

Forty years of change in forage fish and jellyfish abundance across greater Puget Sound, Washington (USA): anthropogenic and climate associations

Correigh Greene*, Lauren Kuehne, Casimir Rice, Kurt Fresh, Daniel Penttila

*Corresponding author: correigh.greene@noaa.gov

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In this text we provide 1) a supplemental figure showing temporal trends in human population density, commercial landings, and NPGO (Fig. S1), 2) the relative abundance of all species caught in surface trawls in the four basins in historical and recent sampling efforts (Table S1), and 3) the annual mean and standard deviation of day CPUE for species classes and individual forage fish species (Table S2) in all sub-basins sampled.

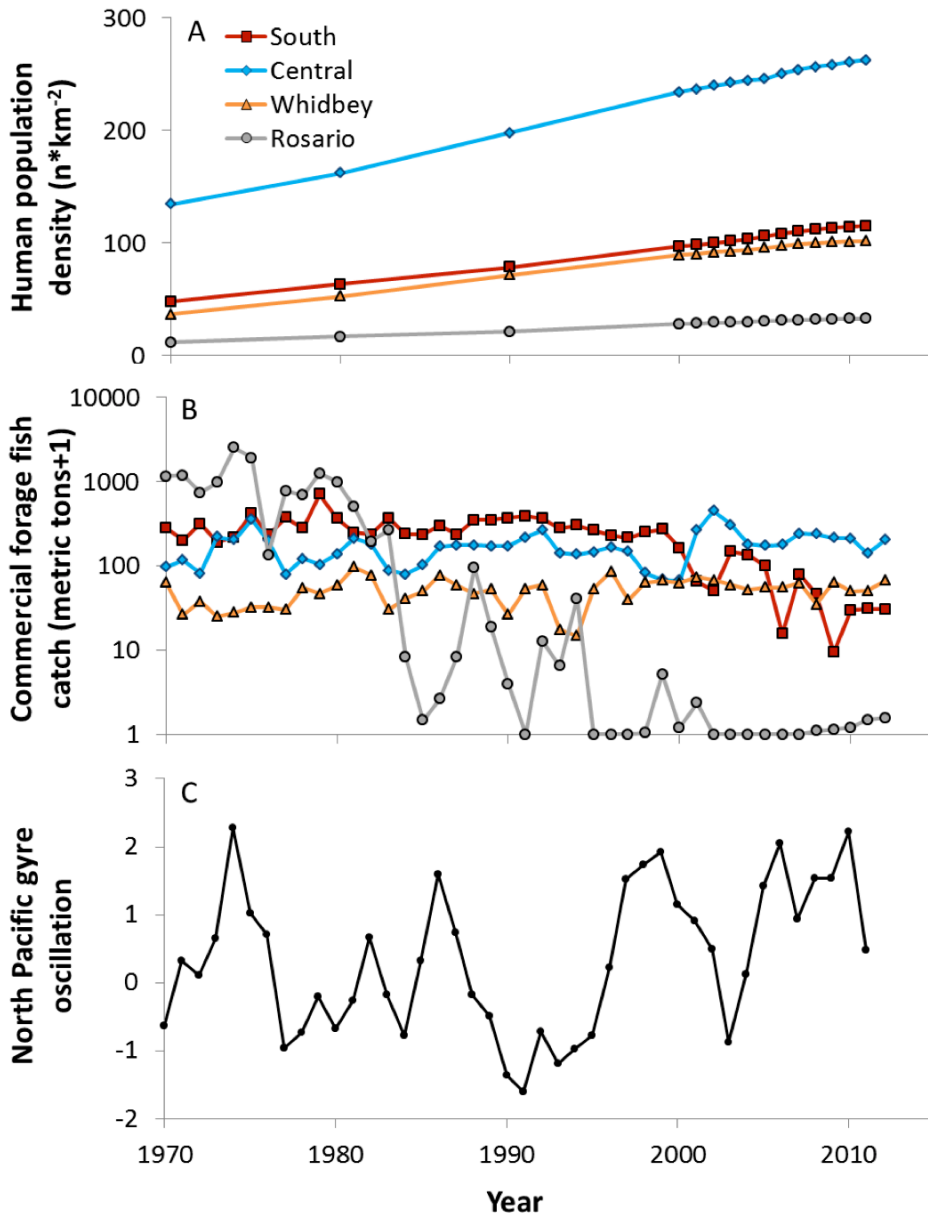


Figure S1. Data for A) average human population density in counties surrounding each sub-basin, B) Commercial catch (metric tons +1 to include 0 catch on log scale) in each sub-basin, and C) the North Pacific gyre oscillation (NPGO) during the decades comprising this study. Markers note years in which measures were estimated. Human population density and NPGO extend to earlier decades, but were not used for analysis.

Table S1. Relative abundance (%) based on catch per unit effort ($n \cdot \text{min}^{-1}$) of taxa captured in each of four sub-basins of greater Puget Sound in historical (1971-1985) and recent surveys (2002-2011). Dashed lines indicate no observations exist.

Common name	Scientific name	Historical				Recent			
		SOU	CEN	WHI	ROS	SOU	CEN	WHI	ROS
Forage fish									
American shad	<i>Alosa sapidissima</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Eulachon	<i>Thaleichthys pacificus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Pacific herring	<i>Clupea pallasii</i>	89.8	95.4	49.2	90.1	0.1	7.9	19.0	11.9
Longfin smelt	<i>Spirinchus thaleichthys</i>	<0.1	<0.1	0.1	0.7	<0.1	<0.1	<0.1	<0.1
Northern anchovy	<i>Engraulis mordax</i>	<0.1	<0.1	0.4	0.1	<0.1	0.1	0.1	0.2
Pacific sand lance	<i>Ammodytes hexapterus</i>	<0.1	<0.1	6.7	0.4	0.2	4.1	19.3	10.1
Surf smelt	<i>Hypomesus pretiosus</i>	4.6	2.3	12.3	1.2	0.1	6.6	19.2	7.9
Three-spine stickleback	<i>Gasterosteus aculeatus</i>	<0.1	<0.1	15.2	5.8	88.7	3.7	33.0	68.2
Undetermined osmerid	Osmeridae	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Total		94.4	97.8	83.9	98.3	89.1	22.5	90.5	98.3
Salmon									
Bull trout	<i>Salvelinus confluentus</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	0.8	0.4	1.8	0.2	2.9	10.4	1.8	0.5
Chum salmon	<i>Oncorhynchus keta</i>	1.8	0.6	0.7	<0.1	7.7	65.5	3.1	0.6
Coho salmon	<i>Oncorhynchus kisutch</i>	0.1	0.2	1.2	0.1	<0.1	1.0	0.3	<0.1
Cutthroat trout	<i>Oncorhynchus clarkii</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pink salmon	<i>Oncorhynchus gorbuscha</i>	<0.1	0.1	10.9	<0.1	<0.1	<0.1	<0.1	<0.1
Sockeye salmon	<i>Oncorhynchus nerka</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Steelhead/rainbow trout	<i>Oncorhynchus mykiss</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined salmon	<i>Oncorhynchus</i> spp.	1.8	0.2	<0.1	<0.1	--	--	--	--
Total		4.5	1.5	14.7	0.4	10.7	76.9	5.2	1.1
Demersal fish									
Bay goby	<i>Lepidogobius lepidus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Bay pipefish	<i>Syngnathus leptorhynchus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1

Blacktip poacher	<i>Xeneretmus latifrons</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Butter sole	<i>Isopsetta isolepis</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cabezon	<i>Scorpaenichthys marmoratus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Copper rockfish	<i>Sebastes caurinus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Crescent gunnel	<i>Pholis laeta</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Dover sole	<i>Microstomus pacificus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
English sole	<i>Parophrys vetulus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Grunt sculpin	<i>Rhamphocottus richardsonii</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Kelp greenling	<i>Hexagrammos decagrammus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Kelp perch	<i>Brachyistius frenatus</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Lingcod	<i>Ophiodon elongatus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Lumpfishes and snailfishes	<i>Cyclopteridae/Liparidae</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Manacled sculpin	<i>Synchirus gilli</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Northern lampfish	<i>Stenobranchius leucopsarus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Pacific cod	<i>Gadus macrocephalus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Pacific hake	<i>Merluccius productus</i>	<0.1	<0.1	0.2	<0.1	--	--	--	--
Pacific sandfish	<i>Trichodon trichodon</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.9	<0.1
Pacific tomcod	<i>Microgadus proximus</i>	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
Penpoint gunnel	<i>Apodichthys flavidus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Pile perch	<i>Rhacochilus vacca</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Plainfin midshipman	<i>Porichthys notatus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Alaska pollock	<i>Theragra chalcogramma</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Pumpkinseed	<i>Lepomis gibbosus</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Quillback rockfish	<i>Sebastes maliger</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
River lamprey	<i>Lampetra ayresii</i>	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.4	<0.1
Rock sole	<i>Lepidopsetta bilineata</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Rockfish	<i>Sebastes spp.</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sablefish	<i>Anoplopoma fimbria</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Saddleback gunnel	<i>Pholis ornata</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sailfin sculpin	<i>Nautichthys oculofasciatus</i>	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Sand sole	<i>Psettichthys melanostictus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--

Shiner perch	<i>Cymatogaster aggregata</i>	0.8	0.5	0.7	0.4	0.1	<0.1	2.4	0.2
Silverspotted sculpin	<i>Blepsias cirrhosus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Snake prickleback	<i>Lumpenus sagitta</i>	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
Soft sculpin	<i>Psychrolutes sigalutes</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Spiny dogfish	<i>Squalus acanthias</i>	0.1	<0.1	<0.1	<0.1	--	--	--	--
Spotted ratfish	<i>Hydrolagus colliei</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Staghorn sculpin	<i>Leptocottus armatus</i>	0.1	<0.1	0.1	0.2	<0.1	<0.1	<0.1	<0.1
Starry flounder	<i>Platichthys stellatus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Striped sea perch	<i>Embiotoca lateralis</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Sturgeon poacher	<i>Podothecus accipenserinus</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Tidepool snailfish	<i>Liparis florum</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Tube-nose poacher	<i>Pallasina barbata</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Tube-snout	<i>Aulorhynchus flavidus</i>	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	0.1	<0.1
Whitebarred prickleback	<i>Poroclinus rothrocki</i>	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Undetermined blenny	Blenniidae	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Undetermined flatfish	Pleuronectidae	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1
Undetermined gadid	Gadidae	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1
Undetermined goby	Gobiidae	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Undetermined greenling	Hexagrammos spp.	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined gunnel	Pholidae	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined lamprey	Petromyzontidae	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Undetermined poacher	Agonidae.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined prickleback	Stichaeidae	<0.1	<0.1	<0.1	<0.1	--	--	--	--
Undetermined sand dab	Citharichthys spp.	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined sculpin	Cottidae	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Undetermined surf perch	Embiotocidae	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2
Total		1.1	0.7	1.4	1.3	0.2	0.6	4.2	0.5
Unknown squid	<i>Loligo</i> spp.	--	--	--	--	<0.1	<0.1	<0.1	<0.1
Unknown juvenile fish		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table S2. Number of sites and tows by year in each sub-basin, and geometric means (and standard deviations) of CPUE ($n \cdot \text{min}^{-1}$) for the three species classes and five most common forage fish species. Data were $\log(x+1)$ transformed to include calculation of zero values and summary statistics were then back-transformed.

Subbasin	Year	Sites (n)	Tows (n)	CPUE							
				Salmon	Demersal fish	Forage fish (all)	Pacific herring	Surf smelt	Pacific sand lance	Three-spine stickleback	Northern anchovy
South	1976	7	8	1.16 (1.82)	0.62 (0.65)	9.33 (90.63)	7.09 (38.45)	1.34 (1.41)	0 (0)	0.09 (0.12)	0.04 (0.01)
	1977	8	31	1.54 (1.41)	0.97 (1.63)	10.23 (10.84)	7.51 (11.23)	1.01 (2.67)	0 (0)	0.01 (0.03)	0.01 (0.04)
	1978	4	18	3.05 (2.68)	1.15 (1.12)	26.08 (4.76)	21.12 (4.57)	4.06 (3.77)	0.03 (0.12)	0.01 (0.02)	0.05 (0.19)
	1979	4	17	2.08 (1.07)	1.15 (1.89)	35.9 (13.98)	34.54 (13.66)	0.57 (2.33)	0.06 (0.24)	0.02 (0.05)	0 (0)
	1980	1	4	13.73 (3.55)	0.55 (0.89)	30.47 (4.54)	25.25 (3.64)	4.96 (5.88)	0.05 (0.1)	0 (0)	0 (0)
	1981	4	8	0.84 (1.4)	0.09 (0.14)	4.4 (3.95)	4.34 (3.83)	0.35 (1.32)	0.02 (0.07)	0 (0)	0.06 (0.18)
	1982	4	15	5.23 (4.05)	0.73 (0.77)	4.5 (5.42)	4.48 (5.39)	0.02 (0.07)	0.05 (0.17)	0 (0)	0.07 (0.23)
	2003	6	44	1.34 (2.71)	0.09 (0.3)	0.16 (0.63)	0.05 (0.16)	0 (0.01)	0.11 (0.6)	0.02 (0.06)	0 (0)
	2011	13	52	4.45 (2.89)	0.12 (0.33)	0.57 (3.47)	0.07 (0.23)	0.05 (0.24)	0 (0.03)	0.45 (3.44)	0 (0)
Central	1976	3	6	0.48 (0.2)	0.65 (1.98)	30.34 (5.33)	27.78 (4.72)	2.41 (6.93)	0 (0)	0 (0)	0.31 (0.85)
	1977	4	19	1.5 (0.8)	1.65 (1.73)	61.71 (7.75)	55.32 (7.71)	1.74 (4.78)	0.01 (0.03)	0.03 (0.13)	0.19 (0.51)
	1978	9	31	1.98 (1.25)	1.48 (1.38)	92.34 (5.31)	79.8 (5.8)	2.72 (3.03)	0.09 (0.21)	0.01 (0.03)	0.01 (0.05)
	1979	10	44	1.25 (1.19)	0.93 (1.25)	84.02 (8.07)	70.52 (9.3)	1.17 (2.74)	0.13 (0.31)	0.01 (0.04)	0.01 (0.04)
	1980	9	41	1.29 (1.23)	0.62 (0.78)	42.08 (6.6)	40.05 (6.74)	0.67 (1.37)	0.08 (0.24)	0.02 (0.06)	0.01 (0.03)
	1981	12	51	1.22 (1.34)	0.2 (0.58)	14.14 (6.15)	13.83 (6.2)	0.17 (0.63)	0.01 (0.04)	0 (0)	0.03 (0.11)
	1982	11	35	1.17 (0.9)	0.1 (0.18)	24.85 (8.01)	24.39 (8.18)	0.01 (0.03)	0.08 (0.22)	0 (0)	0.01 (0.03)
	1983	12	36	1.13 (0.97)	0.21 (0.49)	9.45 (6.33)	9.11 (6.54)	0.1 (0.33)	0.04 (0.09)	0 (0)	0.05 (0.12)

	1984	7	36	1.44 (1.31)	0.5 (0.75)	7.83 (3.77)	7.63 (3.76)	0.18 (0.54)	0.05 (0.12)	0.01 (0.03)	0.02 (0.07)
	1985	7	34	2.48 (1.55)	0.27 (0.58)	15.83 (5.38)	15.29 (5.6)	0.04 (0.11)	0.03 (0.08)	0.02 (0.05)	0.09 (0.16)
	2002	2	17	0.39 (0.83)	0.01 (0.02)	0.18 (0.51)	0.01 (0.02)	0 (0)	0.02 (0.09)	0.17 (0.47)	0 (0)
	2003	14	111	1.29 (2.26)	0.04 (0.18)	0.59 (1.28)	0.25 (0.58)	0.13 (0.71)	0.05 (0.48)	0.14 (0.51)	0 (0.01)
	2011	13	52	4.79 (3.02)	0.02 (0.05)	0.69 (1.25)	0.24 (0.87)	0.13 (0.42)	0.06 (0.49)	0.18 (0.44)	0.02 (0.11)
Whidbey	1971	2*	317	1.73 (1.6)	0.03 (0.17)	0.85 (1.68)	0.23 (0.77)	0.07 (0.26)	0.03 (0.46)	0.54 (1.22)	0.01 (0.04)
	1972	1*	131	5.45 (3.1)	0.26 (0.44)	9.57 (5.99)	2.97 (4.18)	3.69 (3.27)	0.53 (1.82)	2.88 (3.88)	0.07 (0.28)
	1983	5	17	0.3 (0.32)	1.66 (1.62)	74.21 (4.01)	72.86 (4.03)	0.09 (0.28)	0.18 (0.32)	0.02 (0.09)	0.5 (1.13)
	1984	4	25	0.83 (0.77)	0.37 (0.69)	9.08 (1.83)	8.66 (1.83)	0.04 (0.21)	0.16 (0.27)	0.01 (0.04)	0.16 (0.28)
	1985	4	18	0.93 (0.84)	1.01 (1.69)	34.25 (3.09)	33.4 (3.14)	0.01 (0.04)	0.07 (0.19)	0 (0)	0.24 (0.54)
	2003	20	158	0.7 (0.91)	0.4 (1.08)	7.26 (3.11)	2.36 (2.4)	3.36 (2.48)	0.35 (1.2)	0.39 (0.72)	0 (0.03)
	2011	19	92	1.07 (1.34)	0.3 (0.98)	4.89 (3.23)	0.61 (1.48)	0.98 (1.71)	0.25 (1.6)	1.34 (2.13)	0.05 (0.19)
Rosario	1974	10	28	0.37 (0.34)	0.85 (1.21)	33.5 (2.48)	17.53 (3.63)	0.44 (0.91)	0.04 (0.05)	8.77 (1.98)	0 (0)
	1975	10	38	0.35 (0.39)	0.32 (0.35)	14.85 (4.69)	8.32 (5.92)	0.31 (0.73)	0.25 (0.4)	1.8 (1.7)	0.05 (0.12)
	1976	6	12	0.74 (0.57)	1.81 (1.77)	36.8 (9.46)	22.97 (12.93)	1 (2.35)	0.63 (1.52)	0.86 (1.58)	0.27 (0.39)
	1977	1	8	0.51 (0.4)	0.62 (0.89)	20.23 (3.27)	14.14 (4.67)	0.76 (1.58)	0.21 (0.59)	0.5 (0.74)	0 (0)
	2003	12	79	1.06 (0.89)	0.45 (1.1)	37.98 (4.77)	5.61 (4.55)	2.99 (4.27)	1.83 (5.16)	6.12 (5.17)	0.1 (0.61)
	2011	17	61	1.14 (1.29)	0.24 (0.65)	14.57 (6.8)	1.02 (2.59)	0.33 (0.8)	0.05 (0.38)	10.42 (6.96)	0.03 (0.09)

*Continuous tows covered a broad spatial extent that in subsequent years comprised multiple sites.