# Distribution of Rooted Aquatic Plants and Filamentous Algae in the Klamath River, California: Report Update for 2019–2022


Prepared by: Laurel Genzoli, MS

For the Klamath Tribal Water Quality Consortium


August 2022

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**Suggested Citation:**
Genzoli, Laurel. 2022. Distribution of Rooted Aquatic Plants and Filamentous Algae in the Klamath River, California: Report Update for 2019–2022. Prepared for the Klamath Tribal Water Quality Consortium. 23p + Appendices.

# Summary

The middle and lower reaches of the Klamath River flow 190 miles from Iron Gate Dam to the Pacific Ocean. The river is subject to seasonally high nutrient concentrations, warm water temperatures, and hydrologic alteration from dams, resulting in extensive growth of rooted aquatic plants and filamentous algae. Despite acknowledgement that prolific algal and plant growth degrades water quality, fish habitat, and native fishing practices, no previous studies have quantified rooted aquatic plant and filamentous algae distribution and abundance in the Klamath River below Iron Gate Dam. Documenting patterns of algae and aquatic plant growth provides a baseline of data from which to study physical, chemical, and biological mechanisms that influence plant and algae structure in the Klamath River. This data will inform expectations of how aquatic vegetation will change following dam removal and provide a baseline from which to compare riverine vegetation to following dam removal.

In the summers of 2019–2022, we conducted wading and snorkeling surveys of rooted aquatic plants and filamentous algae once per summer between late June and early August at 10–11 reaches in the Klamath River. At each reach, we surveyed six transects in variable habitats that were representative of the reach. At each transect, we surveyed the river cross section at 11 evenly divided points where we estimated the percent cover of filamentous algae and rooted aquatic plants, as well as water depth, substrate type, and plant and algae characteristics.

Rooted aquatic plants in the Klamath River were distributed longitudinally below Iron Gate Dam, while patterns in filamentous algae were more complex. Highest coverage of rooted aquatic plants was observed at sites closest to Iron Gate Dam and decreased with distance downstream from the dam. Percent cover of filamentous algae did not follow a distinct longitudinal pattern, although dominant algal taxa shifted, with *Ulothrix* dominant at sites closer to Iron Gate Dam and *Cladophora* dominant at sites below the Scott River.

Differences in river flows among years likely influenced observed algal and rooted aquatic plant cover. The first year of surveys, 2019, was a relatively high-water year in the Klamath Basin, with multiple winter and spring floods and later onset of summer low-flow conditions, while the following three years had very few winter and spring high flow events. The coverage of rooted aquatic plants was higher in 2020 than in 2019, and higher yet in 2021 and 2022. Observed filamentous algal coverage varied among years, but cover-

age of algae varies within a season due to timing of flow and water temperature. During warm, lower flow years (2020 and 2021) we observed filamentous algae that had already senesced, rather than presenting as high coverage with long, fresh filaments. Flows are likely a major driver of primary producer biomass and composition, with both the timing and magnitude of winter flushing flows and the timing and magnitude of summer low-flow onset influencing the community composition, spatial distribution, and seasonal timing of primary producer assemblages in the Klamath River.

Further research documenting the spatial and temporal patterns of primary producer assemblages will help explain patterns of ecosystem scale productivity and water quality dynamics in the Klamath River. Documenting primary producer assemblages under a range of water-year conditions prior to dam removal will provide baseline data on the range of conditions that exist on the Klamath River with dams in place.

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# 1 Introduction

Algae and aquatic plants are essential components of river ecosystems. The growth of algae and aquatic plants provides an important basis for aquatic food webs, influences water quality, provides habitat for fish, and controls carbon cycling (Hall et al., 2001; Vadeboncoeur and Power, 2017; Genzoli and Hall, 2016; Nichols et al., 2020). Land use and direct alterations to rivers are associated with widespread increases in algae growth rates and biomass (Griffiths et al., 2013; Davis et al., 2012; Sabater et al., 2018). This increase in primary productivity and biomass of algae and aquatic plants, termed eutrophication, is a growing problem to freshwater ecosystems (Smith et al., 2006; Sinha et al., 2017). Eutrophication can degrade water quality and fisheries health by causing large daily fluctuations in pH and dissolved oxygen, promoting toxin-producing species, and altering aquatic food webs (Genzoli and Hall, 2016; Paerl et al., 2018; Power et al., 2015).

The middle and lower Klamath River, flowing approximately 190 miles from the outflow of Iron Gate Dam to the Pacific Ocean, is subject to high nutrient concentrations, warm summer water temperatures, and hydrologic alteration from dams (Oliver et al., 2014; David et al., 2018), resulting in extensive growth of rooted aquatic plants and filamentous algae. Despite acknowledgement that prolific algal and plant growth can degrade water quality, promote salmon parasites, and disrupt indigenous fishing practices (Malakauskas et al., 2013; Genzoli and Hall, 2016), no previous studies have documented patterns of rooted aquatic plants or filamentous algae growth in the Klamath River below Iron Gate Dam.

In the Klamath River, the series of hydroelectric dams that end at river mile 190 artificially stabilize flow and substrate below these dams (U.S. Department of the Interior, 2013). The river becomes less stable with distance downstream from the dams as the river receives inputs of water and sediments from many large, unregulated tributaries. The discontinuity of water and sediment associated with the dams, and the subsequent longitudinal gradient, both due to dams and geographic conditions, provide a gradient of flow and bed stability that is expected to influence filamentous algae and rooted aquatic plant assemblages (Merz et al., 2008; Abati et al., 2016). Documenting the spatial distribution, inter-annual variability, and relative coverage of aquatic plants and filamentous algae provides a framework for further research aimed at understanding how high growth rates and biomass influence water quality and fisheries health. Based on longitudinal gradients and observations from fisheries and water quality professionals, we expected that rooted aquatic plants would cover large areas of stream bed closer to Iron Gate Dam and that coverage would attenuate downstream with distance from the dam due to increased sediment movement during winter high flows. Further, we expected that years with small or fewer winter floods would result in higher summer macrophyte cover at all sites, while large winter floods would promote lower macrophyte cover the following summer due to scour associated with large flows.

# 2 Methods

We conducted surveys for rooted aquatic plants and filamentous algae at 11 reaches (Figure 1, Table 1) in the Klamath River between Iron Gate Dam and the Klamath Estuary from 2019 to 2022. We conducted surveys from late June to mid-July, shifting survey timing slightly from year to year in order to survey around the time that most sites approached their summer baseflows. In 2019 and 2022, we delayed surveys at the most down-river site (Figure 1) until early August due to later flow recession at this site (Figure 2). We generally surveyed reaches starting at the reach closest to Iron Gate Dam and ending near the river mouth. All reaches were surveyed every year except for the reach near Stanshaw Creek (OMR), which was only surveyed in 2019, and the reach Above Beaver Creek (ABC, surveyed in 2019), the latter which we moved to a reach below Beaver Creek, starting at the Klamath Community Center, and ending at Walker Bridge (WB) due to access issues.

At each reach, we surveyed the riverbed to assess the coverage of aquatic vegetation. Reaches ranged from 0.6 to 5.2 miles in length (Table 1), based on river access points. We used kayaks to float each reach, surveying six transects within each reach, with transects chosen among variable habitats represented in the reach. Each transect was a minimum of 100m downstream from the previous transect, and attempts were made to survey transects with more pool-type and riffle-type characteristics throughout the reach length. Areas of rapids and swift current were underrepresented in surveys due to safety concerns and inability of a surveyor being able to access these swift sections. Along some transects, individual quadrants were not surveyed due to especially swift or deep points within a transect. At all transects, a minimum of seven quadrants were surveyed. We attempted to balance transect selection between what was possible to survey safely and what was representative of the reach. Thus, we had to select transects in the field while conducting the first year of surveys. For the following years of surveys, we surveyed in the same river locations as the previous year by navigating to the transect edge based on the latitude and longitude collected the first year of the study. No transects were fully wadeable across the river, confirming that the mixed survey method of wading and snorkeling was necessary.

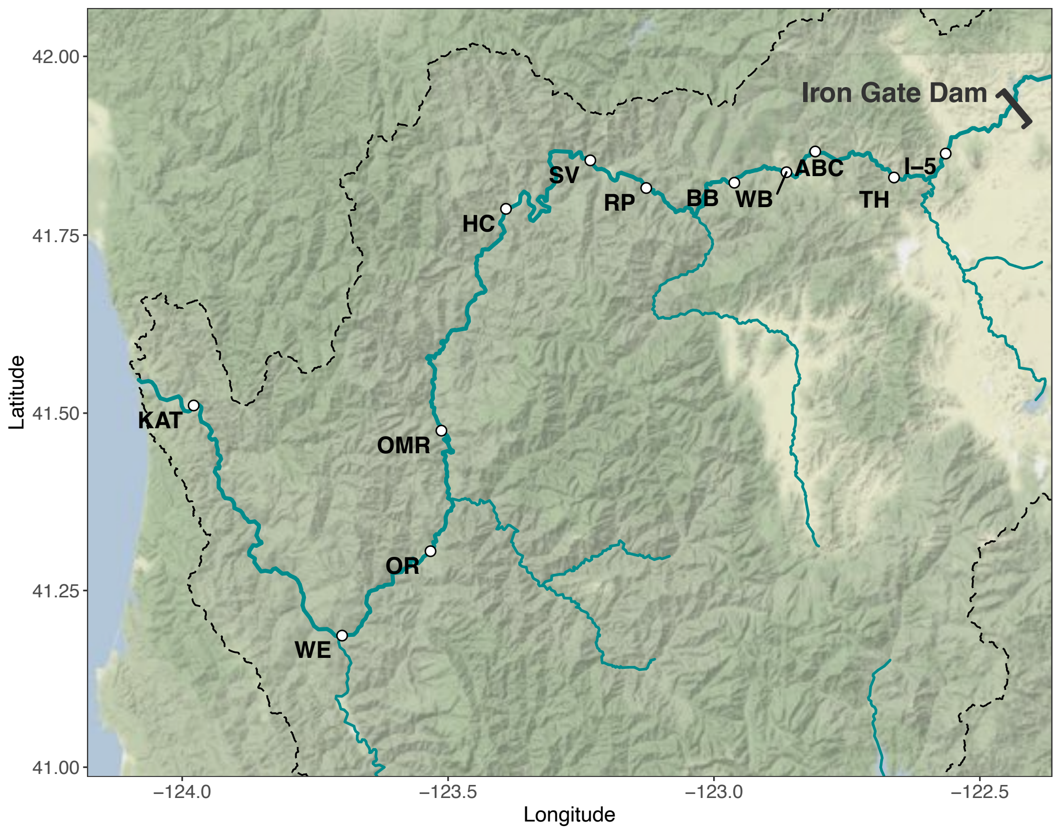



Figure 1. Filamentous algae and aquatic plant survey sites in the Klamath River, CA.

Table 1. Aquatic vegetation reach locations. The latitude and longitude are reported for the downstream (6th) transect of each reach. River mile is approximate and measured from the river mouth. Number in parenthesis behind river mile indicates reach length in miles.

| Site Name | Site Code | End Latitude | End Longitude | River Mile (Length) | Quadrants Surveyed | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **2019** | **2020** | **2021** | **2022** |
| Above I5-Bridge | I-5 | 41.86420 | 122.56434 | 179 (0.9) | 43 | 53 | 57 | 60 |
| Tree of Heaven | TH | 41.83071 | 122.66141 | 172 (1.3) | 53 | 59 | 61 | 63 |
| Above Beaver Cr | ABC | 41.86707 | 122.80956 | 161 (0.9) | 55 | NA | NA | NA |
| Walker Bridge | WB | 41.83807 | 122.86370 | 158 (2.0) | NA | 64 | 65 | 64 |
| Brown Bear | BB | 41.82336 | 122.96172 | 150 (1.0) | 56 | 65 | 64 | 66 |
| Rocky Point | RP | 41.81597 | 123.12736 | 136 (1.6) | 53 | 63 | 62 | 60 |
| Below Seiad Valley | SV | 41.85465 | 123.23254 | 128 (1.1) | 62 | 64 | 63 | 66 |
| Happy Camp | HC | 41.78677 | 123.39106 | 108 (1.4) | 60 | 63 | 66 | 66 |
| Stanshaw Creek | OMR | 41.47537 | 123.51257 | 76 (0.6) | 55 | NA | NA | NA |
| Orleans | OR | 41.30549 | 123.53300 | 59 (1.5) | 58 | 65 | 66 | 62 |
| Weitchpec | WE | 41.18631 | 123.69928 | 43 (5.2) | 55 | 63 | 62 | 51 |
| Klamath at Terwer | KAT | 41.51080 | 123.97840 | 6 (2.0) | 62 | 60 | 62 | 59 |

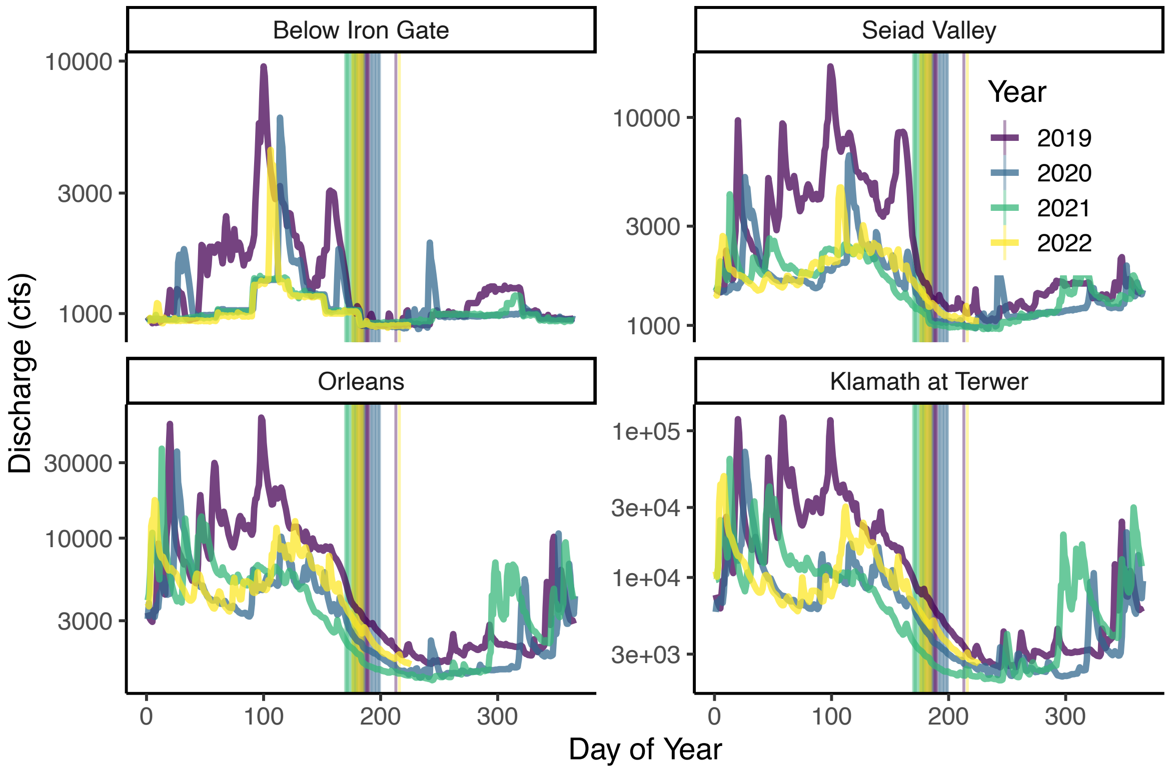



Figure 2. Discharge (cubic feet per second, cfs) for Klamath River U.S. Geological Survey gauging stations. Vertical bars show dates of sampling across years.

Each reach required one day to survey with a team of two people.

We surveyed quadrants along each transect. At the edge of each transect, we recorded longitude, latitude, and wetted width. We divided each transect into 11 evenly spaced quadrants based on river width, which we measured with laser range finders from the river's edge. When possible, the surveyor waded to the quadrant location, which was identified by a shore-based field technician using range finders to locate each quadrant position based on the surveyor's distance from shore. When the river became too deep for wading (>0.8-1.4 m, depending on river velocity), the surveyor transitioned to snorkeling. At each quadrant, the surveyor dropped a 40 × 40 cm weighted PVC square to the riverbed. The surveyor measured water depth using a marked pole or a sonar depth finder (used at quadrants >3 m deep), percent of substrate in each of four size categories (fine, gravel, cobble, boulder/bedrock), and the percent cover of filamentous algae and rooted aquatic plants. Percent cover of algae and plants were recorded separately, such that each category could cover up to 100% of the quadrant with overlapping cover of plants and algae possible. For both substrate and aquatic vegetation, observations of percent cover were made based on visual estimation by the surveyor, aided by markings on quadrant margins showing percent cover increments. We recorded filamentous algae coverage when filaments were >2 cm long. Visually obvious benthic cyanobacteria were recorded, despite being more of a film than presenting as filaments. Additionally, the genus tentatively identified as *Aegagropila*, also referred to here as "unidentified Cladophoraceae" was also recorded as filamentous algae, despite a lack of filaments >2 cm because this green algae forms dense mats that accumulate more biomass than adjacent biofilms. We did not assess biofilms in this study. For each species or genera observed in a quadrant (generally identified to species for rooted aquatic plants and genus for algae), we recorded species or genus code, percent cover of each taxa, plant condition (on a scale of 1-4 corresponding to how fresh or decayed the vegetation was), and the average length of the plant or its filaments within the quadrant (see data sheet included at end of document for details). Mat thickness was recorded in species without obvious filaments.

We calculated the mean percent coverage of rooted aquatic plants and filamentous algae for each reach during each survey year. We present results with taxa combined into these two general categories as well as by individual species or genera.

# 3 Results

We surveyed 11 reaches in 2019, and 10 reaches in each of the following years. Six species of rooted aquatic plants occurred in surveys, as well as filamentous algae from multiple genera. Elodea was the most common rooted aquatic plant, followed by Curly-leaf pondweed (Figure 4, right panel). *Cladophora* was the most common genus of filamentous algae, followed by *Ulothrix* (Figure 4, left panel). Other common filamentous algae included *Oedogonium*, and algae likely in the genus *Aegagropila*, although expert consultation (personal communication, R. Lowe, 01-09-2019) provided only a “likely identification” for this genus, with a recommendation to use genomics methods to confirm the identification. Cyanobacteria were present but covered very small portions of the benthic substrate during surveys.

## 3.1 Longitudinal Trends

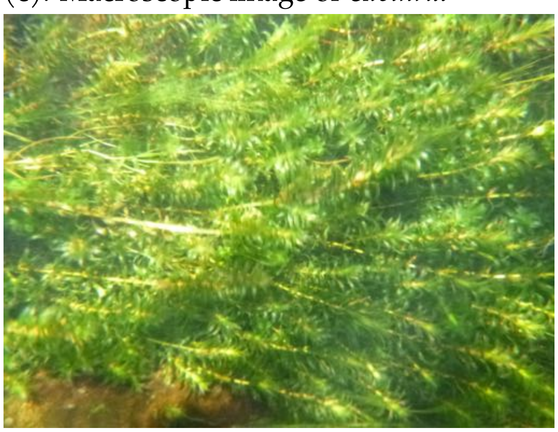
Cover of aquatic plants decreased longitudinally from below Iron Gate Dam to the river mouth, while filamentous algae had more variable coverage. The highest percent cover of aquatic plants in all years was at site I5 (ending upriver from the I5-bridge). The

(a). Filamentous algae covering aquatic plant beds near I-5 Bridge

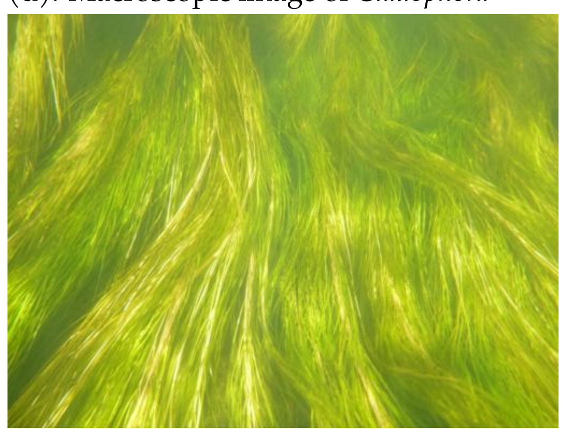
(b). *Cladophora* mats along river edges at Dolan's Bar, near Orleans, CA

(c). Macroscopic image of *Ulothrix*

(d). Macroscopic image of *Cladophora*



(e). Elodea



(f). Sago pondweed

Figure 3. Aquatic plant and filamentous algae coverage (panels a, b), common algae genera (panels c,d), and common rooted aquatic plants (panels e,f) encountered in Klamath River surveys. Photos by Adrienne Chenette (panels a, c, d) and Chippie Kislik (panel b), and the report author (panels e, f).

Table 2. Common and scientific names of rooted aquatic plants documented in surveys in the Klamath River from 2019-2022

| **Common Name** | **Scientific Name** |
|---|---|
| Elodea or waterweed | *Elodea canadensis* |
| Curly-leaf pondweed | *Potamogeton crispus* |
| Richardson's pondweed | *Potamogeton richardsonii* |
| Sago pondweed | *Stuckenia pectinata* |
| Horned pondweed | *Zannichellia palustris* |
| Coontail | *Ceratophyllum demersum* |

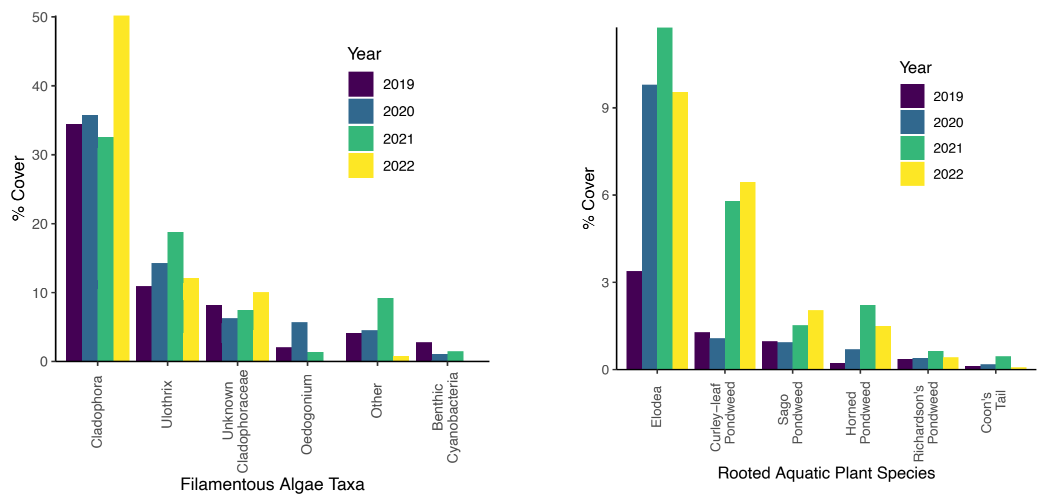



Figure 4. Mean percent cover of common filamentous algae taxa (left panel) and rooted aquatic plant species (right panel) from all sites surveyed. The reach near Stanshaw Creek was excluded in this plot so that data is comparable among the same sites surveyed each year.

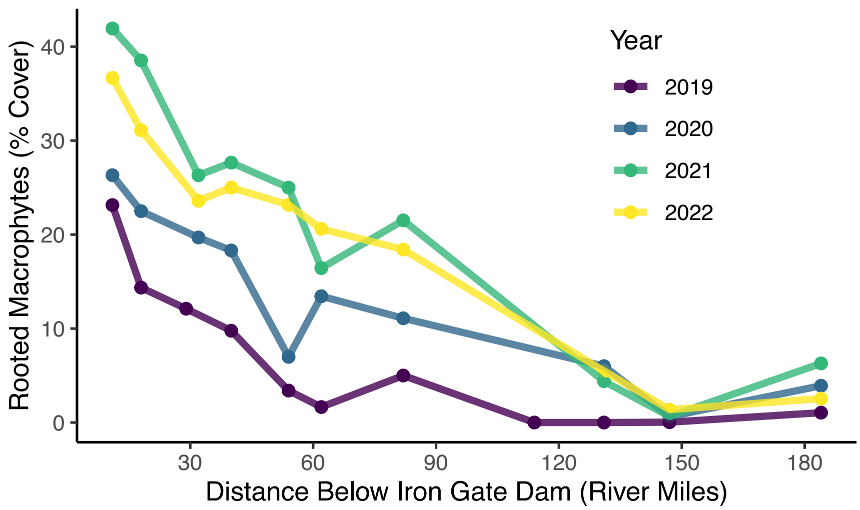



Figure 5. Percent cover of rooted aquatic plants decreased downstream of Iron Gate Dam in all years, while cover generally increased through time.

lowest cover was observed in the reach ending at Weitchpec. Elodea was the most common rooted aquatic plant by coverage area, followed by Curly-leaf pondweed (Figure 7). Four other species of aquatic macrophytes were also present in surveys, but in lower cover (Figure 7, 4).

The total coverage of filamentous algae did not follow the same longitudinal trend as rooted aquatic plants downstream of Iron Gate Dam. Generally, the total percent cover of filamentous algae was lower at sites above Seiad Valley, and higher from Happy Camp to Weitchpec, and then decreased again at the most downstream site (KAT, Figures 6, 8). Specific algal genera showed longitudinal trends. *Ulothrix* was the dominant genus at sites above Seiad Valley (SV) and *Cladophora* was dominant from Seiad Valley to Klamath at Terwer (KAT) most years (Figure 8). These upriver sites dominated by *Ulothrix* had sub-dominant genera present including *Cladophora*, *Oedogonium*, and the genus tentatively identified as *Aegagropila*, while downriver sites dominated by *Cladophora* had lower coverage of sub-dominant macro-algae genera at the time of surveys.

## 3.2 Among Year Differences

Although aquatic plant coverage increased from 2019 to 2021 (and was similar between 2021 and 2022, Figure 5), the longitudinal trend was consistent among years (Figure 6). In 2019, aquatic plants were nearly absent from all survey reaches below Happy Camp, whereas in the following years, aquatic plants were documented in surveys at all sites. Increased establishment of aquatic plants appeared to influence all surveyed reaches of the Klamath River from 2019 to 2021, with no specific reach disproportionately driving the trend of increased plant coverage. An increase in Elodea from 2019 to 2020 drove the increased cover between the first two years of surveys, while an increase of Curly-leaf pondweed drove the additional increase in cover from 2020 to 2021.

The total percent cover of filamentous algae and longitudinal trends in algal cover was similar among years (Figure 6). Longitudinal trends in taxa composition were consistent, with *Ulothrix* dominating at sites above Seiad Valley, and *Cladophora* becoming the dominant taxa below Seiad Valley (Figure 8). One exception was at Happy Camp in 2022, where *Cladophora* was sparse compared to previous years, and macrophytes cover was higher than in previous years. Despite similar cover, the condition of the algae was variable among years during the surveys, especially at downriver sites dominated by *Cladophora* (Figure 9). In 2019 and 2022, *Cladophora* was more recent, while in 2020 and 2021, *Cladophora* was further through its life cycle and more frequently yellowing, breaking off, and being transported down-river, leaving short decaying filaments behind.

# 4 Discussion

## 4.1 River Flows

The difference in flows among years and differences longitudinally along the river likely influenced filamentous algae and rooted aquatic plants in the Klamath River. The first year of surveys, 2019, was a higher-than-average water year, with multiple flood peaks occurring throughout the winter and spring. At Seiad Valley, one peak flow in 2019 exceeded 99% of flow magnitudes, while at Orleans two peaks exceeded 99% of flows there. Near the mouth of the river, the 99% flow magnitude was exceeded three times in 2019. In contrast, 2020 experienced one natural flow pulse in January, but this flow pulse only exceeded the 75%, 98% and 95% flow magnitude at Seiad Valley, Orleans and Terwer, respectively, showing that 2020 peak flows were low compared to both 2019 peak flows and to the long-term record. This single large flow event was driven primarily by tributaries in the lower watershed, and thus had a larger effect on down-river sites than the macrophyte dominated sites closer to Iron Gate Dam (Figure 2). A second pulse flow, released from Iron Gate Dam in April of 2020, was a salmon disease mitigation release (National Marine Fisheries Service, 2019), and although lower than flows released from Iron Gate Dam in

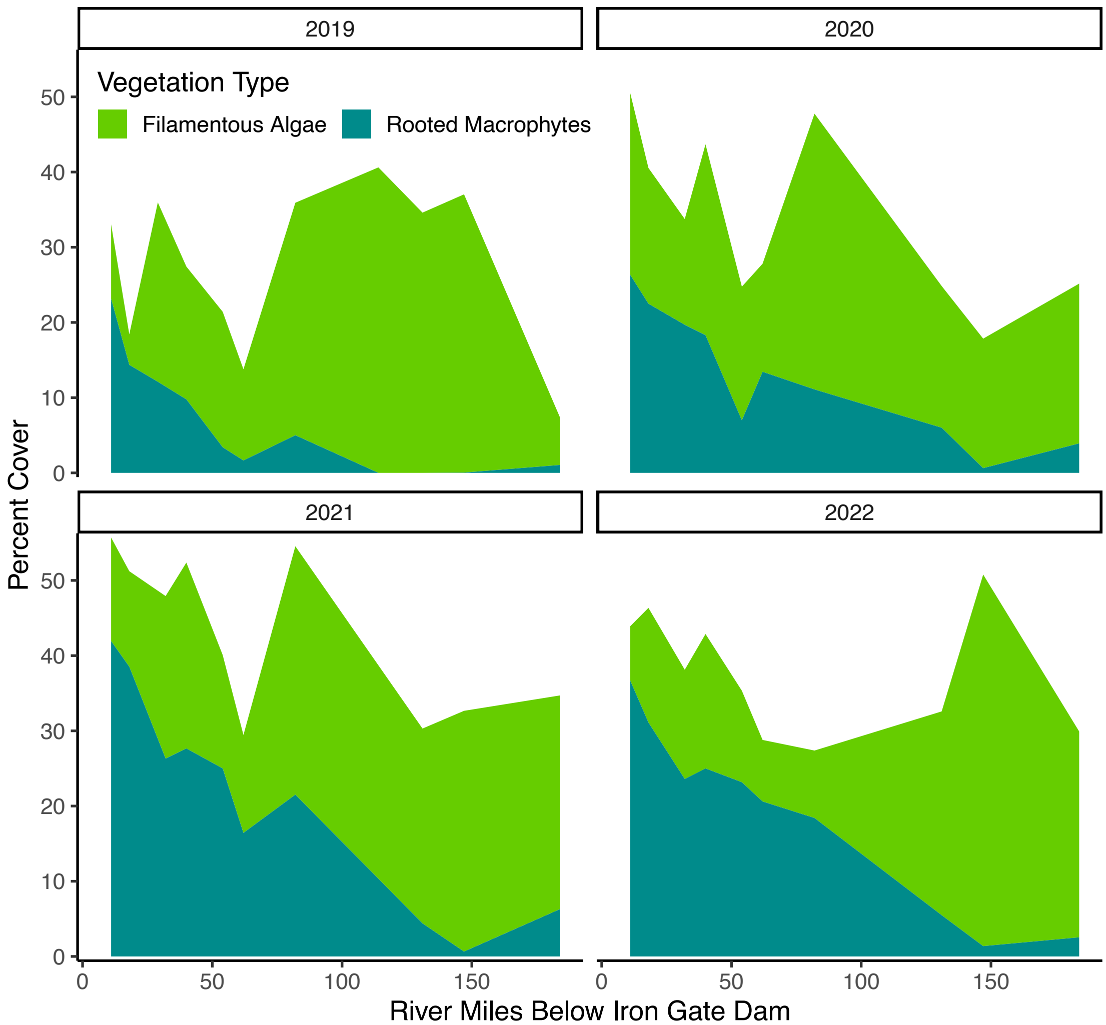



Figure 6. Percent cover of rooted aquatic plants (blue, lower stack) and filamentous algae (green, upper stack) decreased downstream of Iron Gate Dam. Primary producer types are stacked, so that the total area shows the total percent cover of aquatic macro vegetation (filamentous algae and rooted aquatic plants combined).

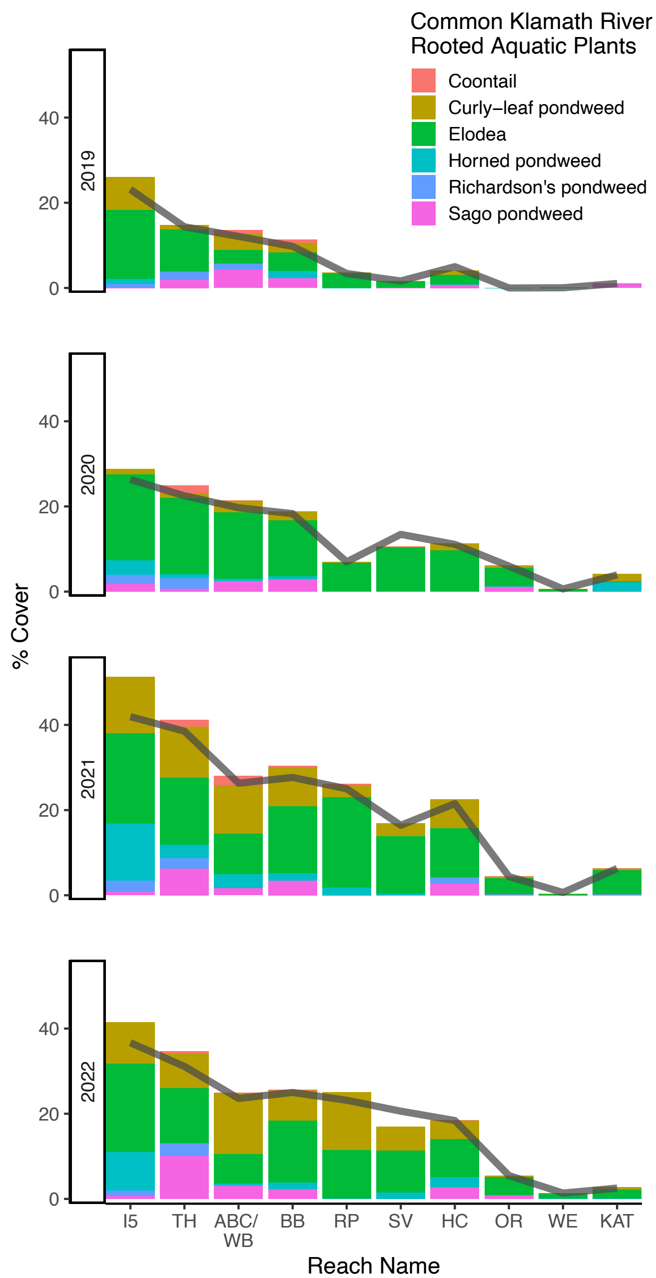



Figure 7. Percent cover of rooted aquatic plants decreased longitudinally downstream of Iron Gate Dam. Bars at each survey reach show total percent cover, with colors showing the different species at each reach.

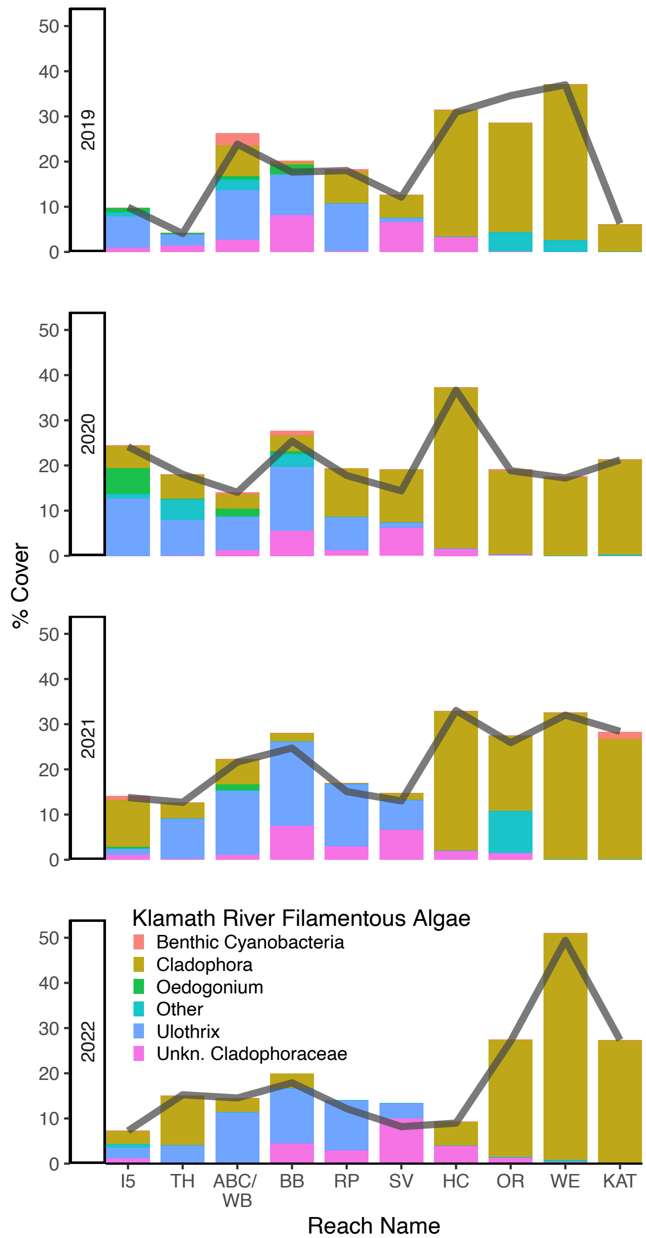



Figure 8. Percent cover of filamentous algae at survey reaches downstream of Iron Gate Dam. Bars at each survey reach show total percent cover, with colors showing the different taxa at each reach.

2019, this flow pulse was the largest flow that occurred on the Klamath River at up-river locations (Iron Gate and Seiad Valley gauges) in 2020. The following two years (2021 and 2022) had similar or lower peak flows at all sites than 2020 flows, such that by 2022, there had been no large winter flow events for three years in a row.

## 4.2 Rooted Aquatic Plant Distribution Patterns

The reduction in the number and magnitude of high flows from 2019 to 2022 likely promoted increased coverage of rooted aquatic plants in the Klamath River. Rooted aquatic plant coverage has been found to decrease with increased flood disturbance (Riis and Biggs, 2003; Henry et al., 1996). Experiments have shown that the decrease in rooted aquatic plant cover in rivers is likely due to uprooting associated with bed disturbance, which would suggest that flow thresholds which cause bed movement would influence the ability for roots to over-winter or seeds to be maintained in the sediments (Riis and Biggs, 2003). Below dams, further interactions between flows and lack of mobile sediments may cause the river bed to be especially resistant to bed movement and the uprooting of aquatic plants, even with flows otherwise large enough to cause bed movement (Ibáñez et al., 2012; Benítez-Mora and Camargo, 2014). Continuing to monitor rooted aquatic plant coverage in the Klamath River over a range of flow conditions will bring further insight into the variability and drivers of aquatic plant dynamics.

Rooted aquatic plants can interact with sediment storage and transport, causing fine sediments to accumulate within rooted aquatic plant patches (Cotton et al., 2006; Kleeberg et al., 2010; Jones et al., 2012). The accumulation of fine sediment in these patches can lead to changes in river bed morphology by increasing sediment storage and decreasing water velocities within dense patches of rooted aquatic plants, while simultaneously promoting higher velocities and channel bed erosion in unvegetated areas of the channel (Schoelynck et al., 2012; Jones et al., 2012). Fine sediment deposition retained in plant patches may create positive feedback loops for more aquatic plants to grow (Schoelynck et al., 2012), but deposition of large amounts of fine sediment may lead to burial that inhibits growth, depending on the quantity and adaptive characteristics of individual species (Brookes, 1986). With removal of the hydroelectric dams and expected deposition of fine reservoir sediments, models of sediment dynamics following dam removal will benefit from considering the extent and coverage of rooted aquatic plants, which are most dense at reaches nearer to Iron Gate Dam, the same reaches where fine sediment is expected to accumulate (Figures 6, 7). Understanding how rooted aquatic plant coverage changes with variable flows in the Klamath River can provide tools for sediment management associated with

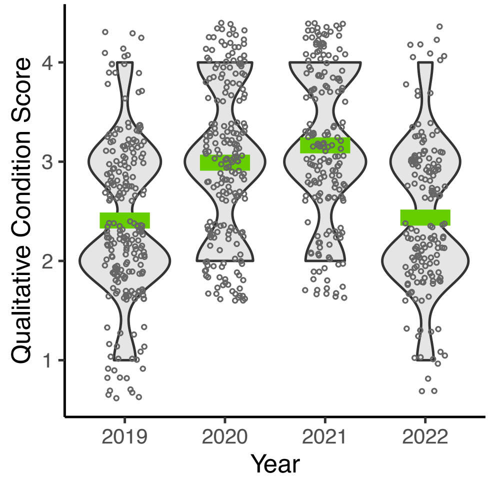



Figure 9. Distribution of qualitative condition scores for *Cladophora*, with 1 indicating very fresh and 4 indicating highly decayed condition. Green bars show the mean condition score for each year across all sites.

dam removal.

## 4.3 Filamentous Algae Distribution Patterns

As with rooted aquatic plants, differences in flow patterns among years likely influenced filamentous algae coverage. Specifically for *Cladophora*, it is likely that 2019 surveys were conducted when the algal filaments were in good condition. Overall, we observed longer filaments, in newer condition in 2019 than in 2020 or 2021 surveys (Figure 9). In 2020 and 2021 surveys we observed extensive areas covered by short filaments of decayed *Cladophora*. In these years, we suspected that longer filaments that had been growing on these substrates earlier in the season had already senesced and detached prior to our surveys. Differences in the qualitative condition score of filamentous algae among years was shown in the field data, where median algal condition in 2019 and 2022 was a "2", meaning algae was in newer condition with only some epiphytes and maintaining structure, whereas in 2020 and 2021, mean condition was "3", meaning that algae was heavily epiphytized, and structure was beginning to weaken or had already detached (Figure 9).

The ability of *Cladophora* to proliferate is dependent on hydrodynamic processes, such that higher shear stress associated with high flow conditions likely limit the establishment of *Cladophora* (Dodds and Gudder, 1992). Once flows recede and *Cladophora* begins to grow, it can add biomass very rapidly, resulting in filaments over 1 m long. The lack of high flows in the spring of 2020 and 2021, and the earlier onset of summer low-flow conditions likely allowed *Cladophora* to begin growing earlier than in 2019, shifting the timing of *Cladophora* proliferations. We observed the freshest *Cladophora* in 2022 surveys. Despite few and low magnitude winter pulse flows in 2022, flows were higher in early summer during survey timing, likely delaying the onset of rapid *Cladophora* growth to coincide with when we surveyed. Despite surveying at similar time periods these four years, we likely did not capture the *Cladophora* at the same phenology due to these differences in water-year. Seasonal surveys occurring bi-weekly or monthly of filamentous algae would be beneficial in understanding the within-year variation in *Cladophora* growth and senescence and would inform how this variation in rapid growth timing contributes to reach-scale primary productivity and water quality dynamics in the Klamath River.

High biomass, along with high water temperatures, likely promote the mid-summer senescence of *Cladophora*, which leads to its detachment. The photosynthetic efficiency of *Cladophora* decreases per unit mass as the filaments increase, and the cells near the attachment point may not be maintained sufficiently to keep the filaments attached to the substrate as biomass increases (Dodds and Gudder, 1992; Kuczynski et al., 2020). Although water temperature limits vary widely for *Cladophora* of different species and in different habitat types, Wong and colleagues found an upper tolerance limit of 23.5 degrees C. for *Cladophora* in seven Canadian rivers (Wong et al., 1978), which is a temperature that often occurs in the Klamath in early to mid-July at sites dominated by *Cladophora*(Asarian and Kann, 2013). Flow is a strong driver of water temperatures in the Klamath River, especially in June and July, with cooler water temperatures in high-flow years than low-flow years (Asarian and Kann, 2013; Asarian et al., 2021). Earlier onset of high water temperatures in 2020 and 2021 may have contributed to earlier senescence than in 2019 and 2022.

Despite a difference in overall coverage of filamentous algae among years, spatial patterns of dominance by specific genera were consistent among years. *Ulothrix* was the dominant genus at sites above Seiad Valley (SV) and *Cladophora* was dominant from Seiad Valley to Klamath at Terwer (KAT) (Figure 8). The reasons that different genera dominate different parts of the Klamath River are unknown, but other studies have also documented variation in dominance of these two genera. In studies in the Laurentian Great Lakes, researchers found *Ulothrix* growing in the more shallow splash zone of the lake, while *Cladophora* was dominant in deeper, more calm areas of the lake (Auer et al., 1983). The researcher there noted that *Ulothrix* optimizes its photosynthetic capacity at higher light conditions, while *Cladophora* is most productive at lower light conditions. Although light conditions are relatable in the Klamath on a reach scale, where mean reach depth is shallower at upriver sites and deeper at down-river sites, we did not observe *Ulothrix* and *Cladophora* within a reach colonizing these habitats according to light conditions along a vertical gradient. Other reasons for the spatial differences in these two species may be related to conditions present during early colonization, including the ability of *Ulothrix* to establish in the spring at sites where flows are lower. Understanding why these dominant species occur where they do, their seasonal growth trajectories, and the impacts they have on further algae growth (such as epiphytes and benthic cyanobacteria) and nutrient cycling, will lead to a better understanding of nuisance algae and associated water quality concerns in the Klamath River.

# 5 Future Monitoring

The four years of data in this report present a range of in-river macro-vegetation conditions from which to compare vegetation to following the removal of hydroelectric dams from the Klamath River. Continued monitoring of filamentous algae and rooted aquatic plants in the Klamath River will help describe additional variation that occurs from year to year with the dams in place, while continued monitoring following dam removal will support understanding how dam removal affects in-river macro-vegetation. A long-term data set of annual macrophyte coverage will also facilitate understanding of how other factors influence filamentous algal and aquatic plant growth dynamics. These data can be used in studies seeking to identify drivers of water quality and fisheries health by considering how filamentous algae and aquatic plant coverage drives ecosystem processes.

Continuation of the surveys described in this report will facilitate comparisons with data collected over the four years reported on here. Opportunities for modifying these surveys to increase site coverage or frequency of surveys or reduce current survey time include conducting quadrant surveys focused on near-shore vegetation in primarily wadeable locations and use of remote sensing with areal images from drones. In the case of near-shore quadrant surveys, surveys similar to the ones described in this report could be conducted, although only quadrants close to shore would be surveyed. Additional transects would be surveyed so that data from 60 quadrants or more would be used to assess a reach. This survey modification would select for areas of higher algae and plant growth, thus total percent cover estimates would not describe an entire reach but would instead be used to compare among reaches or through time, using the same survey technique. Initial analysis comparing all data vs. just near-shore quadrants show similar longitudinal and among year variation in cover, with generally slightly higher coverage in the near shore only data compared to the full transect data reported on in this report. Photos taken with drones are another useful tool to document the coverage of filamentous algae and aquatic plants. Methods were tested in 2019 to assess algal and aquatic plant cover using drones in the Klamath River (Kislik et al., 2020). Recommendations for drone surveys included taking photos at lower solar angles (morning and evening) to avoid sun glint on the water and conducting in-river surveys at the site when the photo is being taken so that image characteristics can be related to visible plant and algae growth at variable depths and water clarity conditions. Because of computationally intensive processing of photos and the labor associated with this processing, drone images may be best suited for surveying a subset of sites to monitor changes through time, rather than to characterize extensive reaches along the river. Drone images will be most useful during windows of higher water clarity, when sediment from high flows and planktonic algae from upstream lakes and reservoirs are low.

Studies assessing the seasonal dynamics of algae and aquatic plant growth within a year will help direct the timing of continued annual monitoring and put the data set describing year-to-year variation in context of seasonal shifts. Understanding seasonal timing of biomass accumulation may also increase our understanding of how nutrients affect primary productivity in the Klamath River. Seasonal dynamics can be documented using similar techniques described in this report, including the modifications described in the above paragraphs, but conducted on more frequent time scales throughout the season. Other opportunities for exploring seasonal dynamics include the use of automated photographic technology (i.e., time-lapse photo from seasonally deployed mounted cameras), and exploring quadrant data collected as part of periphyton monitoring in past years (Gillett et al., 2016).

# 6 Conclusions

Rooted aquatic plants in the Klamath River displayed a longitudinal pattern below Iron Gate Dam, while patterns in filamentous algae coverage were more complex. Highest coverage of rooted aquatic plants was observed at sites closest to Iron Gate Dam in all years, and decreased with distance downstream from Iron Gate Dam. *Elodea* was the dominant rooted aquatic plant observed in the Klamath River, followed by Curly-leaf pondweed. Percent coverage of filamentous algae did not follow a distinct longitudinal pattern, although taxa present did display a longitudinal pattern. At sites closer to Iron Gate Dam (above Seiad Valley), *Ulothrix* was the dominant filamentous algae, whereas *Cladophora* dominated at sites from Seiad Valley to Klamath at Terwer.

Differences in river flows among years likely caused variation in aquatic vegetation cover. While 2019 was a wet year on the Klamath with multiple high flow events and later onset of summer low-flows, the following years had progressively lower flows with few winter and spring floods and generally earlier onset of summer low-flows. Longitudinal decreases in rooted aquatic plant coverage occurred in all years, but overall coverage was lowest in 2019 following the series of high flow events, and gradually increased over the next three years, all of which had much lower peak winter flows. Increased coverage of rooted aquatic plants was attributed primary to increases in *Elodea* and Curly-leaf pondweed. Similar patterns of filamentous algal coverage and taxa distribution were present among years, and changes to coverage was likely due to the surveys being conducted after the peak biomass of *Cladophora* had occurred in some years, as indicated by the shorter filaments and older condition of the observed *Cladophora*, commonly observed after filaments break off and are carried down-river. Flows are likely a major driver of primary producer biomass and composition, with both the timing and magnitude of winter flushing flows and the timing and magnitude of summer low-flow onset influencing the community composition, spatial distribution, and seasonal timing of primary producer assemblages in the Klamath River. Understanding the mechanism for how flows influence primary producer assemblages and cover will require additional analysis of nutrient dynamics, periods of scour, flow influence on herbivores, and the reproductive biology of individual taxa.

Further research documenting the spatial and temporal patterns of primary producer assemblages will help explain patterns of ecosystem scale productivity and water quality dynamics in the Klamath River. Documenting primary producer assemblages under a range of conditions prior to dam removal provides baseline data on conditions that exist on the Klamath River with dams in place, which are essential in comparing conditions following dam removal. Understanding the spatial and seasonal patterns in primary producer assemblages can also inform predictions about sediment dynamics associated with dam removal, while information about changes in assemblages associated with flows could provide management tools aimed at improving water quality and fisheries health in the Klamath River.

# 7 Acknowledgments

The data presented in this report was made possible with the help of many, who contributed to the study design, field data collection, and financial resources needed to carry out the field effort. Mary Power and Bob Hall helped with the data collection protocols, and M. Power also trained the report author in field-based algal identification. Major field work in 2021 and 2022 was performed by Kate Perkins. Additional field assistance by Leah Wessler, Adrienne Chenette, Chippie Kislik, Lanie Goldberg, Katie Guetz, Kaitlyn Woolling, Jessie Moravek, Jess Coming, Joanna Blaszczak, Richard Myers, Thomas Starkey-Owens, Hannah King, and Joshua Cahill made these surveys possible. The Klamath Tribal Water Quality Consortium provided financial support for data analysis and reporting. The Yurok Tribe Environmental Program and Karuk Department of Natural Resources provided additional field support. The University of Montana Bridges Program (Grant No. DGE-1633831) and Flathead Lake Biological Station supported the field surveys reported on here. Thanks to Jacob Kann and Eli Asarian for helpful comments on study design and for review of the report. Cover photo by Chippie Kislik.

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# Supplementary materials

## S1: Klamath River Vegetation Study Data Sheet

## Transect Meta-Data

| | | |
|---|---|---|
| Transect: _____ of _____ | Page: _____ of _____ | Date: _____/_____/_____<br>Time: ______:______ |
| Surveyors: | | Transect narrative: |
| Site: | River width (m): | |
| Pool Run Riffle | Bankside start: LB RB | |
| GPS LB: N W | RB: N W | |

## Quadrant Data

| Quad. # | (m) from start | Depth (m) | Velocity (m/s) | % fines (< 2mm) | % gravel (2-64mm) | % cobb (64-256) | % bould/ bedrock | Macrop % Cover | Fil. Alg. % Cover | Photo time | Notes |
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## Species-Specific Data

| Quad # | Sp. code | % Cover | Condition | Color | Substrate | Strand length (cm) | Sample ID | Notes |
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**Klamath River Aquatic Vegetation Study**

| Transect: _____ of _____ | Page: _____ of _____ | Date: _____/_____/_____ |
|---|---|---|
| Surveyors: | | Time: ______:______ |
| Site: | River width (m): / Max depth (m): | Bankside start: L R |

| Quad # | Sp. code | % Cover | Condition | Color | Substrate | Strand length (cm) | Sample ID | Notes |
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| Common Species | | New Species | |
|---|---|---|---|
| Name | Code | Name | Code |
| Cladophora sp. | CLAD | | |
| Oedogonia sp. | OEDO | | |
| Spirogyra sp. | SPIR | | |
| Ulothrix sp. | ULOT | | |
| Phormidium sp. | PHOR | Condition | |
| Anabaena sp. | ANAB | Description | Code |
| Gomphonemia sp. | GOMP | New growth, bright color, few epiphytes | 1 |
| Biofilm | BIOF | Plants material mostly whole, some-many epiphytes | 2 |
| | | Plant material breaking up and decomposing, heavy epiphytes | 3 |
| Elodia canadensis | ELCA | Plant material unidentifiable or only remnant | 4 |
| Potamogeton crispus | POCR | Color: record for all species, but is most relevant to CLAD | |
| Potamogeton pectinatus | POPE | Description | Code |
| Zannechellia palustris | ZAPA | Green, clean | GR |
| Ceratophyllum demersum | CEDE | Gold, epiphytized | GO |
| Potamogeton richardsonii | PORI | Rust, epiphytized | RU |

**Klamath River Aquatic Vegetation Study**