og Fjordane, Norway	N 61° 02′ 47″	E 007° 01′ 30″
Avacha River estuary	Kamchatka Krai, Russia	N 53° 01′ 30″	E 158° 31′ 00″
Avon River estuary	Southwest England Region, England	N 50° 43′ 47″	W 001° 46′ 22″
Aysén Fjord	Aysén Region, Chile	S 45° 26′ 22"	W 072° 55′ 43"
Bekanbeushi River estuary (Akkeshi Lagoon)	Hokkaido Prefecture, Japan	N 43° 05′ 52″	E 144° 52′ 46″
Bella Coola River estuary	British Columbia, Canada	N 52° 22′ 49″	W 126° 46′ 22″
Beaufort Sea	Alaska, United States	N 71° 45′ 41″	W 146° 03′ 07″
Big Qualicum River estuary	British Columbia, Canada	N 49° 23′ 56″	W 124° 36′ 31″

River/estuary	Location	Latitude	Longitude
Bogataya River estuary	Sakhalinskaya Oblast, Russia	N 49° 59′ 46″	E 143° 59′ 17″
Bol‘shaya River estuary	Kamchatka Krai, Russia	N 52° 43′ 16″	E 156° 13′ 03″
Bras d’Or Lakes	Nova Scotia, Canada	N 45° 48′ 40″	W 060° 49′ 41″
Britannia Creek estuary	British Columbia, Canada	N 49° 37′ 33″	W 123° 12′ 25″
Campbell River estuary	British Columbia, Canada	N 50° 02′ 28″	W 125° 15′ 39″
Carnation Creek estuary	British Columbia, Canada	N 48° 54′ 49″	W 125° 00′ 15″
Carneros Creek estuary	California, United States	N 38° 13′ 18″	W 122° 18′ 40″
Caspian Sea	Azerbaijan, Russia, Kazakhstan, Turkmenistan, and Iran	N 41° 22′ 37″	E 050° 48′ 03″
Chehalis River estuary	Washington, United States	N 46° 57′ 29″	W 123° 50′ 04″
Chesapeake Bay	Maryland and Virginia, United States	N 37° 43′ 63″	W 76° 07′ 56″
Clowholm River estuary	British Columbia, Canada	N 49° 42′ 43″	W 123° 32′ 05″
Columbia River estuary	Washington-Oregon, United States	N 46° 14′ 39″	W 124° 03′ 28″
Connecticut River estuary	Connecticut, United States	N 41° 17′ 38″	W 72° 22′ 57″
Cook Inlet	Alaska, United States	N 60° 52′ 29″	W 151° 44′ 47″
Cosumnes River	California, United States	N 38° 21′ 51″	W 121° 19′ 59″
Cowichan River estuary	British Columbia, Canada	N 48° 45′ 43″	W 123° 37′ 40″
Clyde River estuary	West Central Lowlands, Scotland	N 55° 53′ 00″	W 004° 56′ 14″
Cromarty Firth	Ross and Cromarty, Highland, Scotland	N 57° 10′ 47″	W 004° 05′ 55″
Danube River estuary	Romania-Ukraine	N 45° 20′ 00″	E 029° 40′ 00″
Deer Track Creek estuary	Alaska, United States	N 56° 01′ 31″	W 133° 16′ 25″
Deseado River estuary	Santa Cruz, Argentina	S 47° 45′ 39″	W 065° 53′ 56″
Dieset River estuary	Svalbard County, Norway	N 79° 11′ 00"	E 011° 12′ 00"
Dnieper River	Khersons Oblast, Ukraine	N 46° 30′ 00″	E 032° 18′ 00″
Dordogne River	Aquitaine Region, France	N 45° 02′ 43"	W 000° 36′ 21"
Douro River estuary	Norte Region, Portugal	N 41° 08′ 33"	W 008° 39′ 37"
Duwamish River estuary	Washington, United States	N 47° 34′02″	W 122° 20′ 54″

River/estuary	Location	Latitude	Longitude
Eachaig River estuary	Argyll and Bute County, Scotland	N 56° 02′ 19"	W 004° 59′ 05"
Esk River estuary	Yorkshire and Humber, England	N 54° 29′ 33"	W 000° 36′ 44"
Forth River estuary	Fife Region – Lothian Region, Scotland	N 56° 08′ 16″	W 002° 43′ 34″
Fowey River estuary	South West Region, England	N 50° 21′ 02″	W 004° 37′ 59″
Fraser River estuary	British Columbia, Canada	N 49° 06′ 58″	W 123° 11′ 09″
Freshwater Creek estuary	Nunavut, Canada	N 69° 07′ 07″	W 105° 03′ 11″
Frome River estuary	Southwest England Region, England	N 50° 41′ 18"	W 002° 04′ 51"
Garonne River	Aquitaine Region, France	N 45° 01′ 42"	W 000° 36′ 05"
Gaula River estuary	Sør-Trøndelag County, Norway	N 63° 20′ 33”	E 010° 13′ 37″
Gilbert Bay	Newfoundland and Labrador, Canada	N 52° 34′ 37"	W 055° 54′ 32"
Gironde estuary	Aquitaine Region, France	N 45° 35′ 00″	W 001° 03′ 00″
Gljufur River	South Iceland	N 63° 25′ 09”	W 019° 005′ 49″
Gordon River estuary	Tasmania, Australia	S 42° 43′ 48"	E 145° 58′ 31"
Hals River estuary	Finnmark County, Norway	N 70° 01′ 56″	E 022° 58′ 26″
Hoh River estuary	Washington, United States	N 47° 44′ 58"	W 124° 26′ 20"
Homathko River estuary	British Columbia, Canada	N 50° 55′ 45″	W 124° 50′ 54″
Hood Canal	Washington, United States	N 47° 33′ 51″	W 122° 59′ 48″
Humber River estuary	Yorkshire and the Humber region, England	N 53° 33′ 35"	E 000° 03′ 57"
Izembek Lagoon/Joshua Green River estuary	Alaska, United States	N 55° 18′ 57"	W 162° 50′ 43"
James River estuary	Virginia, United States	N 36° 57′ 21″	W 76° 22′ 20″
Kakanui River estuary	Otago Region, New Zealand	S 45° 11′ 20″	E 170° 53′ 56″
Kalininka River estuary	Sakhalin Oblast, Russia	N 47° 00′ 48”	E 142° 02′ 02”
Kamchatka River estuary	Kamchatka Krai, Russia	N 56° 13′ 35″	E 162° 30′ 00″

River/estuary	Location	Latitude	Longitude
Kamchatka Peninsula	Kamchatka Krai, Russia	N 55° 12′ 20″	E 159° 17′ 48″
Kara River estuary	Tyumen Oblast, Russia	N 69° 09′ 59″	E 064° 47′ 11″
Karaginsky Bay	Kamchatka Krai, Russia	N 58° 59′ 07″	E 163° 08′ 14″
Kemijoki River estuary	Lapland region, Finland	N 65° 46′ 12″	E 024° 27′ 00″
Kennebec River estuary	Maine, United States	N 44° 00′ 24″	W 069° 49′ 16″
Keogh River estuary	British Columbia, Canada	N 50° 40′ 42″	W 127° 20′ 56″
Kerguelen Islands	District of the French Southern and Antarctic Lands	S 49° 21′ 35″	E 69° 47′ 30″
Khaylyulya River estuary	Kamchatka Krai, Russia	N 58° 04′ 51″	E 161° 59′ 04″
King River estuary	Tasmania, Australia	S 42° 11′ 35″	E 145° 21′ 22″
Klamath River estuary	California, United States	N 41° 32′ 49″	W 124° 05′ 00″
Koksoak River estuary	Québec, Canada	N 58° 32′ 11″	W 068° 09′ 29″
Kushiro River estuary	Hokkaido Prefecture, Japan	N 42° 58′ 47″	E 144° 22′ 20″
Kyronjoki River estuary	Southern Ostrobothnia Maakunta, Finland	N 63° 13′ 09"	E 021° 46′ 13"
Lac Guillaume-Delisle	Québec, Canada	N 56° 12′ 13″	W 076° 22′ 26″
Lagunitas Creek estuary	California, United States	N 38° 04′ 48″	W 122° 49′ 37″
La Have River estuary	Nova Scotia, Canada	N 44° 17′ 56″	W 064° 21′ 28″
Lake Llanquihue	Los Lagos Region, Chile	S 41° 08′ 00″	W 72° 47′ 00″
Lake Kamchatka	Kamchatka Krai, Russia	N 56° 18′ 43"	E 162° 49′ 52"
Laval River estuary	Québec, Canada	N 48° 46′ 24"	W 069° 03′ 00"
Lena River estuary	Sakha Republic, Russia	N 72° 08′ 29″	E 126° 50′ 53″
Little Susitna River estuary	Alaska, United States	N 61° 15′ 03″	W 150° 17′ 17″
Livar-Yakha River estuary	Arkhangelsk Oblast, Russia	N 69° 40′ 55"	E 063° 07′ 17"
Loch Eck	Argyll and Bute, Scotland	N 56° 05′ 04″	W 004° 59′ 41″
Loire River	Pays-de-la-Loire, France	N 47° 16′ 21"	W 002° 10′ 54"
Lough Furnace	Mayo County, Ireland	N 53° 55′ 16"	W 009° 34′ 30"
Mackenzie River estuary	Northwest Territories, Canada	N 69° 21′ 00″	W 133° 54′ 20″
Maminkvayam River estuary	Kamchatka Krai, Russia	N 58° 48′ 21″	E 164° 07′ 55″

River/estuary	Location	Latitude	Longitude
Manasquan River estuary	New Jersey, United States	N 40° 06′ 09"	W 074° 02′ 04"
Manawatu River estuary	Manawatu-Wanganui Region, New Zealand	S 40° 28′ 23"	E 175° 13′ 03"
Margaree River estuary	Nova Scotia, Canada	N 46° 25′ 38"	W 061° 05′ 50"
Mattole River estuary	California, United States	N 40° 17′ 40"	W 124° 21′ 11"
Maullin River estuary	Los Lagos Region, Chile	S 41° 36′ 22"	W 073° 36′ 51"
Mersey River estuary	North West England, England	N 53° 26′ 30″	W 003° 01′ 31″
Mezen River estuary	Arkhangelsk Oblast – Nenets Autonomous Okrug, Russia	N 66° 11′ 05″	E 043° 58′ 22″
Miramichi River estuary	New Brunswick, Canada	N 47° 05′ 00″	W 065° 21′ 55″
Mølnargårds River estuary	Sør-Trøndelag County, Norway	N 63° 45′ 55″	E 009° 48′ 40″
Moisie River estuary	Québec, Canada	N 50° 11′ 29″	W 066° 05′ 40″
Nabisipi River estuary	Québec, Canada	N 50° 14′ 00"	W 062° 13′ 10"
Nagara River estuary	Mie Prefecture, Japan	N 35° 04′ 05"	E 136° 42′ 22"
Naiba River estuary	Sakhalin Oblast, Russia	N 47° 26′ 02"	E 142° 45′ 7"
Namsen River estuary	Nord- Trøndelag County, Norway	N 64° 27′ 32"	E 011° 30′ 47"
Nanaimo River estuary	British Columbia, Canada	N 49° 07′ 58″	W 123° 54′ 09″
Nain Bay estuary	Newfoundland and Labrador	N 56° 32 28″	W 61° 41′ 26″
Nastapoka River estuary	Québec, Canada	N 56° 54′ 37″	W 076° 32′ 47″
Nauyuk Lake	Nunavut, Canada	N 68° 20′ 45″	W 107° 40′ 42″
Navarro River estuary	California, United States	N 39° 11′ 31"	W 123° 45′ 40"
Nehalem River estuary	Oregon, United States	N 45° 41′ 00"	W 123° 55 48"
Neiden River estuary	Finnmark, Norway	N 69° 42′ 51"	E 029° 34′ 04"
Netarts Bay	Oregon, United States	N 45° 24′ 10"	W 123° 56 54"
Neva River estuary	Leningradskaya Oblast, Russia	E 59° 55′ 43"	E 030° 12′ 11"
Nisqually River estuary	Washington, United States	N 47° 05′ 32″	W 122° 43′ 12″
Numedals River estuary	Vestfold County, Norway	N 59° 02′ 15″	E 010° 03′ 20″
Olsen Creek estuary	Alaska, United States	N 60° 45′ 36″	W 146° 10′ 27″
Orkla River estuary	Sør-Trøndelag County, Norway	N 63° 19′ 06″	E 009° 50′ 22″

River/estuary	Location	Latitude	Longitude
Oslofjord	Vestfold County, Norway	N 59° 20′ 47"	E 010° 35′ 23"
Penobscot River estuary	Maine, United States	N 44° 30′ 30″	W 068° 48′ 01″
Petitcodiac River estuary	New Brunswick, Canada	N 45° 51′ 20″	W 064° 33′ 25″
Petite Cascapédia River estuary	Québec, Canada	N 48° 10′ 09″	W 065° 49′ 20″
Petrohue River estuary	Los Lagos, Chile	S 41° 23′ 21″	W 072° 18 14″
Pettaquamscutt River estuary	Rhode Island, United States	N 41° 26′ 31″	W 071° 26′ 27″
Ponoi River estuary	Murmansk Oblast, Russia	N 66° 58′ 59"	E 041° 16′ 53"
Porcupine Creek estuary	Alaska, United States	N 56° 07′ 51″	W 132° 39′ 27′
Potomac River estuary	Maryland, United States	N 37° 59′ 57″	W 076° 14′ 59′
Prince William Sound	Alaska, United States	N 60° 41′ 26″	W 147° 05′ 49″
Puelo River estuary	Los Lagos, Chile	S 41° .38′ 39″	W 072° 19′ 10″
Puget Sound	Washington, United States	N 47° 43′ 25″	W 122° 26′ 33″
Puntledge River estuary	British Columbia, Canada	N 49° 41′ 59″	W 124° 59′ 52′
Puyallup River estuary	Washington, United States	N 47° 16′ 10″	W 122° 25′ 42″
Quashnet River estuary	Massachusetts, United States	N 41° 34′ 23″	W 070° 31′ 03″
Rakaia River estuary	Canterbury, New Zealand	S 43° 53′ 57″	E 172° 12′ 13″
Rappahannock River estuary	Virginia, United States	N 37° 36′ 04″	W 76° 19′ 18″
Raritan River estuary	New Jersey, United States	N 40° 29′ 59″	W 074° 17′ 15″
Razdol’naya River estuary	Primorsky Krai, Russia	N 43° 20′ 27"	E 131° 48′ 12"
Relconcavi Fjord	Los Lagos Region, Chile	S 41° 40′ 00″	W 072° 21′ 00″
Rhine River estuary	South Holland, Netherlands	N 51° 58′ 54″	E 004° 04′ 50″
Ribble River estuary	North West, England	N 53° 43′ 43″	W 002° 56′ 29″
Ribe River estuary	Southern Denmark, Denmark	N 55° 20′ 31″	E 008° 39′ 53″
Rio Grande River estuary	Tierra del Fuego Province, Argentina	S 53° 48′ 09″	W 067° 40′ 54″
Rivière à la Truite	Québec, Canada	N 49° 13′ 32″	W 072° 28′ 05″
Rosewall Creek estuary	British Columbia, Canada	N 49° 28′ 00″	W 124° 46′ 43″
Sacramento River estuary	California, United States	N 38° 03′ 47″	W 121° 51′ 09″
Sacramento–San Joaquin River estuary	California, United States	N 38° 02′ 39″	W 121° 53′ 13″

River/estuary	Location	Latitude	Longitude
Saguenay River estuary	Québec, Canada	N 48° 07′ 45"	W 069° 42′ 09"
St-Jean River estuary	Québec, Canada	N 48° 46′ 12"	W 064° 25′ 44"
Sainte Marguerite River estuary	Québec, Canada	N 50° 08′ 34″	W 066° 36′ 17"
Sakhalin Island	Sakhalin Oblast, Russia	N 50° 26′ 37″	E 142° 54′ 44"
Salmon River estuary	Oregon, United States	N 45° 02′ 48″	W 124° 00′ 22″
San Antonio Creek estuary	California, United States	N 38° 09′ 30″	W 122° 32′ 39″
Santa Cruz River estuary	Santa Cruz Province, Argentina	S 50° 01′ 09″	W 68° 31′ 18″
ScheldtRiver estuary	Flemish Region, Belgium, The Netherlands	N 51° 21′ 00″	E 004° 14′ 44″
Scott Creek estuary	California, United States	N 37° 27′ 35"	W 121° 55′ 05"
Seine River estuary	Normandie, France	N 49° 26′ 05″	E 000° 07′ 03″
Sélune River estuary	Lower Normandy, France	N 48° 38′ 51″	W 001° 23′ 53″
Severn River estuary	South West Region, England	N 51° 33′ 42″	W 002° 42′ 05″
Shimanto River estuary	Kōchi Prefecture, Japan	N 32° 56′ 00"	E 133° 00′ 00"
Simojoki River estuary	Lapland Maakunta, Finland	N 65° 37′ 18″	E 025° 02′ 50″
Sixes River estuary	Oregon, United States	N 42° 51′ 13″	W 124° 32′ 38″
Skagit River estuary	Washington, United States	N 48° 10′ 34″	W 122° 21′ 50″
Skeena River estuary	British Columbia, Canada	N 54° 00′ 58″	W 130° 07′ 12″
Skibotn River estuary	Troms, Norway	N 69° 22′ 45″	E 020° 15′ 38″
Skjern River estuary	Midtjylland Region, Denmark	N 55° 54′ 58"	E 008° 24′ 04"
Smith River estuary	California, United States	N 41° 56′ 18"	W 124° 12′ 13"
Snake River	Washington, United States	N 46° 11′ 10"	W 119° 01′ 43"
Somass River estuary	British Columbia, Canada	N 49° 14′ 40″	W 124° 49′ 22″
Somme River estuary	Picardy, France	N 50° 11′ 27″	E 001° 37′ 40″
Squamish River estuary	British Columbia, Canada	N 49° 40′ 58″	W 123° 10′ 09″
St. Lawrence estuary	Québec, Canada	N 49° 40′ 00″	W 064° 29′ 55″
Strait of Georgia	British Columbia, Canada	N 49° 17′ 58"	W 123° 52′ 22"
Stikine River estuary	Alaska, United States	N 56° 33′ 50″	W 132° 24′ 16″
Storvatn Lake	Finnmark, Norway	N 70° 41′ 35″	E 023° 47′ 09″

River/estuary	Location	Latitude	Longitude
Surna River estuary	Møre og Romsdal, Norway	N 62° 58′ 15″	E 008° 39′ 23″
Susquehanna River estuary	Maryland, United States	N 39° 33′ 10″	W 075° 06′ 02″
Swinomish River estuary	Washington, United States	N 48° 27′ 34″	W 122° 30′ 55″
Sylvia Grinnell River, estuary	Nunavut, Canada	N 63° 44′ 17″	W 068° 33′ 50″
Syokanbetsu River estuary	Hokkaido, Japan	N 43° 51′ 19″	E 141° 30′ 38″
Syr-Darya River estuary	Kyzylorda Province, Kazakhstan	N 46° 06′ 02″	E 060° 52′ 17″
Tagus River estuary	Lisboa Region, Portugal	N 38° 41′ 31″	W 009° 10′ 04″
Taku River estuary	Alaska, United States	N 58° 18′ 55″	W 134° 02′ 44″
Tana River estuary	Finnmark County, Norway	N 70° 30′ 00″	E 028° 23′ 00″
Tay River estuary	Dundee County, Scotland	N 56° 27′ 44"	W 002° 48′ 57"
Tees River estuary	North Yorkshire County, England	N 54° 38′ 26"	W 001° 09′ 10"
Teno River	Lappland, Finland	N 69° 36′ 44"	E 025° 58′ 32"
Thames River estuary	East England Region, England	N 51° 30′ 00″	E 000° 45′ 54″
Thompson River	British Columbia, Canada	N 50° 14′ 10″	W 121° 34′ 56″
Tomales Bay	California, United States	N 38° 08′ 55″	W 122° 53′ 52″
Toyohira-gawa River plain	Hokkaido Prefecture, Japan	N 43° 07′ 56″	E 141° 30′ 58″
Trondheimsfjord	Nord-Trøndelag County, Norway	N 63° 39′ 00″	E 010° 49′ 00″
Tuloma River estuary	Murmansk Oblast, Russia	N 68° 53′ 22″	E 033° 00′ 43″
Tvarminne (estuary of Svartå River)	Southern Finland	N 59° 50′ 4″	E 023° 14′ 5″
Tyne River estuary	Tyne and Wear County, England	N 55° 01′ 04″	W 001° 25′ 12″
Uka River	Kamchatka Krai, Russia	N 57° 49′ 14″	E 162° 07′ 27″
Utka River estuary	Kamchatka Krai, Russia	N 53° 08′ 28″	E 156° 21′ 41″
Utkholok River estuary	Kamchatka Krai, Russia	N 57° 42′ 33″	E 156° 51′ 28″
Varzina River estuary	Murmansk Oblast, Russia	N 68° 20′ 58"	E 038° 17′ 55"
Varzuga River estuary	Murmansk Oblast, Russia	N 66° 16′ 12″	E 036° 56′ 41″
Volga River estuary	Astrakhan Oblast, Russia	N 45° 43′ 18″	E 047° 59′ 30″

River/estuary	Location	Latitude	Longitude
Waimakariri River estuary	Canterbury Region, New Zealand	S 43° 23′ 26″	E 172° 42′ 43″
Western Arm Brook estuary	Newfoundland Labrador, Canada	N 49° 49′ 17″	W 056° 30′ 41″
Whiskey Creek estuary	Oregon, United States	N 45° 23′ 40″	W 123° 56′ 10″
Willamette River	Oregon, United States	N 45° 37′ 24″	W 122° 47′ 22″
Willapa River estuary	Washington, United States	N 46° 42′ 27″	W 123° 51′ 01″
White Sea	Arkhangelsk and Murmansk Oblasts, Russia	N 65° 41′ 20″	E 037° 15′ 27″
Winchester Creek estuary	Oregon, United States	N 43° 40′ 25"	W 124° 10′ 42"
Wood River	Alaska, United States	N 59° 10′ 07"	W 158° 33′ 04"
Yaquina River estuary	Oregon, United States	N 44° 36′ 44″	W 124° 01′ 04″
Yamato River estuary	Osaka Prefecture, Japan	N 34° 36′ 28″	E 135° 26′ 55″
York River estuary	Québec, Canada	N 48° 49′ 13″	W 064° 33′ 40″

The locations listed above refer to the following political or administrative divisions of the associated countries.

Country	Political or administrative division
Argentina	Province
Australia	State; Territory
Belgium	Region
Canada	Province; Territory
Chile	Region
Denmark	Region
England	Region
Finland	Maakunta (Region)
France	Region
Iceland	Region
Ireland	Province
Japan	Prefecture
Kazakhstan	Province; District
Netherlands	Province
New Zealand	Region
Norway	County, except for Svalbard and Jan Mayen
Portugal	Region
Russia	Krai, Oblast

Scotland	County
Sweden	County or Ian
Ukraine	Oblast and Autonomous Region
United States of America	State

Appendix 3

Estuary Primer: An Overview of Estuarine Ecosystems and Salmonids for Citizen Scientists

I wrote this book with a broad audience in mind, ranging from Citizen Scientists to students, to professional estuarine scientists and practitioners. Today, both professional scientists and the interested public are involved with the complexities of managing salmon habitat in estuaries. “Citizen Science,” where volunteers aid in aspects of scientific research such as monitoring and observation (e.g., Jamieson et al. 1999), is growing in popularity around the world.

My intent in this Appendix is to provide some important general ecological and salmonid-specific information for Citizen Scientists working with salmonids in estuaries, including Atlantic and Pacific salmon, sea-going trout, and char. I give a brief history of general estuarine ecology and describe how in recent decades this science intersects with our knowledge of estuarine salmonids. As appropriate, I refer the reader to the chapters of the main book containing detailed aspects of the science briefly outlined here.

It is my hope that this section may assist groups in launching their own investigations and also aid, together with the glossary found in the book, in understanding the details in the main chapters. For further, more detailed information on the ecological concepts explored in the book (e.g., competition), readers can consult a number of introductory aquatic ecology books (e.g., Gotelli and Ellison 2004; Begon et al. 2005;* Smith and Smith 2008).

Note: * indicates a reference in the reference section of the main book; all other references are in Appendix 4 under the categories of particular species, Multiple Species of Salmonids, Salmonid Estuarine Habitat, or Methods.

Estuary Science

Estuaries, the areas where rivers flow into the ocean, were among the earliest areas studied by natural historians, the predecessors of contemporary ecologists. The term “estuary” can be traced back to a document from Spain dating to about 621 that emphasized tidal action. In 1833, the geologist Charles Lyell defined an estuary as “inlets of the lands which are entered both by rivers and tides of the sea” (Lyell 1833, cited in Tagliapietra et al. 2009), which is remarkably similar to the modern definition (Tagliapietra et al. 2009). Charles Darwin learned how to make observations in nature by walking along the Firth of Forth, an estuary in Scotland, and recognized estuaries in South America during his voyage on the *Beagle.* In addition to their intrinsic value as a natural study site, estuaries were considered as places to dispose wastes and sewage. The "Great Stink" of 1858 in the Thames River in London was resolved, at least by the standards of the time, by the construction of a collecting network of sewage drains; the sewage was discharged in the upper layers of the estuary on ebbing tides (Tinsley 1998). Historical studies of estuary ecosystems in Europe therefore tended to focus on water quality rather than estuary function. In North America, some of the earliest studies in estuaries were also water quality–oriented, such as the study of the Raritan River estuary in New Jersey dealing with sewage (Ketchum 1954), and Tully's work (1949) at the Somass River estuary in British Columbia relating to pulp mill effluent. A good overview of the history of estuarine research in Europe is given by McLusky (1999).

The mixing of fresh water with ocean water in estuaries was first recognized in the mid-1900s as a key process for aquatic productivity and biodiversity in fundamental oceanography works such as those by Sverdrup and colleagues (1942) and Ekman (1953). From an ecological viewpoint, these early studies identified the most influential process in estuaries as the rapid change caused by tides and river flow on the salinity and chemical composition of the water. Ocean salt water is heavier than fresh water, which results in ocean water in estuaries forming a salt wedge on the bottom under the freshwater from the river. This wedge results in a two-layer circulation system. Another critical physical factor of estuary function is the degree of change in salinity at a given point. This will depend on the volume and rate of discharge from the river, as well as the tidal levels (Beadle 1972).

Aquatic organisms living in salt water use energy to pump salt water out of their cells in a process known as osmosis. The regulation of salt is known as osmoregulation, and if an excess of salt moves into an aquatic organism's cells, the results are lethal. Estuarine organisms are specialized to cope with the osmoregulatory stress due to the rapid changes in salt concentration; these adaptations have been the historical focus of estuarine scientific studies. Estuaries are not necessarily known for a high diversity of species, possibly because few species are adapted to rapid changes in salinity (Beadle 1972). Estuaries were, however, recognized in early studies as being very productive, i.e., showing a high rate of accumulation of biological material (biomass) (Warren 1971). An example on land might be weight of grass clippings from the spring and summer mowing of a lawn – the production would be the biomass of grass produced that year. An example from fisheries would be the biomass of fish produced in a year. The early classic text on ecology by Odum (1971) pointed out how mixing of the lighter fresh water with heavier ocean water in constricted bodies of water like estuaries (see Figure 4) tends to result in a “nutrient trap” – one of the factors leading to their high potential for production. Temperature is the other key factor that can affect productivity in estuaries; exposure to nonoptimal temperatures can directly affect the growth rate and survival of organisms. Climate change is of particular concern, because even a slight warming of freshwater streams and their estuaries can have an effect on salmonids.

Productivity in ecosystems can be organized into a number of trophic levels or groupings of organisms depending on what kind of organic material they consume or produce. The levels form part of a food web. Plants and algae use energy from the sun, nutrients, and carbon dioxide in photosynthesis to produce carbohydrates; this is known as *primary production* and forms the base or lowest level of most food webs (with the exception of bacteria, which use various chemicals as an energy source). Primary producers are fed upon by grazing animals at the next trophic level in the food web – *secondary production.* An example could be Brant geese grazing on eelgrass. At the apex, or tertiary level of this web, are the predators that feed on the grazers. Eagles feeding on Brant geese would be an example of an apex predator. Biological oceanography texts such as that of Lalli and Parsons (1997*) are good starting points to learn about marine food webs. An example of an estuary food web is given in Figure 17.

Estuarine food webs are complex because, in addition to the direct primary-secondary-tertiary levels, there is another level that is very important in the functioning of an estuary. This level is known as the detrital food level, and it consists of bacteria mixed with decomposing plants (especially eelgrass and sedges) and algae. Many estuarine species of grazing animals at the secondary production level (e.g., amphipods) are important for juvenile salmonids and can use both the direct and indirect food chains, but the detrital food web is often acknowledged as the most important. The detrital food web links estuarine plants to salmonids and is therefore the basis for conservation and restoration of estuary vegetation and links estuarine plants, as described below.

An estuarine organism’s habitat is complex. The complexity stems from the variety of sediments, vegetation, water depths, and water types found at river mouths. In addition to these geographic differences, there is also large variation in time, as the salinity, temperature, water depth, and nutrients change with the ebb and flow of the tides. For example, habitats for salmonids disappear at low tide when waters retreat, but reappear at flood tides as waters advance. In addition to this short-term tidal variation, there is seasonal and geographic variation. One factor causing differences between habitats in estuaries is how much sediment is brought down to the river mouth from inflowing streams. The quantity of sediment delivered to estuaries can depend on many factors, including the geology and land uses in the basin. Sediment load will determine whether mud or sand dominates the estuary. Geographic differences are also related to temperature. The latitudes where salmonids are found range from about 32° to 80° north or south, an area range that brackets major temperature and habitat changes, including seasonal ice cover. Because of this habitat complexity, it is a challenge to assign importance to particular estuarine habitats for salmonids as they use these habitat mosaics.

Salmonids in Estuaries

Salmonids are any of various fishes of the family Salmonidae, which includes the salmon, trout, grayling, and whitefish. For the purposes of this primer, I discuss only the salmon and trout species that migrate between rivers and the ocean via the estuary. Salmonids, like all fish, are affected by their habitat – the physical and chemical characteristics of the water they live in, their food supply, and the other organisms (including competitors and predators) coexisting with them. A number of textbooks dealing with these aspects are available, including the classic fish ecology textbook by the Russian biologist Nikolsky (1963). This is a good general text for learning about salmonid ecology, as the book covers both Atlantic and Pacific species of salmonids in some detail. More recent texts by Diana (2004), Helfman and colleagues (1997), Crisp (2000), Hart and Reynolds (2002), and Moyle and Cech (2004) are also very useful.

The life history of salmonids has been clearly established only since the early 1900s, and these studies focused on the life of Atlantic salmon in rivers and oceans, at least in Europe. Only the general aspects of salmonid biology were known to science prior to this period; some naturalists in the eighteenth century thought that Atlantic salmon spawned in the ocean (Netboy 1980*). Studies of the growth ring patterns on Atlantic salmon scales by Dahl (1911) and Gilbert (1913*) for Pacific salmon helped with our understanding of their ecology. We now know that many salmonids are anadromous and reproduce in fresh water, and migrate to and from the ocean via the estuary in a variety of patterns. Figure 1 shows a generalized picture of the life history of Pacific salmon. A detailed description of the various life stages (fry, smolt, kelt, and others) is provided in Chapter 2.

Because large salmonids returning to spawn in the rivers were caught in the estuaries for food, knowledge of estuarine ecology of the adult fish preceded that for the younger and small life history stages (fry and smolts) migrating to the ocean. First Nations people often resided adjacent to estuaries, and salmonids were a key food source for their villages. Commercial fishers became very familiar with the migration timing of adult salmon because they targeted their nets in estuaries at specific times and locations when the fish were abundant. By the nineteenth century, fishing became so efficient that the governments of the day became concerned about conservation of the salmon stocks. Atlantic salmon in England's estuaries were among the first fish species to be subject to systematic annual monitoring of catches, with subsequent suggestions for conservation and management of the specific river stocks (Salmon Fisheries Act of 1861 in England; see Buckland 1880*). At about the same time, Atlantic salmon catch management in estuaries began in the United States and Canada (Collette and Klein-MacPhee 2002). Management of Pacific salmonid catches in estuaries has an equally long history (see Parsons 1993 for Canadian fisheries), and because of the iconic status of these species, hundreds of studies and research documents have been published on the topic (see Groot and Margolis 1991*).

Detailed studies of the estuarine ecology of juvenile salmonids were slower to develop, because the juvenile life stages in the estuary, the smaller fry and smolts, were not harvested and required special techniques such as small mesh nets to capture them. The fry and smolts were also thought to have short residency in the estuary and to move quickly to the ocean. Studies on the estuarine ecology of juvenile salmonids started to become more frequent by the mid-twentieth century as techniques for tracking the migrations and behaviour of the small fish became available. The important study by Reimers (1973*) on Chinook salmon fry and smolts in an Oregon estuary was one of the first to show that these life history stages took up residency in the estuary. Counting the growth rings on scales of adult Chinook salmon showed that young fish that lived in the estuary for longer periods survived better to adulthood. Also initiated at that time were studies of the physiology of fry and smolts that looked at the response of body chemistry and enzyme systems to changes in salinity and temperature (e.g., Brett 1952*). These results were directly applicable to understanding how young salmonids could tolerate the changes in water chemistry they encountered in the estuary, which in turn related directly to the effects of pollution on salmonids in estuaries, a concern long identified (see Buckland 1880*). Knowledge of the behaviour and physiology of Atlantic salmon smolts in estuaries was significantly advanced by J.E. Thorpe and collaborators (e.g., Thorpe 1994b*). It was not until the 1970s that the feeding ecology of juvenile salmonids in estuaries was documented in detail (see Figure 18). A study of Chum salmon fry feeding in the Nanaimo River estuary in British Columbia was an important first contribution (Sibert et al. 1977*). These studies linked food supply to habitat as well as to predation, because marsh vegetation and algae growing in the shallow water habitats provided detritus and possibly shelter from predators. Interestingly, biologists in Russia working at the estuary of the Lena River in the Arctic had found similar links to detritus with food webs of a lower-river-dwelling trout (taimen) twenty years earlier (Pirozhnikov 1955), but this detailed food web information was not widely known.

How Citizen Scientists Can Help Conservation of Salmonids and Restoration of Their Habitat in Estuaries

In many countries, conservation of salmonids in estuaries is closely regulated by government officials using standard fisheries management practices such as fishing closures, measures to protect weak stocks migrating with large “runs” (populations of salmonids from specific rivers that are travelling together), and monitoring of catches. In some regions, however, illegal poaching is an issue. Observations by citizens and use of systems such as the “Observe, Record, Report” telephone hotline used by Fisheries and Oceans Canada and other agencies in different countries can help prevent this problem. Pollution-related events, such as fish kills from chemical spills, can also be reported in this way. Another important factor to consider is the susceptibility of estuaries to non-native plants and animals. As noted above, estuaries are not necessarily rich in species number, but the complex ecosystem can become vulnerable to invasion by non-native plants and animals, which in turn can dramatically impact the salmonid life cycle, affecting their source of food and habitat. For example, brown trout were not found in Southern Hemisphere estuaries until they were introduced to New Zealand from England in the nineteenth century (Buckland 1880*) and, while sea trout (the estuary-using form of brown trout) are now the focus of a very important recreational fishery, implications for the native fauna is only now being explored in detail. Citizens can help avoid accidental colonization of estuaries by non-native species by aiding in monitoring and reducing the spread of such species through volunteer removal efforts with a local conservation organization.

The importance of estuarine habitat, especially vegetation, is one of the key paradigms of salmonid estuarine ecology and has led to major involvement of citizens in restoration projects. In the past few decades, there has been a significant increase in the number of local and regional naturalists’ associations, partnerships, councils, and nongovernmental organizations with an interest in the topic.

A detailed description of how to do estuarine habitat restoration is beyond the scope of this primer, but the basic concept usually involves a few options, depending on local circumstances, by breaching dikes or installing culverts to reintroduce water into areas previously flooded, or planting of vegetation.

Preservation of habitat is the best way to ensure its existence in perpetuity. Purchasing of land can be aided by donations of funds to appropriate agencies such as the Nature Trust, the Land Conservancy, and the Nature Conservancy. A number of guidebooks and websites are available and are listed at the end of this primer.

Another very important way in which citizens can help estuarine habitat is through regular observations of watersheds that have reduced flow because of water diversions and dams. Freshwater discharge is vital to estuary functions such as the maintenance of the two-layer flow system, which maintains estuarine productivity. Mapping of estuaries, vegetation, and tidal systems is another way in which Citizen Science can be of benefit. Inexpensive techniques such as global positioning systems (GPS) can be employed by citizens and data shared through community mapping websites. Oceanographic data in the estuary can also be obtained by fishers and citizen scientists with boats, and underwater observations can be made by scuba divers.

Awareness and a good understanding of estuarine science can go a long way towards ensuring healthy salmonids and estuaries. Interested citizens can make a difference by spreading awareness and participating in Citizen Science so that this integral part of our ecosystem can remain healthy and resilient in the face of human pressures and provide habitat for salmonids for generations to come.

Representative Websites of Interest to Estuary Citizen Scientists

Note: Some important websites are also listed in the "References" section of the main book.

Canada

Community Mapping Network. Includes a video introduction to the Community Mapping Network and the shoreline videos available for many shores in BC. http://www.cmnbc.ca/.

Department of Fisheries and Oceans. Musquash estuary, New Brunswick. "The Musquash estuary was officially designated as Canada's sixth marine protected area (MPA) on December 14, 2006." http://www.inter.dfo-mpo.gc.ca/Maritimes/Oceans/OCMD/Musquash/Musquash-MPA.

Hudson Bay Programme. "The Estuaries of Hudson Bay: A Case Study of the Study of the Physical and Biological Characteristics of Selected Sites." F. Schneider-Vieira, R. Baker, and M. Lawrence 1994. http://pubs.aina.ucalgary.ca/misc/46955.pdf.

Nature Conservancy of Canada. Grand Codroy estuary, Newfoundland and Labrador. http://www.natureconservancy.ca/en/where-we-work/newfoundland-and-labrador/featured-projects/the_grand_codroy_estuary.html.

Nature Trust of British Columbia. Pacific Estuary Conservation Program. Deals with estuaries on the coast of British Columbia. http://www.naturetrust.bc.ca/about-us/partners/programs/.

Pacific North Coast Integrated Management Area (PNCIMA). "The Pacific North Coast Integrated Management Area initiative's aim is to ensure a healthy, safe, and prosperous ocean area by engaging all interested parties in the collaborative development and implementation of an integrated management plan for PNCIMA." http://www.pncima.org/media/documents/atlas/pncima_atlas_map-12_estuaries.pdf.

Province of British Columbia. "Estuaries in British Columbia." http://www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf.

Walter and Duncan Gordon Foundation. Mackenzie River estuary, Yukon Territory. "The Mackenzie Basin: Why it matters to Canada and the world." http://gordonfoundation.ca/sites/default/files/images/Lesack_rosenberg-with-refs-2p.pdf.

UNESCO: Ecological Sciences for Sustainable Development. Bras d'Or Lakes, Nova Scotia. "The Bras d'Or estuary and its associated watershed is one of Canada's charismatic ecosystems and is part of the UNESCO Biosphere Reserve Network." http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/europe-north-america/canada/bras-dor-lake/.

United States

Estuary Education, a component of the National Estuarine Research Reserve System. "Access factsheets that contain information and images on a select group of estuarine plants and animals that are endangered or are species of concern." http://estuaries.noaa.gov/About/Home.aspx.

Kennebec Estuary Land Trust. "Protecting the land, water, and wildlife of the Kennebec estuary." http://kennebecestuary.org/about-us/the-kennebec-estuary.

Lower Columbia Estuary Partnership. "Part of the National Estuary Program since 1995, the Lower Columbia Estuary Partnership works to protect and restore the nationally significant Lower Columbia River estuary with on-the-ground improvements and education and information programs. LCREP works within a 146-mile segment of the Columbia River and nearby acreage from the Bonneville Dam to the mouth of the Pacific Ocean." http://www.estuarypartnership.org/.

National Estuarine Research Reserve System. “The National Estuarine Research Reserve System is a network of 28 areas representing different biogeographic regions of the United States that are protected for long-term research, water-quality monitoring, education and coastal stewardship.” http://estuaries.noaa.gov/About/Default.aspx?ID=116.

Nature Conservancy. “Natural Intersection: Understanding and Conserving Alaska’s Estuaries.” http://blog.nature.org/science/2013/10/03/alaska-estuary/.

Puget Sound Partnership, Washington State. “The Puget Sound Partnership is a state agency serving as the backbone organization for Puget Sound Recovery.” http://www.psp.wa.gov/aboutthepartnership.php.

US Environmental Protection Agency, National Estuary Program. “The National Estuary Program (NEP) is a network of voluntary community-based programs that safeguards the health of important coastal ecosystems.” http://water.epa.gov/type/oceb/nep/index.cfm#tabs-2.

International – North America

Conservation Law Foundation. “Restoring New England’s Estuaries.” http://www.clf.org/our-work/ocean-conservation/restoring-new-englands-estuaries/.

Gulf of Maine Council. “The Gulf of Maine Council on the Marine Environment, created in 1989 by the governments of Maine, Massachusetts, New Brunswick, New Hampshire and Nova Scotia, works to foster environmental health and community well-being throughout the Gulf watershed. The mission of the Gulf of Maine Council is to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations.” http://www.gulfofmaine.org/2/.

United Kingdom

Dee Estuary Conservation Group. “Representing 25 local and national bodies with interests in the wildlife of the Dee Estuary.” http://www.deeestuary.co.uk/decg.htm.

Forth Estuary Forum, Firth of Forth, Scotland. “The Forum is a voluntary partnership of organisations around the Forth with an interest in the wellbeing of the Forth and its coastal communities.” http://www.forthestuaryforum.co.uk/.

Joint Nature Conservation Committee. "Plymouth Sound and Estuaries." http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0013111.

Northern Ireland Department of the Environment. "Roe Estuary Nature Reserve." http://www.doeni.gov.uk/niea/protected_areas_home/nature_resintro/nature_reserves_roe.htm.

Ireland

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Inland Fisheries Ireland. "Sea trout from the Irish coast." http://www.fishinginireland.info/salmon/seatrout.htm.

Europe

European Commission guidance document. "The implementation of the Birds and Habitats Directives in estuaries and coastal zones with particular attention to port development and dredging." http://ec.europa.eu/transport/modes/maritime/doc/guidance_doc.pdf.

European Environment Agency. "Coasts and seas." Has links to several very informative websites on estuaries. http://www.eea.europa.eu/themes/coast_sea.

Hamburg Port Authority. "Elbe Estuary and the Port of Hamburg – present situation and future perspectives." http://deltanet-project.eu/files/presentation/elbe-hamburg.pdf.

International Baltic Sea Foundation for Nature Conservation. http://www.baltcf.org.

KnowSeas. The Knowledge-based Sustainable Management for Europe's Seas (KnowSeas) project is supported by the European Commission under the Environment (including climate change) Theme of the 7th Framework Programme for Research and Technological Development. The four-year project started in April 2009, has 32 partners from 15 countries, and is coordinated by the Scottish Association for Marine Science. http://www.knowseas.com/.

Marine Biodiversity and Ecosystem Functioning (MarBEF). "MarBEF, a network of excellence funded by the European Union and consisting of 94 European marine institutes, was a platform to integrate and disseminate knowledge and expertise on marine biodiversity, with links to researchers, industry, stakeholders and the general public." Ecological restoration of estuaries in North Western Europe. http://www.marbef.org/wiki/Ecological_restoration_of_estuaries_in_North_Western_Europe.

North Atlantic Salmon Conservation Organisation. "Protection, Restoration and Enhancement of Salmon Habitat Focus Area Report." "In 2003 the Norwegian Parliament established a system of national salmon rivers and national salmon fjords where the wild Atlantic salmon is granted special protection. Today the scheme comprises 52 national salmon rivers and 29 national salmon fjords." http://www.nasco.int/pdf/far_habitat/HabitatFAR_Norway.pdf.

Tidal River Development (TIDE). "A project co-financed by the Interreg IVB North Sea Region Programme and implemented between 2010 and 2013. The TIDE partnership carried out numerous interdisciplinary, inter-estuarine comparative studies on natural processes, management systems and measure implementation and developed a web-based toolbox containing valuable knowledge, management tools and good practice examples." http://www.tide-project.eu/.

Vision and Strategies Around the Baltic Sea (VASAB). "BALANCE – Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning." http://www.vasab.org/index.php/projects/balance.

International

State of the Salmon. "State of the Salmon builds knowledge across borders, linking a greater understanding of Pacific salmon (genus *Oncorhynchus*) to their improved management and conservation around the Pacific Rim." http://www.stateofthesalmon.org/.

Appendix 4

Additional Literature Consulted

Categorization of Additional Literature Consulted

The references are arranged according to species or major topic that the paper or report deals with. In instances where two species of salmonids are listed in the title, the paper is categorized by the species that is listed first. Examples of species names that often occurred together in one paper were Atlantic salmon and sea trout, pink salmon and chum salmon, and Dolly Varden and bull trout. If more than two species of salmonids were discussed in the paper, the paper was categorized under “Multiple Species of Salmonids.” Some papers did not list a species in the title, and I categorized them according to my knowledge of their subject matter.

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Amago

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Arctic Char

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Appendix 5

Colour Photos Linked to Figures in the Book

Figure 2

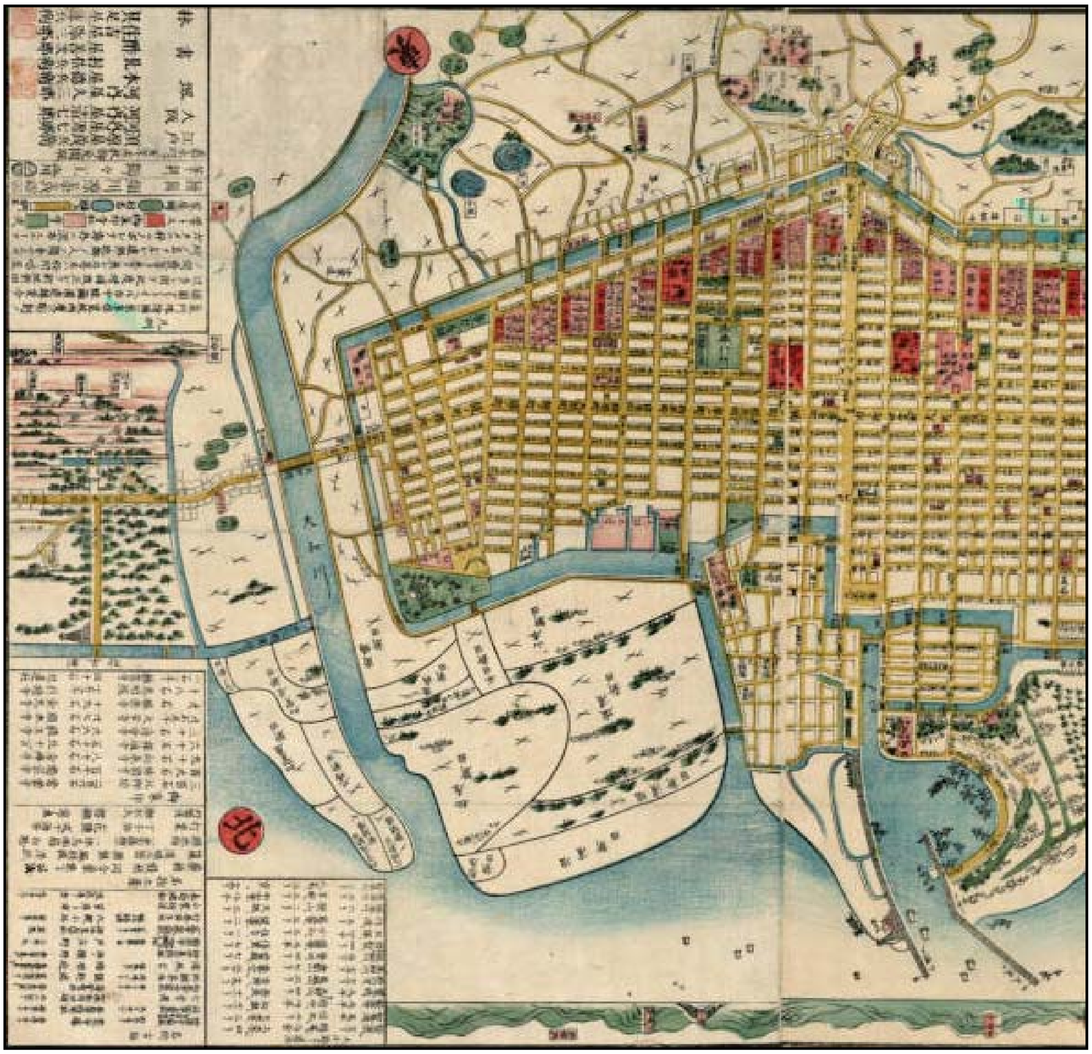
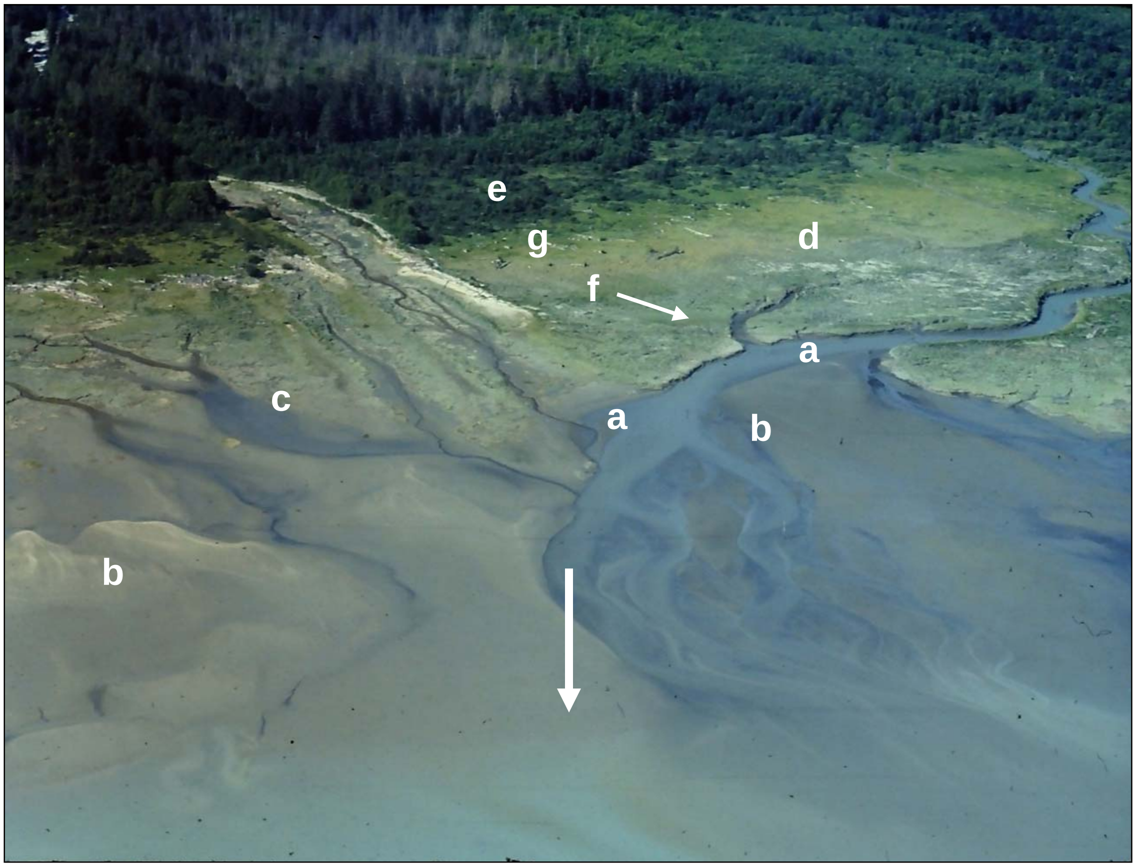


Figure 2 The Yamato River estuary, Japan, from the eighteenth century, showing how the mouth of the river was straightened for shipping.
Notes: Development of the port is indicated by streets and roads. This estuary is now completely developed and is part of Sakai City, near Osaka.
Source: From Japanese Maps of the Tokugawa Era, University British Columbia, Digital Collection, with permission.

Figure 8

Beach and vegetation habitat near Tvärminne, Finland, on the Baltic Sea near the estuary of the Svartå River.
Source: Photo by Dr. Alf Norkko, Tvärminne Zoological Station, reproduced with permission.

Figure 9



Eastern sector of the outer Homathko River estuary, an undisturbed estuary on fjordic
Bute Inlet, British Columbia.

Notes: a = riverine channel of a branch of the main river, b = sandflats, c = mudflats, d = brackish marsh, e = riparian vegetation, f = tidal channel, g = wet meadow, h = tidal swamp-forested. Arrow in lower centre is seaward towards the coastal zone. On the left, a new channel recently created by the main river breaking through the forested flood plain can be seen.

Source: Photo by author, August, 1980.

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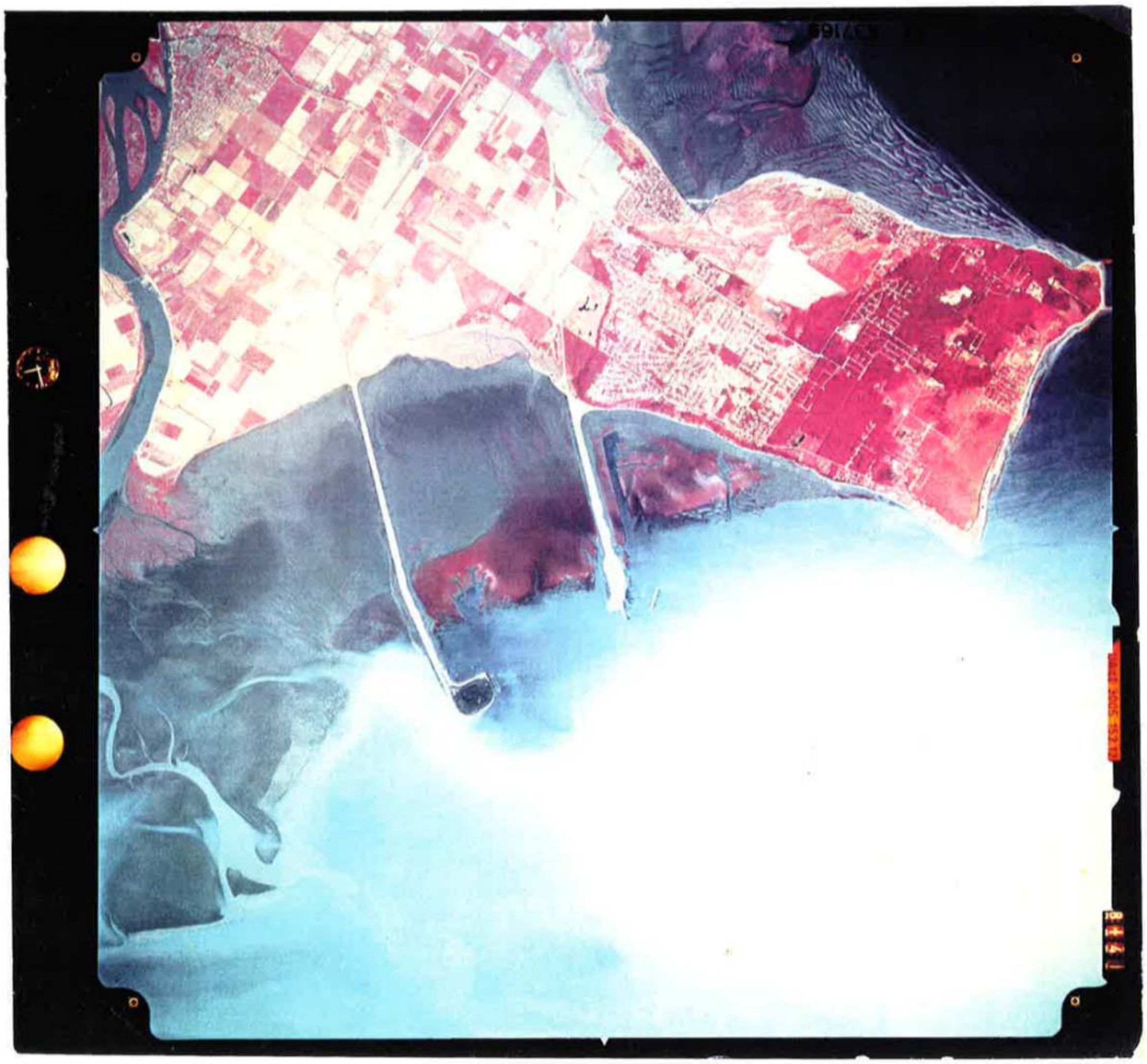
Figure 10

Intertidal zone of Bute Inlet, British Columbia, in the coastal zone further seaward from the outer Homathko River estuary shown in Figure 9.
Note: Macroalgae at the low and mid-intertidal zone grade into riparian vegetation at higher elevations.
Source: Photo by Neil McDaniel; August, 1967, reproduced with permission.

Figure 11 (right panel)



Aerial infra-red photograph of Roberts Bank, Fraser River estuary, British Columbia, Canada, taken at low tide in 1975.

Notes: The causeway shown in the centre leads to a coal port terminal built on an artificial island. In the right centre, another causeway leads to a ferry terminal. An eelgrass bed lies in the low intertidal zonation between the two causeways. Sand flats and salt marsh are found in the higher intertidal. See left panel in the main book to locate sampling locations used by Macdonald, 1994.

Source: Photo by Tarbotton and Harrison, 1996, reproduced with permission.

Figure 13

Left panel: Brown trout, Klamath River estuary, California. Right panel: Sea trout, Rio Grande River estuary, Argentina.
Source: Brown trout photo by Mike Wallace, California Fish and Wildlife, Arcata, California, reproduced with permission. Sea trout photo by Lynn Palensky, Portland, Oregon, reproduced with permission.

Figure 14

Antennae for PIT tags and fyke net used to assess migrations and residency of juvenile Chinook salmon at a tidal channel in the Salmon River estuary, Oregon.
Source: Reproduced from Hering et al. 2010, copyright 2008 Canadian Science Publishing or its licensors. Reproduced with permission.

Figure 22

Sea wall at the St. Lawrence River estuary (Île d'Orleans) near Québec City. Woody debris from fragmented riparian vegetation has collected at the base of the seawall. *Source:* Photo by author, April, 2011.

Orkla River Estuary, Norway

Training walls at the Orkla River estuary, Norway, looking downstream.
Source: Photo by author, June, 2005.

The Mølnargårds River Estuary, Norway

The Mølnargårds River estuary near the museum in Botngård, Sor-Trondelag County, Norway.
Source: Photo by author, June, 2005.

Nisqually River Estuary, Washington

Breaching a dike to restore a previously isolated portion of the Nisqually River estuary, Washington. *Source:* Photo by the US Fish and Wildlife Service, reproduced with permission.