ASSESSMENT OF STREAM RESPONSES TO CLIMATE CHANGE, WETLAND LOSS, AND WATERSHED DEVELOPMENT IN COOK INLET

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Introduction:

Both climate change and development are impacting freshwater resources in the Cook Inlet basin ecoregion of Southcentral Alaska, the fastest growing region of the state. The goal of this project was to provide information that Alaska wetland managers can use for furthering actions in the Alaska Wetland Program Plan, specifically prioritizing wetland monitoring and assessment and developing a watershed approach to wetland mitigation in Alaska.

In addition to development, rapid climate change may also be altering stream conditions in watersheds of Southcentral Alaska. Alaska warmed at more than twice the rate of the lower 48 states over the second half of the 20th century (Chapin et al. 2014) and annual temperatures in Southcentral Alaska increased by 1.2 °C over that same period (Stafford et al. 2000). Both wetlands and ponds are shrinking in Southcentral Alaska due to higher evapotranspiration during warmer and longer growing seasons (Klein et al. 2005, Riordan et al. 2006). Climate change impacts to streams are less certain due to the scarcity of long-term datasets in Alaska, although predicted impacts include increased stream temperatures, decreased spring freshet as a result of decreasing snowpack, increased discharge in winter due to more precipitation falling as rain, and decreased baseflow due to higher evapotranspiration (Leppi et al. 2014, Wobus et al. 2015, Mauger et al. 2017). The cumulative impacts of development and climate change are explored across watersheds in the Cook Inlet basin for the first time in this described work.

The last extensive aquatic resource monitoring program in the Cook Inlet basin was conducted by the Environment and Natural Resources Institute at UAA (now the Alaska Center for Conservation Science - ACCS) approximately 20 years ago (Rinella and Bogan 2007). This project included revisiting historic sampling sites to assess trends in water quality and biological community composition over the last 20 years in response to climate change, wetland loss, and watershed development. Monitoring sites were selected at that time that span a range of watershed development, while ensuring that some watersheds have limited development to measure recent and future impacts from climate change. Undeveloped watersheds provide reference conditions against which performance goals can be established for stream mitigation and restoration.

Stream biological communities are important indicators of stream condition because they integrate effects of different stressors over time and provide an indication of their aggregate impact. Macroinvertebrates have been widely used for bioassessment because they generally have low mobility and one to two-year life spans. They also provide an important food resource for Pacific salmon (Wipfli and Baxter 2010), all five species of which contribute to important commercial, subsistence, and sport fisheries in the Cook Inlet basin. ACCS has been monitoring aquatic resources, including stream biological communities, across Alaska for over 20 years. In 2007, ACCS completed macroinvertebrate and diatom multi-metric indices for sites across the Cook Inlet basin and identified metrics that could discriminate undisturbed reference sites from impacted sites. The sites used to develop these multi-metric indices were sampled approximately 20 years ago and provide an opportunity to evaluate changes in biological communities in response to both development and climate change. That multimetric index has also been tested in other systems to detect effects of urbanization (Rinella and Bogan 2010). Expected changes in biological communities from a warming climate include species replacement where new species expand into Alaskan streams and cold water taxa are lost (Heino et al. 2009, Pound et al. 2021). In streams where watershed development impacts physical habitat and water quality, species loss may prevail where sensitive macroinvertebrate taxa disappear, and pollution tolerant taxa increase their abundance (King et al. 2011).

The goal of this project was to provide information on the status and trends of streams in the Cook Inlet basin ecoregion in response to wetland loss, watershed development, and climate change. Stream condition is closely tied to upstream cumulative wetland condition and function (i.e., quantity and quality). Outputs from the project can inform planned actions in the Alaska Wetland Program Plan (2015), such as Goal 3 under Core Element: Monitoring and Assessment and Goal 5 under Core Element: Regulation. This project also supports Goal 3: the development of a wetland monitoring and assessment strategy, by informing the effectiveness of wetland mitigation across watersheds with various levels of wetland impacts. Project results can also be used by state and federal regulatory agencies in developing a comprehensive wetland mitigation strategy (Goal 5), specifically objective 2 to establish a “watershed approach” to compensatory mitigation. The assessment of stream condition can be linked to the performance of wetland 404 mitigation projects in the upstream watershed in addition to identifying impaired watersheds that may provide opportunities for mitigation. Additionally, the baseline monitoring data at non-impacted streams described here will be useful for establishing performance standards and success criteria for stream mitigation projects. This is a key information gap as comprehensive monitoring of biological communities in streams has not been conducted in the last 20 years across the Cook Inlet basin, until this recent work.

Alaska Center for Conservation Science (ACCS), in partnership with Cook Inletkeeper, presents an analysis of trends in water quality and biological community composition over the past 20 years in response to wetland loss, climate change, and watershed development in the Cook Inlet basin ecoregion of Southcentral Alaska. This work also provides a current baseline of stream condition against which future changes can be measured. The project was composed of three tasks: 1) monitor biological communities and water quality in 20-30 streams across the Cook Inlet basin ecoregion, 2) develop a geospatial database of climate, wetland, and development indicators at multiple spatial scales for all sampling sites, and 3) assess stream condition responses to climate change, wetland loss, and watershed development. Project outputs include a database of benthic macroinvertebrates (individual taxa and assemblages) and water chemistry data for Cook Inlet basin streams over a three-year period; a geospatial database of climate, wetland, and development indicators for all priority watersheds; and an assessment of benthic macroinvertebrate community composition and water quality changes over the last two decades.

Study Area:

Our sampling and mapping efforts cover nine 8-digit HUCs in the Cook Inlet Basin ecoregion. This ecoregion encompasses the western half of the Kenai Peninsula, the Anchorage municipality, and lowlands in western Cook Inlet and the Susitna area. This ecoregion experiences a mild climate for its latitude, with a transitional climate between maritime and continental, with corresponding gradients in temperature and precipitation. Past and present glaciation affects the entire area, with silty mudflats and glaciated headwaters. Peatlands and other wetlands (e.g. bogs, fens, and swamps) are found throughout the region. Numerous bogs throughout the region are characterized by black spruce and shrub communities. Forested areas in the region range from coastal temperate rainforests to continental taiga forests characterized by black spruce, white spruce, Lutz spruce, balsam poplar, black cottonwood, paper birch, and quaking aspen. The area is generally free of permafrost. In general, the Cook Inlet ecoregion features the most settlement and development in Alaska, although that land use impact is not uniformly distributed across the region.

TABLE 1 USGS HUC8 IDENTIFIERS FOR THE COOK INLET BASIN ECOREGION WATERSHEDS.

Hydrologic Unit Code	Name
19020301	Lower Kenai Peninsula
19020302	Upper Kenai Peninsula
19020401	Anchorage
19020402	Matanuska
19020501	Upper Susitna River
19020502	Chulitna River
19020503	Talkeetna River
19020504	Yentna River
19020505	Lower Susitna River

The Cook Inlet region includes three boroughs (the Kenai Peninsula borough, the Matanuska Susitna borough, and the Anchorage municipality), which are comparable to counties in other parts of the United States, with their own governance structures and taxation authority. Regulations around land development are largely decided at a borough level, thus creating a gradient of land use and development history across the Cook Inlet region. Most Alaskans live in the Southcentral region of Alaska in the Municipality of Anchorage (40% of Alaska's total population), the Mat-Su Borough (14%), and the Kenai Peninsula Borough (8%). Over the last 20 years, the combined population across these three areas has grown by 24% (http://live.laborstats.alaska.gov/pop/index.cfm). With population growth comes expanded infrastructure across the landscape requiring wetland fill, which adversely affects both wetlands and the streams draining them. Wetlands support healthy streams by filtering out pollutants and sediments, absorbing rainfall during storm events, and recharging groundwater during baseflows and drought (U.S. EPA 2015, Gracz and Glaser 2017). An investigation into urbanization impacts in Alaska's largest city, Anchorage, found that stream conditions deteriorated at impervious watershed areas of approximately 5% (Ourso and Frenzel 2003).

FIGURE 1 PROJECT AREA WITH SITE NAMES LABELED.

Site Selection:

Sample sites were selected from ~140 sites that were historically sampled for macroinvertebrate communities between 1997 and 2010. Those historic sites were sampled, in part, to develop a multimetric macroinvertebrate index for Cook Inlet. For the current study, a subset of those historic sites were selected to span a range of development impacts, ensuring that some sites had low impact from development in the watershed, based on *a priori* discussions with the project team. 28 sites on the road system were selected for sampling. Three sites that were only accessible by helicopter were sampled on the west side of Cook Inlet in 2021, but were not sampled in 2020, due to COVID-19 travel restrictions preventing aviation-assisted fieldwork. Sample dates and years by site are in the appendix (Appendix Table 1), and Figure 2 shows examples of representative study sites.

FIGURE 2 EXAMPLES OF STUDY LOCATIONS FROM ANCHORAGE'S SOUTH FORK CHESTER CREEK (LEFT) AND THE KENAI'S NINILCHIK RIVER (RIGHT). A DEPLOYED TEMPERATURE LOGGER IS VISIBLE IN THE LOWER PORTION OF THE PHOTO OF SOUTH FORK CHESTER CREEK.

Biological Monitoring:

Macroinvertebrates were collected in 2020, 2021, and 2022 to capture possible interannual variation in abundances and to ensure detection of rare taxa. Sites were sampled after peak snowmelt and before salmon returning to spawn, minimizing the impacts of physical disturbance on the biological communities. Sampling followed the Alaska Stream Condition Index protocols (Major and Barbour 2001). Benthic macroinvertebrates were collected from a variety of habitats (e.g., bottom substrates, woody debris, macrophytes, and leaf packs) in proportion to their availability using a 350 µm mesh D-net over a 100-meter reach. A total of 20 samples were collected and composited per site and preserved in 70% ethanol.

Invertebrates were identified back in the lab using dissecting microscopes. Samples were evenly distributed on a Caton sampler. Grids in the sampler were randomly selected and organisms were removed from each grid until a sub-sample target number of 300 (+/- 20%) individuals was reached. Then a five-minute search for large and rare invertebrate taxa was conducted, in case those were missed via the subsample processing. Invertebrates were then enumerated and identified to the lowest practicable taxonomic level using standard references (see Appendix 2). A random subsample of Chironomidae larvae captured in the fixed count were slide mounted and identified to genus. Representative specimens from each identified taxon were kept as vouchers, stored in 1-dram vials with 90% ethanol.

Water Quality Monitoring and Physical Habitat Measurements:

Temperature loggers were installed at each site during the first site visit, and data were downloaded during each subsequent visit, with loggers being reinstalled or replaced, as needed. Temperature monitoring followed the stream temperature data collection standards for Alaska (Mauger et al. 2015). All loggers were spot checked using a two-point temperature bath and checked against a NIST-certified logger or thermometer before deployment to ensure accuracy of at least 0.20 degrees Celsius. Point measurements were taken at site revisit to check against logger readings. Once data were downloaded from the logger, temperature data were compared to nearby air temperature data to flag possible erroneous readings. Sites had paired loggers installed so that logger temperatures could be compared to one another in the event of a burial, exposure to air, or other event that could influence the accuracy of temperature data. All temperature data have gone through the QA/QC process and have been uploaded and archived to the AKTEMP water temperature database for Alaska (aktemp.uaa.alaska.edu).

Each year, water quality measurements were taken at the time of macroinvertebrate sampling. Water temperature, pH, specific conductance, and oxygen were sampled using a calibrated OTT HydroMet HYDROLAB sonde. A turbidity sample was collected and analyzed using a Hach 2100P Turbidimeter. Physical habitat attributes that could also influence the biological community and water quality were measured, following EPA’s NRSA protocol (USEPA 2017). Discharge was measured using a Marsh-McBirney flow meter and the velocity-area method.

Environmental and Watershed Development Indicators:

We used National Hydrography Dataset Plus (NHDPlus) value added attributes to create a feature layer of upstream watersheds for each sample point. For each catchment that intersected with a sample point, we used FromNode and ToNode data to identify all catchments that drained into the sample point. All catchments within the upstream watershed were then merged to create a watershed for each sample point.

We used National Land Cover Database (NLCD) data (Homer et al. 2004, Jon Dewitz 2020) to calculate land use and percent impervious surfaces for the most recent year available (2016) and change over time (2001 to 2016). Land use types were binned as “Wild Land”, which included open water, perennial ice/snow, barren land, forested areas, dwarf/shrub scrub, grasslands, woody wetlands, and emergent herbaceous NLCD categories, “Low Development”, which included open development, low development, hay, and cultivated land NLCD categories, and “Developed”, which included medium and high development NLCD categories.

We determined wetland percent cover in each watershed using a Cook Inlet-specific wetland coverage dataset (Gracz and Glaser 2017). For areas with no data from Gracz and Glaser (2017), we used National Wetland Inventory data (USFWS 2024). For watersheds in the Mat-Su valley, an additional variable “Wetland Loss” was calculated using a dataset compiled by Gracz (2018).

To determine climactic impacts, we used Daymet annual precipitation, average annual maximum temperature, average annual minimum temperature, and average annual snow water equivalent (Thornton et al. 2022). Averages of each climate variable were calculated for each watershed for the most recent year available (2022). Additionally, change over time was calculated from 2001 to 2022 using watershed averages for each year.

Land cover, impervious surface, wetland percent, and wetland loss were all calculated using the Tabulate Area tool in ArcGIS Pro (version 3.3.0). Climate variables were calculated using Zonal Statistics in ArcGIS Pro (version 3.3.0).

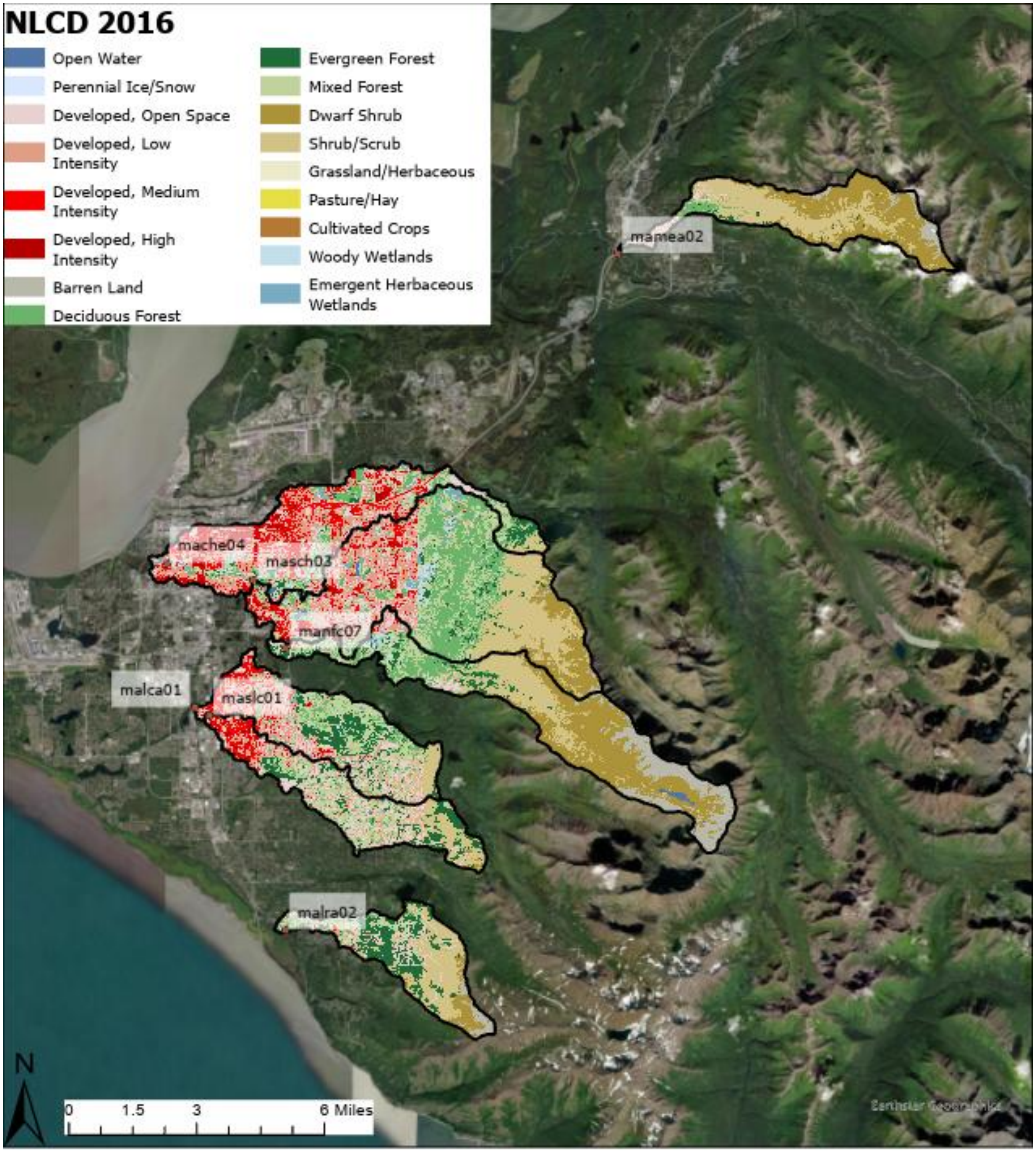

FIGURE 3 MAP OF STUDY WATERSHEDS IN THE ANCHORAGE MUNICIPALITY. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

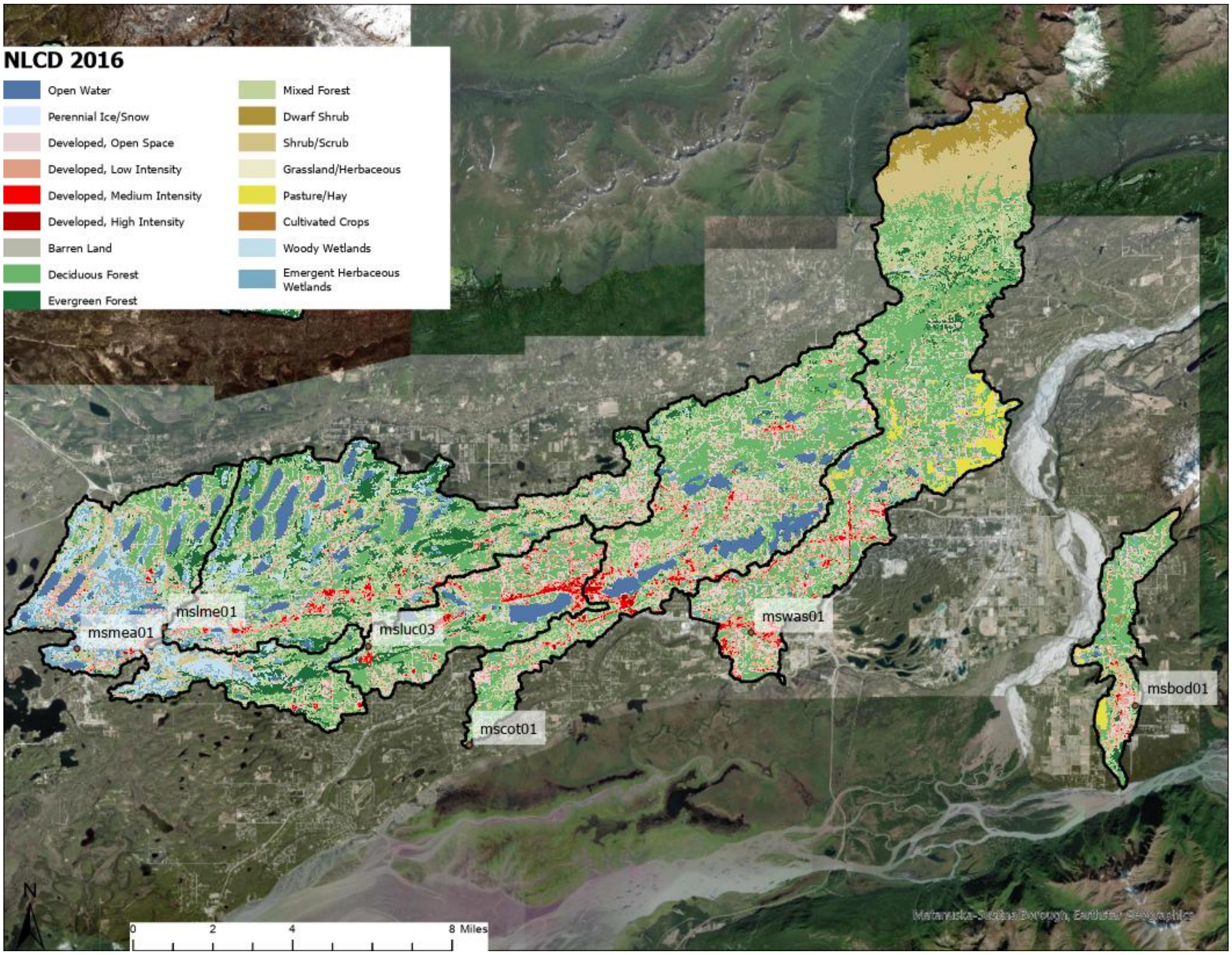

FIGURE 4 MAP OF STUDY WATERSHEDS IN PALMER AND WASILLA. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

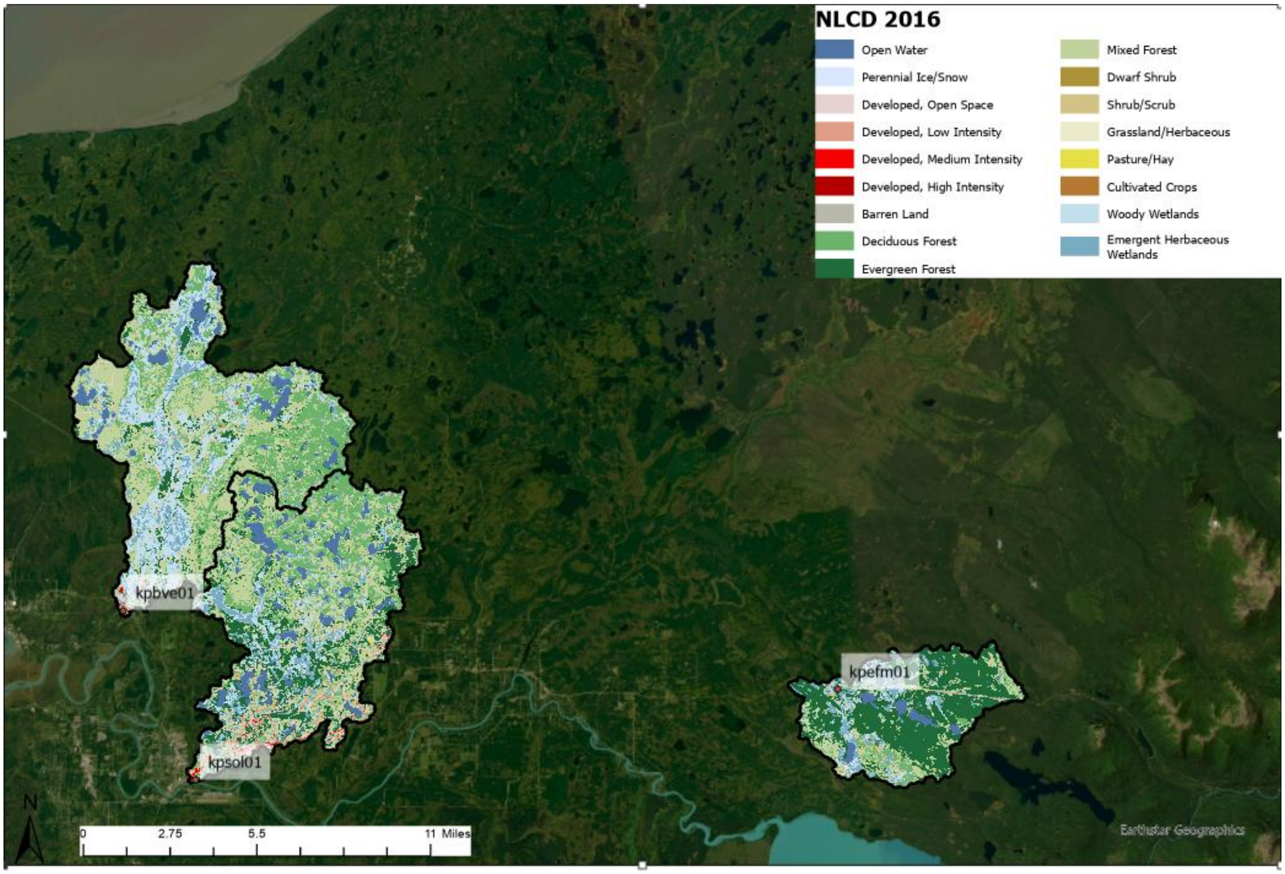

FIGURE 5 MAP OF STUDY WATERSHEDS IN THE NORTHERN PORTION OF THE KENAI PENINSULA BOROUGH. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

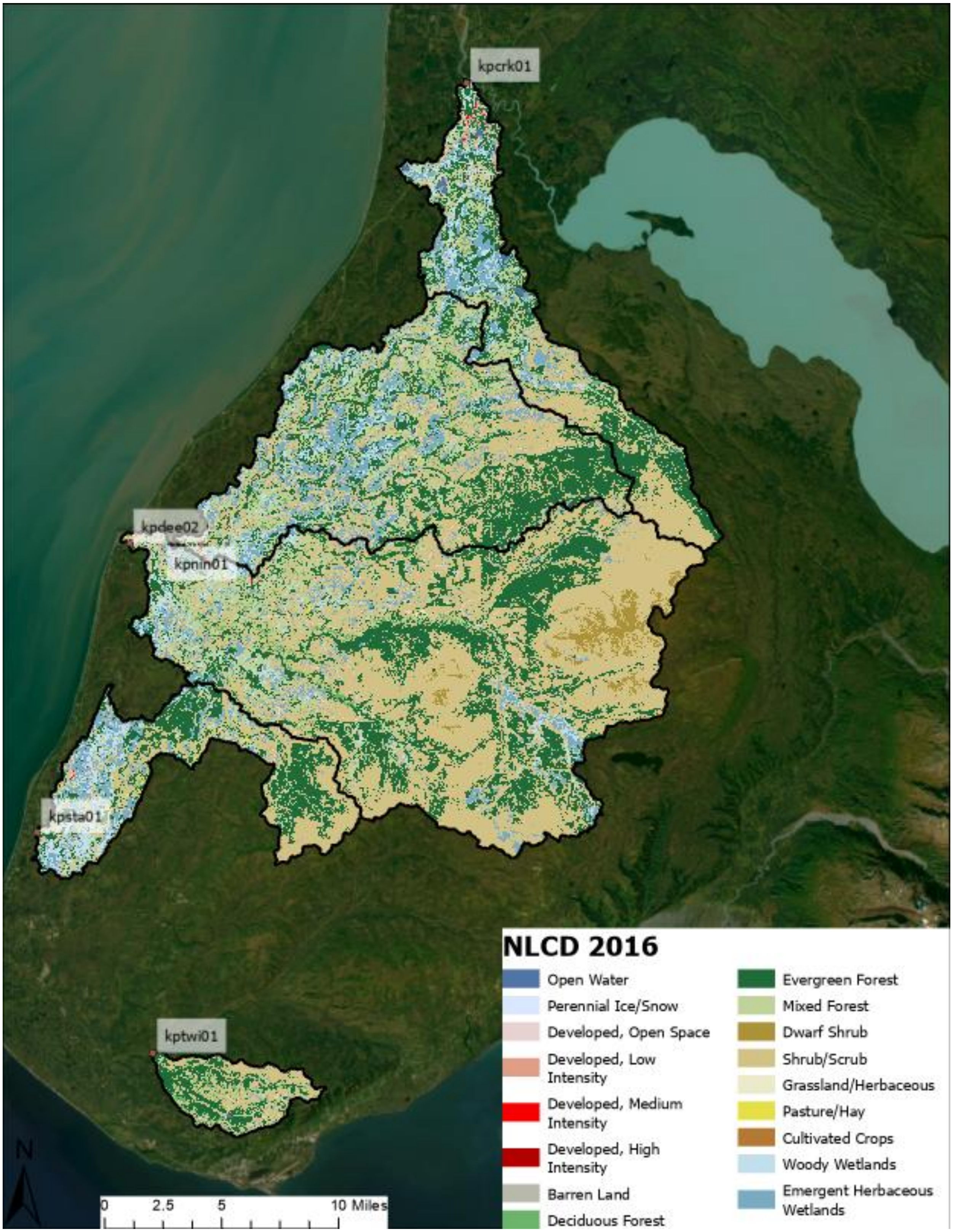
kpcrk01
kpdee02
kpnin01
kpsta01
kptwi01
NLCD 2016
Open Water
Perennial Ice/Snow
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Dwarf Shrub
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
N
0 2.5 5 10 Miles

FIGURE 6 MAP OF STUDY WATERSHEDS IN THE SOUTHERN KENAI PENINSULA BOROUGH. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

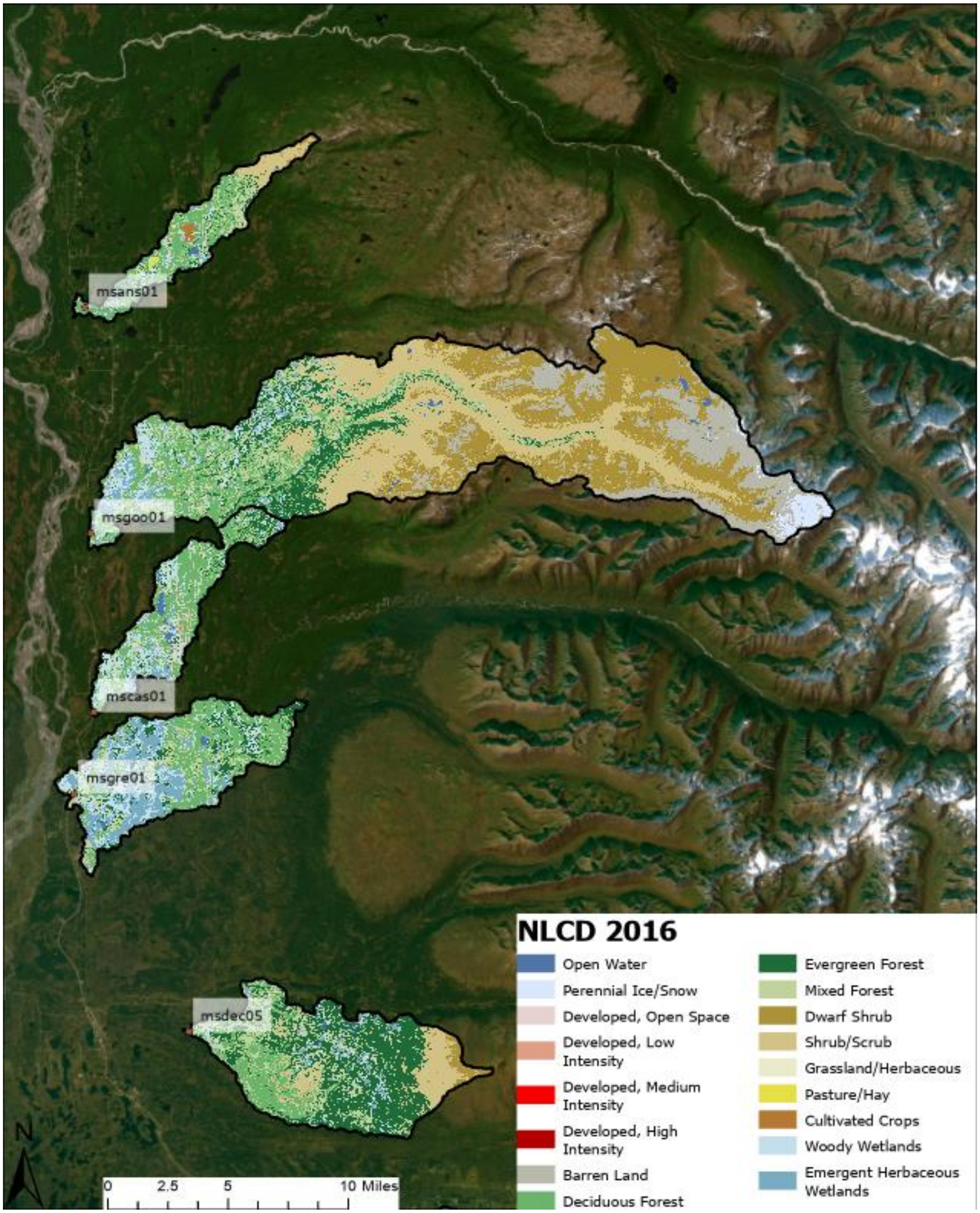

FIGURE 7 MAP OF STUDY WATERSHEDS IN THE NORTHERN PORTION OF THE MATANUSKA SUSITNA BOROUGH. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

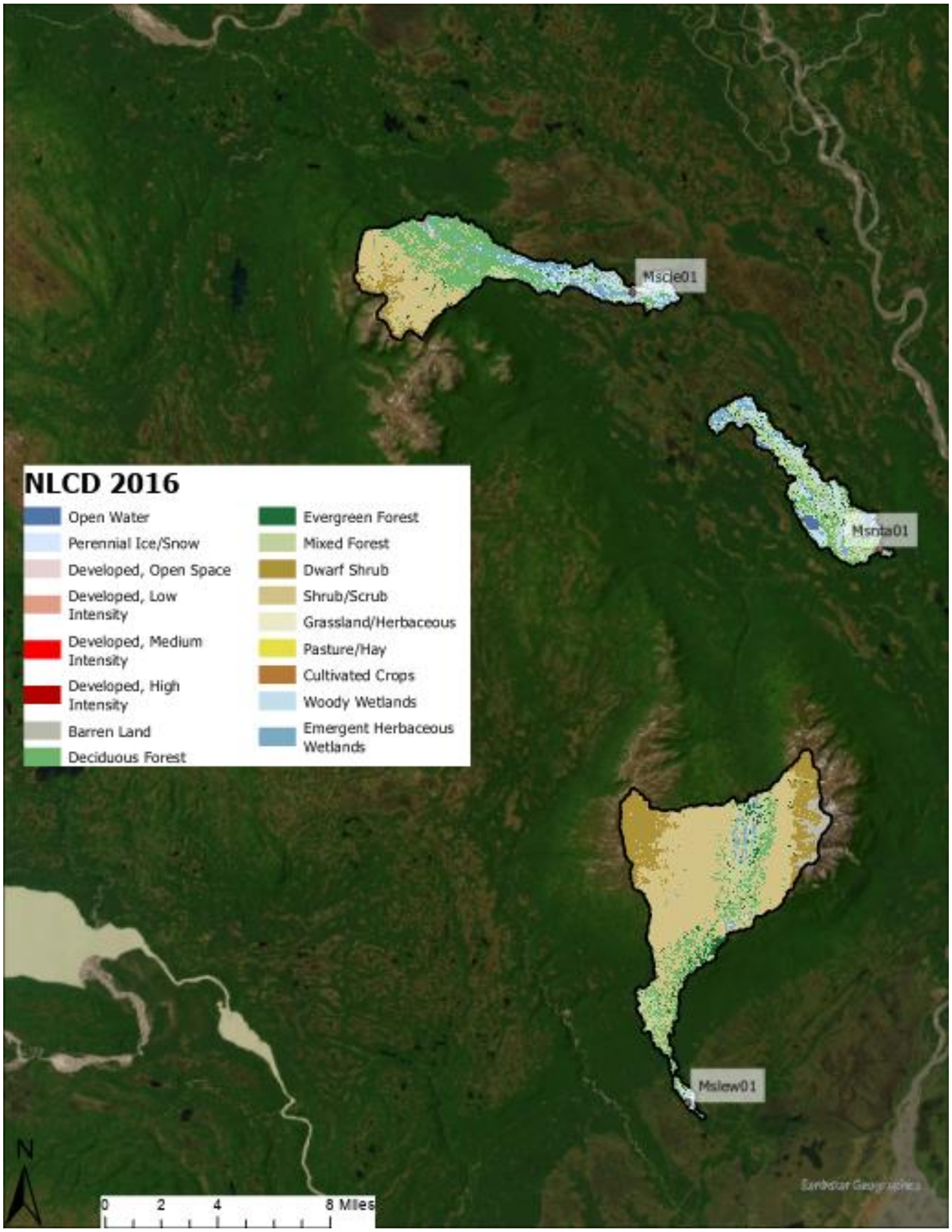

FIGURE 8 MAP OF STUDY WATERSHEDS IN THE EASTERN PORTION OF THE KENAI PENINSULA BOROUGH. SITE NAMES ARE LABELED AND NLCD DATA FROM THE RECENT SAMPLING PERIOD IS SHOWN FOR COMPARISON.

Because the NLCD was not updated for the present-day sampling period, we explored the possibility of using alternative methods to classify land cover and land use change over the study area and sampling time periods. To do this, we collated different combinations of parcel data, tax records, and aerial imagery from the Matanuska-Susitna Borough, the Anchorage Municipality, and the Kenai Peninsula Borough. Data sources from the Matanuska-Susitna Borough included a parcel dataset and an aerial imagery dataset. Data sources from the Kenai Peninsula Borough included a parcel dataset and a tax records and buildings dataset. Data sources from the Municipality of Anchorage include tax parcels, property information, and aerial imagery. All data sources were layered over NHD flowlines. Parcel information, tax records, and building records were used to link cadastral parcels to building information to determine the year that they were built. aerial imagery was used to determine the year of development for roads, since the state of Alaska does not keep geospatial records about the time when roads were constructed. The amount of developed area was then determined within the entire watershed, as well as within 100 meter and 300 meter buffers of the NHD flowline upstream from the sampling point. Prior studies suggest that those buffer sizes are adequate for capturing development that will likely impact nearby water quality (Allan 2004, Tran et al. 2010). The breakpoints for development timing were determined by the sampling dates in each watershed.

TABLE 2 DATASETS USED FOR THE PARCEL DEVELOPMENT MAPPING EXERCISE.

Agency	Dataset	Methods	Link
Mat-Su Borough	Parcels	Link Cadastral parcels to building information to obtain year built	Cadastral Parcels
Mat-Su Borough	Aerial Imagery	Determine year of development for roads using a historical sequence of imagery: years 2004, 2011, 2016, 2017, 2020, 2021, 2022, 2023	Aerial Imagery Datasets
Kenai Peninsula Borough	Parcels	Link Cadastral parcels to building information to obtain year built	Parcels

Agency	Dataset	Methods	Link
Kenai Peninsula Borough	Tax Records / Buildings	Contains year built information for structures	Assessing Department
Municipality of Anchorage	Tax Parcels	Link parcel polygons to property information table to obtain year built	Tax Parcels
Municipality of Anchorage	Property Information	Contains year built information for structures	Property Information
Municipality of Anchorage	Aerial Imagery	Use historic imagery (1950, 1960, 1970, 1980, 1990, 2002, 2004, 2006, 2009, 2015) to verify earlier development year for parcels with recent	Historic Imagery
NHD	Streams	Buffer flowlines within each watershed	National Hydrography Dataset

While this approach had potential to more accurately capture localized land use and the timing of land use change in the watersheds, discrepancies among boroughs and municipalities in how data is collected, collated, and served make these data difficult to compare. Moreover, since these data sources are intended to inform tax collection, rather than capture watershed impacts, they could present misleading trends in land use. For example, in Anchorage, parking lots are classified as vacant, which is true from a tax structure perspective, but makes them equivalent to undeveloped land, which is not equivalent when considering the impact of impervious surfaces on runoff in the watershed. The Kenai Peninsula Borough's parcel dataset includes a large number of large parcels (>40 acres) that could be identified as "developed" due to a single small structure while the vast majority of the parcel remains in a natural state. Ultimately, while we present this data on development at a parcel scale as a complement to the NLCD information, we urge caution in using this type of data for other ecological applications, unless boroughs and municipalities are able to create comparable data standards and have datasets that are interoperable. Because of the uncertainties and potential errors in this approach, we did not use this dataset to analyze community change and water quality impacts. However, future work could focus on ways to refine this methodology for detecting land use change at finer spatial and temporal resolutions than the NLCD.

Biological Community Change Assessment:

To assess the changes in macroinvertebrate communities in response to development, we used multiple approaches. First, we summarized changes over time in individual taxa presence-absence and relative densities for all sites. Then we calculated Bray-Curtis dissimilarities across all sites and years over the historic and current time periods, and ordinated them using non-metric multidimensional scaling (NMDS). We partitioned changes in community composition into species replacement (turnover) and species loss (nestedness) following methods outlined in Balsega et al. (2010).

To determine how individual taxa responded to land use change, we used Threshold Indicator Taxon ANalysis (TITAN, Baker and King 2010), which identifies abrupt changes in taxa occurrence and abundance along an environmental gradient in addition to measuring the synchrony of those changes across the macroinvertebrate community. We utilized two environmental gradients for this analysis, differences in watershed development over time and cumulative watershed impacts in the current period. Thresholds of watershed development that lead to stream impairment have not previously been determined across the Cook Inlet basin but were found to be as low as 2% in Maryland's Coastal Plain (King et al. 2011).

Data Quality Control:

The Hydrolab and turbidimeter were calibrated using standard solutions before each sampling day. Precision requirements for each measurement parameter and instrument or method are shown in Table 2. The Hydrolab was deployed upstream of the sample reach to avoid any influence from disturbance while sampling and was left in situ for at least 15 minutes to obtain a stable reading.

TABLE 3 DATA QUALITY OBJECTIVES FOR BENTHIC MACROINVERTEBRATE SAMPLING, IN-SITU WATER QUALITY MEASUREMENTS, CONTINUOUS WATER TEMPERATURE LOGGERS, TURBIDITY, AND STREAM DISCHARGE.

Measurement Category	Measurement Parameter	Instrument/ Method	Precision
Benthic macroinvertebrates	Replicate sample metric values	ENRI Technical Level Methods	RPD ≤ 20%
Benthic macroinvertebrates	Replicate sample metric scores	ENRI Technical Level Methods	RPD ≤ 5%
Benthic macroinvertebrates	Replicate sample MMI Score	ENRI Technical Level Methods	RPD ≤ 5%
Benthic macroinvertebrates	Sorting efficiency	ENRI Technical Level Methods	PSE > 90%
Benthic macroinvertebrates	Sites sampled/year	ENRI Technical Level Methods	30
Water quality	pH	HydroLab MS5	0.2
Water quality	Sp Cond	HydroLab MS5	4.5 µS/cm
Water quality	DO	HydroLab MS5	2%
Water quality	Temperature (°C)	Onset HOBO Pro v2	+0.25°C
Water quality	Turbidity (NTUs)	Hach 2100P Turbidimeter	If <1.0, 0.2 NTU If >1.0, 0.4 NTU
Water quantity	Discharge (CFS) (replicate samples)	Marsh-McBirney or OTT MF Pro / Velocity-Area Method	If <1.0, 0.2 CFS If 1.0-5.0, 0.4 CFS If 5.0-10.0, 0.6 CFS If >10.0, 0.8 CFS

RPD – relative percent difference, calculated as $\frac{|a-b|}{\frac{a+b}{2}} * 100$

PSE – percent sorting efficiency.

NTU – nephelometric turbidity unit.

CFS – cubic feet per second.

Land Use, Climate, and Wetland Cover Results:

Overall, land use did not change drastically between the two sampling periods. The largest increases were in the conversion of wildlands to impervious surfaces and to low intensity development (Figure 9). Watersheds in the region got slightly warmer, although some did get cooler (Figure 10), and nearly all watersheds experienced an increase in precipitation and snow water equivalent (Figure 10). The study watersheds spanned a range of present land use (Figure 11), with low intensity developed land comprising anywhere from 0% to over 35% of the watershed and impervious surfaces comprising anywhere from 0% to 45% of the watershed. The study watersheds also spanned a range of climatic conditions (Figure 12), with annual precipitation ranging from 475 to 1550 mm and average monthly maximum temperatures ranging from 4 to 9 degrees Celsius. Land use and climate were not strongly correlated, possibly due to the coarse resolution of both the Daymet and NLCD databases (Figure 13).

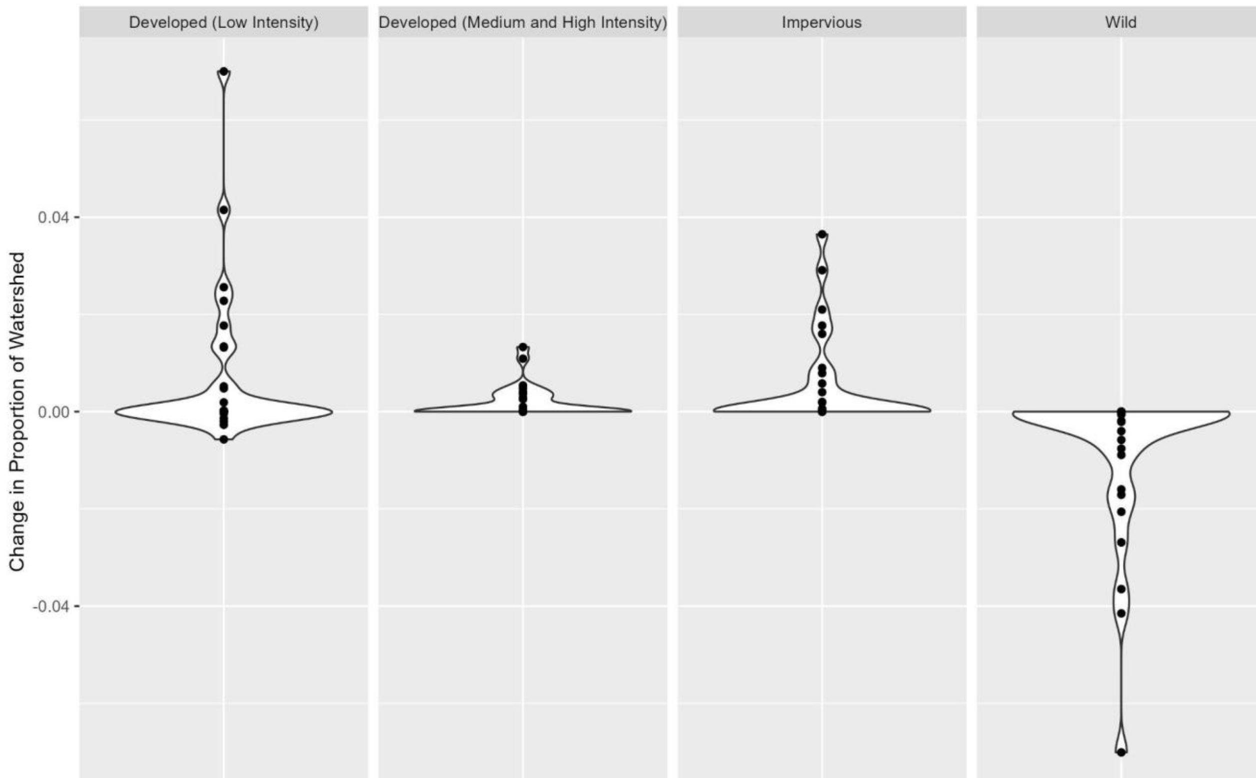

FIGURE 9 LAND USE CHANGE ACCORDING TO DIFFERENCES BETWEEN 2001 AND 2016 NLCD DATASET IN EACH WATERSHED.

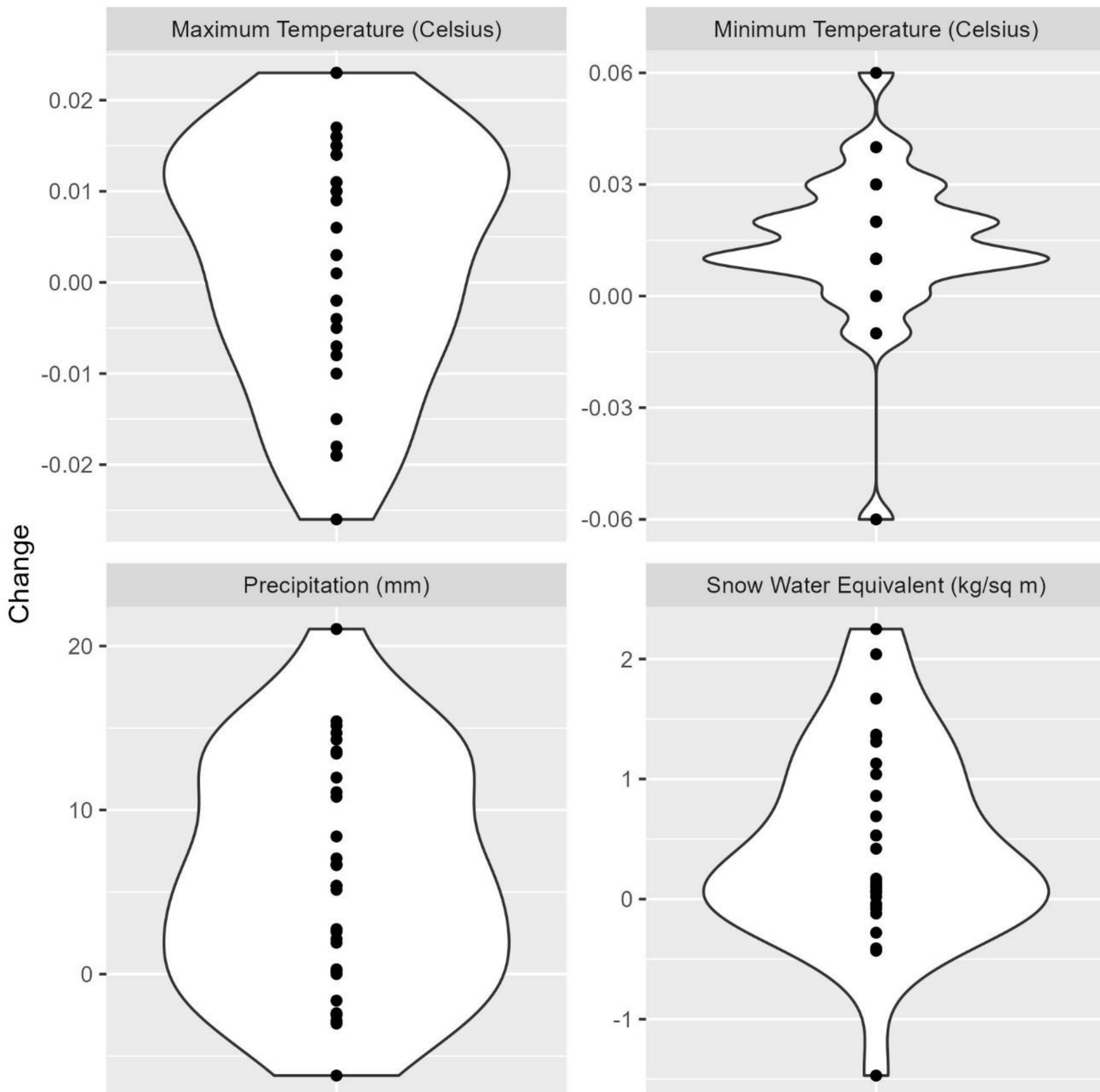

FIGURE 10 CLIMATE CHANGE ACCORDING TO DAYMET DIFFERENCES IN MAXIMUM TEMPERATURE, MINIMUM TEMPERATURE, PRECIPITATION, AND SNOW WATER EQUIVALENT BETWEEN 2001 AND 2022 IN EACH WATERSHED.

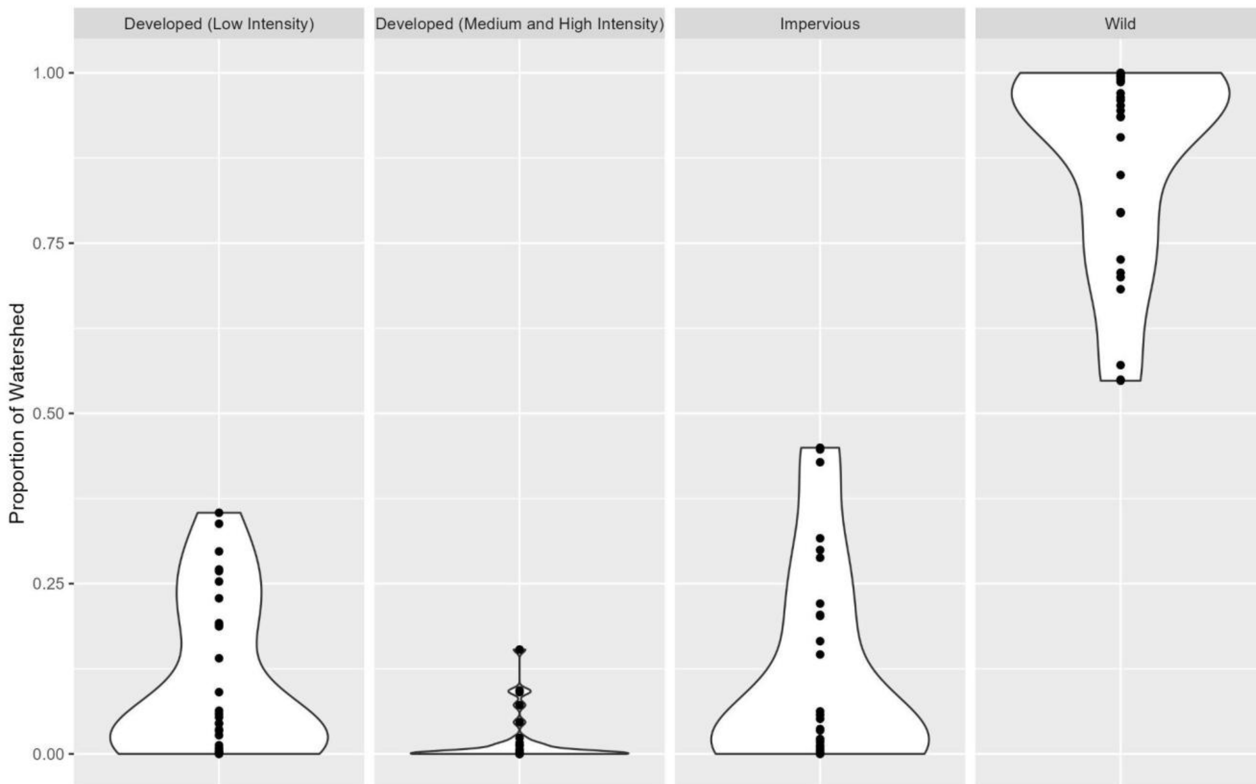

FIGURE 11 PRESENT LAND USE AS A PROPORTION OF WATERSHED AREA ACCORDING TO 2016 NLCD DATASET IN EACH WATERSHED.

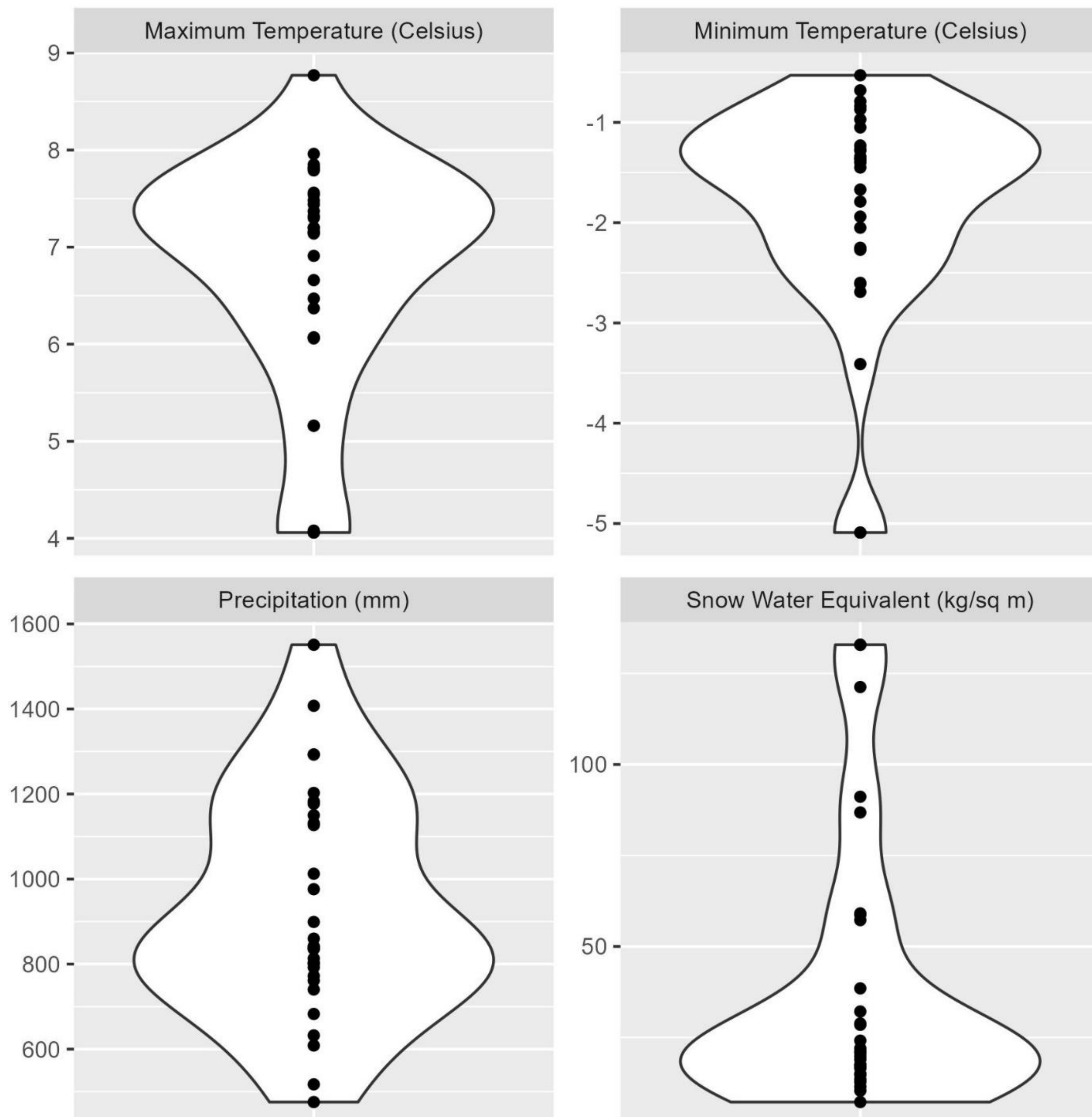

FIGURE 12 PRESENT CLIMATE BASED ON DAYMET DATA FROM 2022.

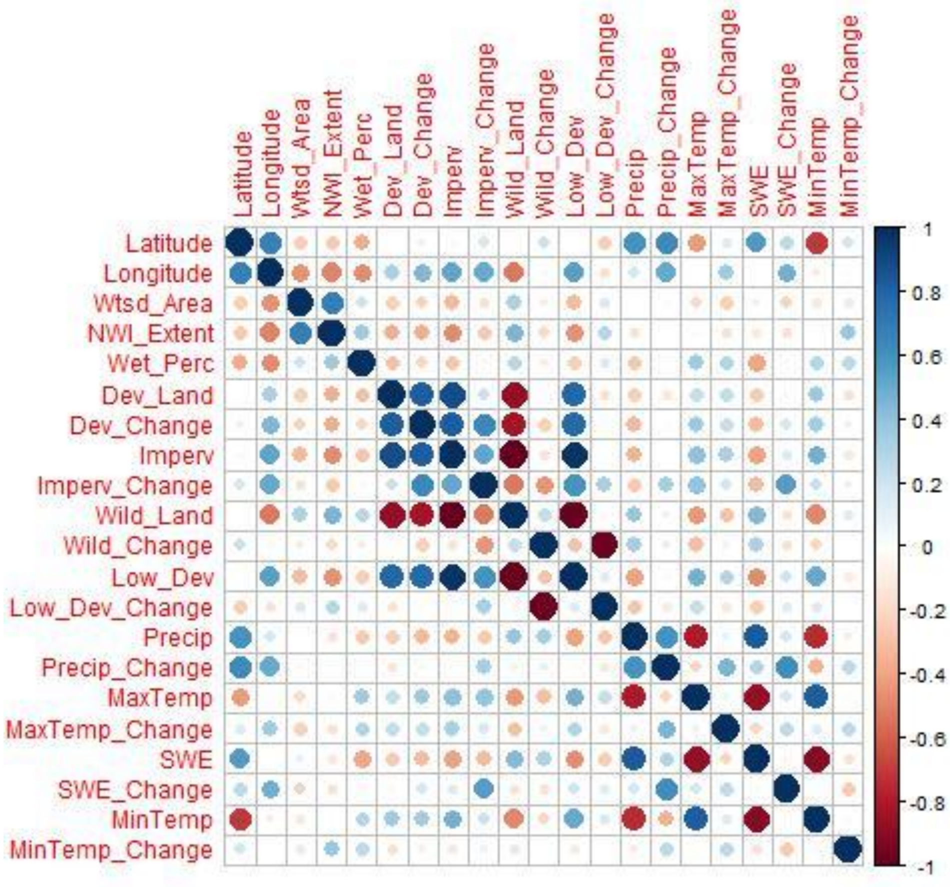

FIGURE 13 CORRELATION PLOT OF ENVIRONMENTAL COVARIATES BY WATERSHED. 1 INDICATES THE STRONGEST POSSIBLE POSITIVE CORRELATION, WHILE -1 INDICATES THE STRONGEST POSSIBLE NEGATIVE CORRELATION. WTSD_AREA IS WATERSHED AREA; NWI_EXTENT IS WETLAND EXTENT IN THE WATERSHED, BASED ON THE NATIONAL WETLAND INVENTORY; WET_PERC IS THE PERCENTAGE OF THE WATERSHED COMPRISED OF WETLANDS, BASED EITHER ON THE NATIONAL WETLAND INVENTORY OR THE COOK INLET WETLANDS LAYER; DEV_LAND IS THE EXTENT OF DEVELOPED LAND (MEDIUM AND HIGH INTENSITY) FROM NLCD 2016; DEV_CHANGE IS THE CHANGE IN DEVELOPED LAND (MEDIUM AND HIGH INTENSITY) FROM NLCD 2001 TO 2016; IMPERV IS THE EXTENT OF IMPERVIOUS SURFACE BASED ON NLCD 2016; IMPERV_CHANGE IS THE CHANGE IN IMPERVIOUS SURFACE FROM NLCD 2001 TO 2016; WILD_LAND IS THE EXTENT OF UNDEVELOPED LANDS BASED ON NLCD 2016; WILD_CHANGE IS THE CHANGE IN UNDEVELOPED LANDS FROM NLCD 2001 TO 2016; LOW_DEV IS THE EXTENT OF DEVELOPED LAND (LOW INTENSITY) FROM NLCD 2016; LOW_DEV_CHANGE IS THE CHANGE IN DEVELOPED LAND (LOW INTENSITY) FROM NLCD 2001 TO 2016; PRECIP IS THE AVERAGE ANNUAL PRECIPITATION ACROSS THE WATERSHED FOR 2022, BASED ON DAYMET DATA; PRECIP_CHANGE IS THE CHANGE IN AVERAGE ANNUAL PRECIPITATION FROM 2001 TO 2022 BASED ON DAYMET DATA; MAXTEMP IS THE AVERAGE ANNUAL MAXIMUM TEMPERATURE ACROSS THE WATERSHED BASED ON DAYMET DATA; MAXTEMP_CHANGE IS THE CHANGE IN AVERAGE ANNUAL MAXIMUM TEMPERATURE FROM 2001 TO 2022 BASED ON DAYMET DATA; SWE IS THE AVERAGE SNOW WATER EQUIVALENT ACROSS THE WATERSHED BASED ON DAYMET DATA FROM 2022; SWE_CHANGE IS THE CHANGE IN AVERAGE SNOW WATER EQUIVALENT ACROSS THE WATERSHED FROM 2001 TO 2022 BASED ON DAYMET DATA; MAXTEMP IS THE AVERAGE ANNUAL MINIMUM TEMPERATURE ACROSS THE WATERSHED BASED ON DAYMET DATA; AND MAXTEMP_CHANGE IS THE CHANGE IN AVERAGE ANNUAL MINIMUM TEMPERATURE FROM 2001 TO 2022 BASED ON DAYMET DATA.

Water Quality Results:

Temperatures on sampling dates across all sites and years ranged from 4.4 to 17.6 degrees Celsius, with an average temperature of 10.7 degrees Celsius. pH ranged from 6.6 to 8.23, with an average of 7.45, and specific conductance ranged from 12.6 to 385 µS @ 25 °C, with an average of 150.2. Turbidity ranged from 0.3 to 9.2 NTUs, with an average of 2.4. Oxygen ranged from 8.62 to 13.51 mg/L, with an average of 10.97, and from 85.2 to 115.2% saturation, with an average of 98.44%.

With the exception of turbidity, water quality metrics did not differ among sampling years (Table 3, Figure 14). Turbidity was significantly higher in 2022 than in 2020 (difference 1.21, p=0.045). Mean weekly temperatures varied by site, but less so by year (Figure 15).

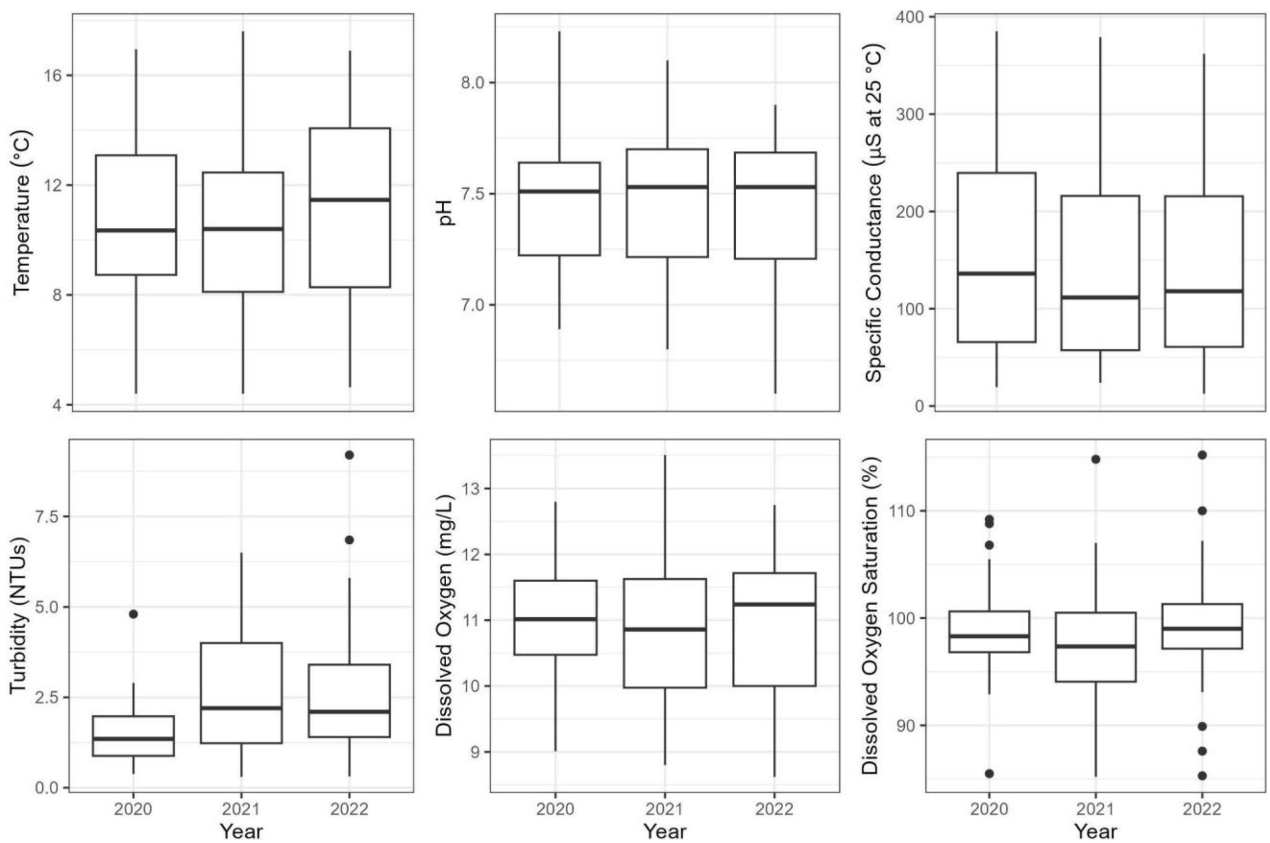

FIGURE 14 BOXPLOTS OF WATER QUALITY PARAMETERS BY SAMPLING YEAR.

TABLE 4 SUMMARY OF ANOVA RESULTS ON THE EFFECT OF SAMPLING YEAR ON MEASURED WATER QUALITY PARAMETERS.

Water Quality Parameter	Predictor	Df	Sum of Squares	Mean Squares	F Value	Pr(>F)
Dissolved Oxygen (mg/L)	Year	2	0.46	0.2298	0.195	0.823
Dissolved Oxygen (mg/L)	Residuals	84	98.84	1.1767	-	-
Dissolved Oxygen Saturation (%)	Year	2	101.1	50.53	1.541	0.22
Dissolved Oxygen Saturation (%)	Residuals	84	2753.7	32.78	-	-
Turbidity (NTUs)	Year	2	22.64	11.319	3.554	0.0333
Turbidity (NTUs)	Residuals	78	248.44	3.185	-	-
Specific Conductance (µS @ 25 °C)	Year	2	4016	2008	0.17	0.844
Specific Conductance (µS @ 25 °C)	Residuals	84	989945	11785	-	-
pH	Year	2	0.062	0.03117	0.313	0.732
pH	Residuals	83	8.259	0.09951	-	-

Water Quality Parameter	**Predictor**	**Df**	**Sum of Squares**	**Mean Squares**	**F Value**	**Pr(>F)**
Temperature (°C)	Year	2	9.5	4.728	0.407	0.667
Temperature (°C)	Residuals	84	975.3	11.611	-	-

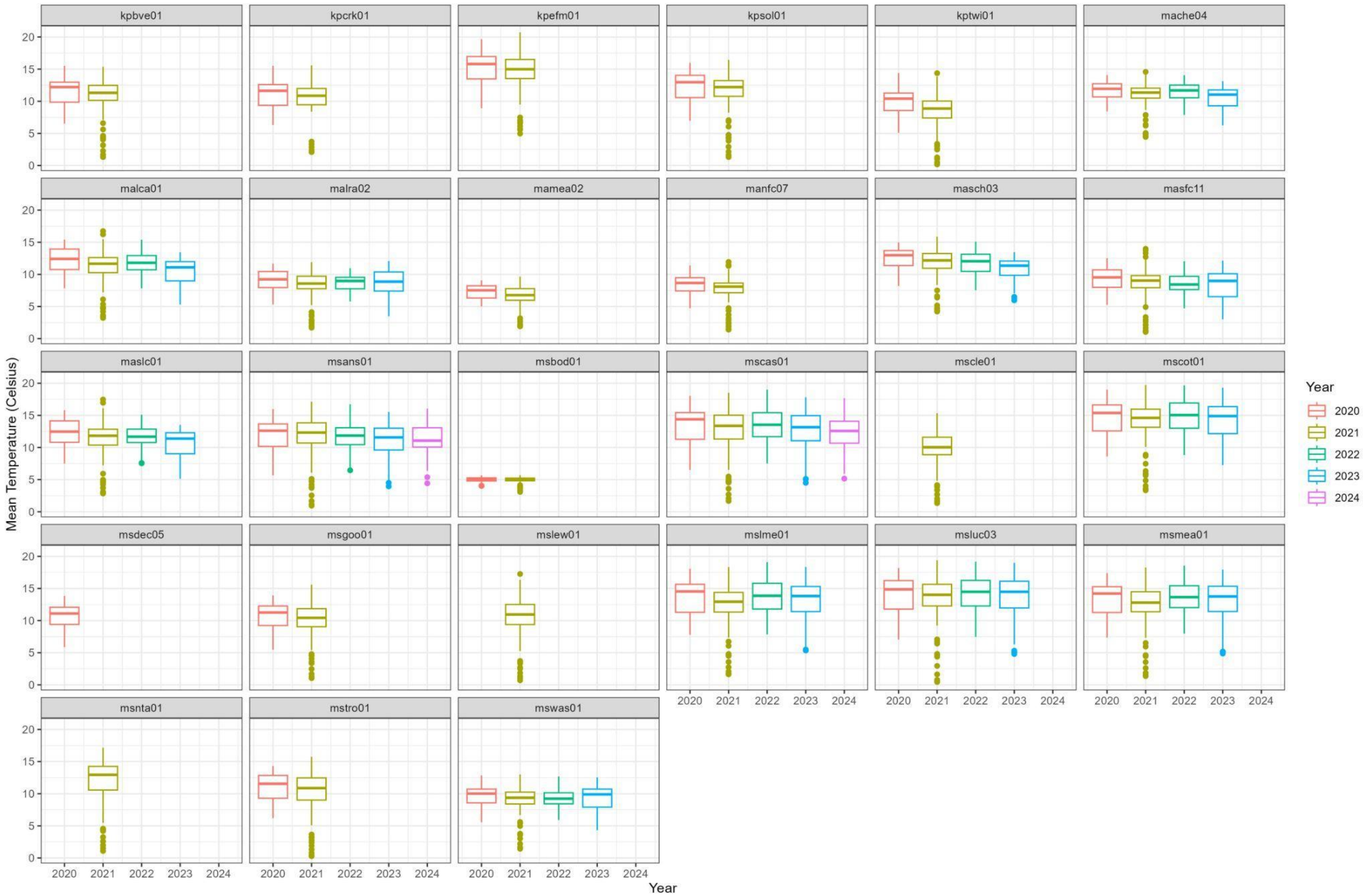

FIGURE 15 MEAN WEEKLY TEMPERATURE BY YEAR, COLLECTED AT EACH SITE USING DATA LOGGERS. ALL DATA HAVE BEEN UPLOADED AND ARE AVAILABLE ON THE AKTEMP FRESHWATER TEMPERATURE DATABASE.

Biological Community Change Results:

The Cook Inlet Macroinvertebrate Index (CIMI) did not differ significantly between the two major time periods in this study (Figure 16, t=-0.750, df=134.43, p=0.4545). This aggregate analysis, though, masks site-level differences (Figure 17). Some sites experienced an increase in the CIMI, while others experienced a decrease. Overall, these site-level changes showed weak relationships with changes in land use (Figure 18) and climate (Figure 19). Looking only at the present-day sampling period, the CIMI showed positive relationships with the proportion of undeveloped land in the watershed (Figure 20) and the amount of precipitation (Figure 21), and negative relationships with the amount of developed land and impervious surfaces (Figure 20) and did not show any strong relationships with watershed factors, such as latitude and watershed area (Figure 22). Overall, species richness did not change dramatically between the 2000s sampling time point and the present day 2020s sampling time points (Figure 23).

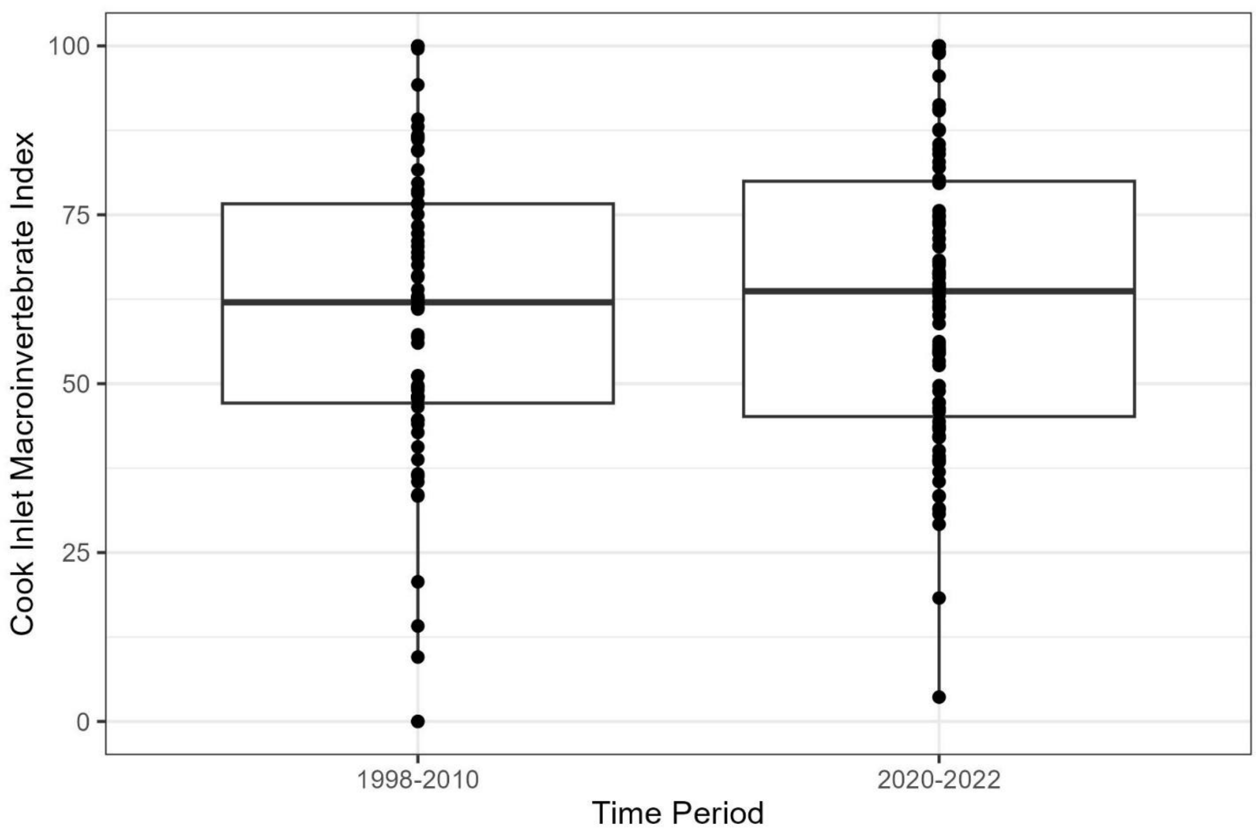

FIGURE 16 BOXPLOTS OF COOK INLET MACROINVERTEBRATE INDEX FROM EACH SAMPLING POINT AND WATERSHED SEPARATED OUT BY THE TWO TIME PERIODS. HIGH VALUES INDICATE HEALTHIER MACROINVERTEBRATE COMMUNITIES COMPARED TO LOWER SCORES.

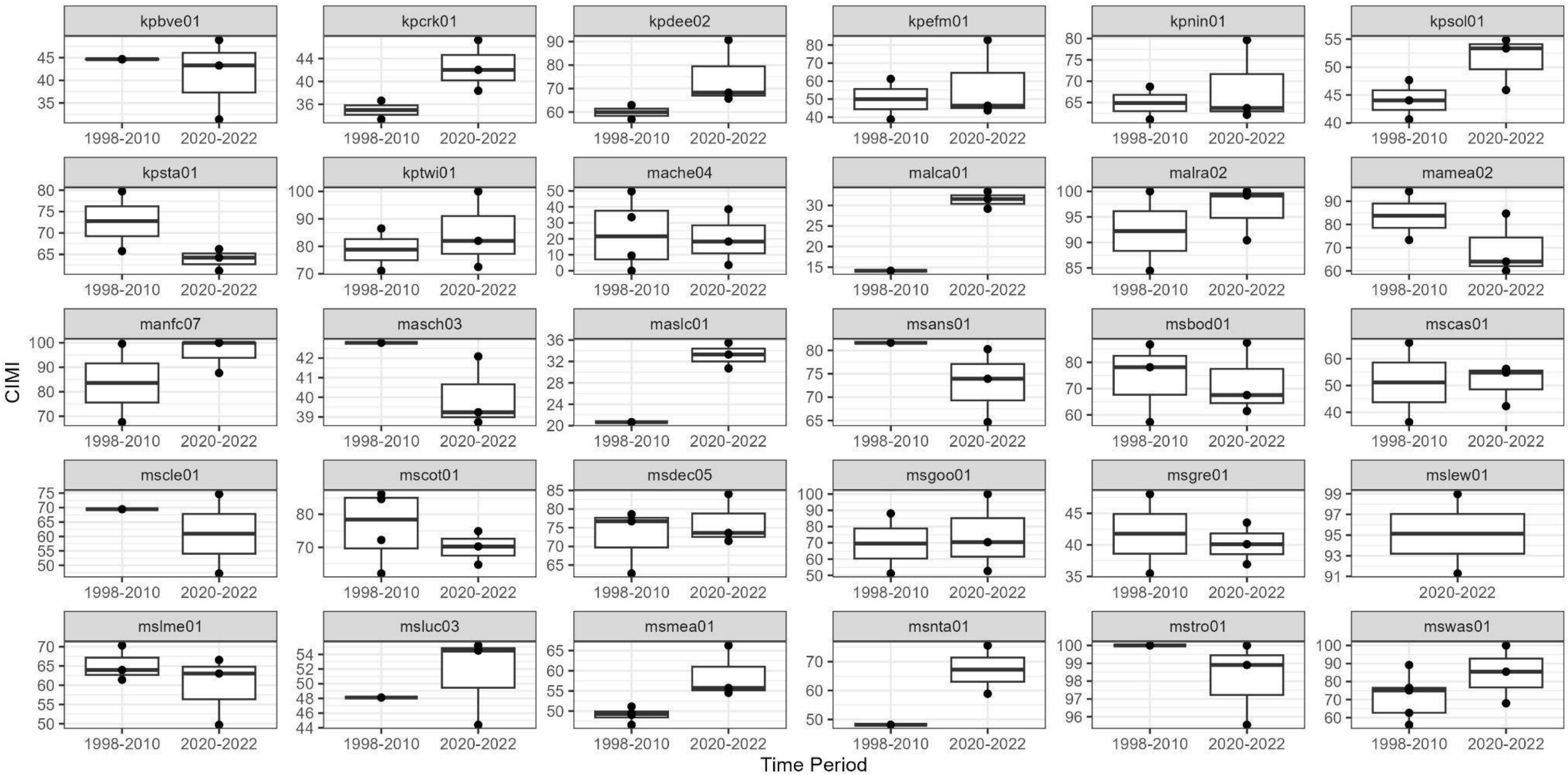

FIGURE 17 BOXPLOTS OF COOK INLET MACROINVERTEBRATE INDEX FROM EACH SAMPLING POINT SEPARATED OUT BY THE TWO TIME PERIODS AND DIFFERENT WATERSHEDS. HIGH VALUES INDICATE HEALTHIER MACROINVERTEBRATE COMMUNITIES COMPARED TO LOWER SCORES.

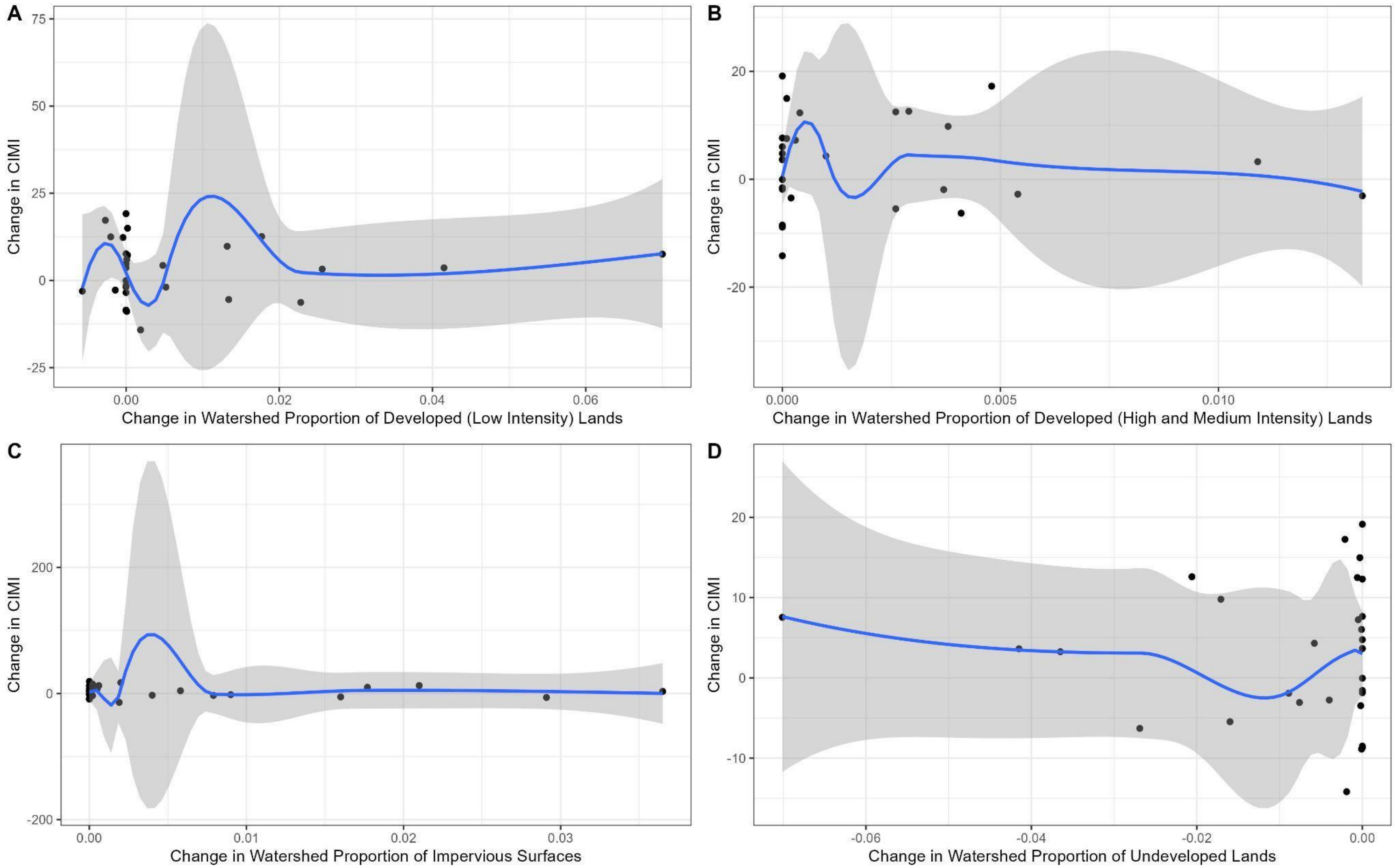

FIGURE 18 CHANGE IN THE COOK INLET MULTIMETRIC INDEX AS A FUNCTION OF CHANGE IN THE WATERSHED PROPORTION OF LOW INTENSITY DEVELOPMENT (A), HIGH AND MEDIUM INTENSITY DEVELOPMENT (B), IMPERVIOUS SURFACES (C), AND UNDEVELOPED LANDS (D).

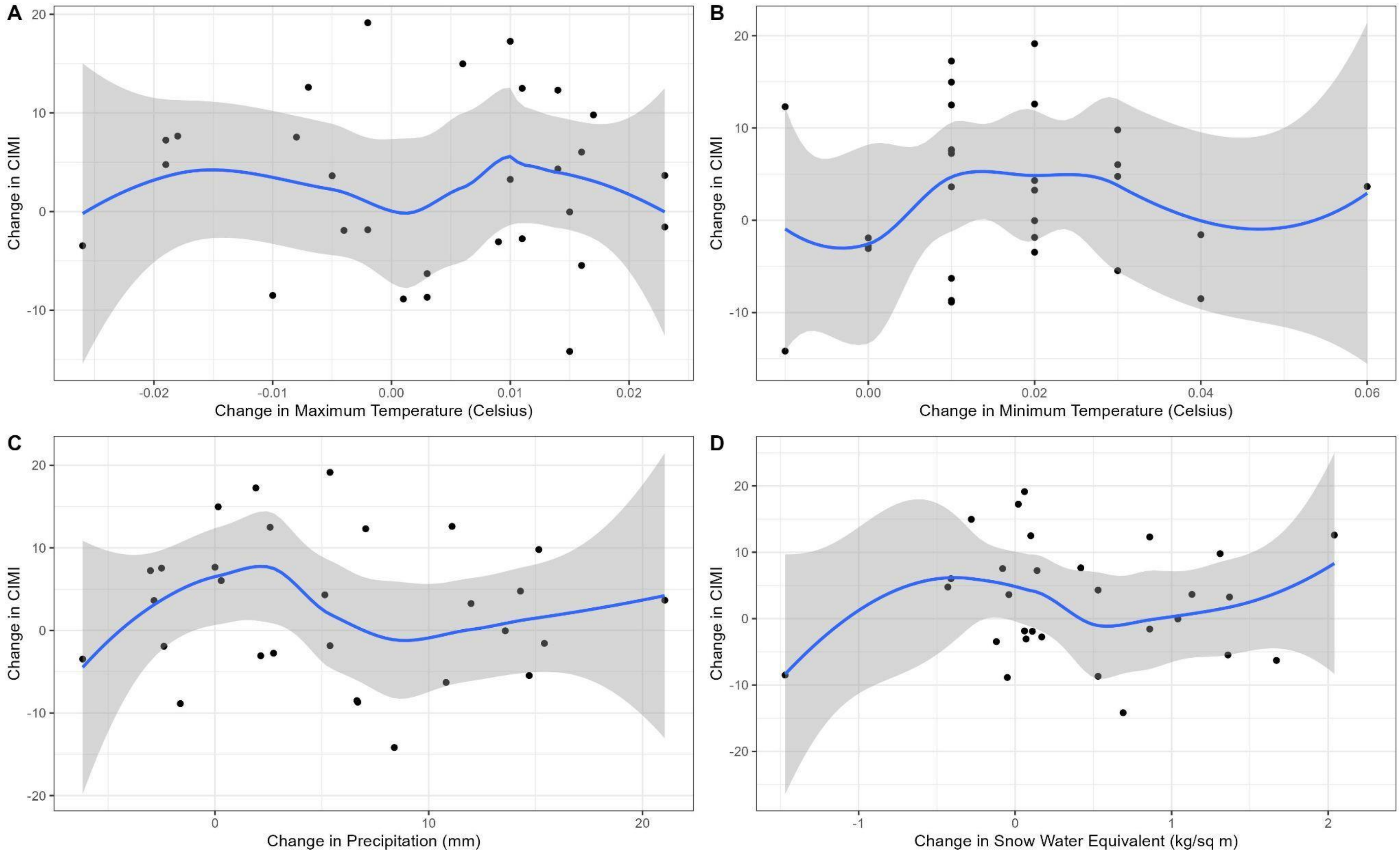

FIGURE 19 CHANGE IN THE COOK INLET MULTIMETRIC INDEX AS A FUNCTION OF CHANGE IN THE WATERSHED AVERAGE MAXIMUM TEMPERATURE (A), MINIMUM TEMPERATURE (B), PRECIPITATION (C), AND SNOW WATER EQUIVALENT (D).

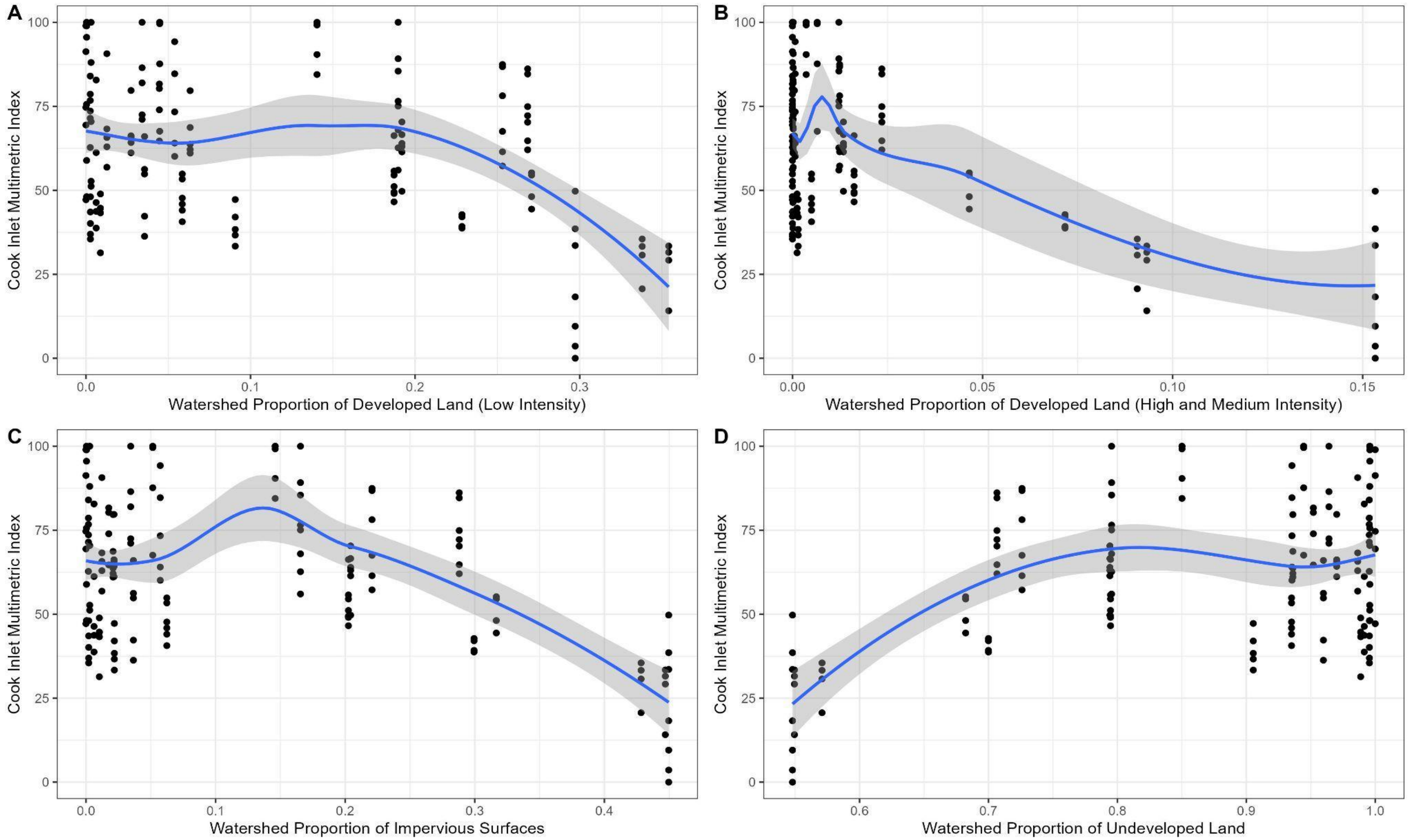

FIGURE 20 PRESENT DAY VALUES OF THE COOK INLET MULTIMETRIC INDEX AS A FUNCTION OF THE WATERSHED PROPORTION OF LOW INTENSITY DEVELOPMENT (A), HIGH AND MEDIUM INTENSITY DEVELOPMENT (B), IMPERVIOUS SURFACES (C), AND UNDEVELOPED LANDS (D).

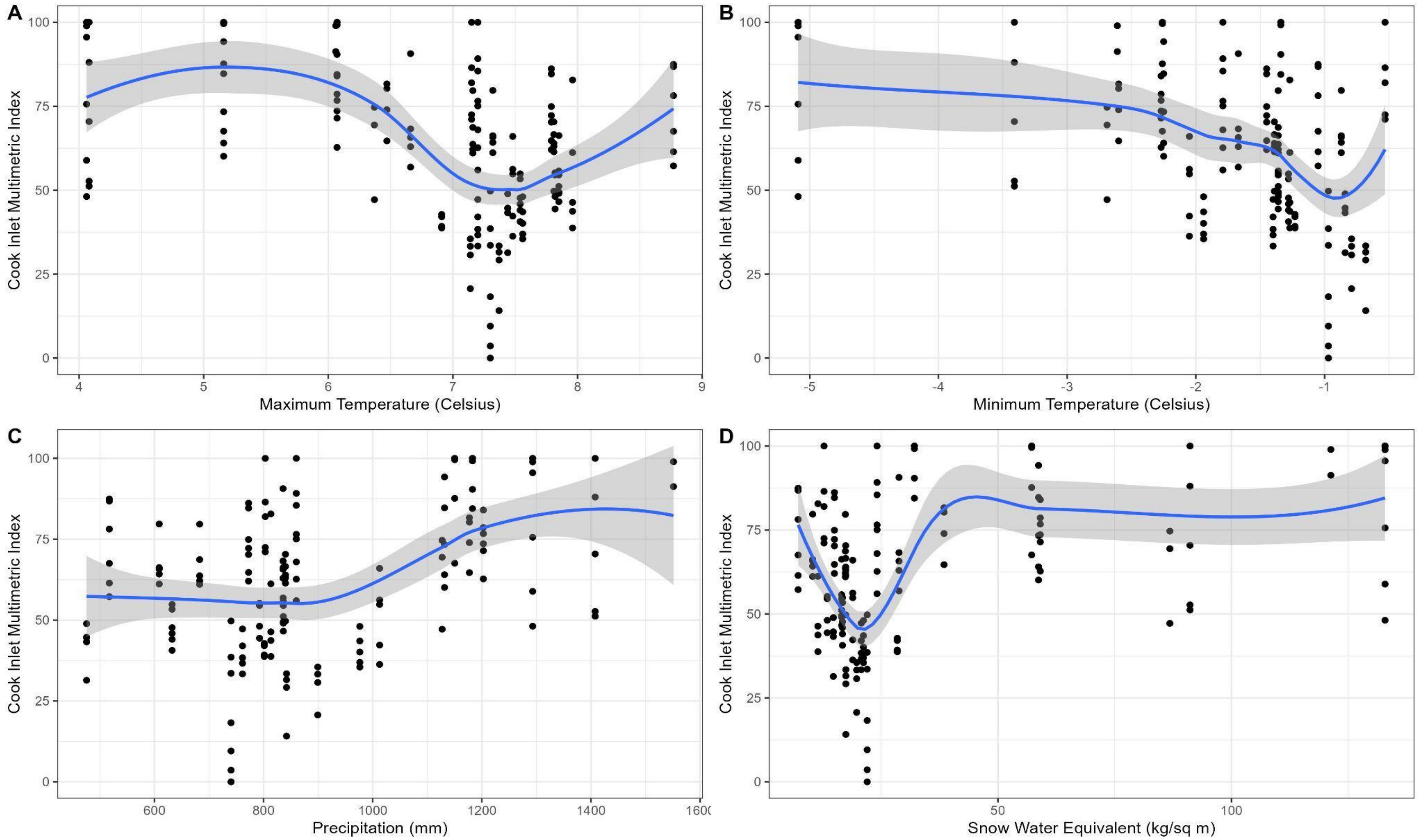

FIGURE 21 PRESENT DAY VALUES OF THE COOK INLET MULTIMETRIC INDEX AS A FUNCTION OF THE WATERSHED AVERAGE MAXIMUM TEMPERATURE (A), MINIMUM TEMPERATURE (B), PRECIPITATION (C), AND SNOW WATER EQUIVALENT (D).

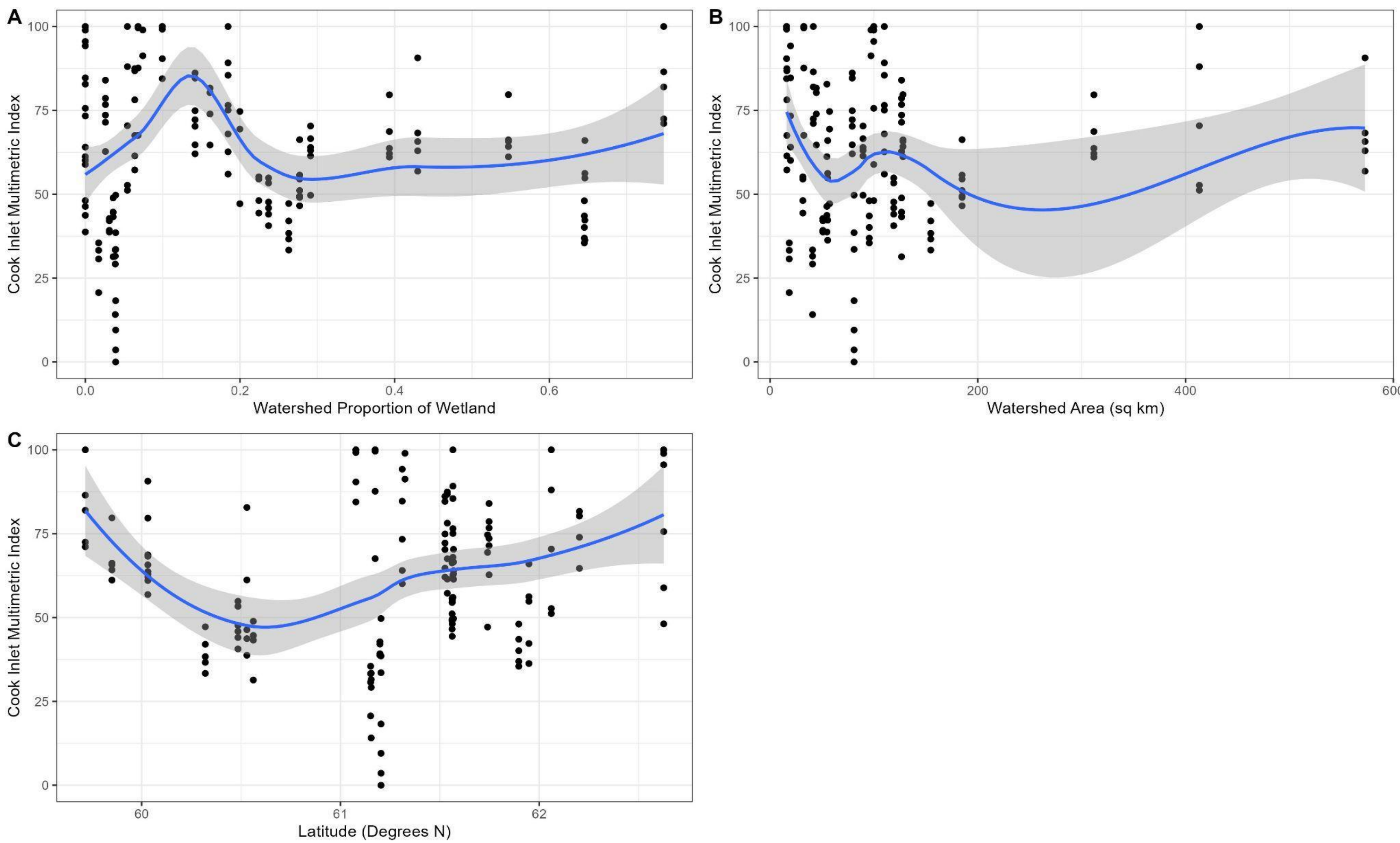

FIGURE 22 PRESENT DAY VALUES OF THE COOK INLET MULTIMETRIC INDEX AS A FUNCTION OF THE WATERSHED PROPORTION OF WETLAND (A), WATERSHED AREA (B), AND LATITUDE (C).

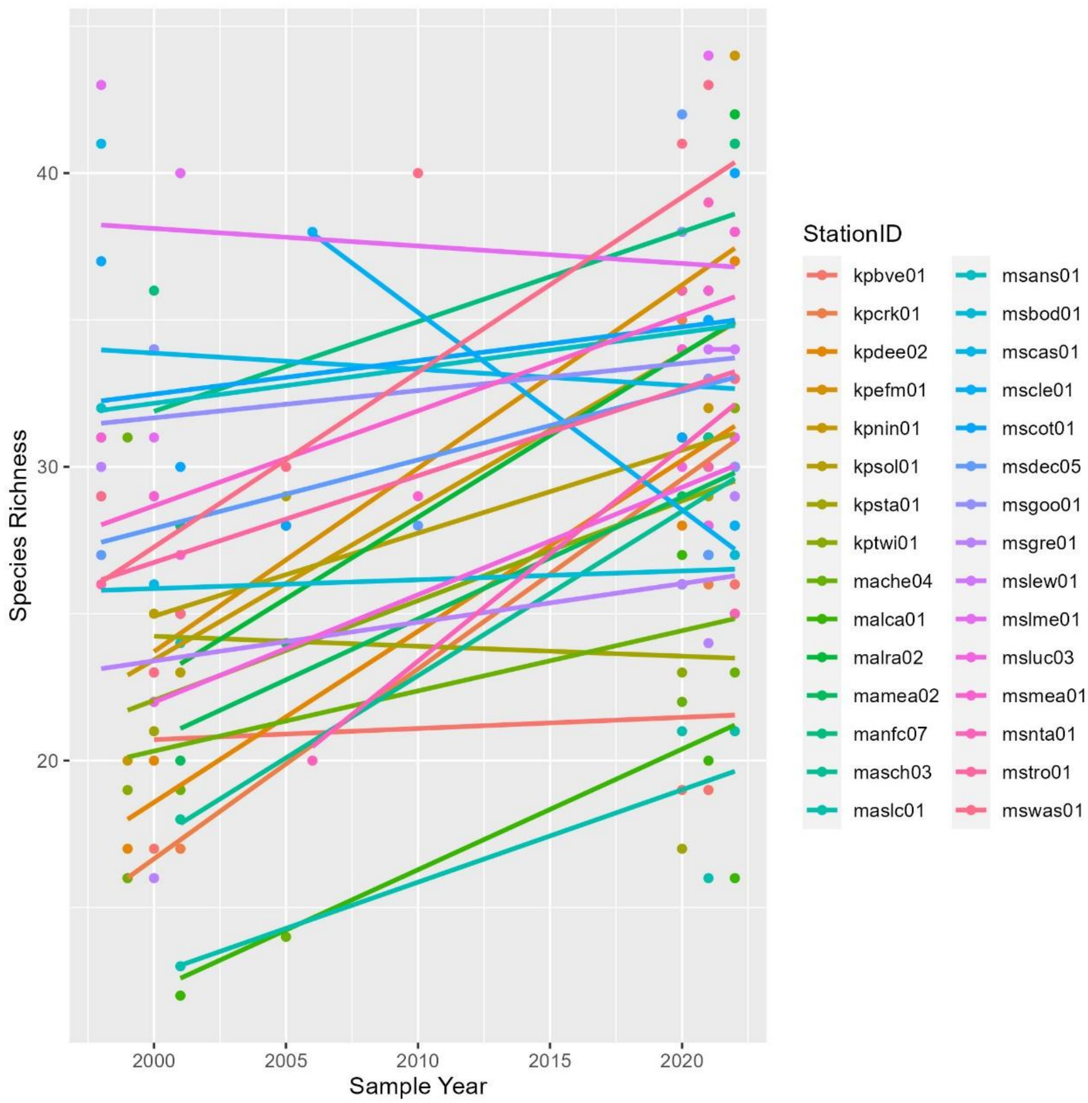

FIGURE 23 SPECIES RICHNESS AT EACH SAMPLE SITE DURING EACH SAMPLE YEAR. LINES REPRESENT A SIMPLE LINEAR MODEL FOR EACH SITE

Threshold Indicator Taxa Analysis Results:

Overall, there were not a large number of pure and reliable taxa indicating threshold responses to watershed factors, climate, or land use.

Chironomid taxa were very responsive to watershed, climatic, and land use changes (Figures 24, 25, and 26). The stonefly, *Zapada*, was also sensitive to both land use and climatic drivers (Figures 25 and 26), which is notable, since that genus is an important food resource for juvenile salmon. Many taxa responded positively to impervious cover (Figure 25), including three different Orthoclad midges (*Cricotopus/Orthocladius*, *Brillia*, and *Orthocladius (Euorthocladius)*), two chironomids in the Diamesinae subfamily (*Pagastia orthogonia* and *Pagastia partica*) and one annelid (Clitellata). A hydroptilid caddisfly (*Stactobiella*) and a simulid black fly (*Simulium*) both responded negatively to impervious cover in the watershed. Similar taxa responded positively and negatively to developed land (Figure 26). Within Orthocladiinae, some taxa responded positively (*Orthocladius nr. Rubicundus*) while others responded negatively (*Orthocladius (Euorthocladius)* and *Brillia*) to wetland extent (Figure 24), highlighting the importance of finely resolved taxonomic identifications.

Different taxa were sensitive to different stressors, making it complex to predict future food web and ecosystem structure in the region, but also highlighting specific taxa that may be key indicators of land use or climatic change. For example, specific Orthoclad midges (*Orthocladius (Euorthocladius)* and *Brillia*) appear to be strong predictors of wetland extent and impervious surface impacts in Cook Inlet watersheds.

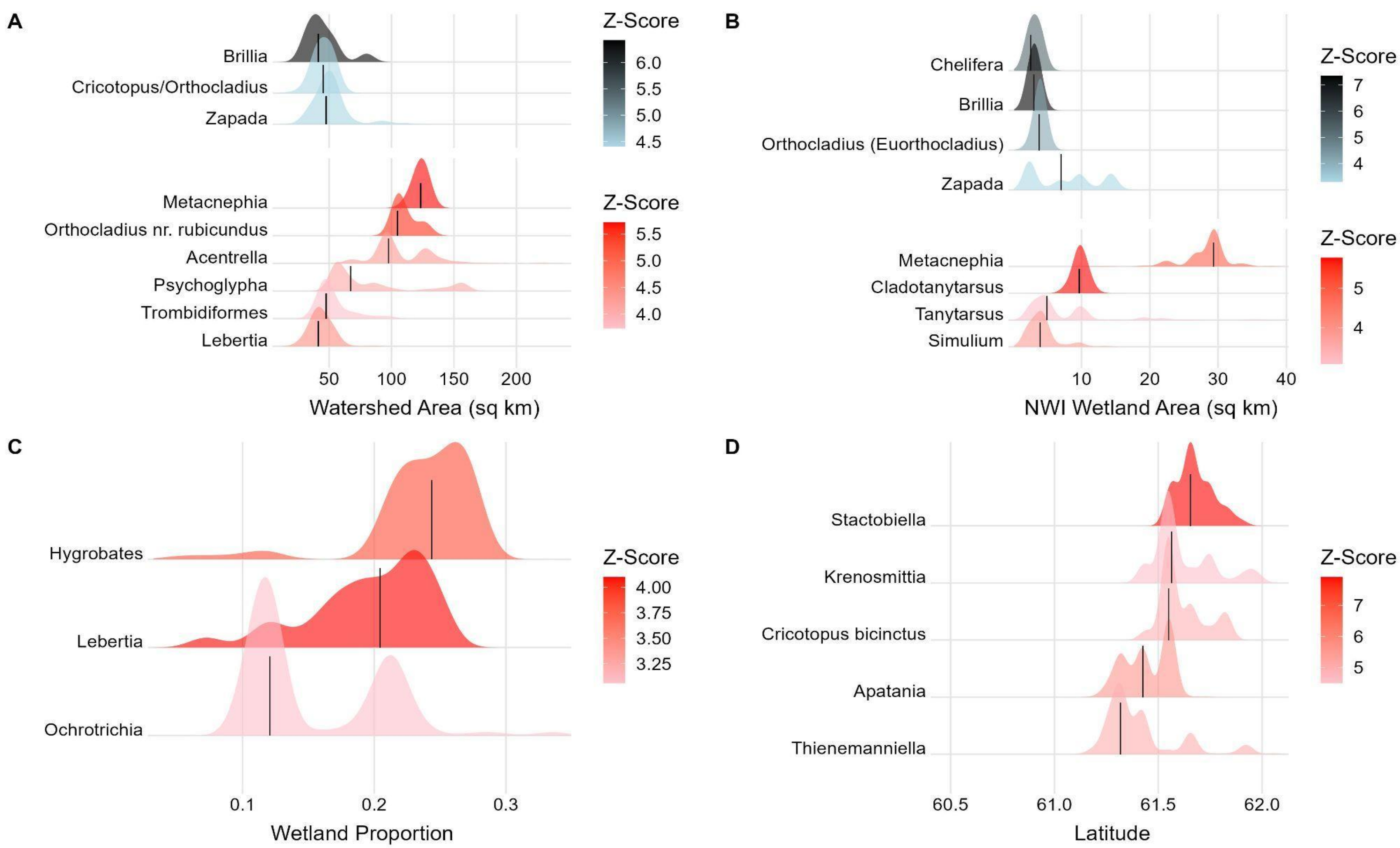

FIGURE 24 RESULTS FROM TITAN ANALYSIS FOR PURE AND RELIABLE TAXA TO INDICATE RESPONSES TO WATERSHED AREA (A), NWI WETLAND AREA (B), WETLAND PROPORTION OF THE WATERSHED (C), AND LATITUDE (D).

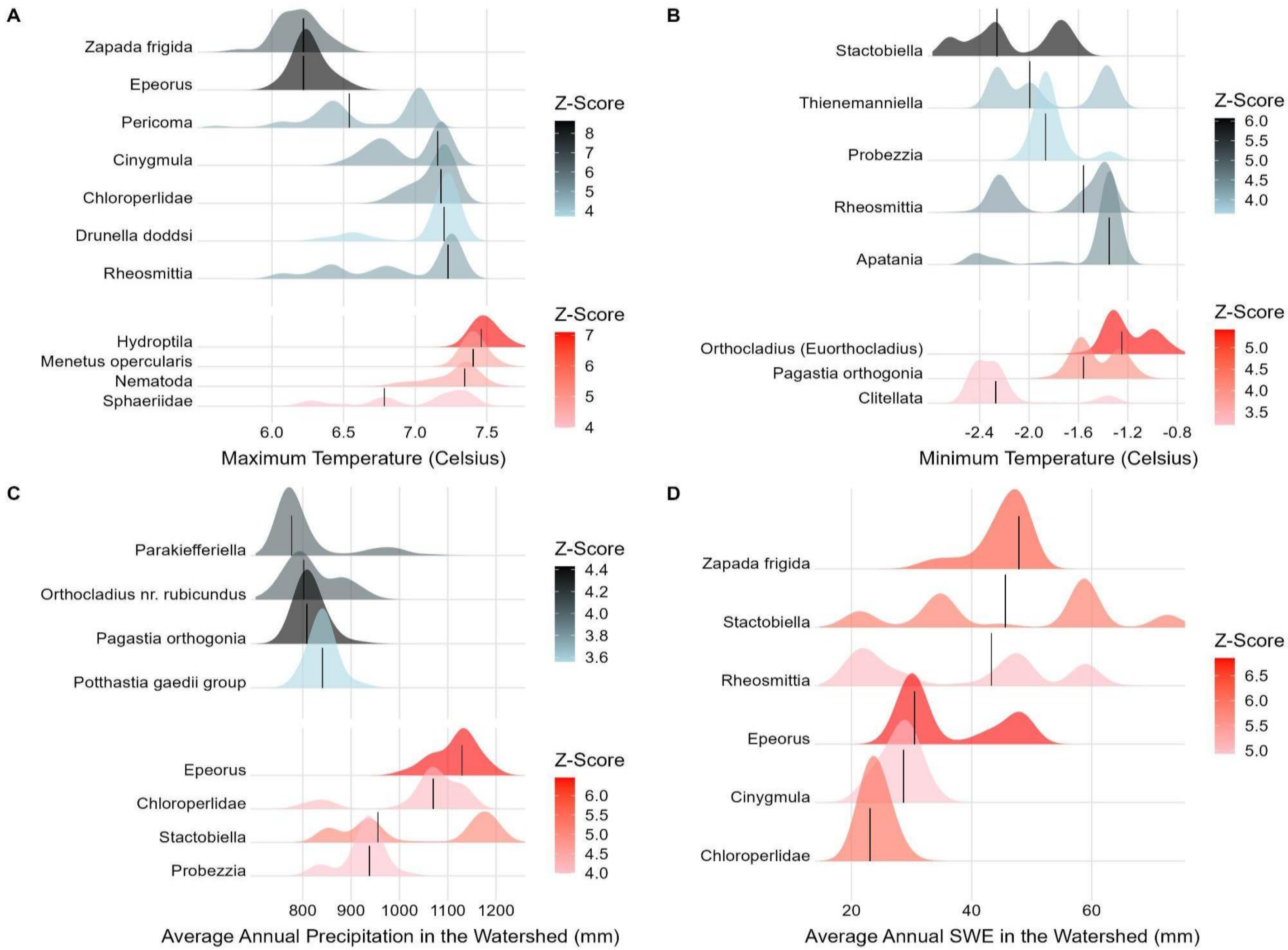

FIGURE 25 RESULTS FROM TITAN ANALYSIS FOR PURE AND RELIABLE TAXA TO INDICATE RESPONSES TO MAXIMUM TEMPERATURE (A), MINIMUM TEMPERATURE (B), AVERAGE ANNUAL PRECIPITATION (C), AND SNOW WATER EQUIVALENT (D).

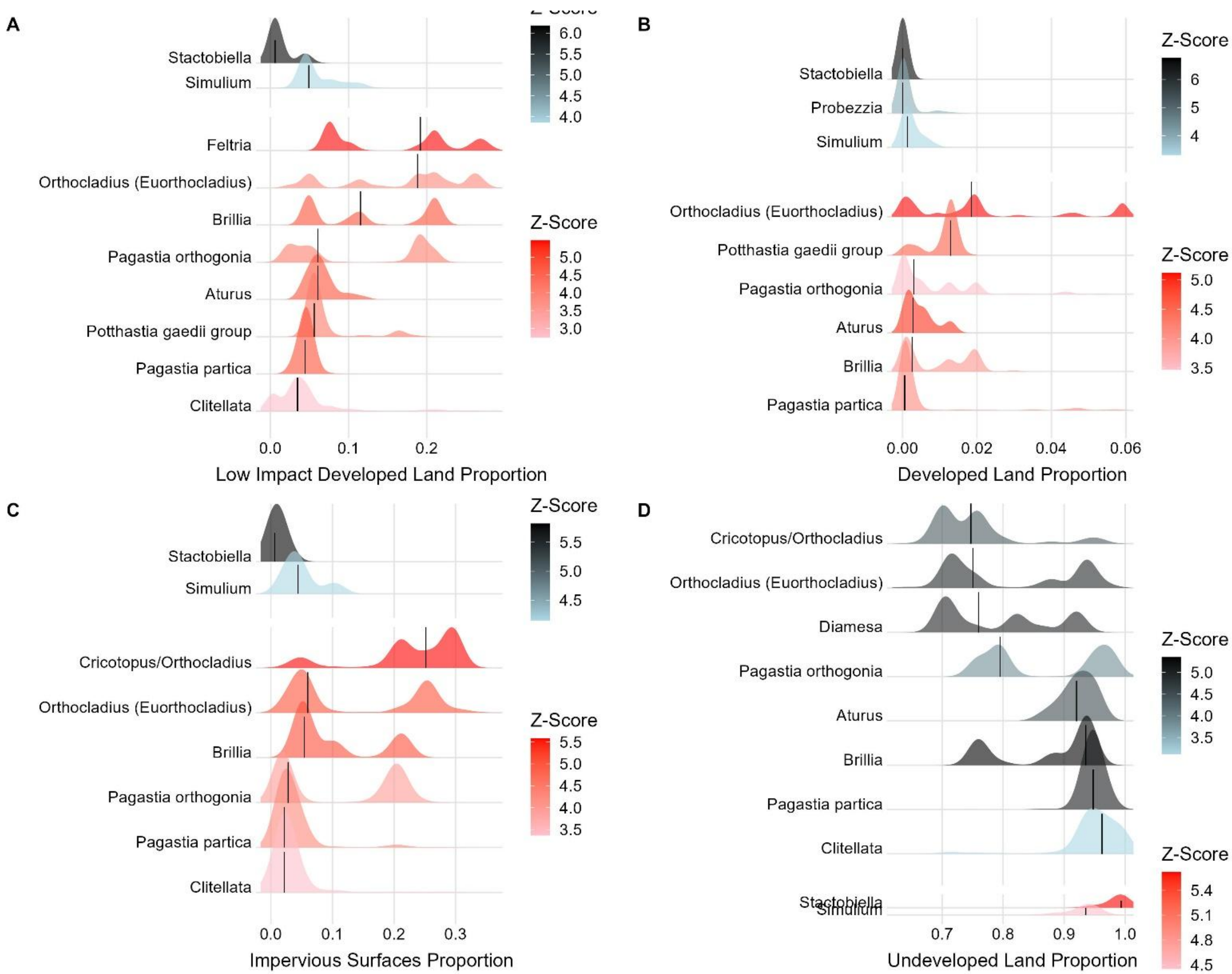

FIGURE 26 RESULTS FROM TITAN ANALYSIS FOR PURE AND RELIABLE TAXA TO INDICATE RESPONSES TO THE WATERSHED PROPORTION OF LOW INTENSITY DEVELOPMENT (A), HIGH AND MEDIUM INTENSITY DEVELOPMENT (B), IMPERVIOUS SURFACES (C), AND UNDEVELOPED LANDS (D).

Conclusions and Future Work:

Overall, the condition of macroinvertebrate communities in Cook Inlet has not experienced drastic changes from the early 2000s to the 2020s, as measured by the Cook Inlet Multimetric Index and species richness. It is worth noting that those types of aggregate metrics can mask important community changes, however (Larsen et al. 2018). While major changes in impairment were not detected, locally rare species may still have been replaced with more dominant taxa or other subtle shifts in species composition may have occurred that could have food web or ecosystem impacts. In addition to studies like this one that focus on the effects of development and climate change on biological impairment, future work could focus on how development might change stream insect communities that are important food resources for juvenile salmon, for example.

Certain taxa appear to be potential indicators of wetland extent and impervious surfaces, and identification of macroinvertebrate taxa, particularly midges, at fine resolution is needed to detect these community and population-level changes in the future. Wetland programs could focus on these sentinel taxa for detecting thresholds where wetland development causes changes in biological in-stream communities. Future work could focus on methodology for testing whether the taxa identified in the TITAN analysis are in fact suitable indicator taxa in both this region and other similar regions in Alaska.

More finely resolved land cover and wetland extent data would also improve our understanding of development impacts in this region. The NLCD is not updated regularly or on schedule for Alaska, making it a challenging data source for current information on land use, although it does allow for comparisons with other U.S. states and larger geographic scales. Future work could focus on developing more localized land use maps and aligning them with NLCD methodology to make those datasets more intercomparable. We presented a first attempt at doing so here, but ran into challenges with different data frameworks at borough and municipal levels, making their parcel development data challenging to harmonize. Additionally, more work on wetland mapping and wetland loss assessments would help to better characterize these covariates.

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Appendices

APPENDICES 1 SAMPLING DATES AND YEARS BY SITE.

StationID	Collection Date	Year
kpbve01	6/19/2000	2000
kpbve01	6/14/2001	2001
kpbve01	6/4/2020	2020
kpbve01	5/31/2021	2021
kpbve01	6/10/2022	2022
kpcrk01	6/4/1999	1999
kpcrk01	6/13/2001	2001
kpcrk01	6/1/2020	2020
kpcrk01	5/31/2021	2021
kpcrk01	6/9/2022	2022
kpdee02	7/8/1999	1999
kpdee02	6/16/2000	2000
kpdee02	6/3/2020	2020
kpdee02	6/23/2021	2021
kpdee02	6/8/2022	2022
kpefm01	6/15/2000	2000
kpefm01	6/15/2005	2005
kpefm01	6/4/2020	2020
kpefm01	5/30/2021	2021
kpefm01	6/10/2022	2022
kpnin01	6/2/1999	1999
kpnin01	6/13/2001	2001
kpnin01	6/3/2020	2020
kpnin01	6/11/2021	2021
kpnin01	6/8/2022	2022
kpsol01	6/19/2000	2000
kpsol01	6/14/2001	2001
kpsol01	6/18/2005	2005
kpsol01	6/3/2020	2020
kpsol01	5/30/2021	2021
kpsol01	6/9/2022	2022
kpsta01	6/16/2000	2000
kpsta01	6/12/2001	2001
kpsta01	6/2/2020	2020
kpsta01	6/1/2021	2021

StationID	Collection Date	Year
kpsta01	6/8/2022	2022
kptwi01	6/2/1999	1999
kptwi01	6/17/2005	2005
kptwi01	6/2/2020	2020
kptwi01	6/1/2021	2021
kptwi01	6/7/2022	2022
mache04	5/14/1999	1999
mache04	6/8/1999	1999
mache04	6/16/2001	2001
mache04	6/13/2005	2005
mache04	5/26/2020	2020
mache04	5/19/2021	2021
mache04	5/23/2022	2022
malca01	5/23/2001	2001
malca01	5/28/2020	2020
malca01	5/27/2021	2021
malca01	5/24/2022	2022
malra02	5/23/2001	2001
malra02	6/22/2005	2005
malra02	5/29/2020	2020
malra02	5/27/2021	2021
malra02	5/25/2022	2022
mamea02	5/25/2001	2001
mamea02	6/30/2005	2005
mamea02	6/8/2020	2020
mamea02	5/26/2021	2021
mamea02	5/26/2022	2022
manfc07	5/24/2000	2000
manfc07	5/23/2001	2001
manfc07	5/27/2020	2020
manfc07	5/25/2021	2021
manfc07	5/25/2022	2022
masch03	5/21/2001	2001
masch03	5/29/2020	2020
masch03	5/25/2021	2021
masch03	5/25/2022	2022
maslc01	5/23/2001	2001
maslc01	5/28/2020	2020
maslc01	5/26/2021	2021

StationID	Collection Date	Year
maslc01	5/24/2022	2022
msans01	5/15/1998	1998
msans01	6/16/2020	2020
msans01	6/9/2021	2021
msans01	6/7/2022	2022
msbod01	5/12/1998	1998
msbod01	6/19/2000	2000
msbod01	6/15/2001	2001
msbod01	6/8/2020	2020
msbod01	6/7/2021	2021
msbod01	5/31/2022	2022
mscas01	5/14/1998	1998
mscas01	6/20/2000	2000
mscas01	6/16/2020	2020
mscas01	6/9/2021	2021
mscas01	6/2/2022	2022
mscle01	6/20/2006	2006
mscle01	6/17/2021	2021
mscle01	6/13/2022	2022
mscot01	5/13/1998	1998
mscot01	6/16/2000	2000
mscot01	6/15/2001	2001
mscot01	6/21/2005	2005
mscot01	6/10/2020	2020
mscot01	6/7/2021	2021
mscot01	5/31/2022	2022
msdec05	5/13/1998	1998
msdec05	6/20/2000	2000
msdec05	6/4/2010	2010
msdec05	6/12/2020	2020
msdec05	6/8/2021	2021
msdec05	6/7/2022	2022
msgoo01	5/14/1998	1998
msgoo01	6/20/2000	2000
msgoo01	6/15/2020	2020
msgoo01	6/21/2021	2021
msgoo01	6/16/2022	2022
msgre01	5/15/1998	1998
msgre01	6/20/2000	2000

StationID	Collection Date	Year
msgre01	6/12/2020	2020
msgre01	6/9/2021	2021
msgre01	6/2/2022	2022
mslew01	6/17/2021	2021
mslew01	6/13/2022	2022
mslme01	5/15/1998	1998
mslme01	6/15/2000	2000
mslme01	6/15/2001	2001
mslme01	6/11/2020	2020
mslme01	6/8/2021	2021
mslme01	6/1/2022	2022
msluc03	6/15/2000	2000
msluc03	6/10/2020	2020
msluc03	6/7/2021	2021
msluc03	5/27/2022	2022
msmea01	5/15/1998	1998
msmea01	6/15/2000	2000
msmea01	6/15/2001	2001
msmea01	6/4/2010	2010
msmea01	6/11/2020	2020
msmea01	6/8/2021	2021
msmea01	6/1/2022	2022
msnta01	6/22/2006	2006
msnta01	6/17/2021	2021
msnta01	6/13/2022	2022
mstro01	5/14/1998	1998
mstro01	6/15/2020	2020
mstro01	6/21/2021	2021
mstro01	6/16/2022	2022
mswas01	5/11/1998	1998
mswas01	6/13/2000	2000
mswas01	6/18/2001	2001
mswas01	6/23/2005	2005
mswas01	6/2/2010	2010
mswas01	6/17/2020	2020
mswas01	6/4/2021	2021
mswas01	5/27/2022	2022

Appendices 2 Taxonomic references for aquatic invertebrates.

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APPENDICES 3 WATER QUALITY DATABASE.

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
kpbve01	60.56233	-151.122	5/31/2021	9.4	7.1	83	4	9.9	87.4	Hydrolab
kpbve01	60.56233	-151.122	6/10/2022	11.81	7.01	118	6.85	9.08	85.3	Hydrolab
kpbve01	60.56233	-151.122	6/4/2020	9.95	7.26	112.2	N/A	9.65	85.5	Hydrolab
kpcrk01	60.32035	-151.281	6/1/2020	11.22	7.59	88.6	N/A	11.07	102.9	Hydrolab
kpcrk01	60.32035	-151.281	5/31/2021	8.6	7.6	80	4.8	11.3	98	Hydrolab
kpcrk01	60.32035	-151.281	6/9/2022	12.53	7.63	95.1	4.3	11.48	107.2	Hydrolab
kpdee02	60.03099	-151.685	6/3/2020	9.6	7.4	63	2.4	11.5	101	Hydrolab
kpdee02	60.03099	-151.685	6/8/2022	11.46	7.5	57.1	1.6	11.24	103.2	Hydrolab
kpefm01	60.52948	-150.459	5/30/2021	10.7	7.2	125	1.47	9.6	87.4	Hydrolab
kpefm01	60.52948	-150.459	6/10/2022	16.45	7.28	132.8	1.1	8.62	89.9	Hydrolab
kpefm01	60.52948	-150.459	6/4/2020	15.88	7.54	131.5	0.71	9.82	99.4	Hydrolab
kpnin01	60.03112	-151.597	6/4/2020	10.78	7.72	76.7	1.7	12.05	108.8	Hydrolab
kpnin01	60.03112	-151.597	6/8/2022	14.04	7.71	86.5	2.6	11.81	115.2	Hydrolab
kpsol01	60.48466	-151.054	6/3/2020	9.93	7.52	140.7	2.1	10.96	96.9	Hydrolab
kpsol01	60.48466	-151.054	5/30/2021	10.1	7.5	122	3.8	10.9	97	Hydrolab
kpsol01	60.48466	-151.054	6/9/2022	12.91	7.56	150.5	3	9.81	93.1	Hydrolab

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
kpsta01	59.85076	-151.79	6/2/2020	8.22	7.32	63.7	2.9	11.51	97.8	Hydrolab
kpsta01	59.85076	-151.79	6/1/2021	8.5	7.4	59	6	11.6	97	Hydrolab
kpsta01	59.85076	-151.79	6/8/2022	9.6	7.4	75.8	3.7	11.23	98.9	Hydrolab
kptwi01	59.71671	-151.641	6/2/2020	7.84	8.23	66.4	1.3	12.76	106.8	Hydrolab
kptwi01	59.71671	-151.641	6/1/2021	7.77	7.58	52.6	6.5	13.51	114.8	Hydrolab
kptwi01	59.71671	-151.641	6/7/2022	9.04	7.38	59.6	1.3	11.7	100.6	Hydrolab
mache04	61.20416	-149.894	5/26/2020	8.9	7.2	293	2.5	11.6	100.5	Hydrolab
mache04	61.20416	-149.894	5/23/2022	11.84	7.7	322	2.8	11.39	105	Hydrolab
malca01	61.15468	-149.876	5/28/2020	9.6	7.6	385	N/A	11.2	98.4	Hydrolab
malca01	61.15468	-149.876	5/27/2021	9.3	7.6	379	2.6	11.1	97.5	Hydrolab
malca01	61.15468	-149.876	5/24/2022	7.84	7.64	301.2	4.8	11.51	96.8	Hydrolab
malra02	61.07779	-149.812	5/29/2020	8.9	7.5	147	1.9	11.5	99.5	Hydrolab
malra02	61.07779	-149.812	5/27/2021	7.6	7.7	130	4.4	11.7	98.8	Hydrolab
malra02	61.07779	-149.812	5/25/2022	7.5	7.7	127	9.2	11.9	99	Hydrolab
mamea02	61.31078	-149.576	6/8/2020	5	7.53	234.4	0.86	12.49	97.9	Hydrolab
mamea02	61.31078	-149.576	5/26/2021	5.7	7.7	231	6.4	12.3	98.5	Hydrolab
mamea02	61.31078	-149.576	5/26/2022	4.76	7.73	215	2.8	12.55	97.7	Hydrolab

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
manfc07	61.1748	-149.811	5/27/2020	4.4	7.1	152	1.4	12.8	98.8	Hydrolab
manfc07	61.1748	-149.811	5/25/2021	6.8	7.5	155	0.9	12.5	101	Hydrolab
manfc07	61.1748	-149.811	5/25/2022	5.6	7.6	154	2.1	12.5	99	Hydrolab
masch03	61.19888	-149.834	5/29/2020	11.8	7.5	255	1.9	10.5	96.6	Hydrolab
masch03	61.19888	-149.834	5/25/2021	12	7.7	249	1.6	11.6	107	Hydrolab
masch03	61.19888	-149.834	5/25/2022	11.1	7.8	251	2.35	11.2	101	Hydrolab
masfc11	61.16459	-149.766	5/27/2020	7.4	7.2	81	0.47	11.9	99.2	Hydrolab
masfc11	61.16459	-149.766	5/24/2021	6.95	7.5	81.3	0.5	12.12	99.2	Hydrolab
masfc11	61.16459	-149.766	5/24/2022	5.12	7.23	74.4	1.6	12.61	99.1	Hydrolab
maslc01	61.15186	-149.865	5/28/2020	8.2	7.7	355	N/A	11.6	98.2	Hydrolab
maslc01	61.15186	-149.865	5/26/2021	11.2	7.7	342	2.2	11.1	101	Hydrolab
maslc01	61.15186	-149.865	5/24/2022	7.93	7.73	251.2	5.7	11.73	99	Hydrolab
msans01	62.20237	-150.066	6/16/2020	12.73	7.26	44	0.84	10.3	97.4	Hydrolab
msans01	62.20237	-150.066	6/9/2021	11.2	7.2	37.6	0.65	10.5	95.3	Hydrolab
msans01	62.20237	-150.066	6/7/2022	14.72	N/A	41	0.7	10.1	99	Hydrolab
msbod01	61.53781	-149.022	6/8/2020	4.54	7.55	353.7	N/A	12.14	94	Hydrolab
msbod01	61.53781	-149.022	6/7/2021	4.4	7.56	356	0.85	12.1	94.2	Hydrolab

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
msbod01	61.53781	-149.022	5/31/2022	4.64	7.81	362	0.32	12.75	98	Hydrolab
mscas01	61.94826	-150.053	6/16/2020	14.41	7.1	49.2	1.2	9.62	94.1	Hydrolab
mscas01	61.94826	-150.053	6/9/2021	12.5	7.07	48.4	1.3	10.12	96	Hydrolab
mscas01	61.94826	-150.053	6/2/2022	15.6	6.7	39.8	1.7	9.7	97	Hydrolab
mscle01	61.7402	-150.959	6/17/2021	8.17	7.08	68	1.84	11.9	100.5	Hydrolab
mscle01	61.7402	-150.959	6/13/2022	6.44	7.01	62	1.2	11.9	97.3	Hydrolab
mscot01	61.7402	-150.959	6/10/2020	14.15	7.82	264.3	1.08	10.4	101.3	Hydrolab
mscot01	61.52632	-149.528	6/7/2021	14.8	8.1	260	2.8	10	99.5	Hydrolab
mscot01	61.52632	-149.528	5/31/2022	16.9	7.9	277	1.7	9.9	102	Hydrolab
msdec05	61.74767	-149.933	6/12/2020	10.75	7.12	74.3	0.96	10.86	98.1	Hydrolab
msdec05	61.74767	-149.933	6/8/2021	8.87	7.81	68.1	1.02	10.7	93.7	Hydrolab
msdec05	61.74767	-149.933	6/7/2022	10.31	7.25	81.6	1.7	11.4	101.1	Hydrolab
msgoo01	62.06091	-150.059	6/15/2020	11.7	7.1	35	2	10.6	97.8	Hydrolab
msgoo01	62.06091	-150.059	6/21/2021	12.5	7.7	36	1.7	10.75	101.9	Hydrolab
msgoo01	62.06091	-150.059	6/16/2022	10.9	7	30.2	1.3	11.6	101.3	Hydrolab
msgra01	61.8974	-150.079	6/12/2020	16.03	6.89	47.8	4.8	9.44	95.8	Hydrolab
msgra01	61.8974	-150.079	6/9/2021	12.2	6.8	46.8	6.3	9.25	87.1	Hydrolab

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
msgra01	61.8974	-150.079	6/2/2022	12	6.6	41.1	5.8	9.5	87.6	Hydrolab
mslew01	61.8974	-150.079	6/17/2021	12.45	7.34	46.4	0.88	10.82	100.5	Hydrolab
mslew01	61.8974	-150.079	6/13/2022	11.17	7.17	36	3.1	11	100.8	Hydrolab
mslme01	61.56897	-149.759	6/11/2020	14.55	7.64	211.1	0.95	10.71	105.5	Hydrolab
mslme01	61.56897	-149.759	6/8/2021	12.4	7.06	205	2.2	9.4	88.3	Hydrolab
mslme01	61.56897	-149.759	6/1/2022	15.32	7.62	216.3	1.1	10.7	106.1	Hydrolab
msluc03	61.56216	-149.604	6/11/2020	16.95	7.64	346.4	0.38	9.01	92.9	Hydrolab
msluc03	61.56216	-149.604	6/7/2021	17.6	7.82	357	1.9	8.8	93	Hydrolab
msluc03	61.56216	-149.604	5/27/2022	16.5	7.5	341	2.15	9.3	95.1	Hydrolab
msmea01	61.56153	-149.826	6/11/2020	15.38	7.64	223.6	1.7	10.89	109.2	Hydrolab
msmea01	61.56153	-149.826	6/8/2021	12.6	7.3	211	2.87	8.9	85.2	Hydrolab
msmea01	61.56153	-149.826	6/1/2022	16.13	7.64	213	1.5	10.92	110	Hydrolab
msnta01	61.61042	-150.687	6/13/2022	14.1	7.2	97	1.9	9.8	96.7	Hydrolab
msnta01	61.61042	-150.687	6/17/2021	14.53	7.22	101	3	9.84	95.8	Hydrolab
mstro01	62.62614	-150.225	6/15/2020	11.17	7.23	19.4	0.65	10.88	98.9	Hydrolab
mstro01	62.62614	-150.225	6/21/2021	13.2	7.9	24	0.3	10.46	100.5	Hydrolab
mstro01	62.62614	-150.225	6/16/2022	12.8	6.8	12.6	0.7	10.8	101.3	Hydrolab

Site ID	Latitude	Longitude	Survey Date	Temperature (Celsius)	pH	Specific Conductance	Turbidity (NTUs)	DO (mg/L)	DO (%)	Instrument Used
mswas01	61.56583	-149.314	6/17/2020	9.05	7.74	164.8	N/A	11.1	96.3	Hydrolab
mswas01	61.56583	-149.314	6/4/2021	7.95	7.7	160.5	4	11.4	97.2	Hydrolab
mswas01	61.56583	-149.314	5/27/2022	8.63	7.64	153.5	5.7	11.42	98.2	Hydrolab