

Standardization and Initial Analysis of 1990-2013 Phytoplankton and Zooplankton Data for Upper Klamath Lake (Phase I)

Jacob Kann

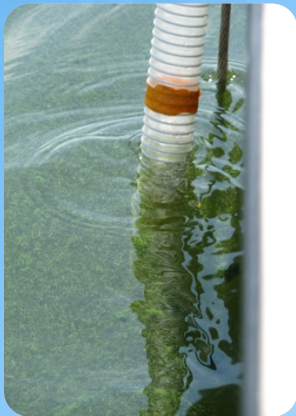
Aquatic Ecosystem Sciences, LLC.

J. Eli Asarian

Riverbend Sciences

Ann St. Amand

PhycoTech, Inc.



Prepared for:

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Jacob Kann

Aquatic Ecosystem Sciences, LLC.
295 East Main St., Suite 7
Ashland, OR 97520

J. Eli Asarian

Riverbend Sciences
Weaverville, CA

Ann St. Amand

PhycoTech, Inc.
Saint Joseph, MI

Prepared for:

Klamath Tribes Natural Resources Department

PO Box 436
Chiloquin, OR

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Photo credits for cover page (clockwise from upper-right):

A. Upper Klamath Lake, 8/12/2013 (J. Kann); B. *Microcystis* bloom in Agency Lake, 8/12/2013 (J. Kann); C. *Aphanizomenon* bloom near Eagle Ridge, 8/12/2013 (J. Kann); D. *Aphanizomenon* and integrated tube sampler, 8/12/2013 (J. Kann); E. Sampling using integrated tube sampler, 8/12/2013 (J. Kann).

EXECUTIVE SUMMARY

Given the importance of Upper Klamath and Agency Lakes in providing habitat for species of concern to the Klamath Tribes, as well as the algal bloom-driven water quality dynamics affecting those species, the Klamath Tribes initiated a long-term water quality monitoring program for the lake system in 1990. The collection of phytoplankton and zooplankton species composition, abundance, and biomass data was considered especially important due to the role of algal blooms in water quality degradation associated with the decline of native endangered fish populations.

Although there were several early efforts to analyze the phytoplankton/zooplankton data, and the databases have been annually maintained and updated, beginning in 1998 multiple laboratories were utilized to analyze the phytoplankton and zooplankton data. Due to inter-lab issues that were outlined during annual quality assurance reviews of the data, it became apparent that analysis of the long-term database would be hampered by a lack of standardization among the labs over the entire 1990-2013 period. Thus this report provides the first comprehensive standardization of the phytoplankton/zooplankton databases on which further analyses can be performed. In addition, an initial analysis of seasonal, inter-annual, and spatial trends is provided, including preliminary statistical trend analyses. These databases will provide the basis for Phase II of this effort which will include a more comprehensive analysis of both time-series trends and interaction with environmental variables using multivariate techniques.

Inter-lab issues encountered during the standardization effort included: different methods for calculating biomass (biovolume for phytoplankton and length/weight regressions for many of the zooplankton), different size classes used for zooplankton life stages, differing species identifications for both phytoplankton and zooplankton, differing counting units (e.g., enumeration of cells vs. algal units for some phytoplankton species), varying levels of taxonomic detail (aggregating to the genus level vs. species level), inconsistent assignment of species within a genus, outdated names and taxonomy updates, incorrect genus classification, and missing zooplankton biomass data.

Subsequent to careful review of the datasets that included reviewing archived slides, number of detections by each lab/year, calculated mean cell/organism size, review of previous standardization efforts and interlab QA samples, and evaluation of seasonality, we created four versions of the database (four each [one original and three standardized versions] for phytoplankton and zooplankton). These are:

- 1) “**original database**” version retaining the original data as reported by the laboratories (without any taxonomic standardization/renaming or re-calculation of biovolume) for archival purposes.
- 2) “**partially standardized database**” version that includes a consistent density and biovolume/biomass time series based on taxonomic updates to modern conventions (e.g., species that have been reassigned a new genus), standardized naming for apparently misidentified taxa, and corrects misspellings.
- 3) “**analysis database**” version that combines taxa to emphasize long-term comparability. For example, in genera such as *Fragilaria* where species level identification varied among labs, species were combined to the genus level. This is the version we recommend for data analyses.
- 4) “**supplemental analysis database**” version which is identical to the “analysis database” for most taxa but allows for a greater level of detail in a subset of years. For example, it includes picoplankton (only analyzed by PhycoTech during 2008-2013) as well as splitting taxa for three of the genera (*Fragilaria*, *Stephanodiscus*, and *Cymbella*) into respective

morphological sub-groups rather than combining to the genus level (genus level aggregation was necessary for evaluation of the entire time period).

Although these standardized databases now provide the basis for analysis of the full 1990-2013 period for all major taxonomic groups as well as dominant species (particularly for the most dominant species such as *Aphanizomenon flos-aquae* and *Daphnia pulicaria*), the complexity of issues in the timeframe and budget allocated necessitated that further refinement be moved into the Phase II effort. Following are further recommendations to standardize the phytoplankton and zooplankton databases

Phytoplankton Recommendations

- Additional evaluation and adjustments to further improve long-term comparability for less common taxa
- Resolve outstanding taxonomic issues, including confirming the presence of *Pseudanabaena rutilus-viridis*, a toxin-producing filamentous cyanobacteria that grows in the fascicles of *Aphanizomenon flos-aquae* (Kling et al. 2012). Kling confirmed the identification morphometrically in late fall 2014 material, but it needs to be confirmed genetically. Archival slides dating back to 2007 indicate that the taxa is the predominant *Pseudanabaena* species in the lake, and may be contributing to microcystin production.
- Further confirmation of the relative abundance of both Cyanobacteria and Chlorophyte picoplankton back to 2007.
- Further review of species where only algal units were enumerated and develop volume/cell density relationships.
- Evaluate and standardize biovolume calculations for genera such as *Rhodomonas* where different species identified over time were aggregated
- Evaluate and standardize chlorophyll-a due to a change in laboratory methods in 2008.
- Further filter the supplemental database to restrict time periods to only those species for which they are valid. In other words, if the valid time series for a particular species is 2008-2013, then do not include that species for the remaining years (see Section 3.3 for description of current usage for the supplemental database)

Zooplankton Recommendations

- Further evaluate mean weight and length-weight regressions. As discussed in sections 3.3.2 and 3.3.3 we applied standardization to zooplankton weights where warranted; however, additional evaluation and adjustments could further improve long-term comparability. For example we calculated average weights from each lab for each taxa (Table 9, Table 10), but only were able to provide detailed evaluation of the common taxa, and not the rare ones. Evaluation of the weights and application of adjustments for less common taxa (which we did not do due to time constraints), would improve the data but is not likely to affect overall trends.
- Further evaluation of among-lab length-weight regression differences and adjustment where necessary. For example, by modelling the effect of alternate length-weight regressions on predicted biomass within the PhycoTech dataset we were able to standardize biomass over the time period. Due to time constraints, we only applied that approach to taxa in the genus *Daphnia* (Figure 26 in section 3.3.2.2) but it would be beneficial to apply that same approach to other taxa where the labs also used different regressions equations, including but not limited to: Copepoda nauplii, the Calanoid Copepod *Epischura nevadensis*, Calanoid

copepodids, the Cyclopoid Copepod *Diacyclops thomasi*, Cyclopoid copepodids, Cladocera immature, and all taxa in the rotifer genera *Asplanchna*, *Keratella*, and *Synchaeta*.

- Further filter the supplemental database to restrict time periods to only those species for which they are valid. In other words, if the valid time series for a particular species is 2008-2013, then do not include that species for the remaining years (see Section 3.3 for description of current usage for the supplemental database).
- Further confirmation of adult copepod diversity and DNA analyses to refine identification of the small *Daphnia* species

Preliminary Data Analysis

Due to the considerable effort to standardize the database as described above (the initial complexity of standardizing the phytoplankton and zooplankton databases was far more than anticipated due to among-laboratory issues not initially foreseen), time and budgetary constraints limited the scope of the analysis in this Phase I report. Thus, the analysis provided here are considered preliminary, with the main goal to provide graphical depictions of seasonal, spatial, and inter-annual patterns that allow evaluation of database structure, and to form the basis for Phase II comprehensive analyses.

Notable observations include the elucidation of clear seasonal and inter-annual differences over the period of record, as well as differences between UKL and Agency Lake. For example, although exact timing varies from year to year the general phytoplankton pattern is for diatoms (*Asterionella formosa* was most abundant during February through May peaking in March and April, and *Aulacoseira sp.* and *Fragilaria sp.* peaked in May and June) to dominate during late-winter and early-spring before they are replaced by Cyanobacteria (primarily *Aphanizomenon flos-aquae*), which rise to reach a peak of near 100% biovolume generally by early July. *Aphanizomenon* biovolume then declines mid-summer, and in many years increases (but usually not to early summer levels) to reach another peak in August or September. Aside from diatoms and Cyanobacteria, other taxonomic groups which sometimes reach high percent biovolume are Cryptophytes (*Cryptomonas sp.* and *Rhodomonas sp.*), Chlorophytes, and Xanthophytes (*Tribonema sp.*).

The relative biovolume of Cyanophyta (*Aphanizomenon*) tends to begin earlier and decline earlier in Agency Lake and the relative biovolume of diatoms tends to be lower in the spring but higher in the fall in Agency Lake, with the relative proportion of diatoms and Cyanophytes showing an inverse pattern. Overall site differences were apparent, especially for the Pelican Bay site (PB) which is dominated by spring inflow and wetland plants and does not experience large Cyanophyte blooms. Another Cyanophyte, *Microcystis aeruginosa*, increases in prevalence in mid-summer, generally peaking in August, and was more prevalent in Agency Lake than in UKL.

During the years following dike breaching of the former wetlands between UKL and Agency Lake in 2007 and 2008, there was an apparent increase in the spring diatom bloom of *Asterionella*.

Mann-Kendall trend analyses indicate a potential long-term trend of increasing diatoms and decreasing cyanobacteria in the spring, which was particularly evident in Agency Lake, and the trend appeared to start in 2008. Trends suggest a delay in the timing of the onset and decline of the early summer *Aphanizomenon flos-aquae* bloom, and also included an increasing biovolume trend for some late-summer periods for *Microcystis aeruginosa*.

Other statistically significant trends of note include an apparent spring to early-summer decrease in *Cryptomonas*, *Rhodomonas*, and *Nitzschia*, and increases in both *Fragilaria* and *Asterionella*. In

addition, *Anabaena* sp. (group 2: potentially toxin producing forms) shows an increasing trend in early-summer.

Due both to a combination of high abundance and large size, Cladocerans (*Daphnia* spp.) comprised a larger percent of zooplankton biomass than any other taxonomic group. Abundance, percent abundance, biomass, and percent biomass of adult *Daphnia* and other Cladocerans (*Chydorus sphaericus*, *Leptadora kindtii*, and immature Cladocera) peaks in summer or early fall and is markedly lower in December through February than in other months. Abundance and biomass of adult Calanoid and Cyclopoid Copepods were higher in the spring (through June) than in the summer (June-September), and Rotifer abundance and biomass tended to be higher through August and lower in the fall (*Euchlanis* spp., *Keratella* spp., *Polyarthra dolichoptera*, and *Synchaeta* spp. reach high abundance with a peak in June or July but due to their small size they typically showed low percent biomass abundance and biomass). Calanoid copepods (composed of two taxa: *Leptodiptomus ashlandi* and *Epischura nevadensis*) showed higher abundance, percent abundance, biomass, and percent biomass than Calanoid copepods (primarily *Diacyclops thomasi*).

Some site differences in timing and magnitude were evident, where relative to UKL stations, Agency Lake (stations AN and AS) showed higher percent abundance and percent biomass of Calanoid Copepods later in the season, and overall lower percent abundance of adult Cladocerans. PB showed lower abundance, percent abundance, biomass, and percent biomass of adult Cladocerans and Calanoid copepods (both adults and copepodids), and lower biomass and percent biomass of Copepoda nauplii (as noted above, PB [only sampled through 2006] is dominated by spring inflow and wetland plants).

Notable Mann-Kendall trend tests for zooplankton taxonomic groups and major genera/species for lake-wide averages of UKL and Agency Lake included some spring increases of Copepods including Calanoid copepodids, Cyclopoid copepodids, Copepoda nauplii, *Epischura nevadensis* and *Diacyclops thomasi*. The only statistically significant ($p < 0.05$) trends for *Daphnia* spp. or total adult Cladocerans was increased abundance in Agency Lake for May 1-31. The Cladoceran *Chydorus sphaericus* showed decreasing abundance, percent abundance, biomass, and percent biomass during the spring in Agency Lake, and decreasing biomass and percent biomass during July 1-31 in UKL. The Rotifers *Euchlanis* spp. and *Asplanchna* spp. showed some spring declines in UKL but not Agency Lake. There were no statistically significant trends for total zooplankton.

The above seasonal, inter-annual, spatial, and trend patterns will be explored in further detail in Phase II, including additional seasonal trend testing (e.g., Mann-Kendall Trend Tests) and multivariate techniques (e.g., Non-metric Multidimensional Scaling, NMDS) to evaluate the effects of nutrients, climate, and other physical, chemical, and biological forcing factors on the observed seasonal, spatial, and inter-annual dynamics. A variety of techniques will be utilized, including the identification of natural groupings (e.g., cluster analysis), inter-site relationships defined by similarity coefficients, and NMDS to characterize spatial and seasonal variation in taxonomic groups and dominant species, as well as functional groups (e.g., nitrogen-fixers).

Follow-up Phase II analysis recommendations include:

- Evaluation of the effect of the missing four years (2000-2003) in the phytoplankton data due to inadequate preservation. Based on Helsel and Hirsch (2002), we assumed that a 4-year gap (17% of the 1990-2013 period) does not affect the results of the Mann-Kendall trend tests.
- Parse data into other year groupings for trend testing (e.g., 1990-1999; 2004-2013; 2008-2013).

- Compare seasonal Mann-Kendall trend tests to Regional Kendall tests (the Regional Kendall test is an expansion of the Seasonal M-K test applied to locations rather than seasons; Hirsch et al. 2006).
- Evaluate sensitivity to the minimum sample size used to compute the lake-wide means (differing frequency of stations sampled among years).
- Recompute trend analyses on a subset of stations that were consistently sampled among years (in some years fewer stations were sampled).
- Evaluate sensitivity of trends to differing inter-lab methodological resolution (e.g., a greater number of algal units were counted per sample in 2008-2013 than in 2004-2007, and differences in taxa specific measurement techniques).
- Evaluate the sensitivity of functional groups to lake-wide changes in water quality.

Further recommendations for refined standardization and analyses notwithstanding, the Phase I effort provides the first long-term comprehensive databases for both phytoplankton and zooplankton in Upper Klamath Lake. These databases are especially robust for dominant species, as well as groupings of species (consisting of lumping to the generic level or higher), and form the basis for further detailed multivariate and trend analyses to be undertaken in Phase II.

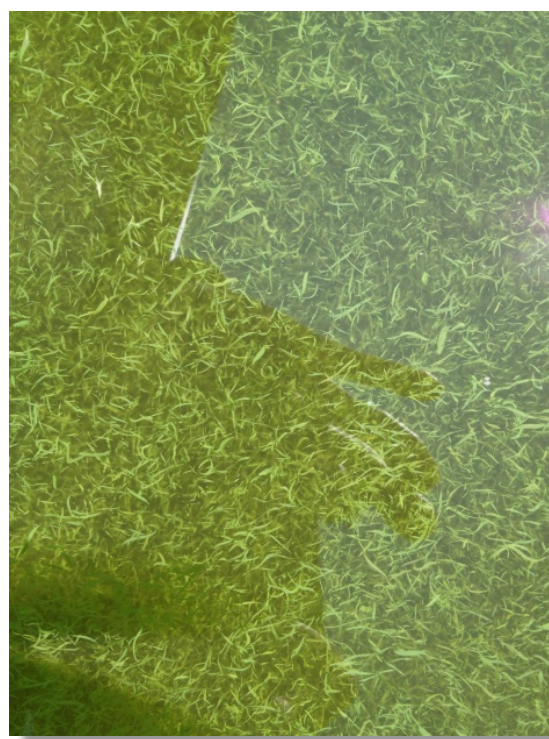
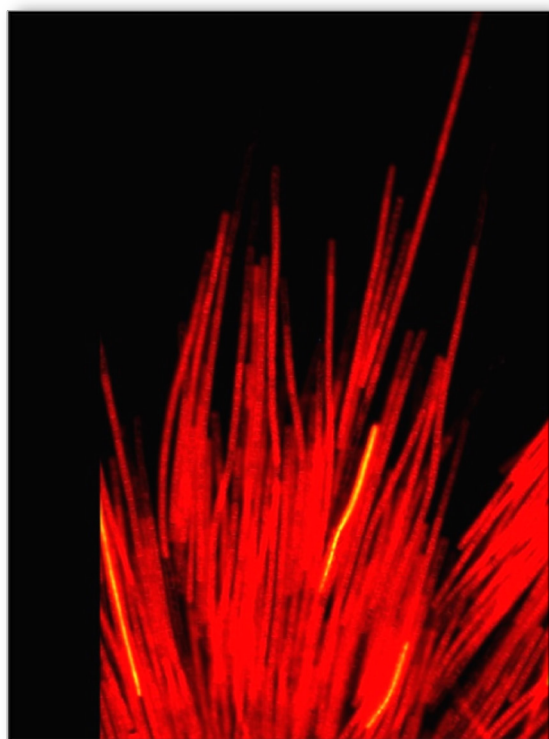
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1 INTRODUCTION

1.1 DESCRIPTION OF STUDY AREA

Upper Klamath and Agency Lakes, Oregon are a large (264 sq. km), shallow (mean depth=2.5 m) lake system located in the uppermost portion of the Klamath River Basin (Figure 1). The lake system serves as a focal point of the entire Klamath River Basin due to its function as the receiving body of water for the ~3800 sq. mi. upper watershed area, and as the headwaters for the Klamath River proper. As such, it provides important in-lake habitat for endangered Lost River and shortnose suckers and other endemic species, as well as provides flow to downstream salmonid populations on the Klamath River.

Although natural in origin, streamflow patterns into and out of Upper Klamath Lake have been altered by irrigation and hydroelectric power diversions, irrigation returns, agricultural activities such as grazing, wetland and riparian loss, deforestation, and by the construction of the Link River Dam at the lake outlet. Unlike typical dams which increase water level and storage, the Link River Dam permits greater control over storage by allowing higher lake elevations to be maintained longer into the early summer period, and allows lake levels to be lowered below pre-dam natural elevations¹.

1.1.1 ROLE OF ALGAL BLOOMS AND WATER QUALITY

The lake system is hypereutrophic and is seasonally dominated by large blooms of the nitrogen-fixing cyanobacterium *Aphanizomenon flos-aquae* (Kann 1998; Kann and Smith 1999). Paleolimnological evidence indicates that *Aphanizomenon flos-aquae* (as indicated by *Aphanizomenon flos-aquae* akinetes preserved in lake sediments) did not appear in UKL until the latter part of the 19th century and increased substantially after that time (Bradbury et al., 2004; Eilers et al. 2004). These studies as well as a more recent coring study showed increases in various indicators (e.g. Ti, Al, tephra, and charcoal) of watershed erosional inputs to UKL in the 20th century, increases in the sediment accumulation rate, sediment enrichment in upper layers of both nitrogen (N) and phosphorus (P), and a decrease in the ratio of N to P in the upper sediment layers (likely due to an increase in P loading relative to N loading in the 20th century) (Bradbury et al. 2004; Eilers et al. 2004; Simon and Ingle 2011). Based on exceedances of water quality standards for dissolved oxygen, pH, and chlorophyll (algal biomass), both lakes were designated as water quality limited for resident fish and aquatic life (ODEQ 1998) and a TMDL requiring watershed phosphorus reduction was subsequently completed in 2002 (ODEQ 2002).

Bloom-driven water quality degradation that includes extended periods of low dissolved oxygen, elevated pH, and toxic levels of un-ionized ammonia has been associated with the decline of native endangered fish populations, including the Federally Listed shortnose (*Chasmistes brevirostris*) and Lost River (*Deltistes luxatus*) suckers (Perkins et al. 2000; Kann and Welch 2005; Wood et al. 2006; Banish et al. 2009). Numerous studies have documented that recurring algal blooms and their decline (Figure 2) are associated with periods of elevated pH, toxic levels of un-ionized ammonia, and depressed dissolved oxygen concentrations (Kann and Smith 1999; Perkins et al. 2000; Loftus 2001; ODEQ 2002; Kann and Welch 2005; Wood et al. 2006; Hoilman et al. 2008; Lindenberg et al 2009; Kannarr et al. 2010; Jassby and Kann 2010; Kann 2011; Kann 2012). In addition, secondary blooms of toxic *Microcystis* can also impair lake water quality in the lakes (Eldridge et al. 2013).

¹ Channels were cut into a basalt sill that acted as a natural dam at the lakes outlet allowing lowering of the lake and use of additional water volume to supply irrigation water to USBR Klamath Project farmland

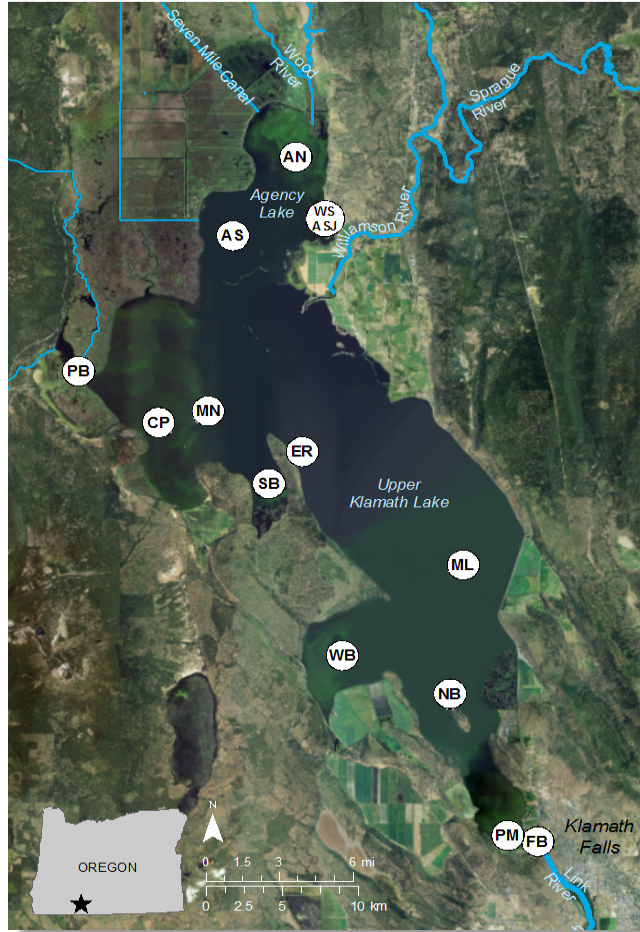


Figure 1. Location of Upper Klamath and Agency Lakes. Oregon. Labelled symbols are the Klamath Tribes water quality and phytoplankton/zooplankton sampling sites. Aerial photo source: 2009 U.S. Department of Agriculture’s National Agriculture Imagery Program.



Figure 2. Satellite photo of Upper Klamath Lake showing typical summer lake-wide blooms of *Aphanizomenon flos-aquae*. Source: 6/17/2001 NASA Earth Observatory <http://earthobservatory.nasa.gov/IOTD/view.php?id=1743>. Inset AFA bloom photo credit: Jacob Kann.

1.1.2 RECENT CHANGES TO THE LAKE SYSTEM

In response to the need to restore watershed function to support phosphorus reduction and fish habitat, numerous restoration projects have been implemented since the late 1990's, including wetland restoration of several large drained wetlands on the periphery of Upper Klamath and Agency Lakes (Figure 3). Several such wetlands are no longer grazed or farmed, and are in varying stages of restoration (e.g. Wong et al., 2011; USBLM, 2005; Carpenter et al., 2009; Duff et al., 2011). One such restoration activity included dike breaching and re-flooding of wetland areas near the Williamson River delta, an area where wetlands had been historically diked, drained, and then converted to farmland/pastureland in the 1940s. In this area, large-scale restoration occurred with the breaching of levees surrounding the western half of the Delta (known as Tulana) in October of 2007 (flooding about 3,500 acres), and another 2000 acres were flooded when dikes were breached on the eastern half of the Delta (known as Goose Bay) in November 2008 (Hayden and Hendrixson 2013).

One aspect of this restoration is a change in connectivity between Agency Lake and Upper Klamath Lake, where although historically they were connected by wetlands, the dikes caused flow of water between the two lakes to be restricted to the narrows (Figure 3). Especially with subsidence and the presence of open-water areas in the restored delta, wind-driven movement of water and circulation patterns between the lakes underwent a substantial change after 2008 (Wood et al. 2014).



Figure 3. Wetland restoration activities on the Williamson River Delta allowing for greater connectivity between Agency Lake and Upper Klamath Lake.

1.2 BACKGROUND

Given the importance of Upper Klamath and Agency Lakes in providing habitat for species of concern to the Klamath Tribes², as well as the algal bloom-driven water quality dynamics affecting those species (described above), the Klamath Tribes initiated a long-term water quality monitoring program for the lake system in 1990. These data include a variety of water quality parameters (e.g., nutrients, chlorophyll, light, and physical parameters such as dissolved oxygen, temperature, and pH) collected throughout the lake system (Figure 1) and have been described and summarized to varying degrees in a series of reports and manuscripts (e.g., Kann 1998; Kann and Smith 1999; Kann and Welch 2005; Jassby and Kann 2010; Kann 2014; Eldridge et al. 2014).

Due to the role of algal blooms in water quality degradation associated with the decline of native endangered fish populations, the Klamath Tribes also collected phytoplankton and zooplankton species composition, abundance, and biomass data concomitantly with water quality data as part of the long-term monitoring program (Figure 1). The primary goal in collecting such data was to relate the seasonal and inter-annual phytoplankton dynamics to their controlling factors (e.g., nutrients and light, etc.) and ultimately to fish health in the UKL lake system. In addition, zooplankton are important for their role as algal grazers and as food for various fish species in UKL. To date, much of the research relating algal blooms to water quality dynamics has primarily relied on chlorophyll-a as a surrogate for algal biomass (e.g., Kann and Smith 1999), and the phytoplankton/zooplankton data have been analyzed only to a limited extent.

Initial phytoplankton/zooplankton data analyses depicting inter-annual differences and seasonal succession patterns are contained in Kann (1993a) and Kann (1993b) for Agency Lake for the years 1990-1992. Further analyses of the 1990-1996 dataset are contained in Kann (1998) and Pan (2005), and Milligan (2009) analyzed phytoplankton data from 2005 and 2006. Although the databases have been maintained and updated since the initial 1990-1996 analyses, beginning in 1998 multiple laboratories were utilized to analyze the phytoplankton and zooplankton data (see full description below)³. Thus, analysis of the full long-term database has been hampered by a lack of standardization among the labs over the entire 1990-2013 period.

Inter-lab issues that became apparent during annual quality assurance review of the data were listed in the “Summary of Issues” and “Metadata” tabs of the electronic Excel databases⁴ that were provided annually. However, resolution of these issues requires a comprehensive standardization effort and review of all data in concert with an expert taxonomist. To prevent bias introduced by varying inter-lab methods such a standardization effort is essential prior to any analyses of the full 1990-2013 databases.

Thus the major objective of this Phase I report is to provide the first comprehensive standardized databases on which further analyses can be performed. These databases will be used in Phase II of this effort for testing of various hypotheses, including those relating to both time-series trends and interaction with environmental variables using multivariate techniques.

² Endangered Lost River and shortnose suckers and redband rainbow trout are important subsistence and cultural species for the Klamath Tribes

³ The 1990-1996 samples were all analyzed by a single laboratory (Aqua I.D.) as were the 2005-2006 samples (Aquatic Analysts) so are not affected by lack of standardization among the labs.

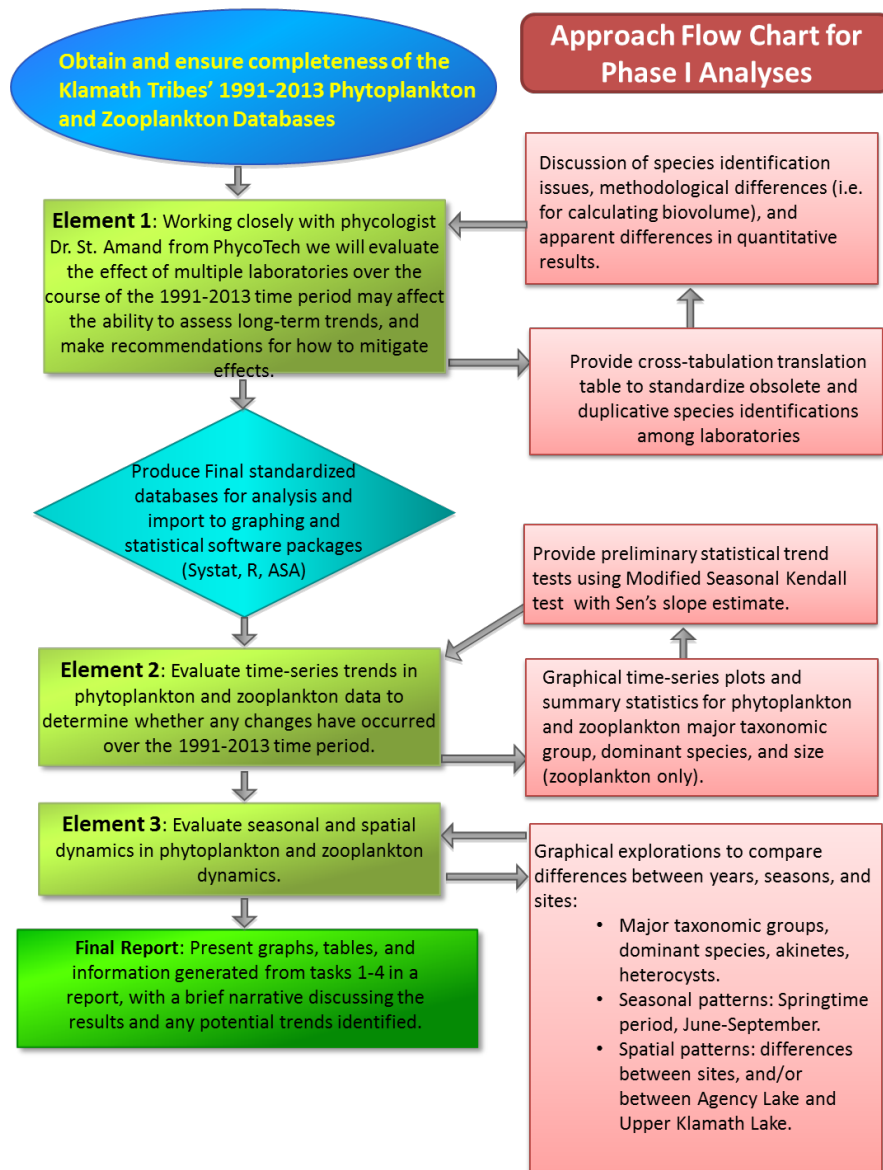
⁴ Klamath_Tribes_ukl_phytoplankton_1990_2013_final_20140503.xlsx and Klamath_Tribes_ukl_zoop_1990_2011_final_20120926.xls

1.3 STUDY GOALS

The primary study goals were to:

1. Provide phytoplankton and zooplankton databases standardized to remove inter-lab differences for species identification and biovolume/biomass over the 1990-2013 period of record, and evaluate how the use of different laboratories (4 for phytoplankton and 3 for zooplankton) over the course of the 1990-2013 period may affect the ability to assess long-term trends.
2. Provide preliminary evaluation of 1990-2013 time-series trends in Upper Klamath Lake planktonic communities using both graphical and statistical time-series analyses, and
3. Provide preliminary analysis of seasonal and spatial dynamics in phytoplankton and zooplankton dynamics.

The following flow-chart depicts the approach utilized for accomplishing the above study goals:



2 METHODS

2.1 PLANKTON AND CHLOROPHYLL-A SAMPLING METHODS

2.1.1 PHYTOPLANKTON AND CHLOROPHYLL-A

Beginning in 1990 the Klamath Tribes began collecting samples for phytoplankton species composition, density and biovolume at several standard and ancillary stations (Figure 1; Table 1). Samples were collected approximately biweekly during the May-October period, and intermittently during other months (Figure 4). As outlined in Kann (1998) and the Klamath Tribes SOP for Upper Klamath Lake Surface Water Field Sampling (Klamath Tribes 2013), a depth-integrated water sample of the entire water column was taken concomitantly with the water quality profiles⁵. This was accomplished by combining a minimum of three replicate hauls from an integrated water column sampler (tube sampler) from each sampling station into a churn splitter (Figure 5). This composite sample was then mixed and portioned off to appropriate collection bottles for the analysis of phytoplankton, chlorophyll *a* (Chl), and phaeophytin. Nutrients (total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate+nitrite nitrogen (NO₃-N+NO₂-N), ammonia nitrogen (NH₄-N), and total nitrogen (TN) were also analyzed for the same integrated water column sample, but are not discussed here. Phytoplankton samples were collected in opaque polyethylene bottles and preserved with Acid-Lugol's solution (APHA 1985) to obtain a final preservation concentration of 1% (1 ml Lugol's/100 ml's of sample).

2.1.2 ZOOPLANKTON

Similar to phytoplankton, in 1990 the Klamath Tribes began collecting samples for zooplankton species composition, density and biomass at several standard and ancillary stations (Figure 1; Table 1; Figure 4). As outlined in Kann (1998) crustacean zooplankton and rotifers were sampled at each location through 2002 using a 12 L Schindler-Patalas trap with 64 mm mesh (Figure 6). Beginning in 2003 a 30 L Schindler-Patalas trap with 64 mm mesh was used (Klamath Tribes 2013). A depth-integrated sample was obtained by taking one sample from between the surface to 1 m depth interval (target depth 0.5 m), one from between the 1 m above bottom to bottom interval (target depth 0.5 m off-bottom), and then combining the two samples for a total of 24 L filtered (60 L in 2003). The exception to this was the deeper Eagle Ridge site (ER) where a third collection was made from the midpoint of the water column (approximately 3 m) for a total of 36 L filtered (90 L in 2003), but only through 2003⁶. Due to very shallow nature of Upper Klamath and Agency Lakes (mean depth = ~2.4 m), the collection method provided a representative water column sample. Zooplankton samples were narcotized with carbonated water⁷ prior to preservation in an ethanol-glycerin solution (Pennak 1989).

⁵ Because of UKL's shallow nature it is polymictic and only undergoes weak and intermittent stratification or water column stability.

⁶ Beginning in 2004 the integrating protocol at ER was similar to other stations.

⁷ CO₂ in the carbonated water serves as a narcotizing agent so that individual zooplanktons are less likely to expel eggs when preserved.

Table 1. Site characteristics of phytoplankton and zooplankton sampling sites in Upper Klamath Lake.

Station	Site ID Code	Site Description	Site Type	Latitude	Longitude
FB	KL0001	Fremont Bridge	Open water	42.238550	-121.805770
PM	KL0002	Pelican Marina	Open water	42.241560	-121.823410
NB	KL0003	North Buck Island	Open water	42.308230	-121.857330
WB	KL0004	Wocus Bay	Embayment	42.326230	-121.921080
ML	KL0005	Mid Lake	Open water	42.368920	-121.849800
ER	KL0006	Eagle Ridge	Open water	42.421920	-121.944390
SB	KL0007	Shoalwater Bay	Embayment	42.407090	-121.964200
MN	KL0008	Mid North	Open water	42.441200	-121.999950
CP	KL0009	Coon Point	Open water	42.435560	-122.029300
PB	--	Pelican Bay	Embayment	42.459883	-122.076367
AS	KL0010	Agency South	Open water	42.523420	-121.985390
AN	KL0011	Agency North	Open water	42.560390	-121.948550
ASJ	--	Agency Jake's	Shoreline	42.531429	-121.931075
WS	--	Weather Station	Shoreline	42.531429	-121.931075

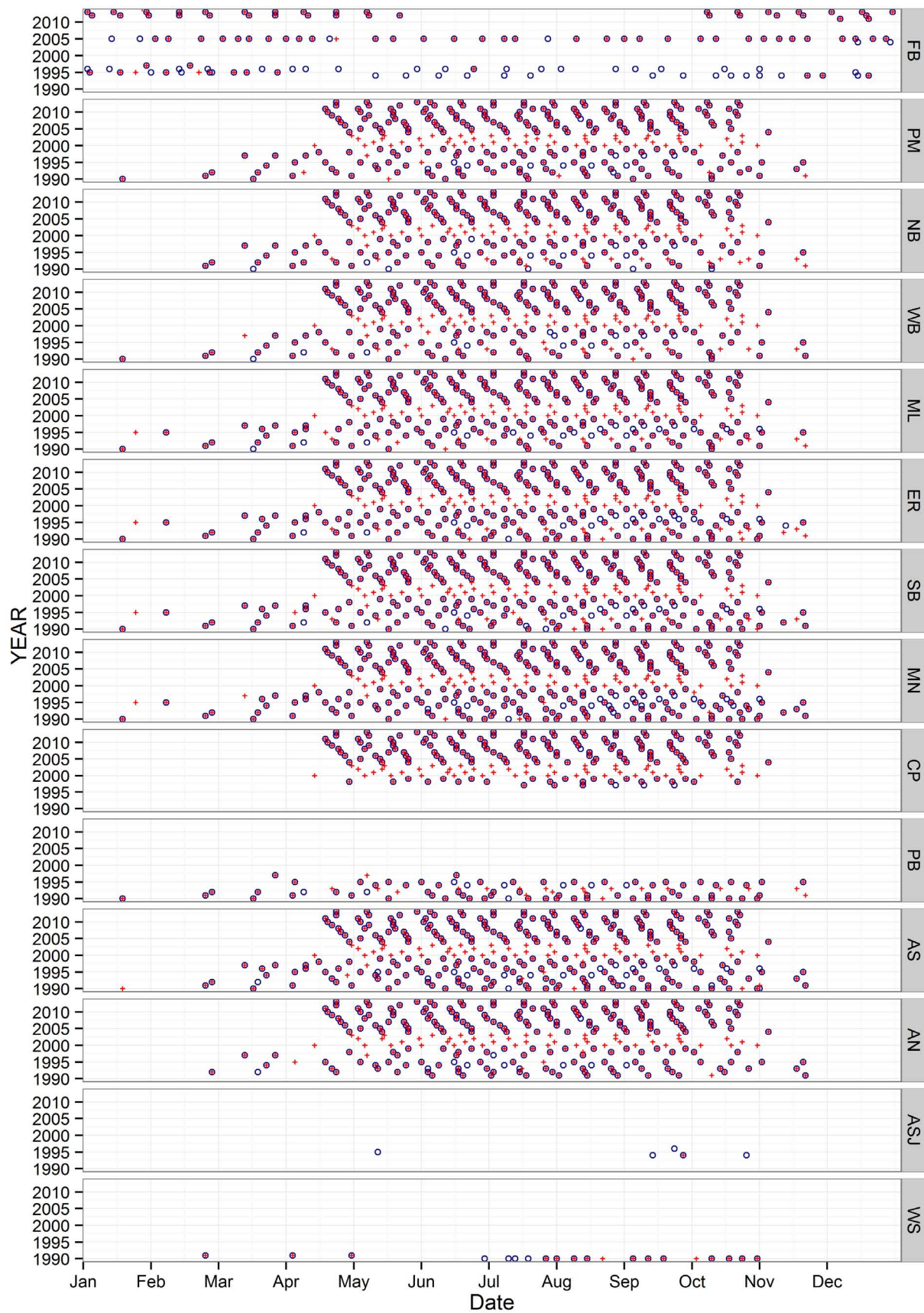


Figure 4. Dates and sites of phytoplankton (blue circles) and zooplankton (red crosses) samples in Upper Klamath Lake, 1990-2013.



Figure 5. Klamath Tribes field crew obtaining phytoplankton samples in Upper Klamath Lake using an integrated water column sampler (tube sampler).



Figure 6. Klamath Tribes field crew obtaining zooplankton samples in Upper Klamath Lake using a Schindler-Patalas plankton trap.

2.2 QUALITY ASSURANCE

Starting in 2005, all sampling trips included at least one duplicate sample with a minimum of 10% duplicate samples collected. Phytoplankton duplicates were obtained from the churn splitter and zooplankton duplicates were obtained using a Folsom Plankton Splitter as outlined in the Klamath Tribes (2013) SOP. These were analyzed with respect to their relative percent difference to determine laboratory reproducibility. In addition, in the years 2005-2007 for phytoplankton only, a second set of duplicate samples were shipped to PhycoTech (the first set was sent to Aquatic Analysts) for interlab comparison of species identification and enumeration. These inter-lab samples were further used to guide database standardization of species identification and biovolume. Graphs and tables summarizing the QA analysis are included in Electronic Appendices 1 and 2.

2.3 BIOLOGICAL LABORATORY ANALYSES

2.3.1 PHYTOPLANKTON

Samples were analyzed by four different taxonomic labs over the 1990-2013 period: 1990-1997 Aqua I.D. (Falls Church, VA—not currently in operation), 1998-1999 BSA Environmental (Beachwood, OH), 2004-2007 Aquatic Analysts (moved during study period from White Salmon, WA to Milwaukie, OR—currently in Friday Harbor, WA), 2008-2013 PhycoTech (St. Joseph, MI). In addition, 2005-2007 interlab QA samples were analyzed by PhycoTech (St. Joseph, MI). A four year gap in the time-series exists in 2000-2003 when under-preservation with Lugol's Iodine resulted in degraded samples by the time they were received by the laboratory.

2.3.1.1 AQUA I.D.

Aqua I.D. utilized the Utermöhl method where algal species abundance was determined using the inverted microscope/settling chamber technique (Utermöhl 1958, Lund et al 1958, APHA 1989, Rott 1981, Willen 1976). Depending on algal density, from 5-50 ml were settled for a minimum of 1.0 hr per cm of chamber height. After settling, the slide was scanned at 100x and 320x magnification to ensure random distribution of organisms. Enough cells were then counted in haphazardly chosen fields until the standard error as a percent of the mean was 10% for dominant species. Cell volume was then determined by measuring cell (or colony for a few species, see below) dimensions of 10 individuals per species in each sample (generally 6-10 samples per date), and averaging among the samples to obtain an average size per species per date. Volumetric equations for shapes most resembling species form were used to determine total cell volume (e.g., Willen 1976). The total biovolume of each species was then computed as cell abundance (individuals L⁻¹) multiplied by average individual volume (μm³). Final biovolume estimates are reported as mm³ L⁻¹, which approximates wet weight biomass in mg L⁻¹. Due to high variability in flake size of *Aphanizomenon flos-aquae*, all counts and volume measurements were made on individual cells within a filament (flakes tended to break apart into filaments during preservation and transport). Heterocysts and akinetes were enumerated separately.

Aqua I.D. reported a few species as colony density rather than cell density. The most common of these species was *Microcystis aeruginosa*; the others were *Coelosphaerium naegelianum*⁸, *Coelosphaerium kuetzingianum*, *Gloeotrichia echinulata*, and *Gomphosphaeria lacustris*.

2.3.1.2 BSA ENVIRONMENTAL

Similar to Aqua I.D. cell numbers of all identified phytoplankton taxa were quantified on a per milliliter basis using the Utermöhl method (Lund et al. 1958). The abundance of common taxa was estimated by random field counts. Rarer taxa were quantified by scanning a strip of the Utermöhl chamber. Counts were performed on a Wilovert inverted microscope equipped with phase-contrast at a magnification of 400x. Recently viable cells were included in the analyses as determined by the respective physiological characteristics of eukaryotes (the presence of chloroplasts and other organelles) and prokaryotes (pigmented cells). At least 400 natural units (colonies, filaments, unicells) were enumerated from each sample. For samples with common colonies or filaments, the counts likely included several thousand cells since total cell numbers of multi-cell units (colonies, filaments) would be quantified

In colonies with extremely small cells (e.g., *Microcystis*), cells were enumerated from a small representative area of the colony containing at least 100 cells. For common filamentous taxa, the total cells per filament were determined by first quantifying the cell number within a known length (e.g., 100 μ m). This process was repeated for 25 filaments of each abundant filamentous taxon, and subsequently used to calculate the mean number of cells per filament length for that taxon. This quantity was applied to measurements of the length and width of each filament encountered so that the total number of cells per filament was estimated.

Cell biovolumes of all identified phytoplankton taxa were estimated on a per milliliter basis using formulae for solid geometric shapes that most closely match the cell shape (Burkholder and Wetzel 1989). Sub-aliquots were examined at 400x under phase contrast with a Wilovert inverted microscope. Cells were settled for at least 20 hours in darkness within an enclosure protected from vibration and temperature alteration (Burkholder and Wetzel 1989). Homogeneity in settling was ensured to determine the minimum number of fields necessary to obtain consistency in enumerating abundant taxa (>5% of the total biovolume) per unit chamber area.

For taxa with substantial size variation (such as diatoms), size classes were designated arbitrarily to determine average cell size (biovolume). For each taxon, 25 cells were measured from each size class (assuming that sufficient numbers were available). Mean biovolumes within each size class were used to calculate the total biovolume contributed by the taxon to its representative sample (Burkholder and Wetzel 1989).

2.3.1.3 AQUATIC ANALYSTS

Aquatic Analysts used a filtration method where semi-permanent microscope slides were prepared from each sample by filtering an appropriate aliquot of the sample through a 0.45 micrometer membrane filter (APHA Standard Methods 1992, 10200.D.2; McNabb 1960). A section was cut out and placed on a glass slide with immersion oil added to make the filter

⁸There have been recent changes to taxonomic naming conventions, but for clarification, the historical names used in the standardized databases will be used in this report (e.g., the commonly accepted revision or *Coelosphaerium* is *Woronichinia*: http://www.algaebase.org/search/species/detail/?species_id=30038)

transparent, followed by placing a cover slip on top, with nail polish applied to the periphery for permanency.

Algal natural units (defined as discrete particles – either cells, colonies, or filaments) were identified and counted along a measured transect of the microscope slide with a Zeiss standard microscope (1000X, phase contrast). Only those algae that were believed to be alive at the time of collection (i.e., chloroplasts intact) were identified and counted. A minimum of 100 algal units were identified and counted in each sample (Standard Methods: APHA 1992, 10200.F.2.c.).

For colonial species the number of cells was estimated during microscopic sample analysis by calculating the average number of cells in a subset of algal units (filaments or colonies) and multiplying the average cells/unit by the total number of units. Average biovolume estimates of each species were obtained from historic calculations of microscopic measurements of each alga⁹. Average biovolumes for algae were stored in a lookup table (Appendix A), and biovolume was calculated by multiplying the number of cells by the average biovolume per cell from the table.

2.3.1.4 PHYCOTECH

PhycoTech used a HPMA permanent mounting method for preparing algal samples for counting (Crumpton 1987, St. Amand 1990). The HPMA method for producing algal sample slides provided an optically clear background while permanently infiltrating and preserving the sample for archival purposes; three slides are made for each sample. Samples were filtered using a Millipore 6 place stainless steel manifold and Millipore 25 mL glass towers with glass frits. Sample volume was measured using Eppendorf and Fisher micro- and macro-pipetors. The slide archive is retained at PhycoTech's facilities. Counts were completed on an Olympus BX51, research-grade compound microscope equipped with Brightfield optics (40x, 100x, 200x, 400x, 1000x), Nomarski optics (100x, 200x, 400x, and 1000x), Phase Optics (200x, 400x, 1000x), a 1.25-2X multiplier, epifluorescence (blue, green and UV Excitation), and a trinocular head for photography, with a SpotFlex digital camera attached. Counts were completed according to standard methods, Part 10200 where a minimum of 400 natural units (NU, colonies, filaments, unicells) and 15 fields at 500x (when possible, maximum of 100 fields) were tallied (APHA 1989, 2012). Based on a Poisson Distribution, 400 NU provides data within 10% of 95% confidence intervals. Data were reported as both Natural Units/mL and Cells/mL. Units for biovolume were reported as $\mu\text{m}^3/\text{mL}$. In addition, taxa were counted above 20-30 μm in Greatest Axial Linear Dimensions (GALD) at 300x (minimum of 15 fields). Fields were spread evenly over the three slides provided for each sample (i.e. 30 total fields, 10 fields per slide). Counting was completed when the standard error of the mean of the total number of natural units per field was less than 10%. For large taxa (200+ μm), an entire whole slide was scanned at 125x. This tiered counting method generally yielded a minimum of 400 natural units per sample. Extremely sparse samples or samples with high particulates yielded less than 400 natural units, but this was a rare circumstance. Identifications were made using an extended key list and primary literature (full list in Appendix M, also available at http://www.phycotech.com/All_Keys_03012008.pdf)

⁹ Aquatic Analysts maintains a database of average biovolume measurements for individual algal species that were measured previously from a variety of lakes in the Northwestern United States. Although not UKL specific, these average values were applied to UKL species enumeration data.

Measuring for biovolume includes measuring GALD and additional measurements including length, width and depth of different aspects of the colony and/or cell. PhycoTech's LIMS, ASA, allows up to 28 separate measurements per taxa. Cell and colony shapes are approximated to a geometric figure and or figures and the appropriate calculations made. Currently, ASA has over 44 different shapes defined. From 10 up to a total of 30 natural units (sometimes higher on exceptionally variable taxa) are measured for each taxa depending on variability and number encountered. Some taxa received a standard measurement if they distort on preservation or are difficult to measure because of small size. Geometric figures were approximated according to several standard references: Bergquist 1985, Olrik et al. 1998, Hillebrand et al. 1999, and St. Amand 1990. Taxa were measured for each sample, and were not averaged per date or season. Samples are enumerated within ASA System directly. ASA System is a database driven program with an integrated virtual TallyMeter module. Up to 400 taxa can be enumerated within any one sample, and the entire database currently contains over 34,000 taxa. All calculations are completed within ASA System, including concentrations, biovolumes, summary statistics and diversity indices.

2.3.2 ZOOPLANKTON

Over the 1990-2013 period, three different labs analyzed samples: 1990-2003: BSA Environmental (Beachwood, OH), 2004: University of Washington (Seattle, WA), 2005-2013: PhycoTech (St. Joseph, MI).

2.3.2.1 BSA ENVIRONMENTAL

Individual species abundance was determined from the depth-integrated sample at each site and date. Measurements of individual species were made on a site-composited sample for each date, and dry weight biomass conversions were made according to Dumont et al. (1975), McCauley (1984), Culver et al. (1985), and Lawrence et al. (1987).

Specifically, the volume of each sample concentrate was measured and three 1-ml aliquots were examined at 100x on a Wilovert inverted microscope equipped with phase contrast. If the total tally was less than 200, additional aliquots up to a maximum of 20ml were examined. Taxonomic identification followed Ruttner- Kolisko (1974), Edmundson (1959), and Pennak (1989). Biomass estimates were based on established length/width relationships (Dumont et al. 1975; McCauley 1984; Lawrence et al. 1987).

The lengths or the lengths and widths of each species encountered were measured from a composite sample formed by pooling approximately 5ml from each sample for that date. The number of specimens examined was equal to 10 for common species and lesser for more rare taxa. For Cladocerans, the length was measured from the tip of the head to the end of the body (shell spines excluded). For copepods, the length was determined from the tip of the head to the insertion of the caudal ramus. The length of rotifers was measured from the tip of the head to the end of the body (spines, toes, etc. excluded). In accordance with McCauley (1984), biomass was computed for the appropriate number of individuals for each sample location and the arithmetic mean biomass was multiplied times the species abundance to produce a species biomass for each sample.

2.3.2.2 UNIVERSITY OF WASHINGTON

During 2004 UKL zooplankton samples were processed at the Laboratory of Dr. Michael T. Brett at the University of Washington (UW) using the following methodology:

The UW lab counted at least 600 individual crustacean zooplankters in each sample, including all rare taxa for the entire sample. If the sample contained less than 600 individuals, the whole sample was counted. Once the count for any specific taxa exceeded 300 individuals, that taxa specific count was truncated and expanded using a ratio between the number of individuals counted when truncated and the other individuals counted for the entire sample. For example, if by the time approximately 1/4 of the volume of the sample was counted; 311, 106, 35 and 85 *Bosmina*, *Cyclops*, *Daphnia*, and *Diaptomus*, respectively, have been counted, and 390, 151, 315 *Cyclops*, *Daphnia* and *Diaptomids*, respectively, are counted for the entire sample, then the number of *Bosmina* will be calculated as $311 \times (856/226) = 1178$. All common crustacean taxa in these samples were identified to species.

Estimates of average individual size for each common taxa on each sampling date were made for estimates of population and community biomass. This was done by measuring the length of the first 8 individuals observed for each common taxa in each sample. For the common taxa *Daphnia pulicaria*, *Daphnia schodleri*, *Leptodiaptomus ashlandi*, *Epischura nevadensis*, *Chydorus sphaericus*, and *Diacyclops thomasi*, biomass estimates were based on established length/width relationships (Dumont et al. 1975; McCauley 1984; Lawrence et al. 1987). For remaining taxa (rotifers, copepodids, and nauplii) an average weight per individual calculated from the previous 1990-2003 BSA database was applied to abundance estimates. Mass estimates for the eggs of each of the common taxa were also obtained. Population biomass is calculated as the abundance (per liter) for that taxa multiplied by its date-specific average mass. Zooplankton community abundance is determined as the sum of the individual population masses.

2.3.2.3 PHYCOTECH

PhycoTech used a HPMa permanent mounting method for preparing zooplankton samples for counting (Crumpton 1987, St. Amand 1990). The HPMa method for producing zooplankton sample slides provided an optically clear background while permanently infiltrating and preserving the sample for archival purposes; one slide was made for each sample. Samples were filtered onto 47 mm filters using a Millipore 3 place stainless steel manifold and Millipore 150 mL glass towers with stainless steel frits. Sample volume was measured using Eppendorf and Fisher macro-pipetors. The slide archive is retained at PhycoTech's facilities. Counts were completed on an Olympus BX51, research-grade compound microscope equipped with Brightfield optics (40x, 100x, 200x, 400x, 1000x), Nomarski optics (100x, 200x, 400x, and 1000x), Phase Optics (200x, 400x, 1000x), a 1.25-2X multiplier, epifluorescence (blue, green and UV Excitation), and a trinocular head for photography, with a SpotFlex digital camera attached. Counts were completed according to standard methods, Part 10200 where a minimum of 200 animals and 15 fields at 125x (when possible, maximum of 100 fields) were tallied (APHA 1989, 2012). Data were reported as animals/mL. Units for biomass were reported as mg/L. Counting was completed when the standard error of the mean of the total number of natural units per field was less than 10%. Extremely sparse samples or samples with high particulates yielded less than 100 animals.

Taxonomic identification followed Ruttner-Kolisko (1974), Edmundson (1959), Pennak (1989), and Dumont et al. (various dates: *Guides to the identification of the Microinvertebrates of the Continental Waters of the World*). Biomass estimates were based on established length/width relationships (Dumont et al. 1975, McCauley 1984, Lawrence et al. 1987). A full list of keys is available in Appendix M and at http://www.phycotech.com/All_Keys_03012008.pdf. For

Cladocerans, the length was measured from the tip of the head to the end of the body (shell spines excluded). For copepods, the length was determined from the tip of the head to the insertion of the caudal ramus. The length of rotifers was measured from the tip of the head to the end of the body (spines, toes, etc. excluded). In accordance with McCauley (1984), biomass was computed for the appropriate number of individuals for each sample location and the arithmetic mean biomass was multiplied times the species abundance to produce a species biomass for each sample.

Measuring for biomass includes measuring animal length and additional measurements including width and depth per taxa, if needed. Rotifer biomass was estimated by approximating to a geometric figure, assuming a density of 1, and converting to wet weight. Dry was estimated as 0.1*wet weight. Currently, ASA has over 44 different shapes defined. Approximately 10 animals were measured (sometimes higher on exceptionally variable taxa) or number encountered. Length:Weight regressions came from the primary literature and are stored in the ASA database. Geometric figures were approximated according to several standard references: Bergquist (1985), Olrik et al. (1998), Hillebrand et al. (1999), and St. Amand (1990). Taxa were measured for each sample, and were not averaged per date or season. Samples are enumerated within ASA System directly. ASA System is a database driven program with an integrated virtual TallyMeter module. Up to 400 taxa can be enumerated within any one sample, and the entire database currently contains over 34,000 taxa. Fecundity was noted for all species encountered up to 10-15 individuals. Fecundity (and sex in copepods) was noted in the Measurement Notes variable¹⁰. In copepods, males are noted by “000.” All calculations are completed within ASA System, including concentrations, biomasses, summary statistics and diversity indices.

2.3.3 CHLOROPHYLL-A

Between 1990 and 2008 water samples for chlorophyll and phaeophytin analysis, preserved in the field with MgCO₃, were shipped to Aquatic Research Inc. Laboratory in Seattle, WA following collection. Chlorophyll-*a* and phaeophytin were determined spectrophotometrically following APHA (1985) standard methods SM18-10200H. The supporting reference for this method is Nusch (1980). Between 2009 and 2013 chlorophyll-*a* and phaeophytin were analyzed fluorometrically at the Klamath Tribes Sprague River Water Quality Lab (SRWQL) using EPA Method-445.0-modified (<http://www.caslab.com/EPA-Methods/PDF/EPA-Method-445.pdf#page=3>)¹¹.

2.4 STANDARDIZATION OF PHYTOPLANKTON AND ZOOPLANKTON DATA

Given high species diversity and continuously evolving taxonomy, as well as differing laboratory methods and levels of taxonomic precision (i.e., some taxonomists may have lumped a taxa to the genus level, whereas others split that same taxa into multiple species or varieties), we conducted a rigorous taxonomic standardization process prior to starting our ecological analysis and assessment of time-series trends. In addition, for phytoplankton, the laboratories used

¹⁰ Fecundity data is not analyzed as part of this initial analysis but will be included in future work as time allows.

¹¹This method change resulted in somewhat higher chlorophyll-*a* concentrations reported after 2008, which is a likely reason for increasing trends in chlorophyll-*a* concentration observed between years 2005–2010 (Eldridge et al. 2014). Comprehensive standardization is required prior to further trend testing for chlorophyll-*a*.

different methods for enumeration and biovolume which also required standardization. Details on this process are included in the Results and Discussion section below.

2.5 DATA ANALYSIS

2.5.1 GRAPHICAL

Graphical time-series analyses for individual taxa were used to screen for taxonomic and biomass anomalies over the 1990-2013 period. Similar analyses were conducted previously (see Electronic Appendices 1 and 2) and provided the basis for the initial standardization contained in those databases. The final taxonomic standardization contained herein (see details below) is based on additional long-term time series graphics that allowed further evaluation of apparent abrupt changes coinciding with the transition between laboratories.

The secondary intent of the Phase I analysis is to provide preliminary analyses of seasonal, spatial and long-term phytoplankton and zooplankton dynamics. A variety of seasonal, spatial, and time-series graphs were created and are included in the report for that purpose. However, the rigorous and time-consuming effort required for database standardization precluded in-depth interpretation of these graphs in the Phase I report, and thus in-depth interpretation, in conjunction with multivariate statistical techniques, is deferred to the Phase II effort.

2.5.2 CALCULATION OF LAKE-WIDE AVERAGES

In addition to evaluating site-specific data, we also calculated lake-wide means for a subset of metrics (i.e., taxonomic groups and dominant genera/species). Lake-wide means for UKL (stations CP, ER, ML, MN, NB, PM, SB, and WB) and Agency lakes (stations AN and AS) were calculated separately¹². The stations ASJ, FB, PB, and WS were not utilized in the lake-wide average because they were not consistently sampled. On a few occasions, some stations were sampled on a day preceding or following remaining stations. In such cases, the dates were standardized so that adjacent sample dates were included in the lake-wide mean¹³. The minimum number of stations used to calculate lake-wide averages was two at UKL and one at Agency Lake¹⁴.

Similar to chlorophyll and nutrient data, algal biovolume and zooplankton biomass data tended to be either normally or log-normally distributed both within a date and seasonally. Based on a comparison of both log transformed ($\log_{10}(x+1)$) and non-transformed data with the normal distribution using the Shapiro-Wilk standard test for normality (*cf.* Systat[®] 2004), the geometric mean tended to provide the best estimate of lake-wide or seasonal central tendency. Prior to calculation of geometric means, zero values were adjusted by adding the minimum non-zero value for a species.

Following the approach of Warton and Hui (2011) for proportion data, the logit transformation defined as $\log(y/[1-y])$ was used for percent biovolume data. Percent values were initially

¹² Previous analyses comparing Agency Lake and Upper Klamath Lake for chlorophyll-a and other water quality parameters show that these parameters are subject to differing timing and magnitude between the lakes (e.g., Kann 2014).

¹³ AN, AS, MN, PM from 8/13/1992 changed to 8/12/1992 and CP and AN on 9/27/2005 changed to 9/26/2005.

¹⁴ Sensitivity to the minimum sample size will be further evaluated in Phase II.

divided by 100 to obtain proportions, zero values were adjusted¹⁵ to the minimum non-zero value for a species, and values of 1 (which occurred only for *Aphanizomenon flos-aquae* and its taxonomic division Cyanophyta) were adjusted by the minimum non-zero value of (1-y). Subsequent to zero and one adjustments, all values were logit-transformed to improve normality prior to calculation of arithmetic means, which were then back-transformed using an antilogit function and multiplied by 100 to get back to original units (0 to 100%).

Following calculation of daily lake-wide means, seasonal means were calculated for each month April through October (except April 1-14 was excluded due to inconsistent sampling) and seasonal periods (April 15-May 30, June 1-September 30, June 1-July 15, and April 15-October 31) as the arithmetic mean of all dates within the period.

2.5.3 EVALUATION OF LONG-TERM TRENDS

Long-term trends in some metrics (i.e., taxonomic groups and dominant genera/species) of zooplankton and phytoplankton were evaluated using the nonparametric Mann–Kendall test for monotonic trend (Helsel and Hirsch 2002). A *p*-value of 0.05 was used as the threshold for statistical significance, but *p*-values of 0.10 are also reported. The Mann-Kendall test does not rely on assumptions of normality of residuals, constant variance and linearity (Helsel and Hirsch 2002). Tests were performed in R 3.1.2 (R Core Team 2014) using the WQ package (Jassby and Cloern 2012).

3 RESULTS AND DISCUSSION

3.1 STANDARDIZATION OF PHYTOPLANKTON DATA

Several versions of the phytoplankton database were prepared, each with its own intended use. This section (3.1) briefly summarizes their contents and the following sections (3.1.1 to 3.1.2) provide details on how they were generated.

The “**original database**” version retains the original data as reported by the laboratories (without any taxonomic standardization/renaming or re-calculation of biovolume) for archival purposes.

A second version titled “**partially standardized database**” includes: 1) a consistent cell density time series; 2) a consistent time series of standardized biovolume; 3) taxonomic updates to modern conventions (e.g., species that have been reassigned a new genus), applies a standardized name to taxa that were apparently misidentified (generally on a one-to-one basis such that multiple taxa were generally not combined in the “partially standardized database”), and corrects misspellings; and 4) the species *Marsionella elegans* was deleted, because it does not

¹⁵ Sample proportions equal to 0 and 1 transform to undefined values using the logit transformation. Thus, after Warton and Hui (2011) a small value ϵ (epsilon) was added to the numerator and denominator of the logit transform, i.e., $\log(y + \epsilon / 1 - y + \epsilon)$. The smallest non-zero proportion (or if counts were equal to one, the minimum non-zero value of 1-y) was used for ϵ .

appear to be a valid algal taxa (it may have been confused with *Marssoniella elegans*, but this is listed as microsporidia (fungi) by AlgaeBase¹⁶ and it was only identified 11 times by Aqua ID).

The third version, titled “**analysis database**” combined taxa to emphasize long-term comparability. For example, in genera such as *Fragilaria* where species level identification varied among labs, species were combined to the genus level. In addition, picoplankton were not included because those taxa were identified only by PhycoTech due to that lab’s use of a higher-powered microscope and different counting procedure, which allowed them to identify and count extremely small species that the other labs did not include. This is the version we recommend for data analyses

A fourth version titled “**supplemental analysis database**” was also prepared which is identical to the “analysis database” for most taxa but includes picoplankton as well as splitting taxa for three of the genera (*Fragilaria*, *Stephanodiscus*, and *Cymbella*) into respective morphological sub-groups rather than combining at the genus level. The picoplanktonic time series is valid only for the samples analyzed by PhycoTech (2008-2013) and the time series of *Fragilaria*, *Stephanodiscus*, and *Cymbella* subgroups is valid for the 2004-2013 samples analyzed by Aquatic Analysts and PhycoTech. In addition it includes the inter-lab duplicate samples from 2005-2007).

3.1.1 TAXONOMIC STANDARDIZATION

3.1.1.1 PROCESSES AND TOOLS USED FOR STANDARDIZATION

The taxonomic standardization protocol included utilization of the following steps and resources:

1. Review archived slides and consult taxonomic keys to confirm PhycoTech’s taxa identification

Because PhycoTech taxa identifications were based on current taxonomic revisions¹⁷, included the type of higher resolution microscopy necessary to evaluate identifying taxonomic features, and included cross-laboratory comparisons with the laboratories involved in this analysis, as well as participation in an international QA/QC exercise (EQAT), the PhycoTech identifications formed the basis for the 1990-2013 taxa standardization process. PhycoTech’s microscope included enhancements not consistently available with the other analysts (Nomarski, Reflected Light and Blue and Green light, and Excitation Epifluorescence). The PhycoTech samples were used to determine a list of the most common taxa, which was then cross-referenced with the other labs to ascertain similarities and differences among taxa identifications. Because PhycoTech had archived all of the UKL samples it had analyzed, Dr. St. Amand was able to review previous slides to confirm identification and compare similar species. Example photomicrographs are shown in Figure 7. Identifications were made using an extended key list and primary literature (full list in Appendix B, also available at http://www.phycotech.com/All_Keys_03012008.pdf).

¹⁶ Guiry, M.D. & Guiry, G.M. 2015. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <http://www.algaebase.org>; searched on 3/16/2015.

¹⁷ Analysis of many of the samples by AID and BSA occurred over 15 years ago (and as long ago as 25 years) and were based on older taxonomic authorities, and AA continued to use older nomenclature even after updates occurred (for example the genus *Melosira* continued to be reported subsequent to the change to *Aulacoseira* –see below).

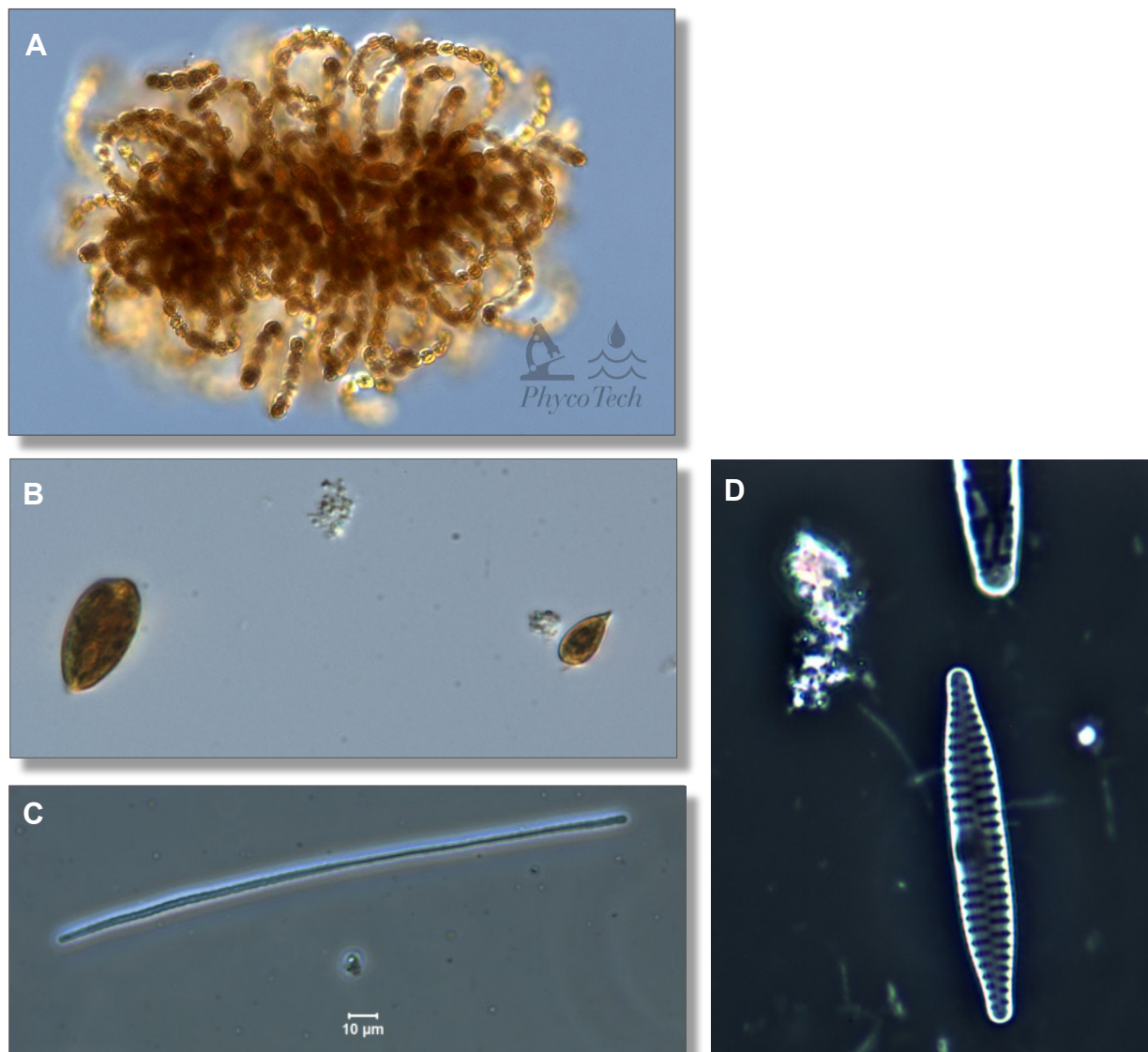


Figure 7. Photomicrographs of (A) *Anabaena lemmermannii*, (B) *Cryptomonas* sp. and *Rhodomonas minuta*, (C) *Pseudanabaena rutilus-viridis*, and (D) *Fragilaria capucina* (combination of all *F. capucina* varieties). Images are from PhycoTech.

2. Count detections by each lab/year

A summary table was created showing the number of detections of each taxa for each year and lab (Appendix A, also see simplified example in Table 2). This table was then reviewed to find cases where a taxa was consistently (i.e., all or most years) detected by a lab, but then was not detected by other labs. For example, the labs identified three taxa with the genera *Chroomonas* and *Rhodomonas*: *Rhodomonas minuta* (Figure 7b) was found by all labs in all years, *Chroomonas* sp. was found many times each year by AID (1990-1997) and then occasionally by PT in 2010 in 2013, but never by BSA (1997-1999) or AA (2004-2007), and *Rhodomonas minuta nannoplanctica* was only found by PT (each year 2005-2013) (Table 2). Thus it was evident that AID and PT split these three taxa to a more detailed level while BSA and AA

lumped them into a single taxa. Thus, for standardized analysis over the 1990-2013 period, we renamed all three as *Rhodomonas minuta* and merged them in our analysis database. All three taxa are in the same size range, are morphometrically very similar and overlap ecologically (differences in how pyrenoid is split and nature of the caudal extension are difficult to discern in preserved material).

Table 2. Summary of species standardization for species in the genera *Rhodomonas* and *Chroomonas*.

Species Name				Cell Size (um ³)				Detections Per Lab and Year																										
Analysis	Partially Standardized Database	Cell Size	Original	Std	AA lookup	AID calc	BSA calc	PT calc	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013		
																																	Rhodomonas minuta	Chroomonas sp
Rhodomonas minuta nanoplantica			34			34																	13	21	38	126	134	142	162	176	173	15		
Rhodomonas minuta			93	20	115	80	94	80	120	113	47	109	110	63	78	6	123	86	130	196	122	146	9	9	14	52	48	48	103	73	107			

3. Calculated average cell size

We calculated cell size for each sample and species by dividing biovolume by cell density. Then we calculated mean and median for each species and each lab (Appendix A, also see simplified example in Table 2). Aquatic Analysts provided cells sizes as a lookup table. Examining these cell sizes provided insight into each lab’s taxa identifications (i.e., we could use cell size to infer what PhycoTech taxa a previous lab might have misidentified).

4. Reviewed previous taxonomic standardization efforts

Project phycologist Dr. St. Amand has previously conducted several taxonomic standardization and QA/QC efforts, including efforts which involved all of the same labs analyzing Klamath Lake algal and zooplankton samples from 1990-2007. This includes St. Amand’s participation in an international QA effort (External Quality Assessment Trials¹⁸ [EQAT]) in 2013 where she passed the phytoplankton identification portion of the exam at 97%. Therefore, she was able to apply specific knowledge about individual taxonomist identification trends towards harmonizing these databases. All taxonomists use a preferred identification scheme and having prior knowledge of each taxonomist greatly helped to align all the taxa encountered by the different labs.

5. UKL interlab QA samples

In 2005-2007, 47 inter-lab QA samples were processed by both PhycoTech and Aquatic Analysts. The results of these samples are presented in Electronic Appendix 1. For example, comparing the dominant species in these samples helped resolve some issues such as which taxa to include in the “miscellaneous microflagellate” standardized taxa. In samples where AA had

¹⁸ <http://www.planktonforum.eu/index.php?id=2&L=1>

counted a high biovolume of “Unidentified flagellate”, PT typically found high biovolume of *Chromulina* sp, *Monomastix astigmata*, and/or *Monomastix minuta*, and AA’s *Mougeotia* spp. appeared to match PT’s *Tribonema* spp. (Table 3). *Mougeotia* and *Tribonema* are in different divisions (Chlorophyta and Xanthophyta, respectively), but the divisions are closely related morphometrically, and both genera have a similar growth form (filamentous), cell size, and coloration. Additional explanation of *Mougeotia* and *Tribonema* is included in section 0 below.

Table 3. Results from a subset of the 2005-2007 inter-lab duplicate samples showing detections and percent biovolume of (A) Taxa standardized to *Tribonema* spp.: *Mougeotia* spp. reported by Aquatic Analysts compared with *Tribonema* spp. reported by PhycoTech.; and (B) Taxa standardized to Miscellaneous microflagellate: Unidentified flagellate and *Chromulina* spp. reported by Aquatic Analysts compared with *Monomastix astigmata*, *Monomastix minuta*, and *Monomastix* spp. reported by PhycoTech. A total of 47 inter-lab samples were collected, but to focus on the identification of the taxa mentioned in the previous sentence, this table only shows those samples where the one of the species of interest comprised $\geq 5\%$ of the reported biovolume. Key to lab abbreviations: AA = Aquatic Analysts, PT = PhycoTech.

Station	Date	Lab	Reported % Biovolume		Reported % Biovolume			
			(A)		(B)			
			Taxa standardized to <i>Tribonema</i> spp.		Taxa standardized to Miscellaneous microflagellate			
		<i>Mougeotia</i> spp.	<i>Tribonema</i> spp.	Unident. flagellate	<i>Chromulina</i> spp.	<i>Monomastix minuta</i>	<i>Monomastix astigmata</i>	
MN	6/7/2006	AA PT	10.3	19.7				
AN	5/10/2006	AA PT	11.7	19.2				
AS	5/10/2006	AA PT	18.4	59.9				
ER	5/24/2006	AA PT	47.9	61.9				
WB	5/24/2006	AA PT	25.8	73.1				
FB	12/13/2005	AA PT		6.7		8.77	15.22	0.02
NB	5/3/2005	AA PT	32.7		0.17	28.59	6.18	
FB	12/7/2005	AA PT				10.18	12.43	
FB	12/21/2005	AA PT				27.75	15.74	0.39
FB	12/27/2005	AA PT				7.73	21.17	

6. Graphical evaluation of seasonality

We constructed and reviewed graphs showing relative and absolute density and biovolume to evaluate in which months a taxa was prevalent.

3.1.1.2 ISSUES ADDRESSED DURING STANDARDIZATION PROCESS

During the standardization process, we encountered and addressed an array of issues.

1. *Aphanizomenon flos-aquae*

Fortunately, all labs properly identified *Aphanizomenon flos-aquae*, which is the most dominant species in UKL.

2. Varying levels of taxonomic detail

The labs varied in their lumping and splitting of taxa. Some identified a taxa to genus, some to species, and some to variety/sub-species). PhycoTech generally identified taxa to a greater level of detail than the other labs, as demonstrated by the total number of taxa identified by each lab: AID 94, BSA 134, Aquatic Analysts 153, and PhycoTech 291.

3. Inconsistent assignment of species within a genus

The genus *Stephanodiscus* provides an example of inconsistent assignment of species within a genus (Table 4). Because *Stephanodiscus niagarae* was identified by all labs and is much larger than the other identified UKL species in the genus, we were able to keep it separate for analysis. However, six additional *Stephanodiscus* species were identified (For example see Figure 8), such that for consistency over the time period species were lumped to the genus level for our primary analysis, and for the “supplemental analysis” we grouped them into two separate taxa based on size classes (*Stephanodiscus minutulus* species group [$\leq 8 \mu\text{m}$] and *Stephanodiscus* Medium species group [$> 8 \mu\text{m}$]).

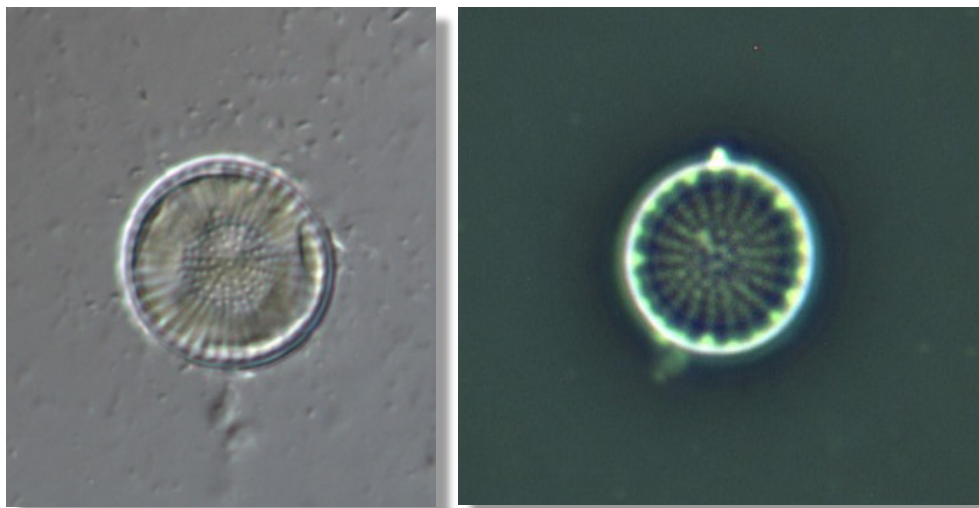


Figure 8. *Stephanodiscus medius* and *S. parvus*, both of which are $\leq 8 \mu\text{m}$.

Table 4. Summary of species standardization for species in the genus *Stephanodiscus*.

Species Name					Cell Size (um ³)				Detections Per Lab-Year																							
Analysis	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc med	BSA calc med	PT calc med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013
Stephanodiscus minutulus	168																					1	7	5								
Stephanodiscus minutula	168																								16	20	10	27	36	63		
Stephanodiscus Medium species group (> 8 um)	Stephanodiscus hantzschii	Stephanodiscus parvus	149	181	85	201																		3	4	39	26	28	54	21	5	
		Stephanodiscus hantzschii	920	120	381	994	679	38	58	62	21	64	64	64	33	34	6	67	56	15	16	21	5	1	1	3	6	6	6	21	25	
	Stephanodiscus medius	1096			679																		2	9	6	19	15	6	58	26	25	
Stephanodiscus niagarae	Stephanodiscus niagarae	179743	8000	157100	153	201062	28	4	1	2	2	2	3	5	55	35	7	4	19	10	4	8	13	27	18	10	7	2				

In addition, the Cyanophyte genus *Anabaena* was standardized into two taxa, *Anabaena spp.* and *Anabaena sp. Group 2*. The Group 2 combines all flexous potentially toxin producing *Anabaena* species that consistently bloom or produce toxins in other systems (e.g. *A. lemmermannii* [Figure 7a], *A. flos-aquae*, *A. circinalis*, and *A. spiroides*) while *Anabaena spp.* contains the remainder of the species which are rare in Klamath Lake and sporadic or non-toxin producers (e.g. *A. macrospora* and *A. augustmalis*).

Table 5. Summary of species standardization for species in the genus *Anabaena*.

Species Name				Cell Size (um ³)				Detections Per Lab-Year																								
Analysis	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc	BSA calc	PT calc	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013
Anabaena aphanizomenoides	Anabaena aphanizomenoides	69				63																		1			1					
Anabaena augustmalis	Anabaena augustmalis	39				42																				2	1	1				
Anabaena macrospora	Anabaena macrospora	68				106																								3		
Anabaena sp. Group 2	Anabaena lemmermannii	Anabaena flos-aquae	58	67	64	2		14	15	12	12	12	13	6	10		22	36	10	41	24	43										
		Anabaena lemmermannii	58				65																		2	6	10	3	1	4	3	19
	Anabaena circinalis	Anabaena circinalis	95				96											1	2							1	1			8	4	
		Anabaena spiroides	95				4												1													
	Anabaena crassa	Anabaena crassa	363																							1				1		
	Anabaena mendotae	Anabaena mendotae	61				66																					33	37	26	23	10

For many other genera for which there were no consistently distinguished taxa, we aggregated them to the genus level for analysis. Examples include the diatom genera *Fragilaria* (Figure 7d), *Navicula*, *Nitzschia*, and *Synedra* and the Chlorophyte genus *Scenedesmus*, all of which had greater than ten species each.

4. Outdated names and taxonomy updates

Phytoplankton taxonomy is constantly evolving. We have updated almost all taxa to current names. For example, the genus *Ankistrodesmus* is now *Monoraphidium*, *Melosira* is now *Aulacoseira*, *Elakatothrix* is now *Quadrigula*, and *Coelosphaerium* is now *Woronichinia*. Two exceptions to maintain consistency were that we have not updated the genus *Anabaena* to its new name (*Dolichospermum*) which changed only relatively recently (Wacklin et al. 2009) and is not yet in wide use. *Anabaena* is of particular interest due to its potential to produce cyanotoxins, although to our knowledge anatoxin has not been detected in UKL or Agency Lake. *Fragilaria* was also maintained due to the complexity of the generic splits given each species sporadic occurrence (*Fragilaria*, *Stauroseira*, *Pseudostauroseira*, *Stauroforma*, *Pseudostaurosiropsis*, *Punctastriata*, and *Staurosirella*).

5. Incorrect genus classification

In some cases, the labs assigned taxa names into the incorrect genus. An examples of this is AID identifying *Chroomonas* sp. in 1990-1997 (not detected by any other labs), which we have standardized to *Rhodomonas minuta* (Table 2). Another example is AID identifying *Oscillatoria* sp. and *Oscillatoria geminata* in 1990-1997, which we have standardized to *Pseudanabaena* sp. in part due to cell size. *Oscillatoria* was rarely identified by PhycoTech in UKL and when present was much larger (cell size 23 μm^3 for *Oscillatoria amphibia* and 158 μm^3 for *Oscillatoria* sp.) than the 3-4 μm^3 reported by AID).

6. Uncertain identifications at the generic level required standardization to higher taxonomic levels

Our standardized taxa *Trebouxiophyceae* sp. (a class in the division Chlorophyta) is an aggregation of seven taxa reported by the labs: Unidentified green alga (AID and AA), *Chlorella* sp. (AA), *Deasonia gigantea* (PT), *Stichococcus bacillaris* (PT), and three size classes of taxa in the family Chlorococcaceae (Appendix A).

In another example, seven taxa were identified in the Pyrrhophyta genera *Gymnodinium*, *Glenodinium*, *Hemidinium*, and *Peridinium*. Due to uncertain identification among labs and difficulties with these taxa and preservation, we combined these into a standardized taxa called *Glenodinium/Peridinium/Gymnodinium* (Appendix A).

7. Incorrect/uncertain division

In some cases, multiple taxa (especially small flagellates less than 4 μm) were combined into a larger group due to inconsistent laboratory counting efforts and differences among taxonomists in recognizing and counting these small cells. For example, our standardized taxa miscellaneous microflagellate is composed of seven taxa: the Chrysophytes *Chromulina* sp. and *Ochromonas* sp. (AA and PT); the Chlorophytes *Monomastix astigmata*, *Monomastix minuta*, and *Monomastix* sp. (PT); and two taxa of unknown division, Unidentified Flagellate (AID, BSA, and AA) and

miscellaneous microflagellate (PT) (Table 6). As noted above, the 2005-2007 inter-lab duplicate samples were helpful in resolving the issues with these taxa.

Another issue that affected a much larger taxa group was the combination of the Xanthophyte *Tribonema* sp (PT), the diatom *Melosira granulata angustissima* (AID and AA), and the Chlorophyte *Mougeotia* sp (AA) which were all standardized to *Tribonema* sp (Table 7), because despite being in different genera, they can be confused due to visually similar characteristics (filamentous, golden color) and are overlapping in the same size class. PT counted and verified at a higher magnification than other labs, facilitating an accurate identification of *Tribonema*. As noted above, the 2005-2007 inter-lab duplicates assisted in determining that AA's *Mougeotia* was actually *Tribonema*. *Mougeotia* sp. identified by AID and PT were retained as *Mougeotia* sp. and not combined with *Tribonema* sp.

8. Picoplankton too small to be identified by labs prior to PhycoTech

PhycoTech's use of a higher-powered microscope with additional enhancement allowed enumeration and identification of picoplankton (i.e., very small single cells) that were not included by previous laboratories. Most picoplankton taxa were in the family Chroococcaceae in the division Cyanophyta, with the most abundant being *Synechococcus elongatus* and two unidentified taxa within the genus *Synechocystis*. The remaining picoplankton taxa were *Synechococcus leopoliensis* and a taxa only identified to family level (Chroococcaceae). To maintain comparability across the entire 1990-2013 dataset, these species were excluded from the "analysis database", but were retained in the "original database", "partially standardized database", and "supplemental analysis database."

Although these species typically comprise only a very small percent of total biovolume in UKL samples, they can be a substantial portion of the natural unit density and cell density. In addition, picoplankton are important both as a food source for zooplankton (all taxa filter the picoplankton, even large daphnids), and are very important in nutrient cycling within the water column due to their rapid growth rates and short doubling times.

Table 6. Summary of species standardization for species in the genera *Chromulina*, *Monomastix*, and *Ochromonas* as well as the taxa unidentified flagellate and miscellaneous microflagellate.

Species Name		Cell Size (um ³)				Detections Per Lab-Year																										
						Std	AA lookup	AID calc	BSA calc	PT calc	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011
miscellaneous microflagellate	Chromulina sp	Chromulina sp	15	20														118	175	105	98											
	Monomastix astigmata	Monomastix astigmata	10																			9	2									
	Monomastix minuta	Monomastix minuta	12																				16	4								
	Monomastix sp	Monomastix sp	113																				33	16								
miscellaneous microflagellate	Unident. flagellate	Unident. flagellate	40	20	38	33	19	15	50	17	50	22	12	41		5		57	73	47	37											
	miscellaneous microflagellate	miscellaneous microflagellate	40																				8	13								
Ochromonas sp	Ochromonas sp	120	85		106																											

Table 7. Summary of species standardization for species in the genera *Tribonema*, *Mougeotia*, *Melosira*, and *Aulacoseira*.

Species Name				Cell Size (um ³)				Detections Per Lab and Year																											
Analysis	Partially Standardized Database	Cell Size	Original	Strnd	AA lookup	AID calc	BSA calc	PT calc	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013			
Mougeotia sp			Mougeotia sp	3016		242480	3016	2						1												1									
Tribonema sp	Tribonema sp		Mougeotia sp	624	624	177												3																	
	Tribonema sp		Tribonema affine	624	624													14	3																
	Tribonema sp	Tribonema subtilissimum	Tribonema subtilissimum	624	671																					3									
	Tribonema sp		Tribonema sp	624	624																					3									
	Tribonema sp		Melosira granulata angustissima	624	250	655			32	43	25	19	48	25	3	9						2	2												
Melosira varians	Melosira varians		Melosira varians	9982	650		9425														3		6	6			2	1	4	1	1	1	10		
Aulacoseira sp	Aulacoseira canadensis		Aulacoseira canadensis	402																															
	Aulacoseira distans		Aulacoseira distans	1357			1357																				1								
	Aulacoseira sp		Melosira distans alpigena	1357	175																														
	Aulacoseira sp		Melosira islandica	1072	1072																														
	Aulacoseira sp		Melosira sp.	873	500																														
	Aulacoseira granulata		Aulacoseira granulata	873	873																														
	Aulacoseira granulata		Melosira granulata	550	8467				9	7	3	5	3	8	1	3																			
	Aulacoseira granulata		Melosira granulata	873	873																														
	Aulacoseira ambigua		Aulacoseira ambigua	1072	922																														
	Aulacoseira ambigua		Melosira ambigua	589																															

3.1.1.3 FINAL LIST OF STANDARDIZED TAXA

Table 8. Final list of taxa in the “analysis database,” sorted by division. “n taxa” is the number of taxa lumped. * signifies that a lab processed only a small portion of the totals samples in a year.

Division	Species Name	n taxa	Number of Detections Per Lab and Year																							
			Aqua ID							BSA			Aquatic Analysts				PhycoTech									
			1990	1991	1992	1993	1994	1995	1996	1997	1997*	1998	1999	2004	2005	2006	2007	2005*	2006*	2007*	2008	2009	2010	2011	2012	2013
Total number of samples→			130	136	129	56	138	177	95	113	8	129	107	131	220	134	168	15	30	48	142	168	167	172	195	198
Chlorophyta	Actinastrum hantzschii	1			4	2	12	4							1			1	1			16	1			
Chlorophyta	Botryococcus braunii	2									2							1					1	5	2	
Chlorophyta	Characium sp.	3									3							2		3	1	1	5			
Chlorophyta	Chlamydomonas sp	2	35	49	71	23	80	45	21	27	3	44	55	28	18	32	30	4	6	12	60	68	87	102	116	180
Chlorophyta	Chlorogonium sp	2																2	1	1	2	17				
Chlorophyta	Chloromonas sp	2																					1	1	1	
Chlorophyta	Cladophora sp	1																							1	
Chlorophyta	Closterium sp	5		1		2				2		15	18	1		1	2					1		1	9	
Chlorophyta	Coelastrum sp	5											1						1		2	4	5	5		
Chlorophyta	Crucigenia sp	6	16	5	6	3	8	7	5	11		7	3	3							2	3	2	1		
Chlorophyta	Diacanthos belanophorus	1																							1	
Chlorophyta	Diacanthos sp	1																		1						
Chlorophyta	Dictyosphaerium sp	4	3	1	11	5	21	11				3	1		1	3			1	9	5	4	22	11	119	
Chlorophyta	Dispora sp	1																							1	
Chlorophyta	Eudorina elegans	2											1								3	3			8	
Chlorophyta	Gloeococcus minor	1																		1	1				1	
Chlorophyta	Gloeocystis sp	2													1	2									1	
Chlorophyta	Golenkinia sp	2																	3						1	
Chlorophyta	Gonium sp	1										1											2			
Chlorophyta	Kirchneriella sp	2	1		8	2	8		3	1		1											1		1	
Chlorophyta	Lobomonas sp	1																					1			
Chlorophyta	Micractinium pusillum	1																							5	
Chlorophyta	Monoraphidium sp	5	63	19	42	11	79	60	10	19		17	5	73	114	74	67	2	2	1	6	10	17	27	31	59
Chlorophyta	Mougeotia sp	1	2					1											1							
Chlorophyta	Nephrocytium agardhianum	1	1		1		1																			
Chlorophyta	Nephroselmis sp	1																		1						
Chlorophyta	Oedogonium sp	1																					4			
Chlorophyta	Oocystis sp	5	5		1	3	6	14	2	3			4	3	9	4	4		1	11		3	5	4	16	
Chlorophyta	Pandorina morum	1	1	1	5		1					8	10							1		2	3	2	1	
Chlorophyta	Paulschulzia tenera	1																		3			1			
Chlorophyta	Pediastrum sp	3	15	1	4	1	1	15	1			3	8	3	1	3			1			5	4	10	18	
Chlorophyta	Phacotus sp	1																		3		1		1		
Chlorophyta	Pyramichlamys dissecta	1																				1		1		
Chlorophyta	Quadrigula sp	4	2	1		1	2	5				6	6						1	1	1	2		4	1	7
Chlorophyta	Scenedesmus sp	12	12	6	28	12	51	26	2	4		3	3	2	1	3	3			7	2	3	20	10	14	
Chlorophyta	Schroederia sp	3	31	23	33	16	25	32	18	35			1	1	1	13		4	16	21	74	61	61	109	103	151
Chlorophyta	Selenastrum minutum	1												1	1	4			1	2					1	
Chlorophyta	Selenastrum sp	1								1																
Chlorophyta	Sorastrum sp	2											1										2			
Chlorophyta	Spermatozopsis exsultans	1																			1	1		3		
Chlorophyta	Sphaerocystis schroeteri	1	19	13	8	1	3	12	1	4		10	12	11	29	14	20	1	7	5	22	3	16	16	23	23
Chlorophyta	Spirogyra sp	1															1						2	1	2	3
Chlorophyta	Staurastrum sp	1	5	1									3							1					2	
Chlorophyta	Tetraedron sp	3	12	1	9	2	20	3	1			2			1							1	1	1	3	
Chlorophyta	Tetrastrum staurogeniaeforme	1												1								1	2		1	

			Number of Detections Per Lab and Year																							
Division	Species Name	n taxa	Aqua ID							BSA			Aquatic Analysts				PhycoTech									
			1990	1991	1992	1993	1994	1995	1996	1997	1997*	1998	1999	2004	2005	2006	2007	2005*	2006*	2007*	2008	2009	2010	2011	2012	2013
Chlorophyta	Trebouxiophyceae sp	7	24	31	3	1	3	6	20			4	6	6	1	4	11	8	48	36	62	64	68	174		
Chlorophyta	Ulothrix sp	1								2					1	3		1					16			
Chlorophyta	Unident Chlorophyta cyst	1																					1			
Chlorophyta	Volvox sp	1												1			1		4							
Chlorophyta	Xanthidium sp	1																				1				
Chrysophyta	Chrysocapsaceae sp	1																2								
Chrysophyta	Chrysococcus sp	2										1				1	1	4	1				1	1		
Chrysophyta	Dinobryon sp	7	24	33	24	13	8	17	3	2			5	2	2	2			2	4		1	1			
Chrysophyta	Gonyostomum ovatum	1																1								
Chrysophyta	Mallomonas sp	3	2	3	1	3	2	1	7	3	1	21	33	22	3	4	8	1	23	10	14	29	40	30		
Chrysophyta	Synura sp	2	1	1		6		3	2									3			1	3	1			
Chrysophyta	Unident Chrysophyceae cyst	1															4	4	15	4	5	3	4	5		
Chrysophyta	Uroglena sp	1															1	2								
Cryptophyta	Cryptomonas sp	6	68	90	90	36	87	72	41	40	1	28	36	80	118	69	78	10	16	25	84	90	92	137	136	161
Cryptophyta	Rhodomonas minuta	3	80	121	114	47	112	110	63	81	6	123	86	130	196	122	146	14	21	42	126	136	143	164	179	180
Cyanophyta	Anabaena sp	4	9	6	3		1	2	1		26	20	4		3		1	1		3	2	1	4			
Cyanophyta	Anabaena sp. Group 2	6	14	15	12	12	12	13	6	10	22	37	10	41	24	43	2	8	10	35	37	30	34	30	28	
Cyanophyta	Aphanizomenon flos-aquae	1	118	131	87	48	85	138	78	92	8	129	106	126	166	116	133	15	28	43	114	149	120	128	129	142
Cyanophyta	Aphanocapsa sp	7									9	7						7	2	1	8	23	16	30	43	
Cyanophyta	Aphanothece sp	3									4							1	1			11	24	12		
Cyanophyta	Chroococcus sp	6	33	5	32	9	46	27	4	12	41	24						1	15	4	4	2	7	5	4	
Cyanophyta	Cuspidothrix issatschenkoi	1																1						1		
Cyanophyta	Cyanodictyon planctonicum	1																							2	
Cyanophyta	Cyanonephron styloides	1																				1	19			
Cyanophyta	Cylindrospermopsis raciborskii	1																					1			
Cyanophyta	Dactylococcopsis irregularis	1																					1	1		
Cyanophyta	Gloeotrichia echinulata	1	2	1				1		2											6	2	6	7	1	
Cyanophyta	Gomphosphaeria sp	1				1				6	3							1					1			
Cyanophyta	Lyngbya sp	1	1							1																
Cyanophyta	Lyngbya subtilissima	1																1								
Cyanophyta	Merismopedia sp	5	1	4	33	3	28	38	1	6								1	1	12	12	4	30	12	22	
Cyanophyta	Microcystis aeruginosa	2	19	7	5		5	18	11	33	20	5	13	8	23	21		10	14	30	57	28	17	20	29	
Cyanophyta	Microcystis sp	2									3								3			1				
Cyanophyta	Oscillatoria sp	2									2	5	1					3						3		
Cyanophyta	Phormidium sp	1																1								
Cyanophyta	Pseudanabaena sp	5	66	80	70	29	71	91	67	68	8	76	33					9	22	30	86	108	72	93	84	106
Cyanophyta	Rhabdoderma lineare	1																					2	2	2	
Cyanophyta	Woronichinia naegeliana	4	3	1	1				10	2								2	5	17	9	18	8	6	3	2
Diatoms	Achnanthes sp	8									1	4	6	5	5	3	1	2	1	1	5				4	
Diatoms	Amphora 1	5											4	5	4	7	1		7	1	5	1	1	5		
Diatoms	Anomoeoneis vitrea	1																			1					
Diatoms	Asterionella formosa	2	26	45	32	13	28	44	19	30	20	26	17	79	30	19	7	8	8	52	64	67	48	58	47	
Diatoms	Aulacoseira sp	9	9	7	3	5	3	8	1	3	2	48	46	21	21	15	31	7	6	9	27	42	61	52	35	
Diatoms	Caloneis sp	7											2	2	2	2				1	1		1	2	3	
Diatoms	Cocconeis sp	3	19	12	5	4	13	7	1	2	2	36	20	2	2	2	8	1	1	5	4	7	6	3	2	2
Diatoms	Cyclostephanos sp	3																	2						1	
Diatoms	Cyclotella sp	6												4	4	4	2		3	3	8	6	18	10	11	
Diatoms	Cymatopleura sp	2										2	2							1	1		1			

			Number of Detections Per Lab and Year																									
Division	Species Name	n taxa	Aqua ID					BSA			Aquatic Analysts				PhycoTech													
			1990	1991	1992	1993	1994	1995	1996	1997	1997*	1998	1999	2004	2005	2006	2007	2005*	2006*	2007*	2008	2009	2010	2011	2012	2013		
Diatoms	Cymbella sp	7	16	5		1	4	6		2	25	22	9	8	1	3	1	1	2	2	5		1	1				
Diatoms	Cymbellonitzschia sp	1											1			1												
Diatoms	Denticula kuetzingii	1															1											
Diatoms	Diatoma sp	4	11	4		2	1	2		1	7	6	1	1	1	1			1				2					
Diatoms	Diploneis sp	4									1	1				1	2							2	1			
Diatoms	Epithemia sp	4									4	3	1	2	2	2			1	2	1							
Diatoms	Eunotia sp	2									1	4	1							9	1	2		2				
Diatoms	Fragilaria sp	15	34	41	16	4	12	18		17	4	48	43	52	70	47	75	6	9	17	53	48	62	62	64	66		
Diatoms	Frustulia rhomboides	1																			1							
Diatoms	Gomphoneis sp	1																			1							
Diatoms	Gomphonema sp	8	11	12	5	2	8	6			1	8	11	5	6	5	9	2		5	6	1	2	3	1	1		
Diatoms	Hantzschia amphioxys	1															1											
Diatoms	Melosira varians	1												3	2	6	6			2	1	4	1	1	1	10		
Diatoms	Meridion sp	1	2					1																				
Diatoms	Navicula sp	27	27	37	15	15	14	15	2		2	25	15	25	33	25	32	5	2	4	15	9	14	5	15	19		
Diatoms	Neidium affine	1														2												
Diatoms	Nitzschia sp	23	17	38	23	11	19	17	3	13		6	4	20	18	14	22	2	4	6	15	15	10	31	38	30		
Diatoms	Pinnularia sp	2	2				2			2	1	22	18	5	6	2	7	1		2	2		3	2				
Diatoms	Reimaria sinuata	1																										
Diatoms	Rhoicosphenia curvata	2	1	1								17	6	4	1	1	8	1			1		3		1			
Diatoms	Rhopalodia sp	1																			1							
Diatoms	Skeletonema potamos (single cell)	3																					2		2			
Diatoms	Stauroneis sp	1		1								4	1			1	2											
Diatoms	Stephanodiscus niagarae	1	28	4		1	2	2	2	3	5	55	35	7	4	19	10	4	8	13	27	18	10	7	2			
Diatoms	Stephanodiscus sp	6	38	58	62	21	64	64	33	34	6	67	56	39	36	54	22	3	11	13	45	46	36	95	66	73		
Diatoms	Surirella sp	8	4	2								10	2	1	2					1	2	3	2	2	6	2		
Diatoms	Synedra sp	11	22	25	37	21	59	32	2	4		16	16	20	39	31	36	7	7	10	32	12	14	35	37	26		
Diatoms	Tabellaria sp	2										4																
Diatoms	pennate diatom	1	5	6	5	1	15	25	6	14																		
Euglenophyta	Euglena sp	1	4	9		6	1					7	5							2	3	2	14	6	5	3	5	13
Euglenophyta	Lepocinclis sp	1																					1			1		
Euglenophyta	Phacus sp	1	7	5	7	2	3	3		6		3	11								1		2	1	3			
Euglenophyta	Trachelomonas sp	2	14	12		1	1	1		1		17	24								1							
Haptophyta	Chrysochromulina parva	2												1	2		1	1	6	10	41	18	35	120	52	43		
Pyrrhophyta	Ceratium hirundinella	1		1									1															
Pyrrhophyta	Glenodinium/Peridinium/Gymnodinium	7	5	14	22	11	16	3	1	1	2	7	13	16	14	9	14	1	4	2	3	9	10	18	8	13		
Unknown	miscellaneous microflagellate	2	19	15	50	17	50	22	12	41		5		120	181	111	110	10	19	37	136	168	167	155	172	164		
Xanthophyta	Ophiocytium sp	1										1																
Xanthophyta	Tribonema sp	3	32	43	25	19	48	25	3	9		15	24	40	46	29	51	3	8	11	21	10	14	29	13	26		

3.1.2 BIOVOLUME STANDARDIZATION

Biovolume standardization was performed subsequent to species standardization as outlined below. Figure 10 summarizes the process used to calculate standardized biovolume for the phytoplankton data.

3.1.2.1 GENERATION OF CELL DENSITY TIME SERIES

One important aspect of biovolume standardization that required consistency was whether labs reported density as algal units (filaments/colonies) or cells. Since biovolume is ultimately computed on a per cell basis, estimates of cell density are generally made by the labs even though algal units (filaments/colonies) are appropriately made during microscopic analysis (see above Laboratory methods section)¹⁹. However, there were several species for which only colonies were reported, and a consistent time-series of cell density needed to be determined prior to standardizing biovolume.

As noted above, Aqua ID reported some taxa as colony density rather than cell density. The most common of these species was *Microcystis aeruginosa* (n= 98). The others were *Coelosphaerium naegelianum* (n=14), *Coelosphaerium kuetzingianum* (n=1), *Gloeotrichia echinulata* (n=4), and *Gomphosphaeria lacustris* (n=1). In addition, average colony size (calculated as ratio of biovolume:density) and biovolume for *Microcystis aeruginosa* was also 1-2 orders of magnitude higher in AID's samples than in samples from the other laboratories, indicating issues with biovolume calculations. Further analysis showed that that AID's estimates of biovolume per colony were in fact volume (i.e., were based on the volume of a solid sphere and were not adjusted by a biovolume:volume ratio to account for non-cellular space within a colony) and not biovolume. Using PhycoTech's 2005-2013 measurements of *Microcystis aeruginosa* we used the calculated mean biovolume:volume ratio to develop a linear regression equation to predict cell density from measured cell volume (Figure 9; n = 269; $r^2=0.75$; $p<0.0001$). We then applied the regression equation to the reported AID *Microcystis aeruginosa* volume values to estimate cell density. Due to time/budgetary constraints, similar volume/cell density relationships were not developed for the remaining species reported as colonies by AID. We retained the original reported biovolumes for these species, which were present only at very low frequency and therefore should have negligible influence on examination of overall trends.

Aquatic Analysts reported colony density for all species as well as cell density for cyanobacteria only. Because Aquatic Analysts used a lookup table²⁰ for biovolume per cell (see above lab method section), rather than measuring biovolume per cell, we were able to calculate cell density by dividing AA reported biovolume by biovolume per cell from the lookup table. For the few species for which the lookup table had multiple values listed for biovolume per cell, we contacted Aquatic Analysts taxonomist Jim Sweet and determined which biovolume value had been used.

¹⁹ An exception to this was that AID and BSA both enumerated individual cells of *Aphanizomenon*. However, an in-depth comparison of total density computed both from individual cells and algal units (filaments) confirmed that for this species final cell density for a sample was not biased by choice of counting unit (Kann 2005).

²⁰ To verify that Aquatic Analysts' did rely on a lookup table, we calculated cell sizes (biovolume divided by density) for 42 non-colonial species for each sample in the Aquatic Analysts 2004-2007 dataset. 2395 of 2441 (98%) calculated cell sizes matched those in the lookup table, including 100% of calculated cell sizes for 33 of the 42 species. Thirteen of the 14 species with ≥ 20 detections (*Ankistrodesmus falcatus*, *Chlamydomonas* sp, *Chromulina* sp, *Cryptomonas erosa*, *Cryptomonas ovata*, *Mallomonas* sp, *Navicula pupula*, *Nitzschia palea*, *Pinnularia* sp, *Rhodomonas minuta*, *Stephanodiscus hantzschii*, and *Stephanodiscus niagarae*) matched cell sizes for $>97\%$ of samples; the only exception was *Synedra cyclosum*, which matched in 86 of 115 (75%) samples.

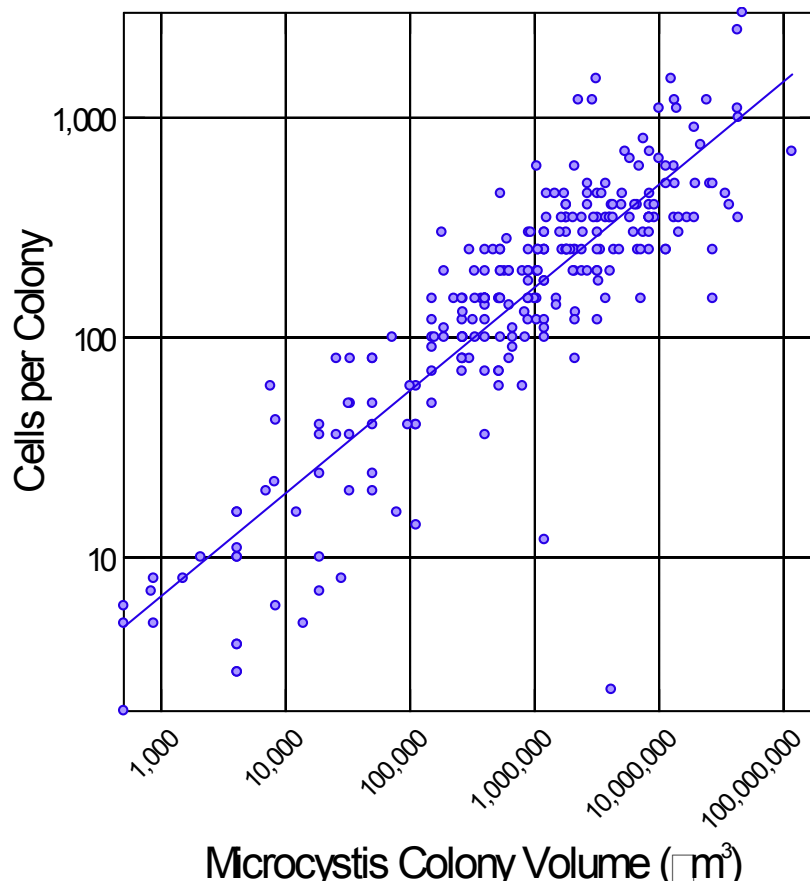


Figure 9. Relationship between *Microcystis* colony volume and number of cells per colony in the 2005-2013 PhycoTech dataset.

3.1.2.2 GENERATION OF BIOVOLUME TIME SERIES FROM CELL DENSITY TIME SERIES AND STANDARDIZED CELL SIZE

Once the time series of cell density for each taxa was assembled using the steps above, cell density was then multiplied by a standardized cell size (i.e., biovolume per cell) (Appendix A) to derive standardized biovolume over the 1990-2013 period. Standardized cell sizes were based on one of three sources, listed in order of decreasing priority: 1) mean of all PhycoTech biovolume measurements²¹ of a taxa (or a closely related taxa) from all 2005-2013 UKL and Agency Lake samples, 2) mean of all PhycoTech biovolume measurements of that taxa (or a closely related taxa) from samples from other North American lake systems, 3) biovolume measurements from other literature sources such as www.algaebase.org or John et al. (2002).

²¹ PhycoTech biovolume measurements were prioritized because they provided the most consistent set of UKL-specific measurements and included laboratory QA checks. AID data were based on actual measurements but taxa standardization precluded biovolume usage; BSA measurements were erroneous in many cases (for example individual *Aphanizomenon* cell biovolumes were initially reported as $1 \mu\text{m}^3$ and were then changed to $10 \mu\text{m}^3$, but measured values are typically $>60 \mu\text{m}^3$); and as noted above, AA values are not measured but are taken from the average of other lakes.

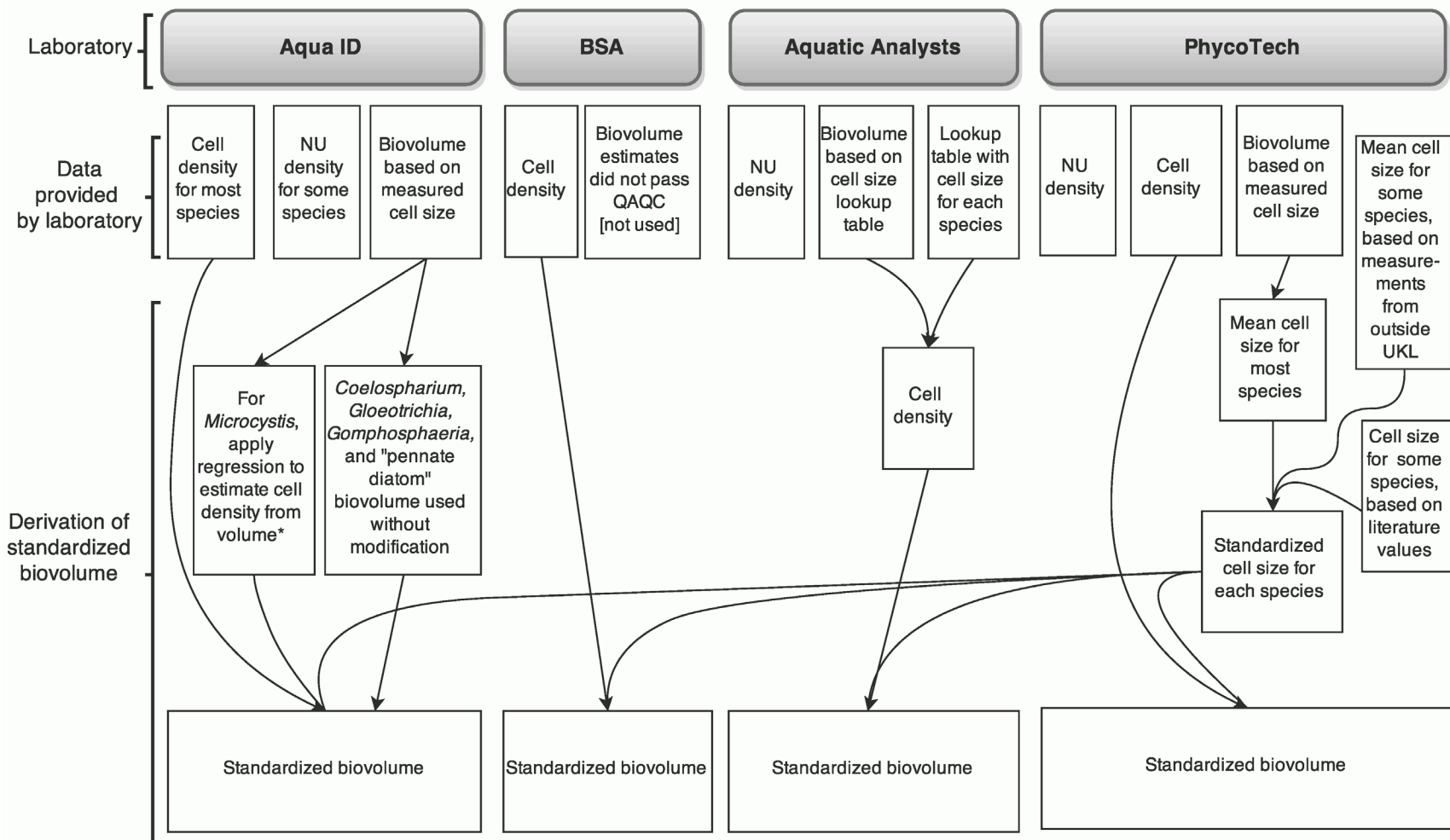


Figure 10. Flow chart showing process used to calculate standardized biovolume for the phytoplankton data.

3.2 PHYTOPLANKTON DATA ANALYSIS

Due to the considerable effort to standardize the database as described above (the initial complexity of standardizing the phytoplankton and zooplankton databases was far more than anticipated due to among-laboratory issues not initially foreseen), time and budgetary constraints limited the scope of the depth of analysis in this Phase I report. Thus, the following analysis sections are considered preliminary, with the main goal to provide graphical depictions of seasonal, spatial, and inter-annual patterns that allow evaluation of database structure, and to form the basis for Phase II comprehensive analyses.

3.2.1 SEASONAL AND SPATIAL PATTERNS

As noted previously (e.g., Kann 1998), phytoplankton dynamics in UKL and Agency Lake are strongly seasonal. Although exact timing varies from year to year the general pattern is for diatoms to dominate during February through April and then decline through June as they are replaced by Cyanobacteria (primarily *Aphanizomenon flos-aquae*), which rise to reach a peak of near 100% biovolume generally by early July (Figure 11, Figure 12, and Figure 14).

Aphanizomenon biovolume then declines mid-summer, and in many years increases (but usually not to early summer levels) to reach another peak in August or September (Figure 16). Aside from diatoms and Cyanobacteria, other taxonomic groups which sometimes reach high percent biovolume are Cryptophytes, Chlorophytes, and Xanthophytes (Figure 11 and Figure 14).

Some site-specific differences in timing and magnitude of taxonomic groups are evident (Figure 14 and Figure 15). For example, the relative biovolume of Cyanophyta (*Aphanizomenon*) tends to begin earlier and decline earlier in Agency Lake (stations AN and AS) than in UKL (Figure 14). Relative biovolume of diatoms tends to be lower in the spring but higher in the fall in Agency Lake, and in general the relative proportion of diatoms and Cyanophytes tends to show an inverse pattern, especially for Agency Lake (Figure 14). Overall site differences are apparent, but especially for the Pelican Bay site (PB) which is dominated by spring inflow and wetland plants and does not experience large Cyanophyte blooms (Figure 15).

The dominant phytoplankton species each have distinct seasonal patterns (Figure 12 and Figure 13). As noted above *Aphanizomenon* is by far the most prevalent species on an absolute and relative basis (Figure 12), and as expected with its extreme dominance during the summer growing season, most other species show an inverse pattern relative to the *Aphanizomenon*. Another Cyanophyte, *Microcystis aeruginosa*, increases in prevalence in mid-summer, generally peaking in August, and is more prevalent in Agency Lake than in UKL (Figure 12). A similar increase in mid- to late-summer was observed for microcystin toxin, a hepatotoxin produced by *Microcystis* (Eldridge et al. 2013).

The Diatom *Asterionella formosa* was most abundant during February through May (peaking in March and April), while the diatom *Aulacoseira sp.* and *Fragilaria sp.* peaked in May and June. Due to its large size, the diatom *Stephanodiscus niagarae* sometimes reached high biovolume (i.e., $>10 \text{ mm}^3/\text{L}$ or even $100 \text{ mm}^3/\text{L}$) and percent biovolume, despite not being consistently present in any month (i.e., lower quartile of biovolume and percent biovolume not greater than zero in any month). *Stephanodiscus sp.* was much more commonly detected than *S. niagarae* but did not reach the higher biovolume of *S. niagarae*. Most *S. niagarae* in the water column is

detrital brought up in the water column from the lake sediments²². *Stephanodiscus sp.* showed the highest biovolume and percent biovolume in November through March with a peak in February. *Synedra sp.* was another common diatom, peaking in February. The Xanthophyte *Tribonema sp.* peaked in May and in June. The Cryptophytes *Cryptomonas sp.* and *Rhodomonas sp.* were present at relatively low levels throughout the year, with somewhat higher levels in October through March.

As noted above the analyses contained herein are preliminary in nature and are mainly shown to demonstrate aspects of the database. In this vein, time-series graphs of sample-date lake-wide average taxonomic group biovolume and percent biovolume during the 1990-2013 period are shown for UKL and Agency Lake in Figure 16 and Figure 17, respectively; similar figures for individual sites are available in Appendix C. Figure 18 and Figure 19 show lake-wide averages of biovolume and percent biovolume for major genera/species in UKL and Agency Lake, respectively; similar figures for individual sites are in Appendix D.

These figures clearly show the seasonal and inter-annual differences over the period of record, as well as differences between UKL and Agency Lake. For example, during the years following dike breaching of the former wetlands between UKL and Agency Lake (described above), there is an apparent increase in the spring diatom bloom of *Asterionella* (Figure 18 and Figure 19), and secondary late-summer *Microcystis* increases are more apparent in Agency Lake than in UKL (Figure 19). Such a trend was also noted by Kann (1998) who observed that a toxic strain of *Microcystis aeruginosa* occasionally appeared during mid-summer and early-fall, forming a visible thin film at the lake surface. However, on a water column mean basis *Microcystis* generally represented a minor portion of the total biomass (also see Figure 12), with the exception of leeward shore accumulations during daily summer wind events.

These differences will be explored in detail in Phase II, including additional seasonal trend testing (e.g., Mann-Kendall trend tests) and multivariate techniques (e.g., NMDS) to evaluate the effects of nutrients, climate, and other physical, chemical, and biological forcing factors on the observed seasonal, spatial, and inter-annual dynamics.

²² *S. niagarae* is rarely found to be alive and healthy in the water column and is thus unique among the other taxa for that reason.

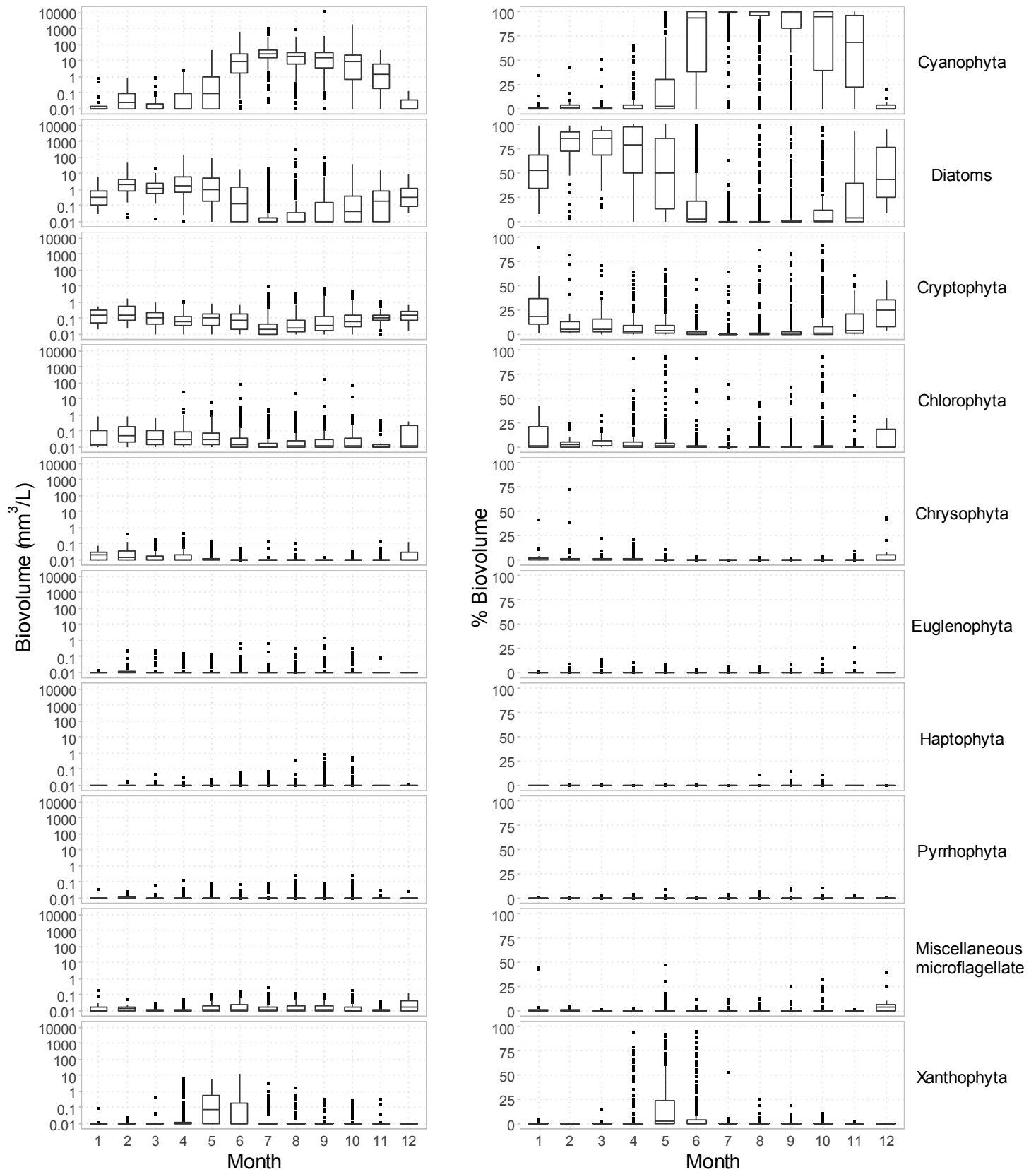


Figure 11. Monthly boxplots of biovolume and percent biovolume of taxonomic groups at all sites in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

January-December, All sites except PB

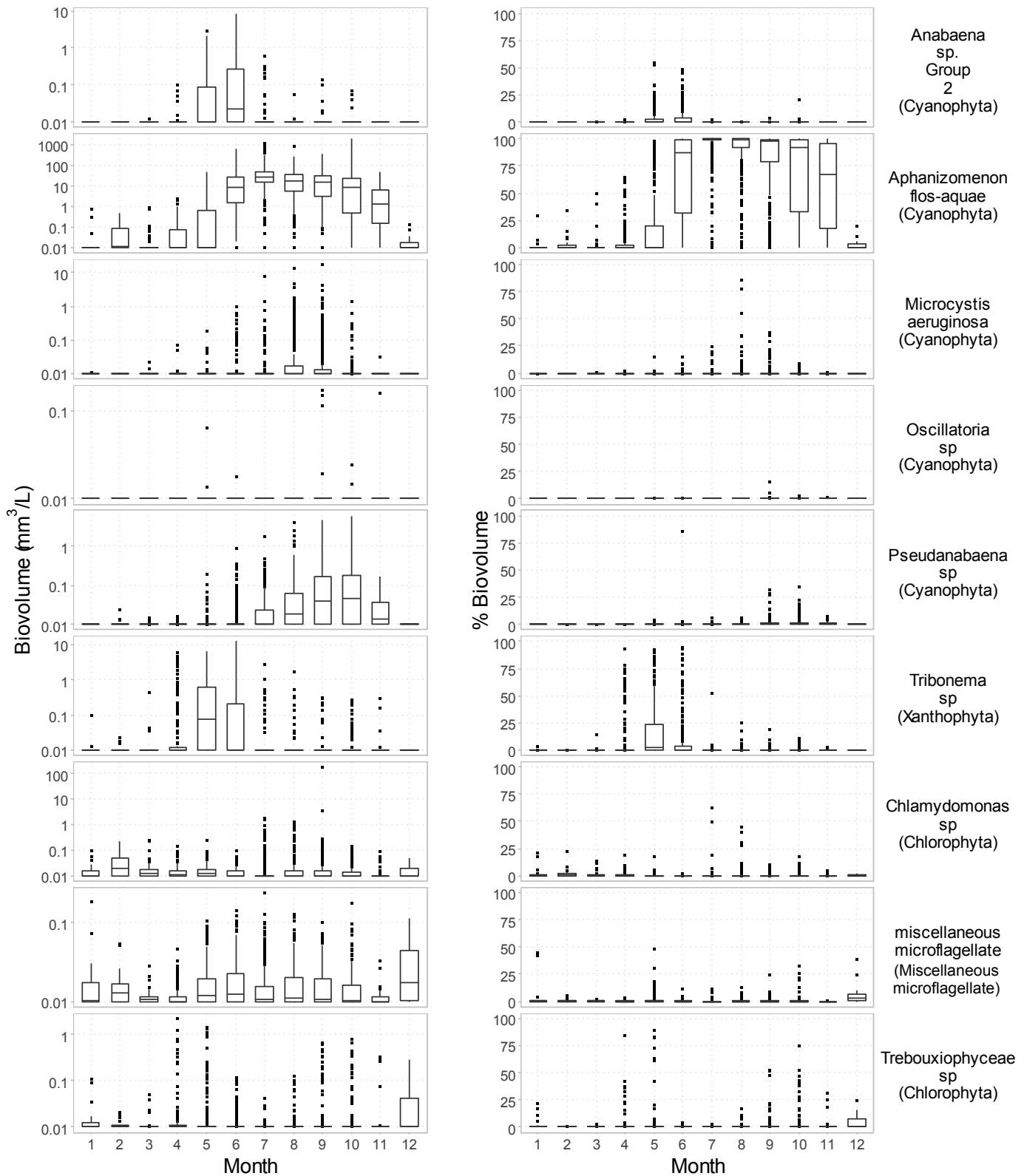


Figure 12. Monthly boxplots of biovolume and percent biovolume of dominant species and genera at all sites (except PB) in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

January-December, All sites except PB

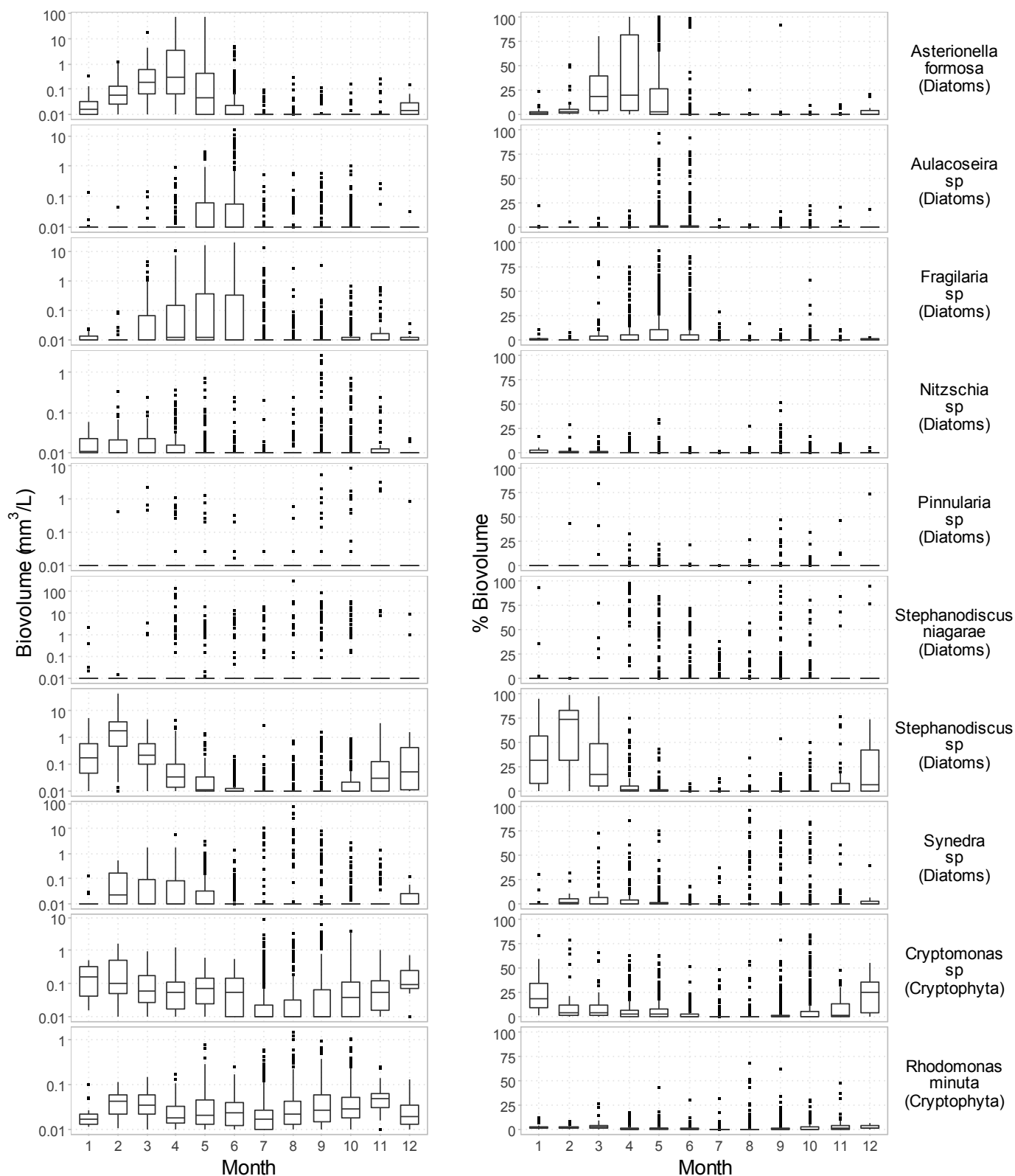


Figure 13. Monthly boxplots of biovolume and percent biovolume of additional dominant species and genera at all sites (except PB) in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

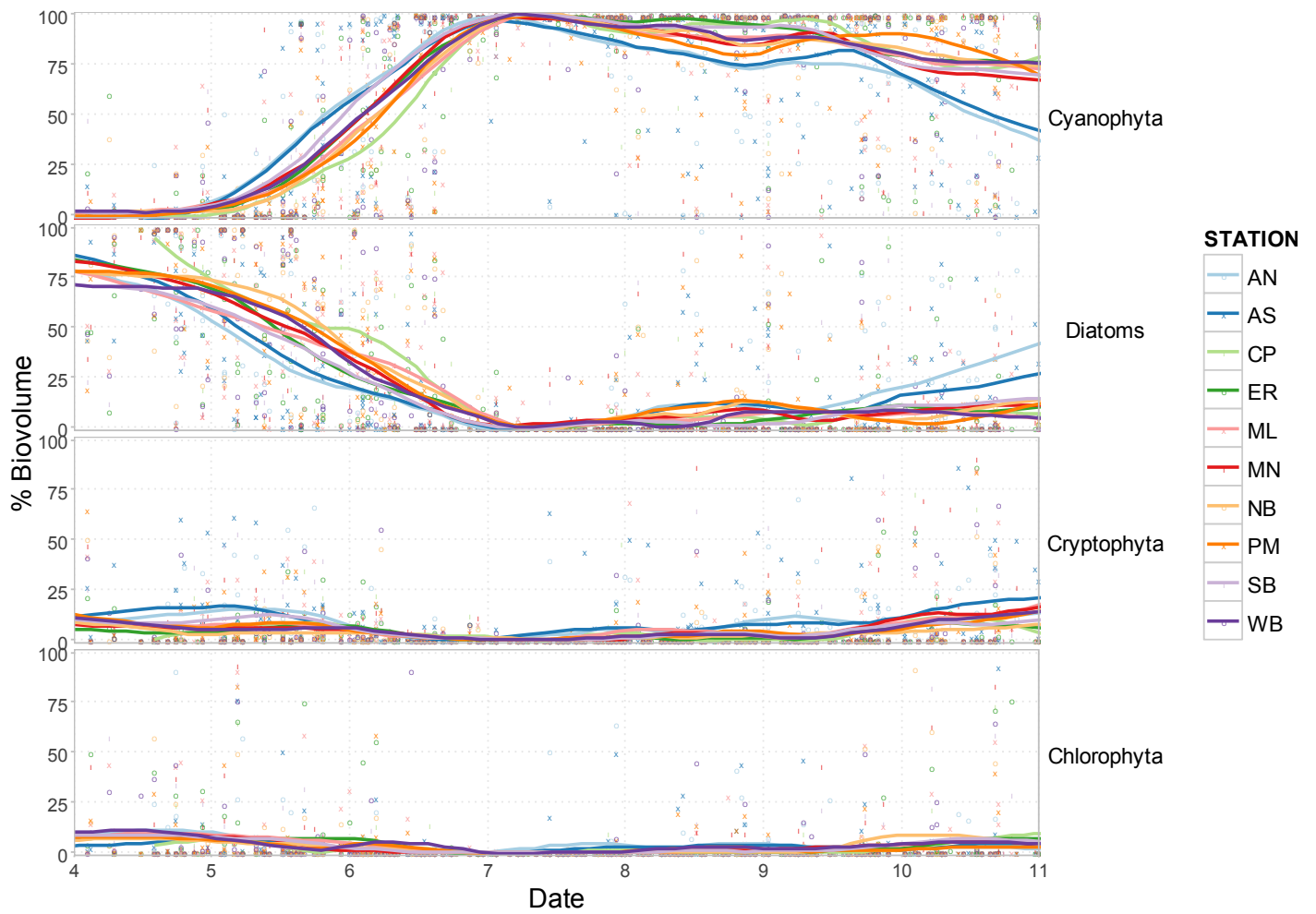


Figure 14. Percent biovolume of taxonomic groups at sites in Upper Klamath and Agency lakes for the months of April-October, 1990-2013. Points are individual samples and lines are a LOESS (Local Regression smoother).

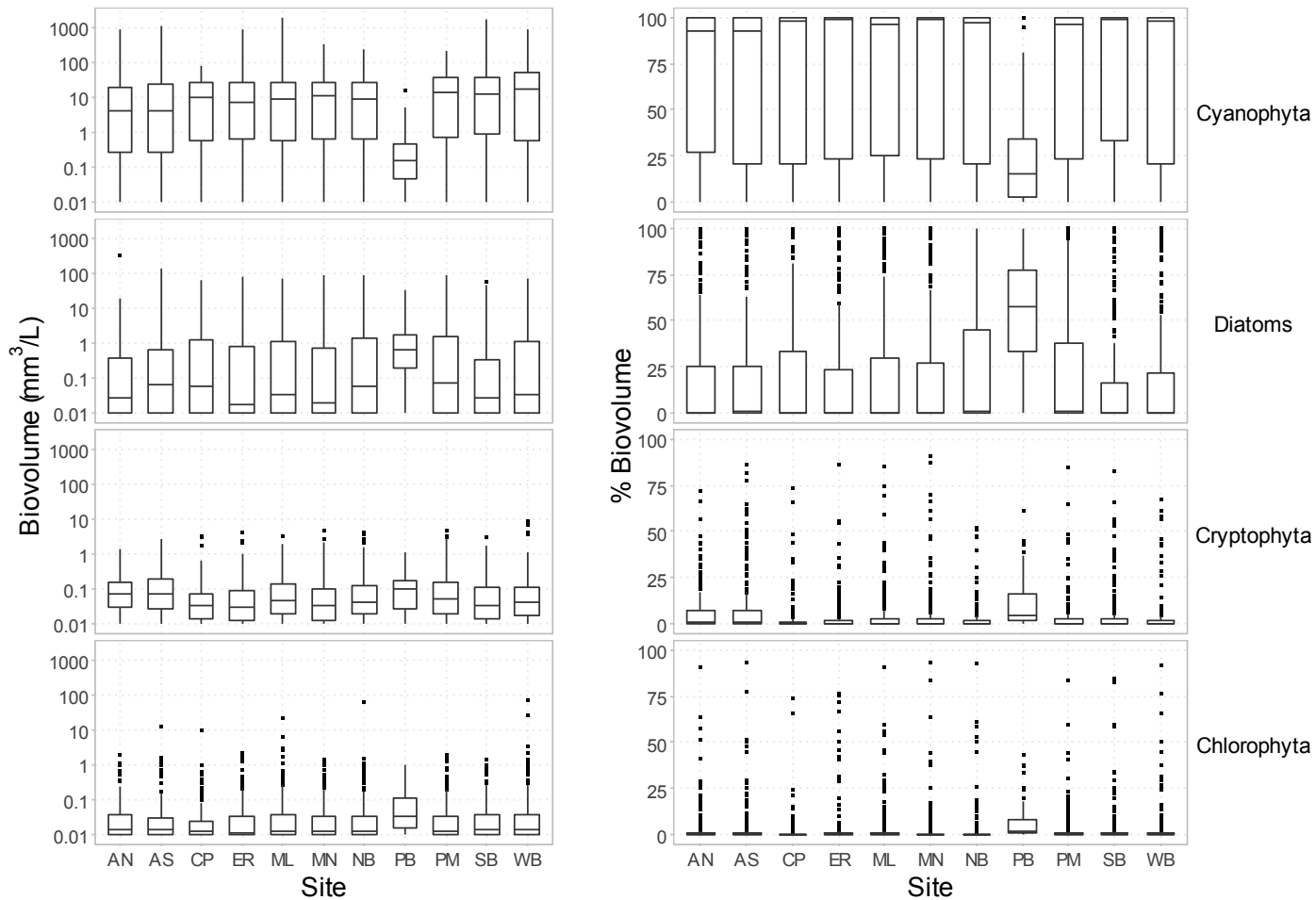


Figure 15. Boxplots of biovolume and percent biovolume of taxonomic groups at long-term stations and station PB in Upper Klamath and Agency lakes for April 15-October 30, 1990-2013.

Phyto Taxonomic Groups and Chlorophyll-a: Upper Klamath Lake Average, April-October

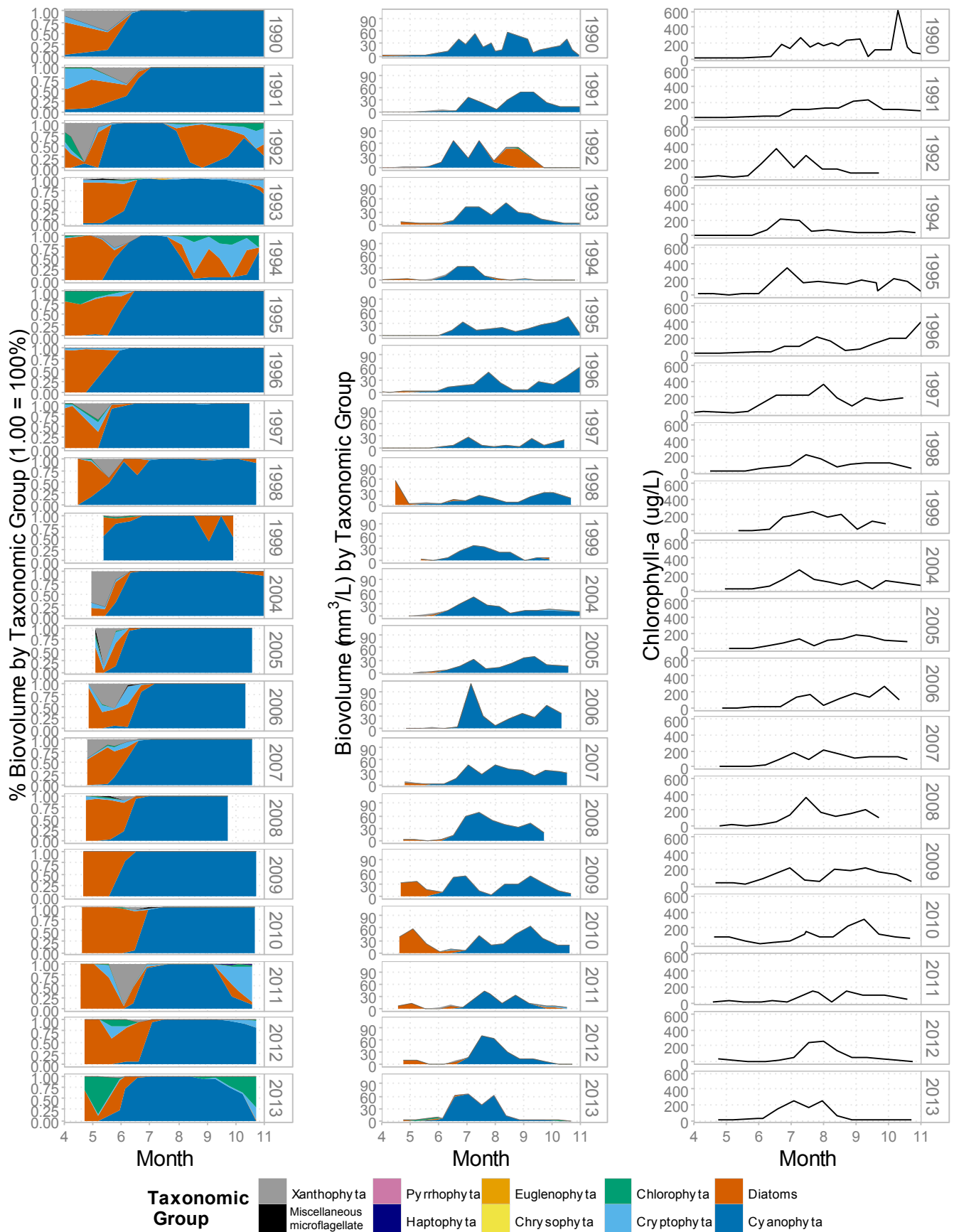


Figure 16. Percent biovolume (left column) and biovolume (middle column) of phytoplankton taxonomic groups for average of Upper Klamath Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a.

Phyto Taxonomic Groups and Chlorophyll-a: Agency Lake Average, April-October

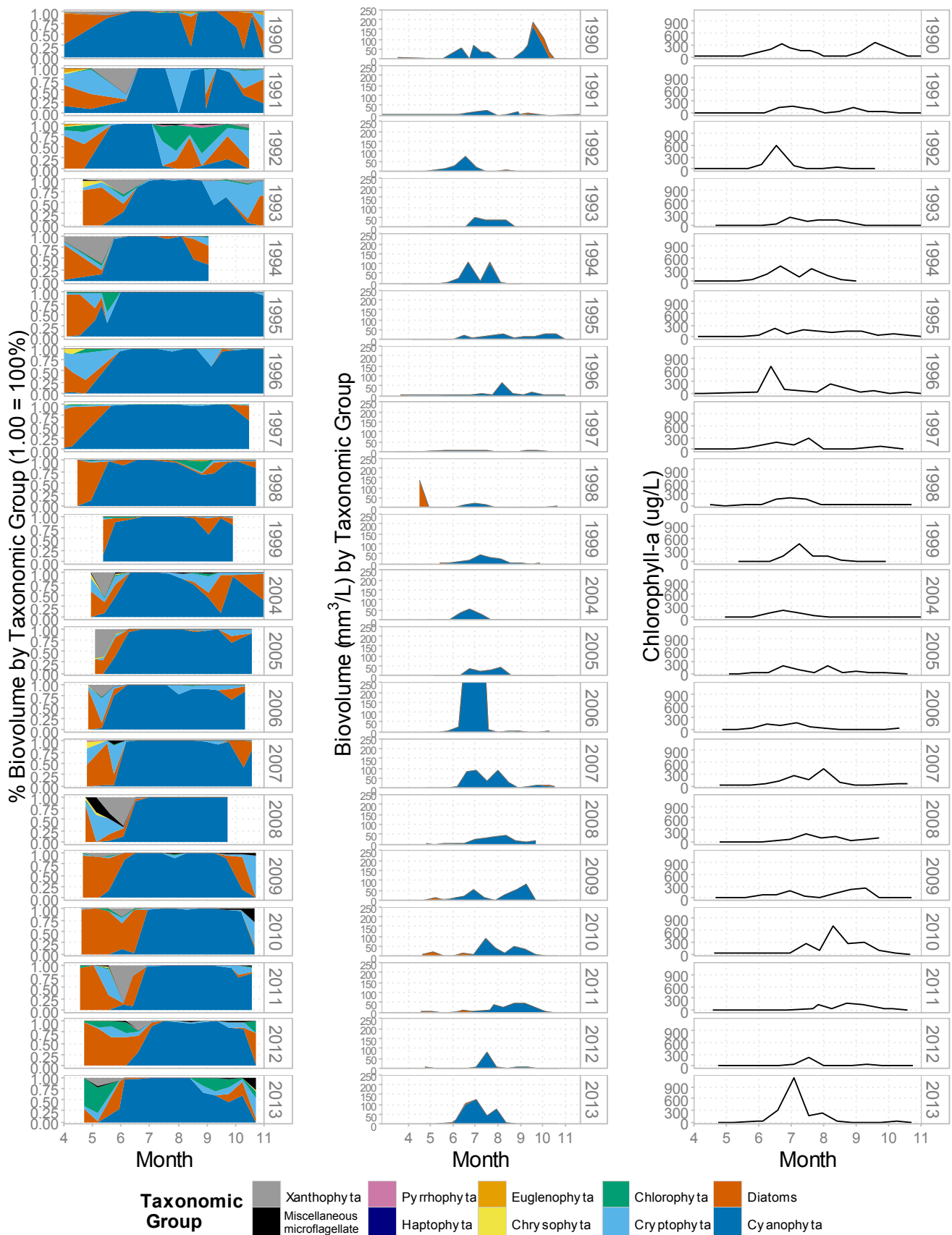


Figure 17. Biovolume (left column) and percent biovolume (middle columns) of phytoplankton taxonomic groups for average of Agency Lake stations during the period April-October, 1990-2013. Y-axis of biovolume truncated in 2006 to increase legibility of other years. Biovolume Right column is chlorophyll-a.

Phyto Genera/Species and Chlorophyll-a: Upper Klamath Lake Average, April-October

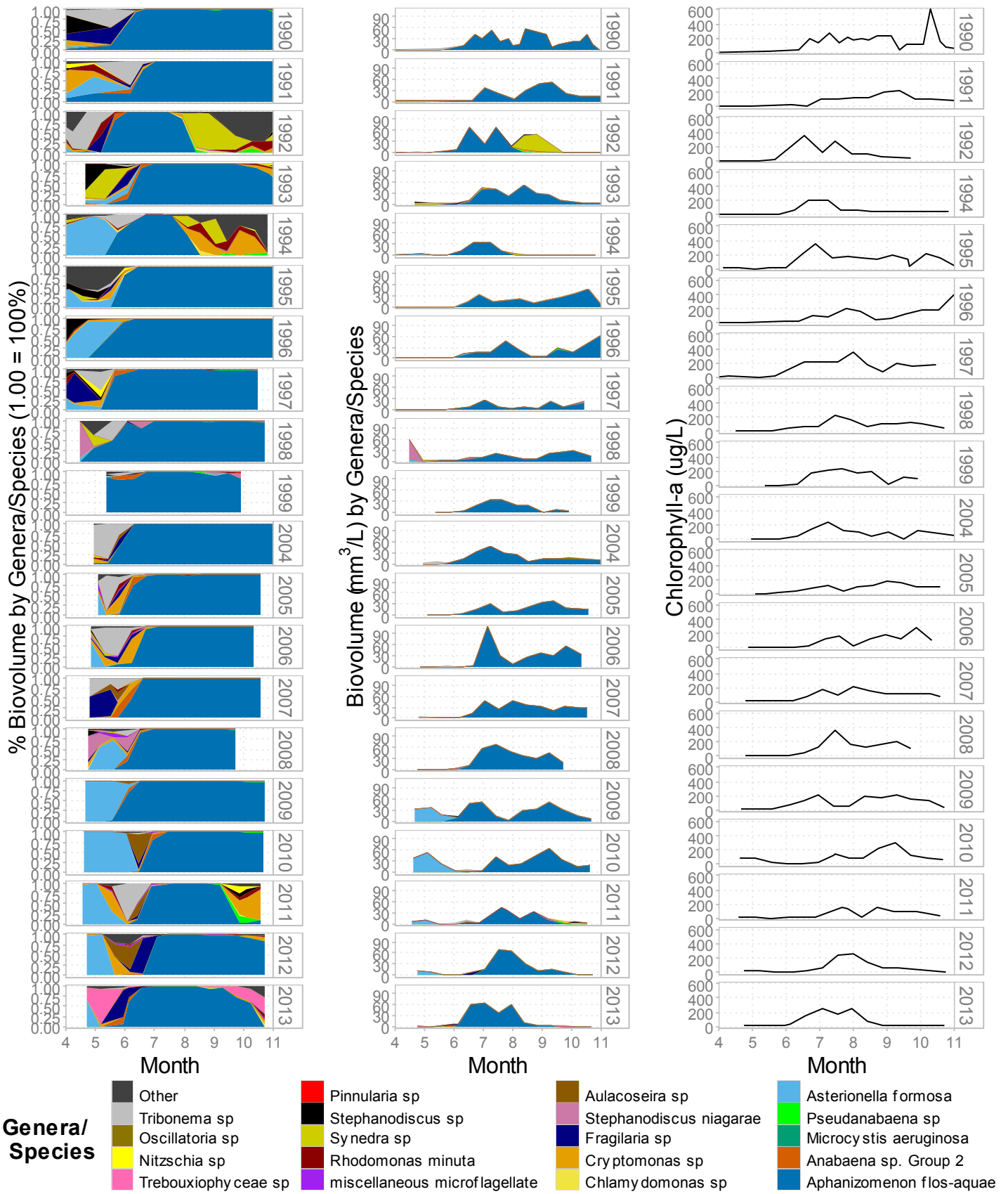


Figure 18. Biovolume (left column) and percent biovolume (middle columns) of dominant phytoplankton genera /species for average of Upper Klamath Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a. "Other" is the sum of all taxa not otherwise included

Phyto Genera/Species and Chlorophyll-a: Agency Lake Average, April-October

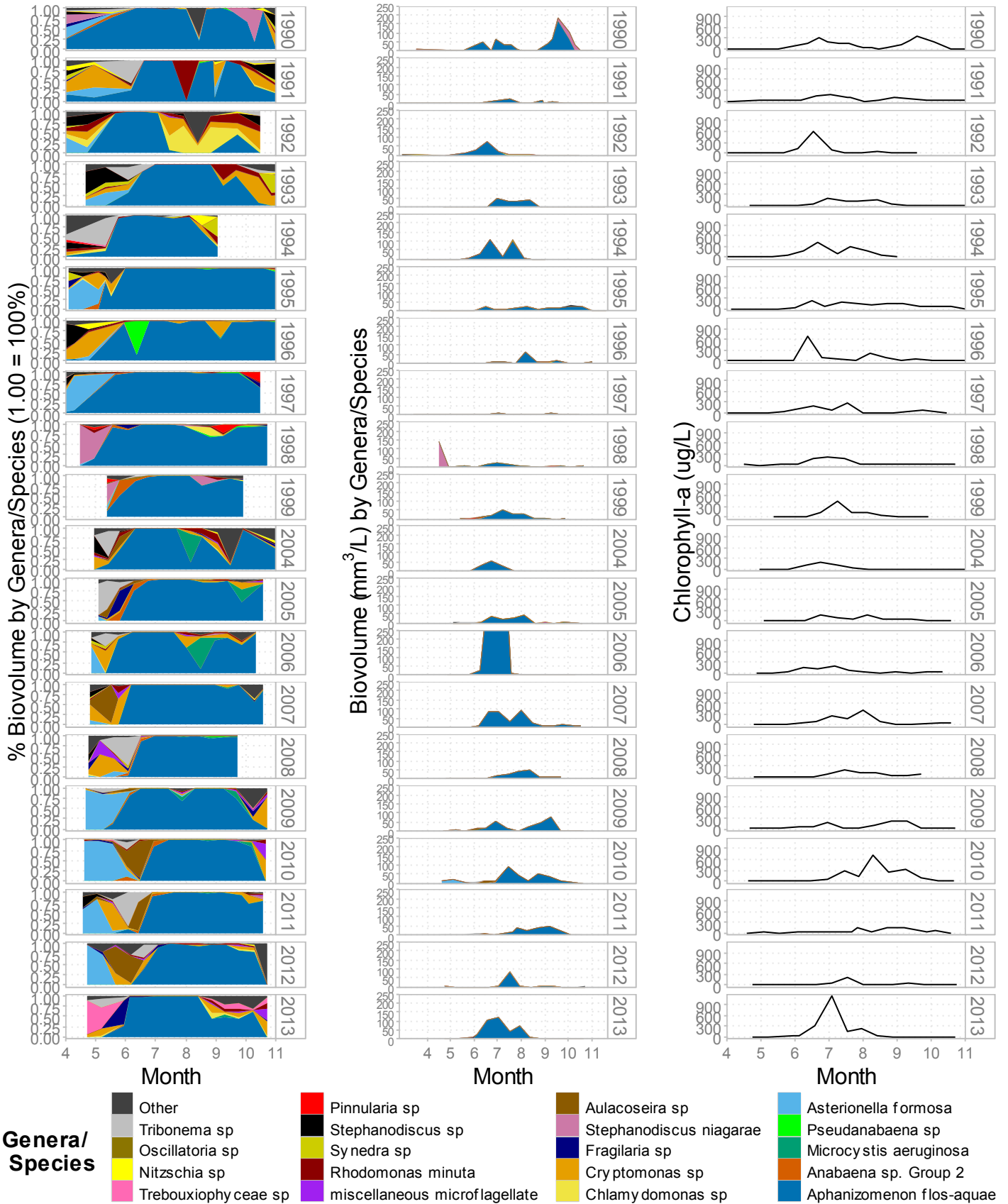


Figure 19. Biovolume (left column) and percent biovolume (middle columns) of dominant phytoplankton genera /species for average of Agency Lake stations for months of April-October, 1990-2013. Y-axis of biovolume truncated in 2006 to increase legibility of other years. Right column is chlorophyll-a. "Other" is the sum of all taxa not otherwise included.

3.2.2 PRELIMINARY LONG-TERM TRENDS

Full results of 1990-2013 Mann-Kendall trend tests for phytoplankton taxonomic groups and major genera/species for lake-wide averages of UKL and Agency Lake are shown in Figure 20. Figures with site-level trends are available in Appendix E and plots of annual time series of lake-wide averages for major genera/species are available in Appendix F.

Graphical time series plots of seasonal lake-wide averages of percent biovolume of phytoplankton taxonomic groups in UKL and Agency Lake for the months of April, May, and June indicates a potential long-term trend of increasing diatoms and decreasing cyanobacteria. The shift from higher Cyanophytes to higher diatoms is particularly evident in Agency Lake, and the trend appeared to start in 2008 during the April 15 to May 30 time period (Figure 21). The declining Cyanophyta trend is statistically significant ($p < 0.05$) for both lakes for April 15-May 30, May 1-30, and June 1- June 30, but is only significant for diatoms during May 1-31 and June 1-30 in Agency Lake, and June 1-30 in UKL (Figure 20).

Biovolume trends in decreasing Cyanophyta and increasing diatoms in April, May, and June are similar to the percent biovolume trends, except June 1-30 percent biovolume was not declining at either lake (Figure 20). Cyanophyta biovolume showed an increasing trend in UKL for July 1-July 30 and Cyanophyta percent biovolume was increasing for August 1-August 30 in Agency Lake. Not surprisingly, trends in *Aphanizomenon flos-aquae* were very similar to those for Cyanophyta; one notable exception was a decrease in *Aphanizomenon flos-aquae* percent biovolume for the April 15-October 30 period, apparently due to the decreases in April, May and June. These trends suggest a delay in the timing of the onset and decline of the early summer *Aphanizomenon flos-aquae* bloom. Trends for *Microcystis aeruginosa* included increasing biovolume August 1-30 at Agency Lake, increasing biovolume for July 1-July 30 and September 1-September 30 at UKL, and increasing percent biovolume October 1-October 30 at UKL (Figure 20).

Other trends of note include an apparent spring to early-summer decrease in *Cryptomonas*, *Rhodomonas*, and *Nitzschia*, and increases in both *Fragilaria* and *Asterionella* (Figure 20). In addition, *Anabaena sp.* (group 2: potentially toxin producing forms) shows an increasing trend in early-summer. Haptophytes decrease and miscellaneous microflagellates increase across all time periods in UKL, but these trends are influenced by greater taxonomic resolution provided by PhycoTech²³ (Figure 20).

These results are considered preliminary and sensitivity analyses are to be performed in the Phase II effort, including the effect of the missing four years (2000-2003) of data, differing frequency of stations sampled in some years, and differing counting resolution among labs. For example, trend analyses will be performed on a subset of stations that were always consistently sampled among years (in some years fewer stations were sampled).

²³Haptophytes were not identified prior to PhycoTech and the frequency of detection for the microflagellates *Chromulina* and *Monomastix* was much higher for PhycoTech—see Table 6)

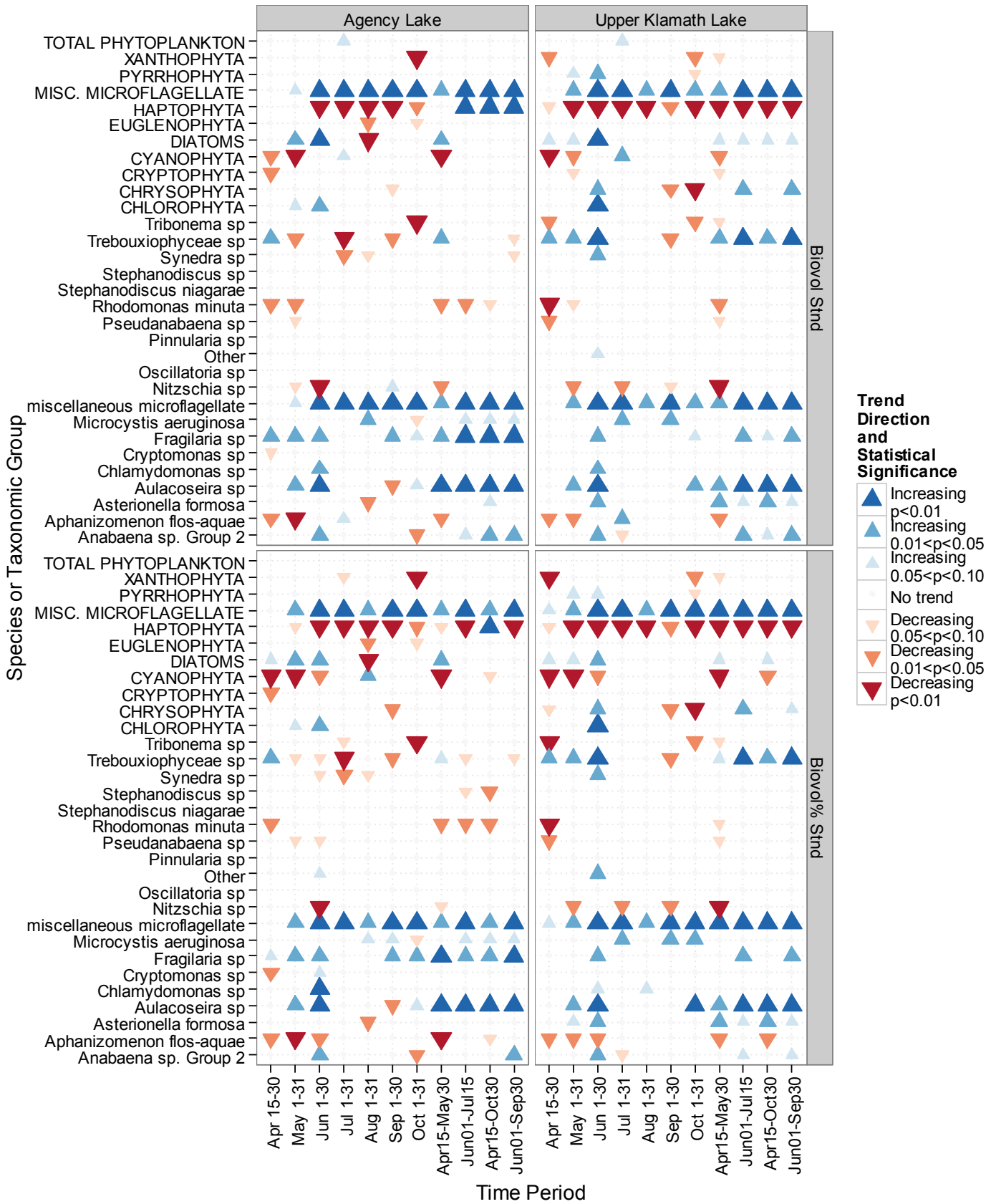


Figure 20. Summary of Mann-Kendall trend tests for phytoplankton taxonomic groups and major genera/species, 1990-2013 for lake-wide averages of biovolume (top panels) and percent biovolume (bottom panels) in Upper Klamath (right panels) and Agency (left panels) Lakes. “Other” is the sum of all taxa not otherwise included.

Lake-Wide Average of Taxonomic Groups by Season and Year

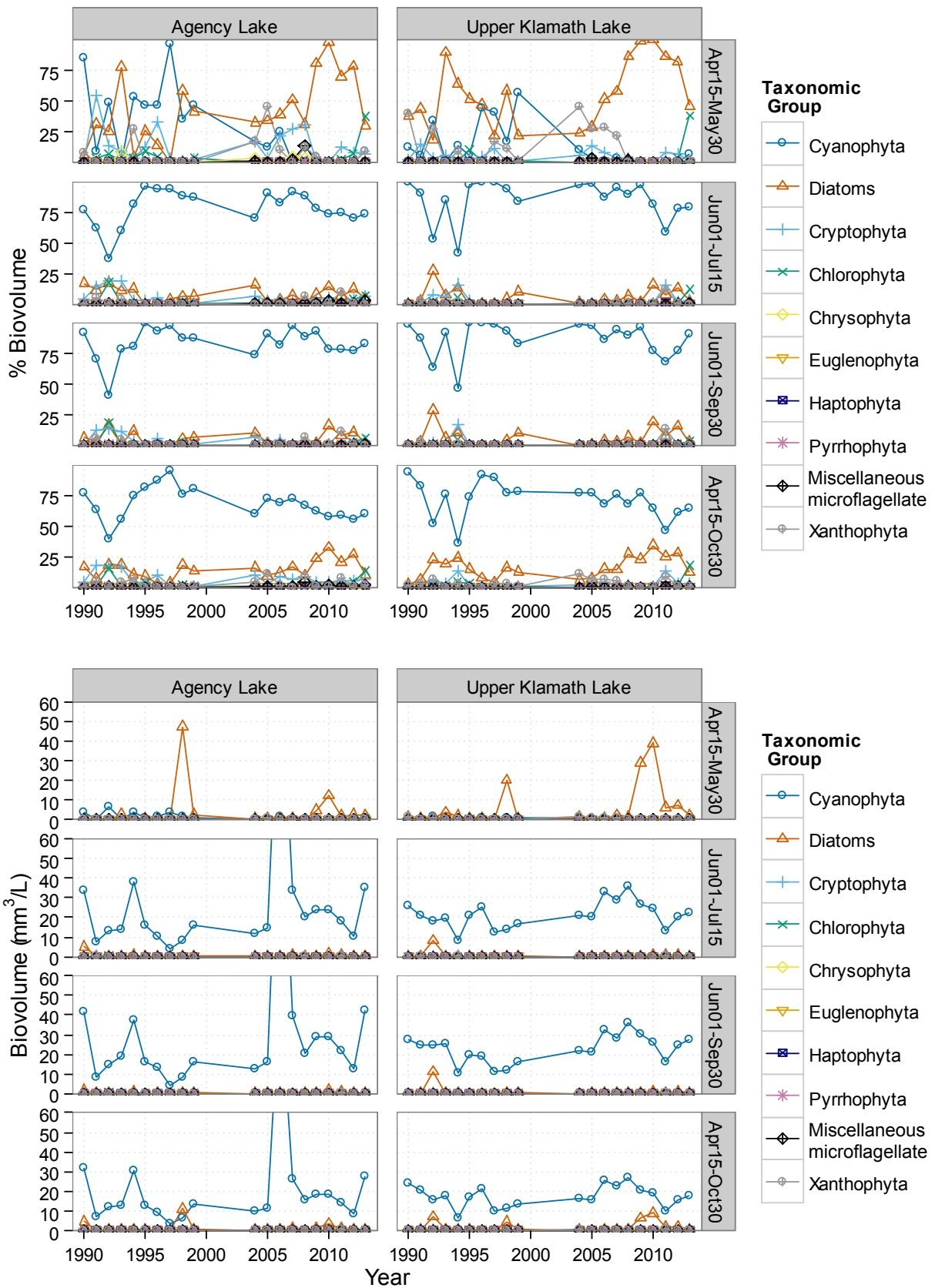


Figure 21. Lake-wide averages of percent biovolume (top four panels) and biovolume (bottom four panels) of phytoplankton taxonomic groups in Agency (left panels) and Upper Klamath (right panels) lakes in four seasonal periods (April 15 - May 30, June 1- July 15, June 1-September 30, and April 15 - October 31), 1990-2013. Note missing four years between 2000 and 2003.

3.3 STANDARDIZATION OF ZOOPLANKTON DATA

Several versions of the zooplankton database were prepared, each with its own intended use. This section (3.3) briefly summarizes their contents and the following sections (3.3.1, 3.3.2, and 3.3.3) provide details on how they were generated.

The “**original database**” version retains the original data as reported by the laboratories (without any taxonomic standardization/renaming or re-calculation of biovolume) for archival purposes.

A second version titled “**partially standardized database**” includes: 1) a consistent abundance time series; 2) a consistent time series of standardized biomass; and 3) taxonomic updates to modern conventions (e.g., species that have been reassigned a new genus), applies a standardized name to taxa that were apparently misidentified (generally on a one-to-one basis, we generally did not combine multiple taxa in the “partially standardized database”), and corrects misspellings.

The third version, titled “**analysis database**” combined taxa to emphasize long-term comparability. For example, for some genera where species level identification varied among labs, species were combined to the genus level (see below). In addition, we excluded two rarely-detected benthic taxa (*Hyalella azteca* and Harpacticoida) from our analysis, because they are not zooplankton (see Section 3.3.2.2 below). Also, we excluded the protist *Diffflugia* sp. which was only identified by PhycoTech; previous laboratories did not count protists and would not have counted it even if it was observed (see Section 3.3.2.2 below). In addition, we excluded the rarely-detected (n=2) Cladoceran *Ilyocryptus spinifer* because the reported weight was extremely large and therefore either the identification or the weight is suspect (see Section 3.3.2.2 below).

A fourth version titled “**supplemental analysis database**” was also prepared which is identical to the “analysis database” for most taxa but splits the genus *Daphnia* into two size classes: *Daphnia pulicaria* (small)/*ambigua* and *Daphnia pulicaria*. This *Daphnia pulicaria* (small)/*ambigua* and *Daphnia pulicaria* supplemental time series is valid for 1997-2013, because prior to 1997 BSA only identified one taxa (*Daphnia schodleri*) in the genus *Daphnia*.

3.3.1 ESTIMATION OF MISSING BIOMASS DATA

Prior to taxonomic standardization, missing biomass data were estimated. For a small percentage of dates/site/species during 1990-2004, the laboratories did not provide biomass data. In such cases, we estimated biomass by multiplying abundance by the average size of an individual. Average sizes were calculated from biomass/abundance ratios from (in decreasing order of preference): 1) Lake-wide averages for a species from the same day (n=8), 2) Lake-wide averages for a species from adjacent sampling date (n=106), or 3) Long-term averages (n=25). There were a total of 140 unique species-date-sites (0.29% of 47784 in the entire 1990-2013 database) which occurred in 105 samples (3.1% of 3441 in the entire 1990-2013 database). An itemized list of the dates/sites/species in which biomass was estimated is included in Electronic Appendix 2. A scatterplot of the relationship between measured size and size estimated from adjacent samples indicates that this appears to an acceptable method for filling small gaps in biomass data (Figure 22).

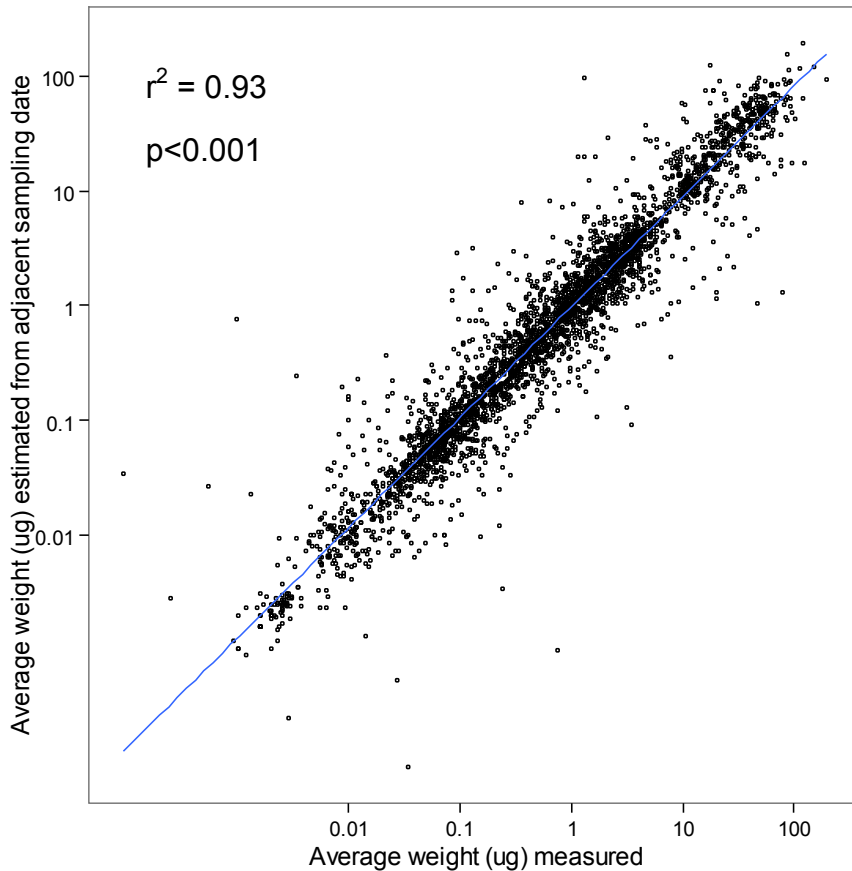


Figure 22. Scatterplot of relationship between measured weight and weight estimated from adjacent sampling date, for all species and samples in 1990-2007 dataset ($n = 4045$). Regression r^2 is with both variables log-transformed.

3.3.2 TAXONOMIC STANDARDIZATION

3.3.2.1 PROCESSES AND TOOLS USED FOR STANDARDIZATION

Similar but not identical to the process for phytoplankton, the taxonomic standardization protocol for zooplankton included utilization of the following steps and resources:

1. Reviewed archived slides and consult taxonomic keys to confirm PhycoTech's taxa identification

For the same reasons noted regarding phytoplankton in section 3.1.1.1 above, the PhycoTech identifications formed the basis for the 1990-2013 taxa standardization process. Dr. St. Amand was able to review previous 2005-2013 slides to confirm identification and compare similar species.

2. Counted detections by each lab/year

A summary table was created showing the number of detections of each taxa for each year and lab (Table 9). This table was then reviewed to find cases where a taxa was consistently (i.e., all or most years) detected by a lab, but then was not detected by other labs.

3. Calculated average animal weight

We calculated average weight for each sample and species by dividing biomass by cell density. Then we calculated mean and median for each species and each lab (Table 9). Examining these weights provided insight into each lab's taxa identifications (i.e., we could use weights to infer which PhycoTech taxa a previous lab might have misidentified). In addition to examining long-term mean and median weights for each lab, for some species we also examined boxplots of weight variation across years, which when used in conjunction with detections of each species for each lab/year, indicates shifts in BSA identification of taxa (e.g., Figure 24).

4. Reviewed previous taxonomic standardization efforts

As noted above regarding phytoplankton in section 3.1.1.1 above, project phycologist Dr. St. Amand has previously conducted taxonomic standardization and QA/QC efforts, including with all of the same labs involved with Klamath Lake algal and zooplankton samples from 1990-2007.

5. Graphical evaluation of seasonality

We constructed and reviewed graphs showing relative and absolute density and biovolume to evaluate in which months a taxa was prevalent.

Table 9. List of zooplankton taxa in the “original database” for Upper Klamath and Agency Lakes, sorted by taxa group and showing species standardization, mean and median average weight for each laboratory, and detections per year. Key to taxa codes: TCALA = Calanoid Copepods Adult, TCALI = Calanoid Copepods (copepodids) Immature, TCYCA = Cyclopoid Copepods Adult, TCYCI = Cyclopoid Copepods (copepodids) Immature, TCLADA = Cladocera Adult, TCLADI = Cladocera Immature, TNAUP = Copepoda Nauplii, THARA = Harpacticoid Copepods Adult, TOSTR = Ostracoda, TPROT = Protists, TROTI = Rotifera.

Taxa Group Code	Species Name			Weight (um ³ /animal)						Detections Per Lab-Year																							
	Analysis Database	Partially Standardized Database	Original Database	BSA calc mean	BSA calc med	UW calc mean	UW calc med	PT calc mean	PT calc med	BSA													UW	PhycoTech									
										1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
				Total number of samples→						130	143	130	130	72	174	46	102	132	106	149	119	109	118	130	191	209	224	130	168	167	172	195	198
TCALA	Epischura nevadensis	Epischura nevadensis	Epischura nevadensis	10.51	5.83	50.33	49.84	10.13	9.65	47	87	87	69	7	3	5	2	23		3	18	8	7	31	1	11	10	6	13	11	27	12	26
TCALA	Leptodiatomus ashlandi	Leptodiatomus ashlandi	Leptodiatomus ashlandi	3.28	3.18	5.68	5.29	3.72	3.79	103			1	47	86	33	93	105	62	89	91	76	99	120	67	114	81	49	78	44	96	111	125
TCALI	Calanoid copepodid	Calanoid copepodid	Calanoid copepodid	0.61	0.44	0.45	0.45	1.54	1.46	103	72	56	50	34	59	30	67	87	39	59	54	49	58	88	75	116	101	63	49	45	107	135	141
TCLADI	Cladocera Immature	Cladocera Immature	Cladocera Immature	1.55	1.60			1.94	1.83								24	4	5	5	21	7	31			3	15	2				1	
TCLADI	Cladocera Immature	Cladocera Immature	Daphnia sp. Neonate	0.90	0.73					60	50	25	21	15	57	13																	
TCLADI	Cladocera Immature	Cladocera Immature	Daphnia (neonates)					1.98	1.84																37	41	11	2	15	5	8	13	19
TCYCA	Acanthocyclops vernalis	Acanthocyclops vernalis	Acanthocyclops vernalis	6.15	6.26			12.05	11.05	87			1									2		4	4	3	2	9		7			
TCYCA	Diacyclops thomasi	Diacyclops thomasi	Diacyclops thomasi	1.74	1.68	2.97	2.73	3.20	3.21	34	115	88	61	66	128	42	84	63	48	70	63	65	99	124	71	71	70	27	49	43	55	38	57
TCYCA	Eucyclops agilis	Eucyclops agilis	Eucyclops agilis	2.00	2.08					4			34		2																		
TCYCA	Eucyclops speratus	Eucyclops speratus	Eucyclops speratus	1.70	1.70					1																							
TCYCA	Macrocyclus albidus	Macrocyclus albidus	Macrocyclus albidus	4.86	4.47					11		7	2			1																	
TCYCA	Tropocyclops prasinus	Tropocyclops prasinus	Tropocyclops prasinus	1.55	1.57			2.34	2.36												6	1		2	1	2		1					
TCYCI	Cyclopoid copepodid	Cyclopoid copepodid	Cyclopoid copepodid	0.27	0.24	0.28	0.28	0.89	0.76	119	111	72	82	58	136	42	74	70	57	63	73	51	83	104	146	136	118	89	115	86	115	118	138
THARA		Harpacticoida	Harpacticoida	0.77	0.72					3				2		1																	
TNAUP	Copepoda Nauplii	Copepoda Nauplii	Copepoda Nauplii					0.12	0.12																184	202	205	116	160	144	162	189	193
TNAUP	Copepoda Nauplii	Copepoda Nauplii	Nauplii	0.87	0.88	0.93	0.93			128	141	121	128	72	174	46	97	126	100	122	113	101	111	129									
TOSTR	Podocopa sp	Podocopa sp	Ostracods Candona sp	4.01	4.01										2																		
TOSTR	Podocopa sp	Podocopa sp	Ostracods Cyclocypria sp	0.99	0.99											2																	
TOSTR	Podocopa sp	Podocopa sp	Podocopa sp					42.20	42.20																1	1	1				1	1	2
TCLADA	Alona sp. with eggs	Alona affinis	Alona affinis	0.42	0.16					16	4	1		1	4																		
TCLADA	Alona sp. with eggs	Alona guttata	Alona guttata	0.65	0.66			1.43	0.75					1	1	5			1						1	1			1				
TCLADA	Alona sp. with eggs	Alona sp. with eggs	Alona sp. with eggs					0.40	0.40																								
TCLADA	Alona sp. with eggs	Alona sp. with eggs	Alona sp	1.15	1.15																												
TCLADA	Acroperus harpae	Acroperus harpae	Acroperus harpae	1.48	1.80					1	2																						
TCLADA	Bosmina longirostris	Bosmina longirostris	Bosmina longirostris	1.38	1.11			1.16	0.98	5	5	2	8	8	21	2	7	1											18		1		
TCLADA	Ceriodaphnia sp	Ceriodaphnia pulchella	Ceriodaphnia pulchella	0.87	0.87											2																	
TCLADA	Ceriodaphnia sp	Ceriodaphnia reticulata	Ceriodaphnia reticulata	2.32	1.50			0.89	0.89	17	7	5	6	5	16		3	3				2										1	
TCLADA	Chydorus sphaericus	Chydorus sphaericus	Chydorus sphaericus	0.98	0.87	2.04	1.89	1.36	1.34	111	89	56	67	15	111	19	56	59	47	50	84	29	82	102	103	91	144	49	96	4	3	3	2
TCLADA	Camptocercus sp	Camptocercus sp	Camptocercus sp														1																
TCLADA	Daphnia sp	Daphnia ambigua	Daphnia ambigua					3.70	3.75																104	107	104	57	62	70	50	66	64
TCLADA	Daphnia sp	Daphnia pulicaria (small)	Daphnia pulicaria (small)					10.37	10.22																16	113	109	69	66	51	65	55	60
TCLADA	Daphnia sp	Daphnia pulicaria (small)	Daphnia schodleri	15.44	12.97	17.17	16.73										97	92	73	134	96	74	60	78									
TCLADA	Daphnia sp	Daphnia pulicaria	Daphnia pulicaria	37.22	35.66	34.67	37.59	37.34	30.33								7	101	61	125	95	75	70	96	186	201	201	107	143	146	146	148	159
TCLADA	Daphnia sp	Daphnia pulicaria	Daphnia pulex	33.46	37.20												15																
TCLADA	Daphnia sp	Daphnia pulicaria	Daphnia schodleri (1990-1996)	56.58	53.19					129	143	84	112	59	146	46																	
TCLADA	Daphnia sp	Daphnia rosea	Daphnia rosea					99.63	91.68																	1	1				1	1	1
TCLADA	Daphnia sp	Daphnia sp	Daphnia dentifera					55.42	55.42																1								

3.3.2.2 ISSUES ADDRESSED DURING STANDARDIZATION PROCESS

During the standardization process, we encountered and addressed an array of issues.

1. Varying levels of taxonomic detail

The labs varied in their lumping and splitting of taxa. Some identified a taxa to genus, some to species, and some to variety/sub-species). UW generally identified taxa to a less level of detail than the other labs, as demonstrated by the total number of taxa identified by each lab: BSA 87, UW 13, and PhycoTech 51. Some species were only identified in samples collected in Pelican Bay (PB), a unique habitat which was sampled only in 1990-1997 and therefore only analyzed by BSA, providing a partial explanation of why BSA identified a greater number of taxa than PhycoTech.

2. *Daphnia*: species identification and weights

Cladocerans in the genus *Daphnia* can reach high densities and have the largest body size of any common zooplankton within UKL and Agency Lake. Current taxonomy from PhycoTech's 2005-2013 samples identifies two common *Daphnia* species, the large *D. pulicaria* and very small *D. ambigua*, as well as two rare species (*D. rosea* and *D. dentifera*) (Figure 24). In addition, to maintain consistency with the 1997-2004 samples, PhycoTech differentiated *D. pulicaria* into two size classes in its counts: *D. pulicaria* and *D. pulicaria* ≤ 1.15 mm, which we refer to in this report as "*D. pulicaria* (small)". This taxonomic understanding was developed in 2005-2006 through extensive correspondence between Dr. St. Amand, zooplankton expert Dr. Allan Vogel (ZP's Taxonomic Services, Salem, OR), Dr. Kann, and Dr. Brett. A unique identifying characteristic of *D. ambigua* is the lack teeth on its claw pecten (Herbert 1995), which the small *D. pulicaria* have (Figure 23).



Figure 23. Teeth on *Daphnia pulicaria* claw.

The level of taxonomic precision for identifying adult taxa within the genus *Daphnia* increased over the study period, and it is clear that from examining calculated average weights that BSA changed its identification of species over time (Figure 24, Table 9). In the 1990-1996 BSA samples, all *Daphnia* were lumped into a single taxa *D. schodleri*. In 1997 BSA identified three

Daphnia taxa: *D. pulicaria* and *D. pulex* (which we determined to both be *D. pulicaria*) and *D. schodleri* (which we determined to be *D. pulicaria* [small]). Identifications by BSA in 1997-2003 and UW in 2004 were the same as by BSA 1997 except that *D. pulex* was only found in 1997. These inconsistencies forced us to lump all *Daphnia* adults for our primary analysis, though for a supplemental analysis valid from 1997-2013, we separate adult *Daphnia* into three groups: *Daphnia pulicaria* (small)/*ambigua*, *Daphnia pulicaria*, and *Daphnia* sp. (Table 9).

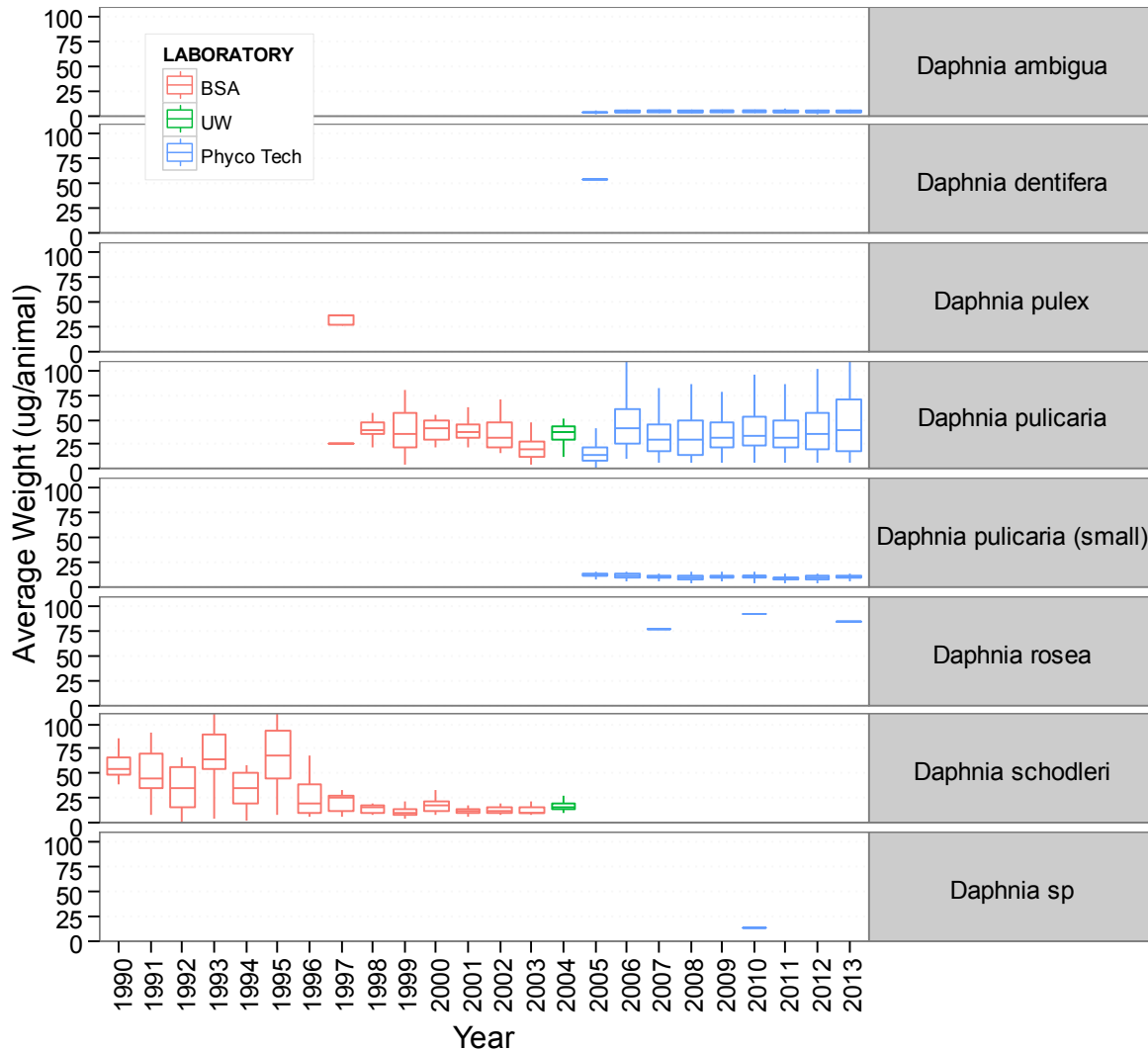


Figure 24. Boxplot of average weight of adults in the genus *Daphnia* for all samples 1990-2013 (all dates and sites), prior to standardization. Outliers are not shown.

In addition to standardizing identification of *Daphnia* taxa, we also adjusted biomass. When PhycoTech began analyzing samples, Dr. St. Amand observed that the length-weight regressions from McCauley (1984) used by BSA and UW in 1990-2004 for *Daphnia pulicaria* and *Daphnia schodleri* (Table 10) resulted in higher weights than the Bottrell et al. (1976) regression used by PhycoTech outside the Klamath Basin (each paper contains regressions determined using slightly different age/sex/species groups which yields different biomass estimates per animal) (Figure 25). In an attempt to maintain consistency with the 1990-2004 data, PhycoTech then utilized the

same length/wt. regressions by BSA and UW. However, because BSA utilized two different regressions (one for *D. schodleri* and one for *D. pulicaria*) and we are now standardizing 1990-1996 *D. schodleri* to *D. pulicaria* and retaining 1997-2013 *D. pulicaria* as *D. pulicaria*, the 1990-2013 standardized *D. pulicaria* time series biomass would be based on two different length-weight regressions (unless adjusted). Therefore, we adjusted the 1990-1996 *D. schodleri* and 1997-2013 *D. pulicaria* biomass data to be consistent across the 1990-2013 period.

Because *Daphnia* lengths were not available for regression application for the early period of record²⁴ we used an alternate approach as follows: 1) we applied the three regressions shown in Figure 25 to all individual 2005-2013 *D. pulicaria* length measurements from PhycoTech's ASA System to calculate mean weights for each sample, 2) we then plotted the mean weight predicted by PhycoTech's preferred equation (Bottrell et al. 1976) against the mean weights predicted by the McCauley 1984 *schodleri* (Figure 26a) and McCauley 1984 *pulicaria* (Figure 26b) equations used by BSA, 3) we then modelled the relationships (power functions explain the relationships almost perfectly with r^2 values >0.999 ; Figure 26) and applied the resulting equations to all samples in our standardized databases to adjust average weights and re-calculate biomass²⁵. *D. dentifera* and *D. rosea* were not adjusted because their biomass was already calculated based on the Bottrell et al. (1976) regression. The adjusted weights follow expected patterns, with *D. schodleri* (subsequently standardized to *D. pulicaria* for analysis) in 1990-1996 (which was an undifferentiated mix of small and large *Daphnia*) showing weights between those of 1997-2013 when the larger (*D. pulicaria* and *D. pulex*) and smaller taxa (*D. schodleri* and *D. pulicaria* [small]) taxa were differentiated (Figure 27). Due to the extremely high r^2 , this approach should result in a nearly identical outcome to acquiring and compiling original length measurements and re-applying standardized taxa-specific length-weight regressions. Thus biomass for the final lumped adult *Daphnia* category is now standardized over the 1990-2013 period of record.

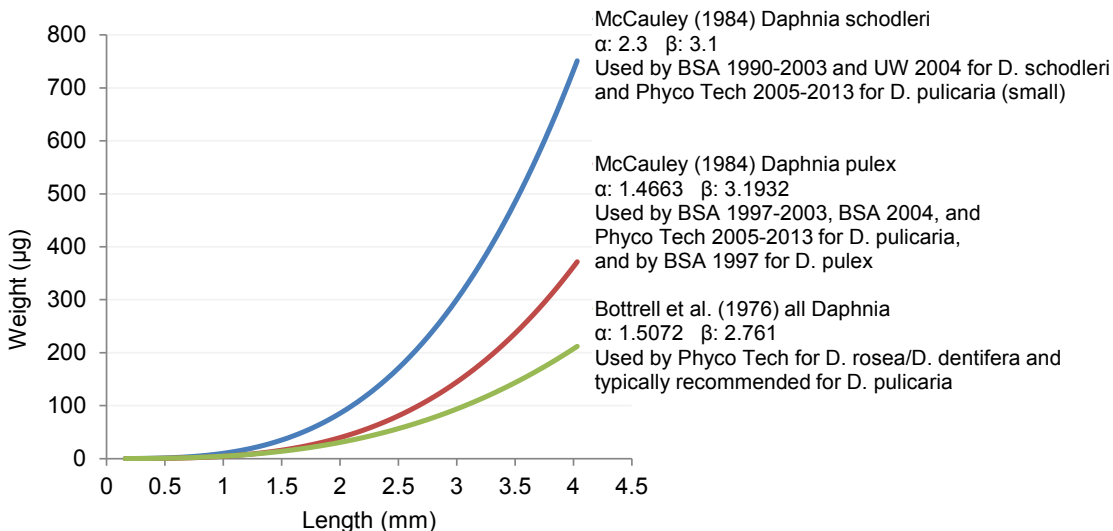


Figure 25. Three length-weight regressions used by BSA, UW, and PhycoTech to calculate individual weights of major *Daphnia* species from measured lengths. α and β are regression coefficients. The range of lengths shown is based on PhycoTech's 2005-2013 measurements ($n = 9617$).

²⁴ The laboratory's original data files containing length measurements were not available for this effort.

²⁵ *D. pulicaria* and *D. pulex* were adjusted using the equation in Figure 26b, and *D. pulicaria* (small) and *D. schodleri* were adjusted using the equation in Figure 26a.

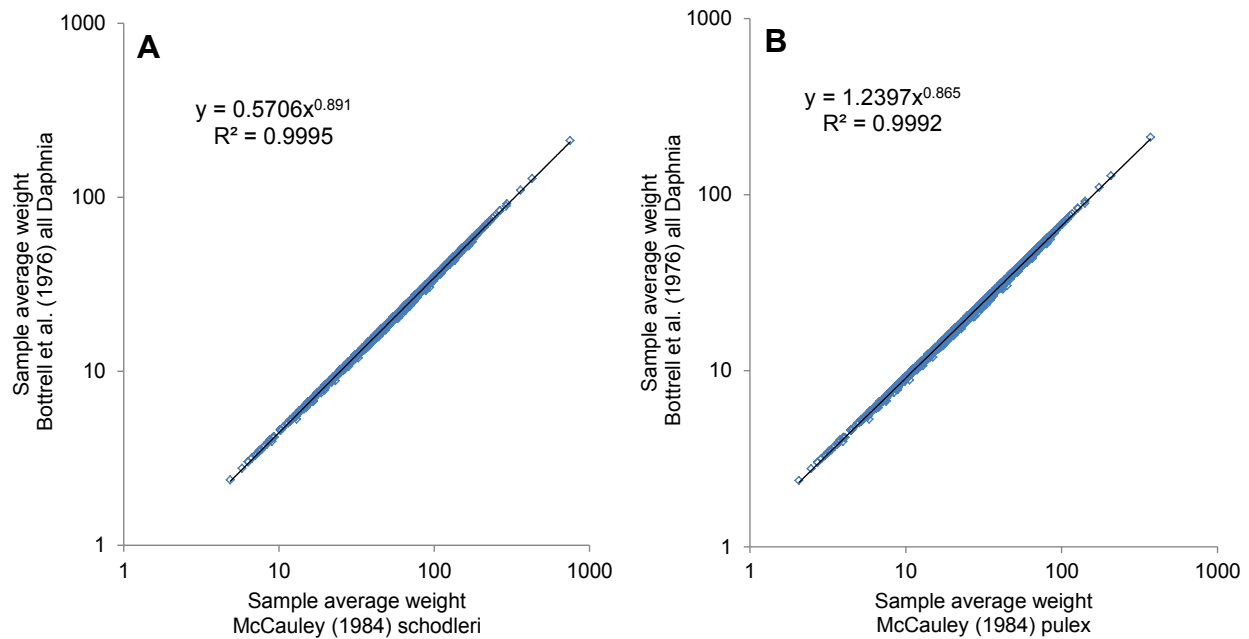


Figure 26. Comparison of *Daphnia* mean weight predicted by Phycotech's preferred equation (Bottrell et al. 1976) and mean weights predicted by the McCauley 1984 *D. schodleri* equation (A) and McCauley 1984 *D. pulicaria* equation (B) equations used by BSA. Axes shown with logged scales for visual clarity, but power regression was applied to unlogged values. n = 9617.

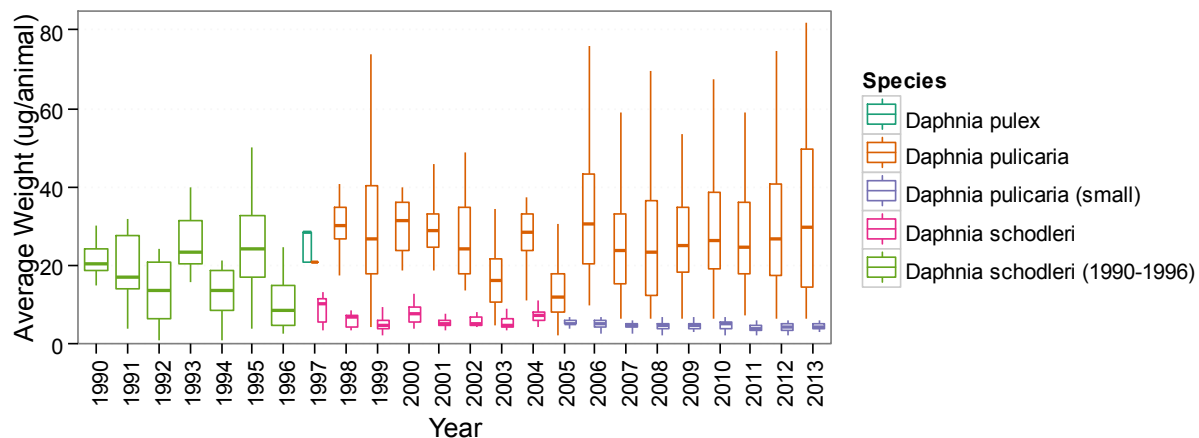


Figure 27. Boxplot of average weight of *Daphnia pulicaria* and *Daphnia schodleri* for all samples 1990-2013 (all dates and sites), after weights were adjusted to Bottrell et al. (1976). Outliers are not shown.

In addition to the *Daphnia* adults described above, laboratories identified immature *Daphnia* as both *Daphnia* Immature/Neonate (BSA 1990-1996, Phycotech 2005-2013) and Cladocera Immature (BSA 1997-2003, Phycotech 2006-2012). For the standardized database and analyses, we standardized these to the order-level: Cladocera Immature. UW did not identify any immature *Daphnia* or Cladocerans and it is unclear whether those individuals were not counted or whether they were lumped into another group.

Table 10. List of zooplankton taxa in the “original database” for Upper Klamath and Agency Lakes, sorted by taxa group and showing our calculation of mean and median average weight (biomass divided by abundance) for each laboratory, detections per lab, and regression coefficients used by each lab to calculate size from length and/or weight. Key to taxa codes: TCALA = Calanoid Copepods Adult, TCALI = Calanoid Copepods (copepodids) Immature, TCYCA = Cyclopoid Copepods Adult, TCYCI = Cyclopoid Copepods (copepodids) Immature, TCLADA = Cladocera Adult, TCLADI = Cladocera Immature, TNAUP = Copepoda Nauplii, THARA = Harpacticoid Copepods Adult, TOSTR = Ostracoda, TPROT = Protists, TROTI = Rotifera. † = regression equation unknown because original source files are no longer available.

Taxa Group Code	Original Taxa Name	Weight (um ³ /animal)						Detections Per Lab				Length/Weight Regression Coefficients						Other Formula		
		BSA calc mean	BSA calc med	UW calc mean	UW calc med	PT calc mean	PT calc med	BSA 1990-1996	BSA 1997-2003	UW 2004	Phyco Tech 2005-2013	BSA alpha	UW alpha	PT alpha	BSA beta	UW beta	PT beta	BSA	UW	PT
TCALA	Epischura nevadensis	10.510	5.828	50.333	49.839	10.128	9.645	305	61	31	117	2.0186	2.0186	1.2519	1.9948	1.9948	2.0712			
TCALA	Leptodiaptomus ashlandi	3.278	3.184	5.679	5.291	3.721	3.788	270	615	120	765	1.0332	1.0332	1.0332	2.6060	2.6060	2.6060			
TCALI	Calanoid copepodid	0.613	0.442	0.454	0.454	1.537	1.464	404	413	88	832	1.0332		1.1017	2.6060		1.7064	0.454		
TCLADA	Alona affinis	0.416	0.156					26	0	0	0	†			†					
TCLADA	Alona guttata	0.653	0.662			1.425	0.753	7	1	0	3	†		3.1261	†		3.1261			
TCLADA	Alona sp. with eggs					0.403	0.403	0	0	0	1			2.7676			3.8400			
TCLADA	Alona sp	1.146	1.146					0	1	0	0	†			†					
TCLADA	Acroperus harpae	1.476	1.800					3	0	0	0	†			†					
TCLADA	Bosmina longirostris	1.379	1.112			1.158	0.979	51	8	0	19	2.7116		2.7359	2.5294		2.8807			
TCLADA	Ceriodaphnia pulchella	0.873	0.873					2	0	0	0	2.8300			3.1500					
TCLADA	Ceriodaphnia reticulata	2.317	1.502			0.889	0.889	56	8	0	1	2.8300		2.4699	3.1500		2.7036			
TCLADA	Chydorus sphaericus	0.978	0.870	2.043	1.891	1.362	1.344	468	407	102	495	4.5430		2.6447	3.6360		1.9796			
TCLADA	Camptocercus sp							0	1	0	0	†			†					
TCLADA	Daphnia ambigua					3.700	3.749	0	0	0	684			1.5400			2.2900			
TCLADA	Daphnia pulicaria (small)					10.366	10.224	0	0	0	604			2.3000			3.1000			
TCLADA	Daphnia schodleri	15.437	12.965	17.167	16.730			0	626	78	0		2.3000		3.1000					
TCLADA	Daphnia pulicaria	37.217	35.656	34.673	37.587	37.338	30.329	0	534	96	1437	1.4663	1.4663	1.4663	3.1932	3.1932	3.1932			
TCLADA	Daphnia pulex	33.458	37.195					0	15	0	0	1.4663			3.1932					
TCLADA	Daphnia schodleri (1990-1996)	56.575	53.187					719	0	0	0	2.3000			3.1000					
TCLADA	Daphnia rosea					99.634	91.679	0	0	0	5			1.5072			2.7610			
TCLADA	Daphnia dentifera					55.418	55.418	0	0	0	1			1.5072			2.7610			
TCLADA	Daphnia sp					13.778	13.778	0	0	0	1			1.9461			3.0557			
TCLADA	Diaphanosoma birgei	3.994	3.304			2.654	2.742	6	4	0	12	1.2894		1.1980	3.0390		2.8887			
TCLADA	Eubosmina coregoni					4.004	4.004	0	0	0	1			3.0871			2.3371			
TCLADA	Eurycercus lamellatus	176.99	42.61					12	0	0	0	†								
TCLADA	Graptoleberis testudinaria	1.087	0.742					3	0	0	0	†								
TCLADA	Leptadora kindtii	39.419	37.728			22.488	19.396	78	1	0	114	†		0.4450			1.8730			
TCLADA	Leydigia leydigi	0.418	0.418					2	0	0	0	†								
TCLADA	Pleuroxus procurvatus	1.088	1.088					2	0	0	0	†								
TCLADA	Pleuroxus striatus	2.804	2.770					6	0	0	0	†								
TCLADA	Pleuroxus sp	2.843	2.843					2	0	0	0	†								
TCLADA	Polyphemus pediculus	12.522	9.388					6	0	0	0	†								

Taxa Group Code	Original Taxa Name	Weight (um ³ /animal)						Detections Per Lab				Length/Weight Regression Coefficients						Other Formula		
		BSA calc mean	BSA calc med	UW calc mean	UW calc med	PT calc mean	PT calc med	BSA 1990-1996	BSA 1997-2003	UW 2004	Phyco Tech 2005-2013	BSA alpha	UW alpha	PT alpha	BSA beta	UW beta	PT beta	BSA	UW	PT
TCLADA	Scapholeberis sp	3.972	3.972					1	0	0	0	†								
TCLADA	Sida crystallina	10.205	8.806					8	0	0	0	†								
TCLADA	Simocephalus serrulatus	36.848	18.749					3	0	0	0	†								
TCLADA	Hyalella azteca	1745	872					5	1	0	0								29.65xL ³	
TCLADA	Ilyocryptus spinifer	1830	1830					2	0	0	0	†								
TCLADI	Cladocera Immature	1.547	1.602			1.935	1.832	0	97	0	21	2.3000			3.1000					
TCLADI	Daphnia sp. Neonate	0.898	0.729					241	0	0	0	†								
TCLADI	Daphnia (neonates)					1.984	1.841	0	0	0	151			2.4600				2.5200		
TCYCA	Acanthocyclops vernalis	6.154	6.256			12.052	11.052	88	2	0	29	†		2.2266				3.2300		
TCYCA	Diacyclops thomasi	1.739	1.683	2.971	2.726	3.204	3.211	534	492	124	481	0.9032	0.9032	1.0300	2.7307	2.7307	2.5050			
TCYCA	Eucyclops agilis	1.996	2.079					40	0	0	0	†								
TCYCA	Eucyclops speratus	1.699	1.699					1	0	0	0	†								
TCYCA	Macrocyclus albidus	4.859	4.466					20	1	0	0	2.0186			1.9948					
TCYCA	Tropocyclops prasinus	1.553	1.565			2.340	2.363	0	7	0	6	†		†	†			†		
TCYCI	Cyclopoid copepodid	0.269	0.239	0.280	0.280	0.885	0.759	620	471	104	1061	0.9032		1.0300	2.7307			2.5050	0.280	
THARA	Harpacticoida	0.770	0.723					5	1	0	0	0.9032			2.7307					
TNAUP	Copepoda Nauplii					0.124	0.116	0	0	0	1555			1.1017				1.7064		
TNAUP	Nauplii	0.874	0.875	0.925	0.925			810	770	129	0	0.6977	†		0.4690				0.925	
TOSTR	Ostracods Candona sp	4.009	4.009					2	0	0	0	†								
TOSTR	Ostracods Cyclocypria sp	0.987	0.987					2	0	0	0	†								
TOSTR	Podocopa sp					42.200	42.200	0	0	0	7									0.42
TPROT	Diffugia sp					0.113	0.115	0	0	0	36									0.52*L*W ²
TROTI	Asplanchna girodi	0.438	0.395	0.538	0.538	0.456	0.046	1	318	87	25				0.23*L ³	0.538		0.52*L*W ²		
TROTI	Asplanchna sieboldi	4.862	4.222					69	10	0	0				†					
TROTI	Ascomorpha sp					0.014	0.011	0	0	0	3									0.12*L ³
TROTI	Bdelloida	0.359	0.029					11	0	0	0									
TROTI	Brachionus angularis	0.046	0.051			0.074	0.074	90	3	0	64				0.12*L ³				0.12*L ³	
TROTI	Brachionus calyciflorus	0.437	0.496			0.181	0.085	68	27	0	46				†					0.12*L ³
TROTI	Brachionus caudatus	0.031	0.028					14	0	0	0				†					
TROTI	Brachionus havenensis	0.104	0.104			0.054	0.062	2	0	0	7				†					0.12*L ³
TROTI	Mytilinia ventralis	0.039	0.021					6	0	0	0				†					
TROTI	Brachionus quadridentatus	0.055	0.067					7	0	0	0				†					
TROTI	Brachionus ureolaris	0.036	0.033					15	0	0	0				†					
TROTI	Colletheca pelagica	0.004	0.004					3	0	0	0				†					
TROTI	Conochilus unicornis	0.038	0.009			0.010	0.009	242	21	0	381				†					0.26*L*W ²
TROTI	Sinantherina sp	0.110	0.110					1	0	0	0				†					
TROTI	Epiphanes sp	0.434	0.311					10	0	0	0				†					
TROTI	Euchlanis alata					0.136	0.133	0	0	0	889									0.1*L ³
TROTI	Euchlanis calpidia	0.183	0.164					203	4	0	0									0.1*L ³

Taxa Group Code	Original Taxa Name	Weight (um ³ /animal)						Detections Per Lab				Length/Weight Regression Coefficients						Other Formula			
		BSA calc mean	BSA calc med	UW calc mean	UW calc med	PT calc mean	PT calc med	BSA 1990-1996	BSA 1997-2003	UW 2004	Phyco Tech 2005-2013	BSA alpha	UW alpha	PT alpha	BSA beta	UW beta	PT beta	BSA	UW	PT	
TROTI	Euchlanis dialata	0.083	0.061					516	0	0	0								†		
TROTI	Euchlanis sp	0.177	0.170					0	127	0	0								†		
TROTI	Filinia longiseta	0.079	0.075			0.025	0.020	34	1	0	32								†		0.52*L*W^2
TROTI	Gastropus hyptopus	0.043	0.044			0.025	0.024	43	0	0	36								†		0.20*L^3
TROTI	Hexarthra mira	0.060	0.060					3	0	0	0								†		
TROTI	Keratella cochlearis	0.004	0.002			0.007	0.007	258	80	0	303										0.02*L^3 0.13*L*W^2
TROTI	Keratella quadrata	0.066	0.071	0.083	0.083	0.120	0.114	469	311	74	741										0.22*L^3*1.05 0.083 0.22*L^3
TROTI	Keratella serrulata	0.052	0.051					21	0	0	0								†		
TROTI	Kellicottia longispina					0.047	0.047	0	0	0	2										0.26*L*W^2
TROTI	Lecane sp	0.048	0.036			0.016	0.010	20	10	0	15										0.1*L^3 0.52*L*W^D
TROTI	Lepadella ovalis	0.009	0.010					13	0	0	0								†		
TROTI	Monommata longiseta	0.019	0.019					1	0	0	0								†		
TROTI	Monostyla bulla	0.021	0.018			0.206	0.206	10	0	0	1								†		0.52*L*W^D
TROTI	Monostyla quadridenta	0.023	0.023					3	0	0	0								†		
TROTI	Notholca acuminata	0.013	0.010			0.021	0.022	80	3	0	44										0.035*L^3 0.035*L^3
TROTI	Notholca foliacea	0.004	0.004					1	0	0	0								†		
TROTI	Notholca squamula					0.028	0.019	0	0	0	10										0.035*L^3
TROTI	Platylas quadricornis	0.097	0.097					2	0	0	0								†		
TROTI	Philodina sp					0.013	0.015	0	0	0	6										0.52*L*W^2
TROTI	Pompholyx sulcata	0.032	0.015			0.054	0.032	26	0	0	66								†		0.52*L*W^2
TROTI	Polyarthra dolichoptera	0.042	0.042			0.056	0.051	290	25	0	450										0.28*L^3 0.28*L^3
TROTI	Polyarthra vulgaris	0.062	0.058	0.077	0.077			0	28	8	0										0.28*L^3
TROTI	Ploesoma sp	2.884	2.884					1	0	0	0								†		
TROTI	Ptygura sp					0.002	0.002	0	0	0	5										0.26*L*W^2
TROTI	Proales sp	0.028	0.023					57	0	0	0								†		
TROTI	Proales sp2	0.023	0.023					79	0	0	0								†		
TROTI	Rotaria sp					0.138	0.063	0	0	0	3										0.52*L*W^2
TROTI	Scardium longicaudam	0.038	0.038					1	0	0	0								†		
TROTI	Synchaeta lakowitziana	0.031	0.022					21	0	0	0								†		
TROTI	Synchaeta pectinata	0.105	0.093	0.111	0.111	0.050	0.016	214	108	17	508										0.1*L^3 0.111 0.26*L*W^2
TROTI	Synchaeta sp					0.011	0.011	0	0	0	1										0.26*L*W^2
TROTI	Trichotria pocillum	0.086	0.061					11	0	0	0								†		
TROTI	Testudinella parva	0.482	0.482					1	0	0	0								†		
TROTI	Testudinella patina	0.049	0.047					2	1	0	0										0.08*L^3*1.1
TROTI	Trichocerca elongata	0.189	0.179			0.010	0.010	14	0	0	1								†		0.52*L*W^2
TROTI	Trichocerca sp	0.077	0.092			0.028	0.014	11	0	0	24								†		

3. Cyclopoid Copepods: differentiation of adults/immature and weight

The most common Copepods in UKL and Agency Lake are *Diacyclops thomasi* in the Cyclopoida order (discussed in this section) and *Leptodiatomus ashlandi* and *Epischura nevadensis* in the Calanoida order (discussed in the following section) (Table 9). The Copepod life cycle begins with eggs, then progresses through five naupliar instars and five copepodid instars before coming adults. Examination of time series trends in abundance and average weight and of Cyclopoid copepodids and *Diacyclops thomasi* indicates a shift following the change in labs to PhycoTech, with higher abundance of copepodids and lower abundance of *Diacyclops thomasi* (Figure 28b). For Cyclopoid Copepods, we have ascertained that BSA was differentiating between copepodids and adults based on size (threshold length of approximately 0.75 mm where fourth and fifth instars look large and very similar to adults with the exception of the relative length of the last urosomal segment) rather than on true sexual maturity, so the fourth and fifth copepodid instars were incorrectly counted as adults. Fourth and Fifth instar Cyclopoid copepodids will be foraging similar to adults, so ecologically, they are very similar with the exception of fecundity.

It is not possible to retroactively adjust Cyclopoid copepodids and adults in the 1990-2004 samples; however, because PhycoTech maintains all their individual length measurements within the ASA System, we were able to obtain a consistent 1990-2013 time series of Cyclopoid copepodids and adults for the standardized databases by adjusting the 2005-2013 data to match the 1990-2004 methods. We queried the individual length measurements of Cyclopoid copepodids from 2005-2013 samples in the ASA System and determined that 28% (844 of 3008) of the copepodids had a length >0.75 mm (see rationale in previous paragraph). Therefore, for the standardized databases we adjusted the 2005-2013 results, transferring 28% of the abundance of Cyclopoid copepodids over to *Diacyclops thomasi* (this species accounts for the vast majority Cyclopoid adults within our samples).

The average weights of Cyclopoid copepodids appear to be substantially lower in the 1990-2004 BSA/UW data than in the 2005-2013 PhycoTech data (Figure 28a). Length/weight regression equations were similar (though not identical, Table 10), so this weight difference is likely due to the mistaken identification of fourth and fifth copepodid instars as adults. Therefore, in the standardized databases, we re-calculated all 1990-2013 biomass data using a weight of 0.512 µg/individual for Cyclopoid copepodids²⁶ and a weight of 2.686 µg/individual for *Diacyclops thomasi*²⁷.

4. Calanoid Copepods: species identifications and weight

Differentiating between copepodids and adults is easier for Calanoid Copepods than it is for Cyclopoid Copepods because the adult reproductive structures are more visible, Females have hook like grasping elements and males have a sclerotized spiniform process with the proximal part fused to the segment, and it appears that BSA differentiated in the same fashion as PhycoTech for Calanoid Copepods (i.e., no major difference in abundance between BSA and PhycoTech, Figure 29b).

²⁶ Derived by applying a length-weight regression to the 0.507 mm mean length from 3008 PhycoTech measurements

²⁷ Derived by applying a length-weight regression to the 0.983 mm mean length from 1645 PhycoTech measurements

As with the Cyclopoid copepodids, the average weights of Calanoid copepodids are lower in the 1990-2004 BSA/UW data than in the 2005-2013 PhycoTech data (Figure 29a). This is likely due to the use of different regression equations (Table 10). Therefore, in the standardized databases, we re-calculated all 1990-2013 data using a weight of 1.401 μg /individual for Calanoid copepodids²⁸.

There also appears to be an issue in the BSA data with inconsistent identification of *Leptodiaptomus ashlandi* and *Epischura nevadensis*, the two dominant species of Calanoid Copepods. In all years except 1991-1993, the abundance of *Leptodiaptomus ashlandi* was far higher than *Epischura nevadensis*; however, in 1991-1993 *L. ashlandi* was not detected while *E. nevadensis* had high abundance (Figure 29b). *E. nevadensis* is typically larger than *L. ashlandi*, but average weights of *E. nevadensis* in 1991-1993 closely match those of *L. ashlandi* in the remaining years (i.e., Figure 29a), providing strong evidence that the high abundance of *E. nevadensis* in 1991-1993 was a result of erroneous identification and was in fact *L. ashlandi*. Thus, for our standardized databases, we changed all *E. nevadensis* with a mean weight $<7 \mu\text{g}$ ²⁹ in 1991-1993 to *L. ashlandi*, which results in annual mean abundances for both species similar to those in the remainder of the years (Figure 30) corroborating the standardization process. After standardization, the mean ratio of *E. nevadensis*: *L. ashlandi* abundance for 1991-1993 BSA (0.058, i.e., 5.8%) is intermediate between the ratio for the remaining BSA years (0.025) and 2005-2013 PhycoTech (0.074). Mean weights for *E. nevadensis* were substantially higher in the BSA and UW data (excluding the erroneous 1991-1993 data) than in the PhycoTech data, apparently due to the use of different length-weight regressions (Table 10); therefore, in the standardized databases, we re-calculated all 1990-2013 biomass data using a weight of 10.13 μg /individual for *E. nevadensis*³⁰.

²⁸ Derived by applying a length-weight regression to the 0.639 mm mean length from 3300 PhycoTech measurements

²⁹ Graphical analyses show a clear demarcation in size between the two species at 7 μg (data not shown).

³⁰ The mean weight calculated from 514 samples in which PhycoTech found *E. nevadensis*.

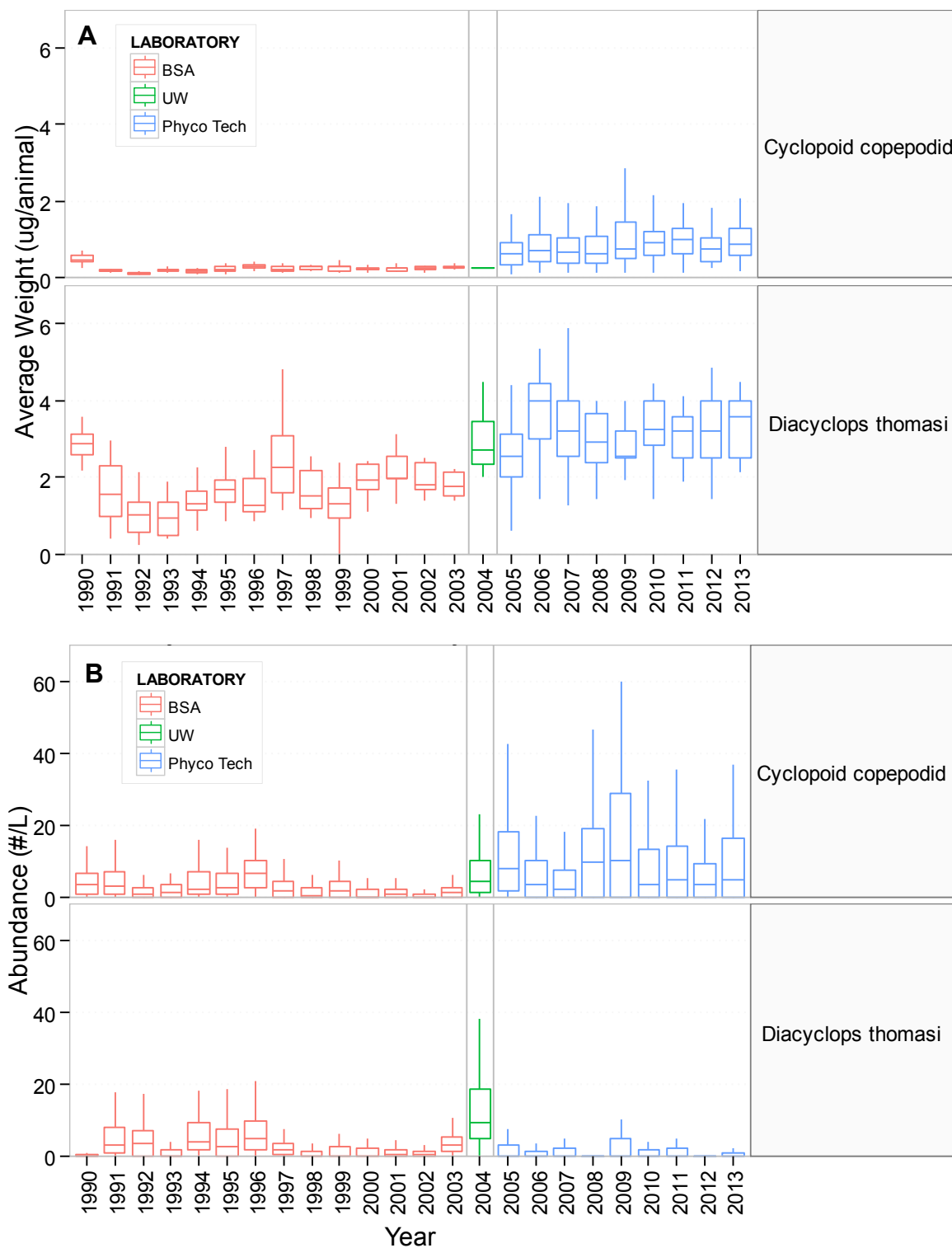


Figure 28. Boxplots of (A) average weight and (B) abundance of Cyclopoid Copepodids and *Diacyclops thomasi* for all samples (all dates and sites) 1990-2013. Outliers are not shown.

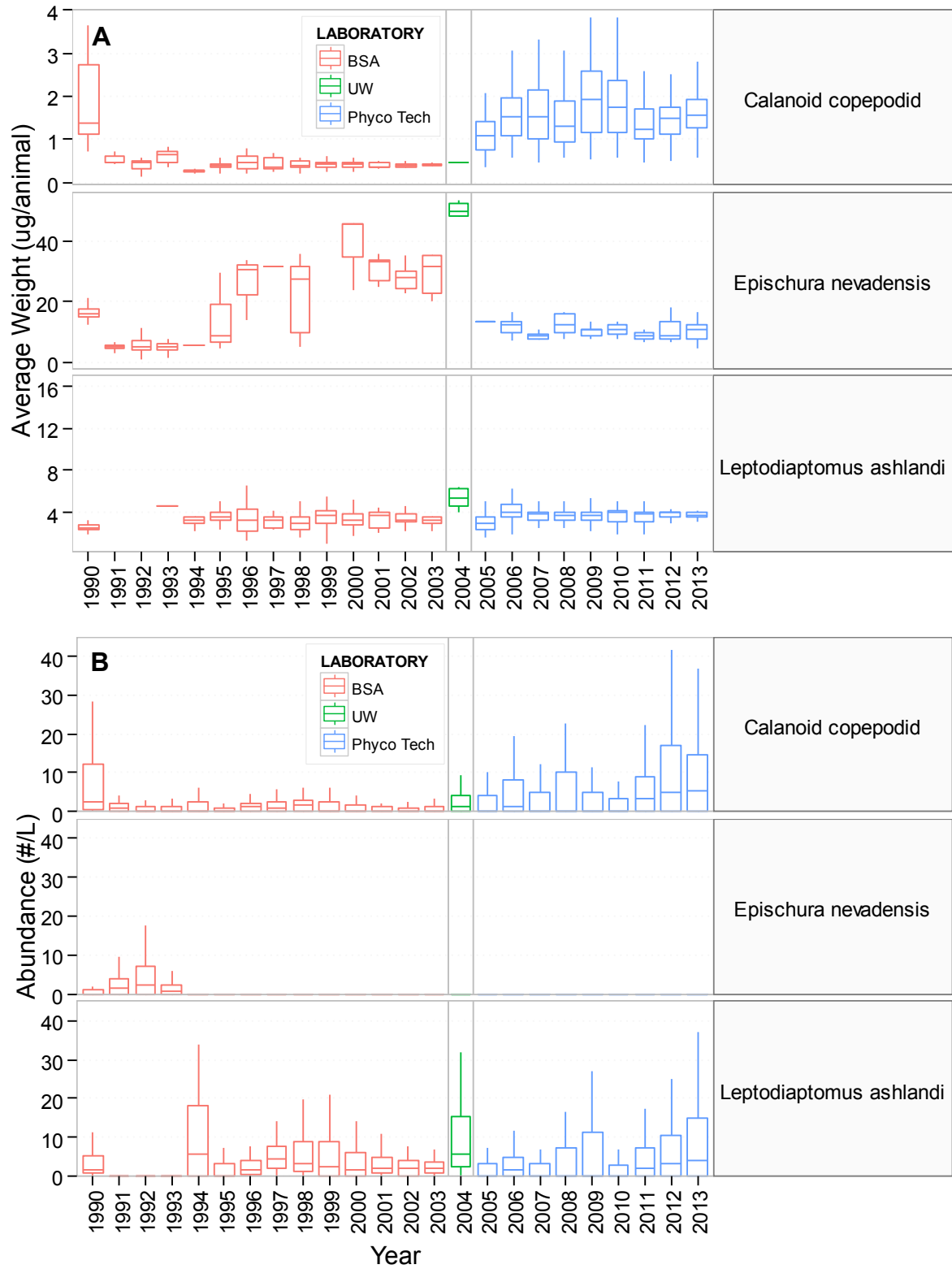


Figure 29. Boxplots of (A) average weight and (B) abundance of Calanoid Copepodids, *Epischura nevadensis*, and *Leptodiaptomus ashlandi* for all samples 1990-2013 (all dates and sites). Outliers are not shown.

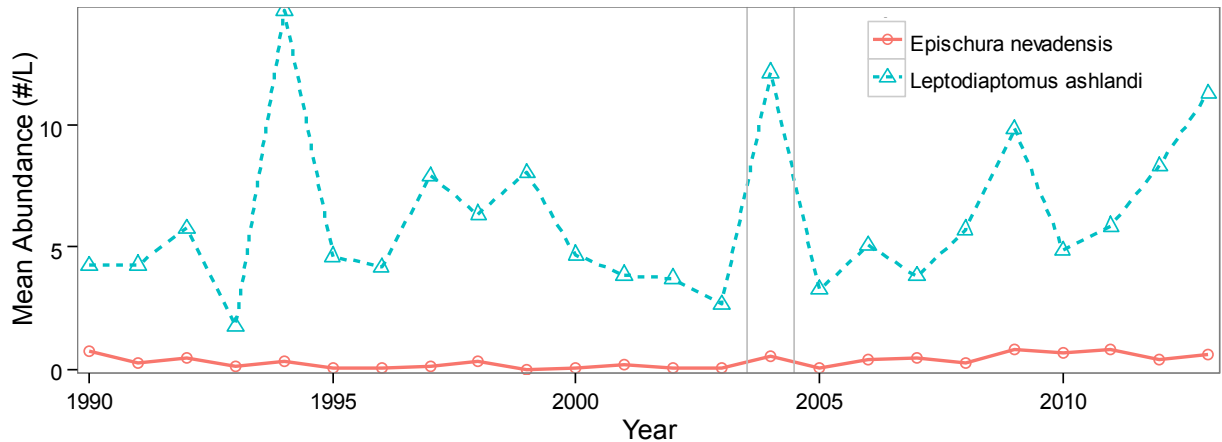


Figure 30. Time series of mean abundance of *Leptodiatomus ashlandi* and *Epischura nevadensis* for the April 15-October 30 periods at long-term stations in 1990-2013, after adjusting to correct apparently erroneous identification of *L. ashlandi* as *E. nevadensis* in 1991-1993.

5. Copepoda nauplii weight

Copepoda nauplii appear to have been properly identified by all laboratories, although abundances appear to be somewhat lower during 1997-2003 than other periods (Figure 31b). Average weight of Copepoda nauplii was much lower in the 1990-2003 BSA data and 2004 UW data than the 2005-2013 PhycoTech data (Figure 31a). We conducted a sensitivity analysis to compare the weights predicted by the length-weight regression used by PhycoTech and the length-weight regression used by BSA, and determined that the differences between the regression equations completely explain the difference in average weights; therefore, in the standardized databases, we re-calculated all 1990-2013 Copepoda nauplii biomass data using a weight of 0.120 $\mu\text{g}/\text{individual}$ ³¹.

³¹ Derived by applying a length-weight regression to the 0.151 mm mean length from 10,874 PhycoTech measurements

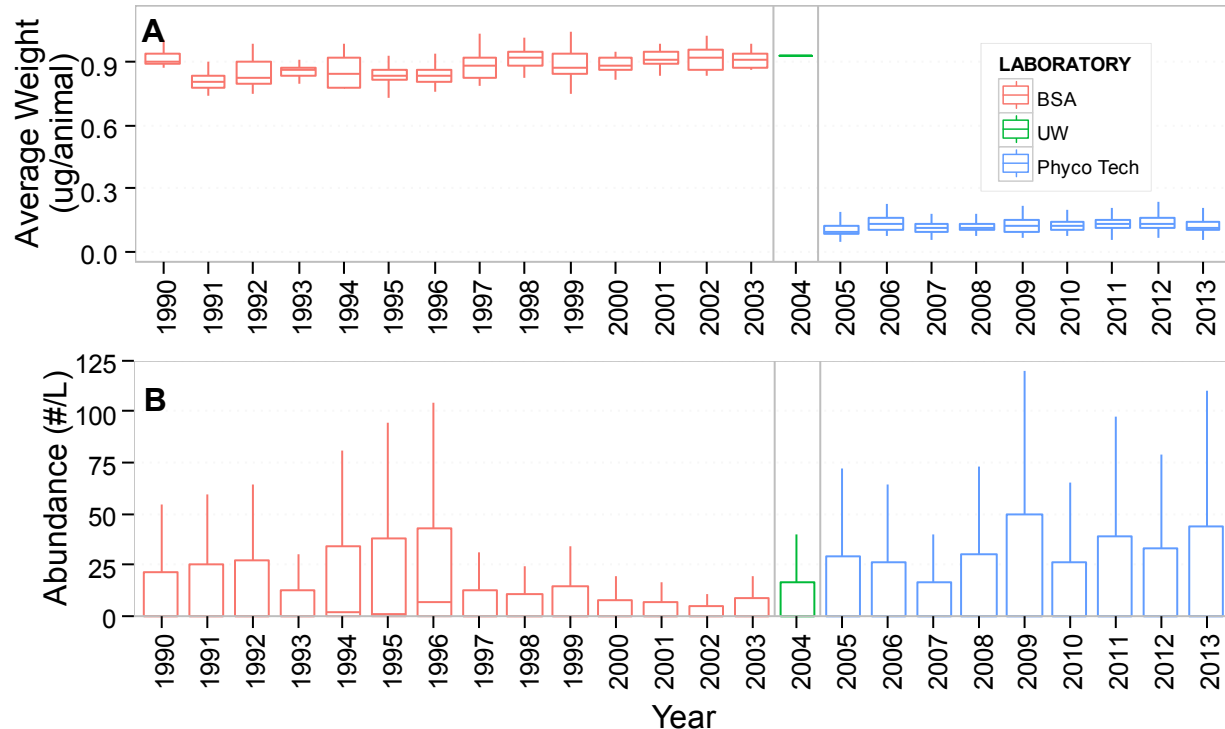


Figure 31. Boxplots of (A) average weight and (B) abundance of Copepoda nauplii for all samples 1990-2013 (all dates and sites). Outliers are not shown.

6. Rotifer identification issues: *Asplanchna* spp., *Euchlanis* spp., and *Synchaeta* spp.

When preserved, species in the genera *Asplanchna*, *Euchlanis*, and *Synchaeta* curl into a ball and are difficult to distinguish from each other. Isolating individuals and dissolving them in bleach allows the trophus to become visible, facilitating identification. PhycoTech's current taxonomy for species in these three taxa, confirmed through dissolving, is *Asplanchna girodi*, *Euchlanis alata*, *Synchaeta pectinata*, and *Synchaeta* spp. (Figure 32). The annual number of detections of *Synchaeta pectinata* has a relatively consistent range within each lab (except for zero detections in 2002 which we cannot explain), suggesting the lab consistently identified this species (Figure 32).

In contrast there appears to be substantial inconsistencies among labs, and among years within BSA's dataset, for taxa within the genera *Euchlanis* and *Synchaeta*. A comparison of PhycoTech's detections (Figure 25) indicates BSA and UW apparently identified *Euchlanis alata* as either *Asplanchna sieboldi* or *Asplanchna girodi*. *Asplanchna* is generally larger than *Euchlanis*, so we used weight data (calculated by sample) to re-assign identifications for the standardized databases. First, BSA and UW *Asplanchna sieboldi* with average weight <4 ug or *Asplanchna girodi* with average weight <0.7 ug were standardized to *Euchlanis alata*, resulting in a consistent number of detections per year for *Asplanchna* and *Euchlanis* among labs. Second, for the remaining BSA *Asplanchna sieboldi* (i.e., those ≥ 4 ug) and *Asplanchna girodi* (i.e., those ≥ 0.7 ug), 75.43% of the abundance of those taxa in each sample was also shifted to *Euchlanis alata*. Using the 75.43% adjustment factor enabled the ratio of *Asplanchna* spp.:*Euchlanis alata* for BSA 1990-2003 and UW 2004 to equal the ratio of *Asplanchna* spp.:*Euchlanis alata* in the 2005-2013 PhycoTech data (i.e., 0.0032, or 0.32%). Following taxa standardization, biomass was re-calculated using 0.136 μg /individual (the mean of PhycoTech

Euchlanis alata from 2005-2013) for all *Euchlanis* and 0.456 $\mu\text{g}/\text{individual}$ (the mean of PhycoTech *Asplanchna girodi* from 2005-2013) for all *Asplanchna*. For analysis, *Asplanchna* and *Euchlanis* were each aggregated to the genus level. The resulting post-standardization annual time series of abundance is shown in Figure 33 confirming the standardization process.

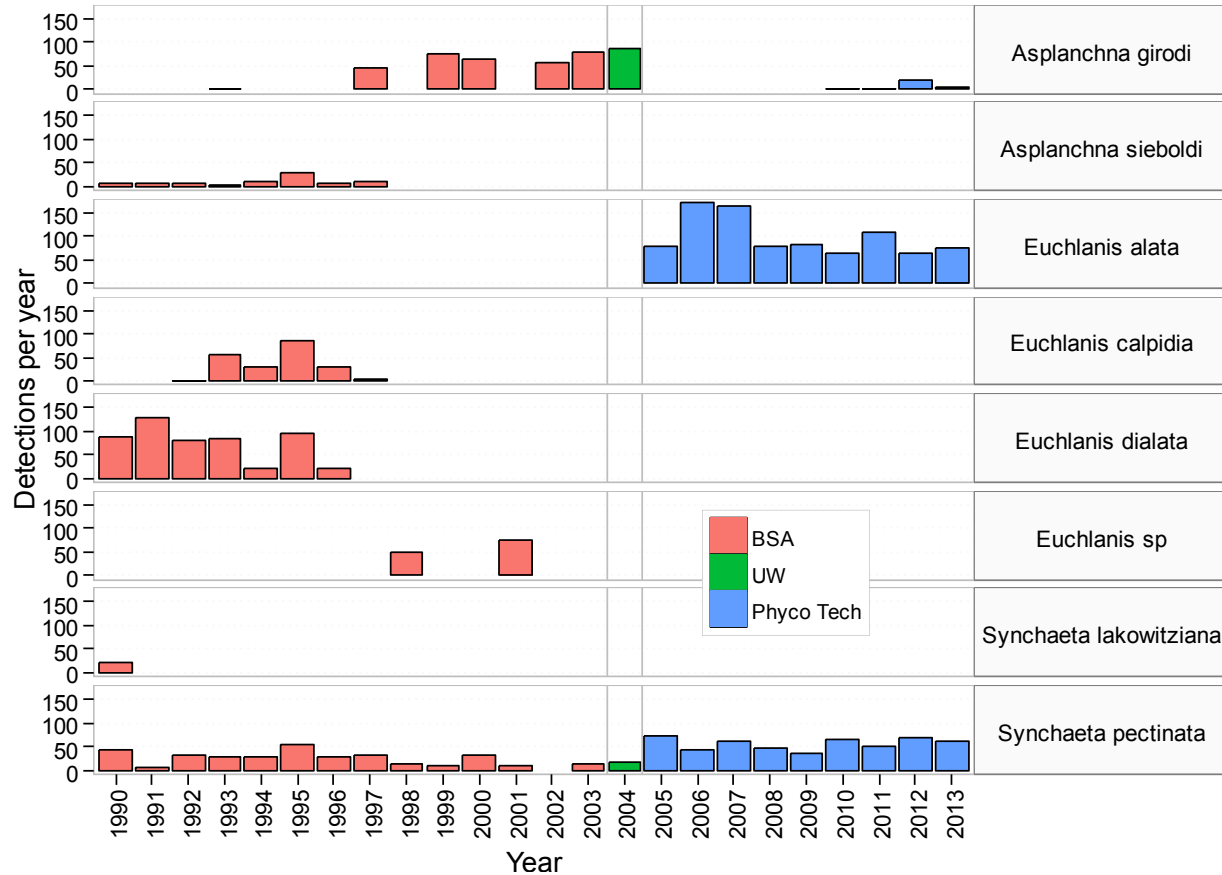


Figure 32. Number of detections per year for species in the genera *Asplanchna*, *Euchlanis*, and *Synchaeta* for all sites and dates 1990-2013.

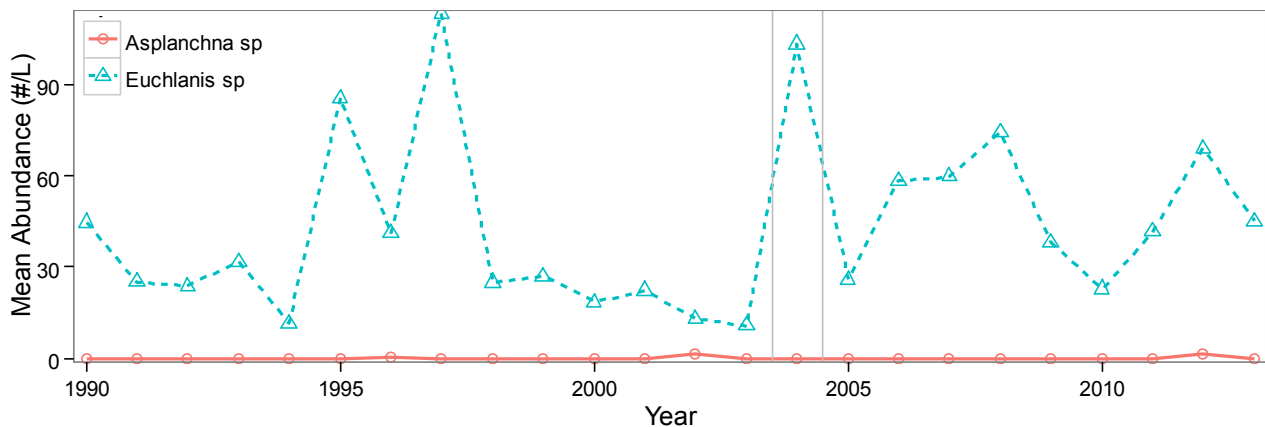


Figure 33. Time series of mean abundance of *Asplanchna* spp. and *Euchlanis* spp. for the April 15-October 30 periods at long-term stations in 1990-2013, after adjusting to correct apparently erroneous identifications of *Euchlanis* spp. as *Asplanchna* spp. in 1990-2003.

7. Inconsistent assignment of species within a genus

For some genera, there were no consistently distinguished taxa (i.e., each lab identified species in a different way) so we aggregated them to the genus level for our primary analysis. Examples not already discussed elsewhere in section 3.3.2 include the Cladoceran genus *Alona* and the rotifer genera *Brachionus*, *Keratella*, *Notholca*, and *Trichocerca*.

Species within the genus *Polyarthra* were identified differently among the labs, but PhycoTech found only one species (*Polyarthra dolichoptera*), so we standardized all *Polyarthra* species to *Polyarthra dolichoptera* for the standardized databases.

A few genera were only identified within a single lab, and were only detected a few times. Examples include the rotifer genera *Testudinella* spp. and *Rotaria* spp., which we standardized to the genus level.

8. Uncertain identifications at the generic level required standardization to higher taxonomic levels

We standardized the Ostracod genera *Candona* sp and *Cyclocypria* sp to the subclass-level Podocopa because genus determinations in Ostracods are difficult and they are relatively rare in the system, so the genera were rolled back to the subclass level.

9. Exclusion of taxa from analysis database but retained in partially standardized database

We excluded two rarely-detected taxa of benthic species from our analysis, because they are not zooplankton, but retained them in the partially standardized database. These included the amphipod *Hyaella azteca* (identification questionable, likely *Gammarus*) and Harpacticoida in the order Copepods.

The protist *Diffugia* sp first appeared in PhycoTech's samples in 2012 and 2013. Following large numbers in 2013, Dr. St. Amand conducted limited spot checks of archived samples from 2005-2011 and did not see it. Previous laboratories did not count protists, so would not have counted it even if it were observed; therefore, it was excluded from our analysis.

The Cladoceran *Ilyocryptus spinifer* was only detected in two samples, both in 1995 by BSA. The reported weight was extremely large relative to what is described in taxonomic keys and therefore either the identification or the weight is suspect. Since it was rare and suspect, we excluded it from our analysis.

3.3.2.3 FINAL LIST OF STANDARDIZED TAXA

Table 11. Final list of zooplankton taxa in the “analysis database,” sorted by taxa group. “n taxa” is the number of taxa lumped. Key to taxa codes: TCALA = Calanoid Copepods Adult, TCALI = Calanoid Copepods (copepodids) Immature, TCYCA = Cyclopoid Copepods Adult, TCYCI = Cyclopoid Copepods (copepodids) Immature, TCLADA = Cladocera Adult, TCLADI = Cladocera Immature, TNAUP = Copepoda Nauplii, THARA = Harpacticoid Copepods Adult, TOSTR = Ostracoda, TPROT = Protists, TROTI = Rotifera.

Taxa Group Code	Species Name	n taxa combined	Number of Detections Per Lab and Year																								
			BSA													UW	PhycoTech										
			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
	Total number of samples→		130	143	130	130	72	174	46	102	132	106	149	119	109	118	130	191	209	224	130	168	167	172	195	198	
TCALA	<i>Epischura nevadensis</i>	1	47	8	10	4	7	3	3	2	23		3	18	8	7	31	1	11	10	6	13	11	27	12	26	
TCALA	<i>Leptodiaptomus ashlandi</i>	1	103	79	77	66	47	86	33	93	105	62	89	91	76	99	120	67	114	81	49	78	44	96	111	125	
TCALI	Calanoid copepodid	1	103	72	56	50	34	59	29	67	87	39	59	54	49	58	88	75	116	101	63	49	45	107	135	141	
TCYCA	<i>Acanthocyclops vernalis</i>	1	87			1									2			4	4	3	2	9		7			
TCYCA	<i>Diacyclops thomasi</i>	1	34	115	88	61	66	128	39	84	63	48	70	63	65	99	124	156	144	135	92	124	97	121	126	142	
TCYCA	<i>Eucyclops agilis</i>	1	4			34			2																		
TCYCA	<i>Eucyclops speratus</i>	1	1																								
TCYCA	<i>Macrocyclops albidus</i>	1	11		7	2				1																	
TCYCA	<i>Tropocyclops prasinus</i>	1											6	1					2	1	2		1				
TCYCI	Cyclopoid copepodid	1	119	111	72	82	58	136	38	74	70	57	63	73	51	83	104	146	136	118	89	115	86	115	118	138	
TCLADA	<i>Acroperus harpae</i>	1	1	2																							
TCLADA	<i>Alona</i> sp. with eggs	4	16	4	2		2	8			1	1							1	1			1		1		
TCLADA	<i>Bosmina longirostris</i>	1	5	5	2	8	8	21	2	7	1											18			1		
TCLADA	<i>Camptocercus</i> sp	1								1																	
TCLADA	<i>Ceriodaphnia</i> sp	2	17	7	5	6	5	16	2	3	3				2											1	
TCLADA	<i>Chydorus sphaericus</i>	1	111	89	56	67	15	111	19	56	59	47	50	84	29	82	102	103	91	144	49	96	4	3	3	2	
TCLADA	<i>Daphnia</i> sp	9	129	143	84	112	59	146	46	99	113	85	144	103	89	85	108	189	204	208	127	147	157	157	163	170	
TCLADA	<i>Diaphanosoma birgei</i>	1				2	4			1		1				2			1	1	1	1		1	1	1	5
TCLADA	<i>Eubosmina coregoni</i>	1																						1			
TCLADA	<i>Eurycercus</i> sp	1	6	4	1			1																			
TCLADA	<i>Graptoleberis testudinaria</i>	1			1		2																				
TCLADA	<i>Leptadora kindtii</i>	1	52	1	1	7	3	13	1			1							10	31	19	7	9	1	12	12	13
TCLADA	<i>Leydigia leydigi</i>	1						2																			
TCLADA	<i>Pleuroxus</i> sp	3		2		1	1	5																			
TCLADA	<i>Polyphemus pediculus</i>	1	3			1		2																			
TCLADA	<i>Scapholeberis</i> sp	1						1																			
TCLADA	<i>Sida crystallina</i>	1	3	1				4																			

3.3.3 RE-CALCULATION OF BIOMASS FOR SUBSET OF TAXA FOLLOWING TAXONOMIC STANDARDIZATION

As noted above in section 3.3.2, during the process of taxonomic standardization it became clear that due to inconsistencies in taxa identification and/or the use of different regressions equations for calculating biomass from length measurements, it was necessary to re-calculate biomass for several taxa to get a consistent/comparable time series across the entire 1990-2013 time period.

These taxa included various *Daphnia* species, Copepoda nauplii, the adult Calanoid Copepods *Leptodiptomus ashlandi* and *Epischura nevadensis*, Calanoid copepodids, the adult Cyclopoid Copepod *Diacyclops thomasi*, Cyclopoid copepodids, and all taxa in the rotifer genera *Asplanchna* and *Euchlanis*.

The biomass standardization methods/justification are integrally linked with taxa standardization so are described above in concert with the taxonomic standardization process. Taxa-specific solutions were applied to address each of these issues, resulting in as consistent dataset as possible given the issues and inherent limitations. Each of these solutions are discussed above in section 3.3.2.

3.4 ZOOPLANKTON DATA ANALYSIS

As with phytoplankton, due to the considerable effort required to standardize the database as described above (the initial complexity of standardizing the zooplankton database was far more than anticipated due to among-laboratory issues not initially foreseen), time and budgetary constraints limited the scope of the depth of analysis in this Phase I report. Thus, the following analysis sections are considered preliminary, with the main goal to provide graphical depictions of seasonal, spatial, and inter-annual patterns that allow evaluation of database structure, and to form the basis for Phase II comprehensive analyses.

3.4.1 SEASONAL AND SPATIAL PATTERNS

The seasonal dynamics of zooplankton in UKL and Agency Lake are shown in Figure 34 through Figure 48. Due both to a combination of high abundance and large size, Cladocerans (*Daphnia* spp.) comprise a larger percent of biomass than any other taxonomic group. Abundance, percent abundance, biomass, and percent biomass of adult *Daphnia* and other Cladocerans (*Chydorus sphaericus*, *Leptodora kindtii*, and immature Cladocera) peaks in summer or early fall and is markedly lower in December through February than in other months (Figure 34 through Figure 38). This trend was previously noted by Kann (1998) who showed a positive relationship between large *D. pulicaria* and *Aphanizomenon flos-aquae* during the summer in UKL. Abundance and biomass of adult Calanoid and Cyclopoid Copepods were higher in the spring (through June) than in the summer (June-September) (Figure 34 and Figure 35). Rotifer abundance and biomass tended to be higher through August and lower in the fall.

Rotifers including *Euchlanis* spp., *Keratella* spp., *Polyarthra dolichoptera*, and *Synchaeta* spp. reach high abundance with a peak in June or July but due to their small size they typically showed low percent biomass (Figure 34 through Figure 38). Copepoda nauplii reached their lowest abundance, percent abundance, and biomass in June through September (Figure 34, Figure 35, Figure 38). Calanoid copepods (composed of two taxa: *Leptodiptomus ashlandi* and *Epischura nevadensis*) had higher abundance, percent abundance, biomass, and percent biomass

than Calanoid copepods (primarily *Diatom thomasi*) (Figure 34 through Figure 38). Ostracods were rare (Figure 34 and Figure 35).

Some site differences in timing and magnitude are evident (Figure 38, Figure 39, Figure 40). Relative to UKL stations, Agency Lake (stations AN and AS) showed higher percent abundance and percent biomass of Calanoid Copepods later in the season, and lower percent abundance of adult Cladocerans (Figure 38, Figure 39). PB showed lower abundance, percent abundance, biomass, and percent biomass of adult Cladocerans and Calanoid copepods (both adults and copepodids), and lower biomass and percent biomass of Copepoda nauplii (Figure 39 and Figure 40). As noted above, PB (only sampled through 2006) is dominated by spring inflow and wetland plants. Site specific differences will be further explored in Phase II.

As with phytoplankton the analyses contained herein are preliminary in nature and are mainly shown to demonstrate aspects of the database. In this vein, time-series graphs of sample-date lake-wide average taxonomic group biovolume and percent biovolume during the 1990-2013 period are shown for UKL and Agency Lake in Figure 41/Figure 42 and Figure 43/Figure 44, respectively; similar figures for individual sites are available in Appendices G and H. Figure 45/Figure 46 and Figure 47/Figure 48 show lake-wide averages of abundance, percent abundance, biomass, and percent biomass of major genera/species at UKL and Agency Lake, respectively; similar figures for individual sites are in Appendices I and J.

These figures clearly show the seasonal and inter-annual differences in relative and absolute abundance and relative and absolute biomass over the period of record, as well as differences between UKL and Agency Lake. These differences will be explored in detail in Phase II, including additional seasonal trend testing (e.g., Mann-Kendall trend tests) and multivariate techniques (e.g., NMDS) to evaluate the effects of nutrients, climate, and other physical, chemical, and biological forcing factors on the observed seasonal, spatial, and inter-annual dynamics.

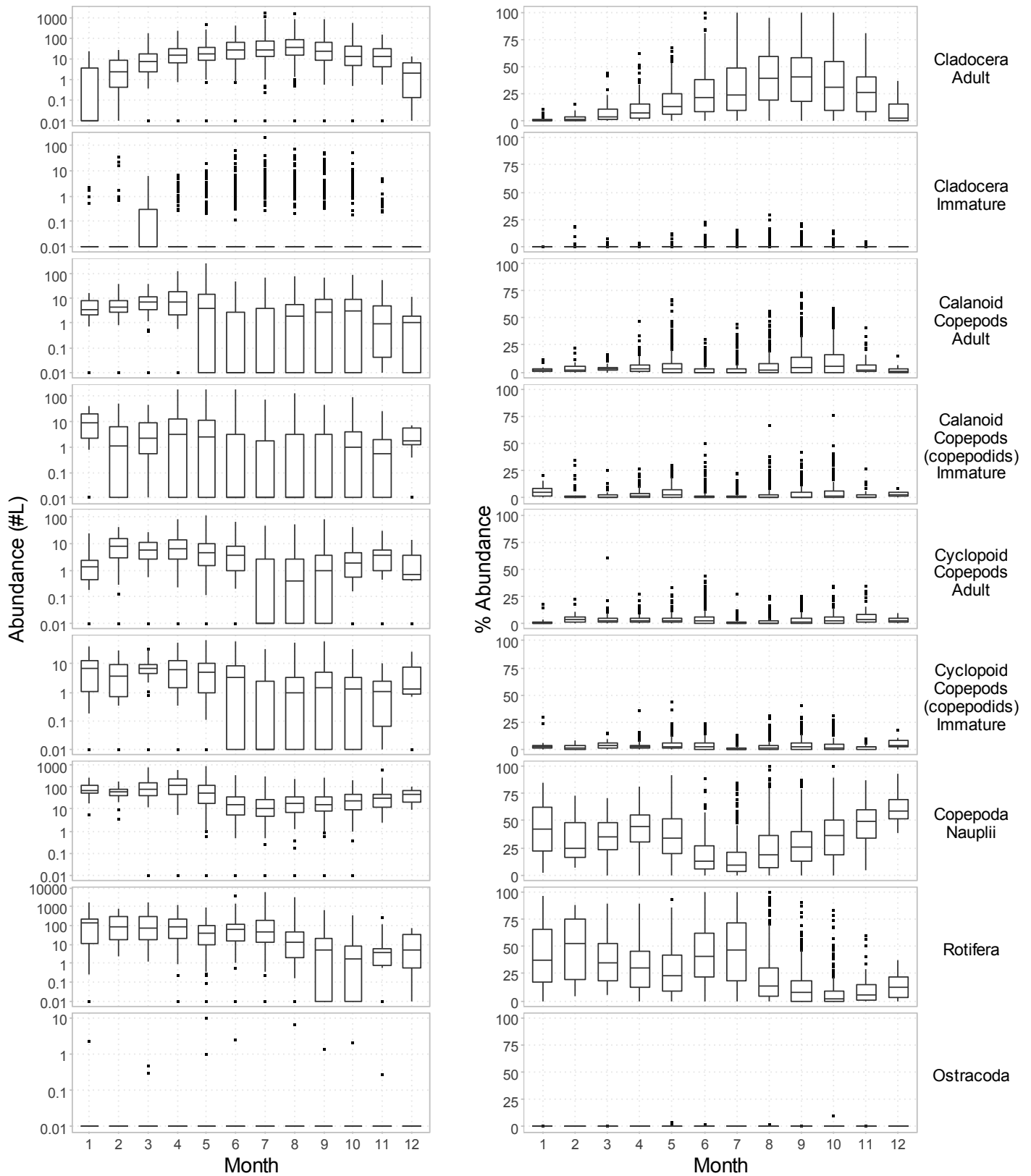


Figure 34. Monthly boxplots of abundance and percent abundance of zooplankton taxonomic groups at all sites in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

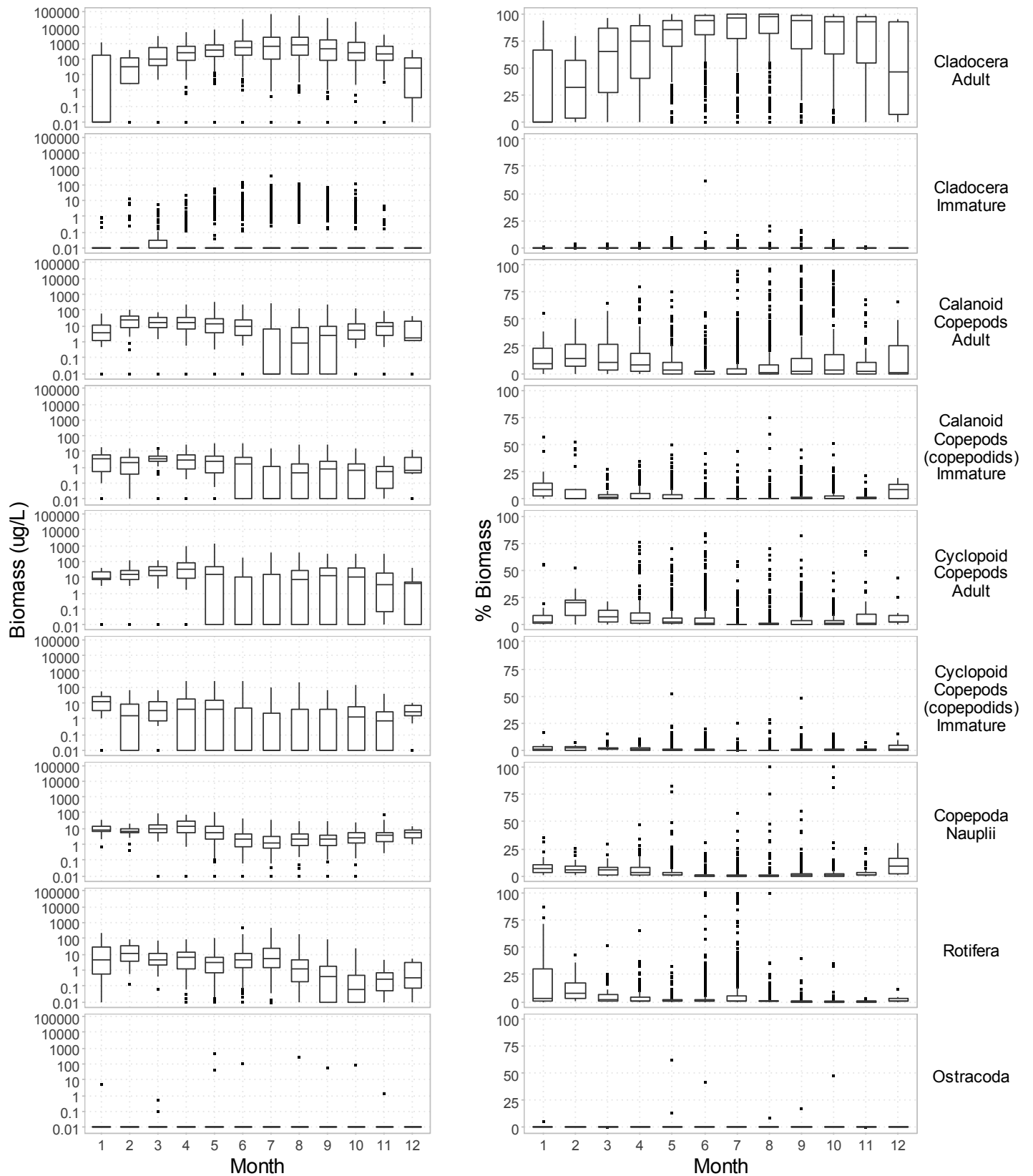


Figure 35. Monthly boxplots of biomass and percent biomass of zooplankton taxonomic groups at all sites in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

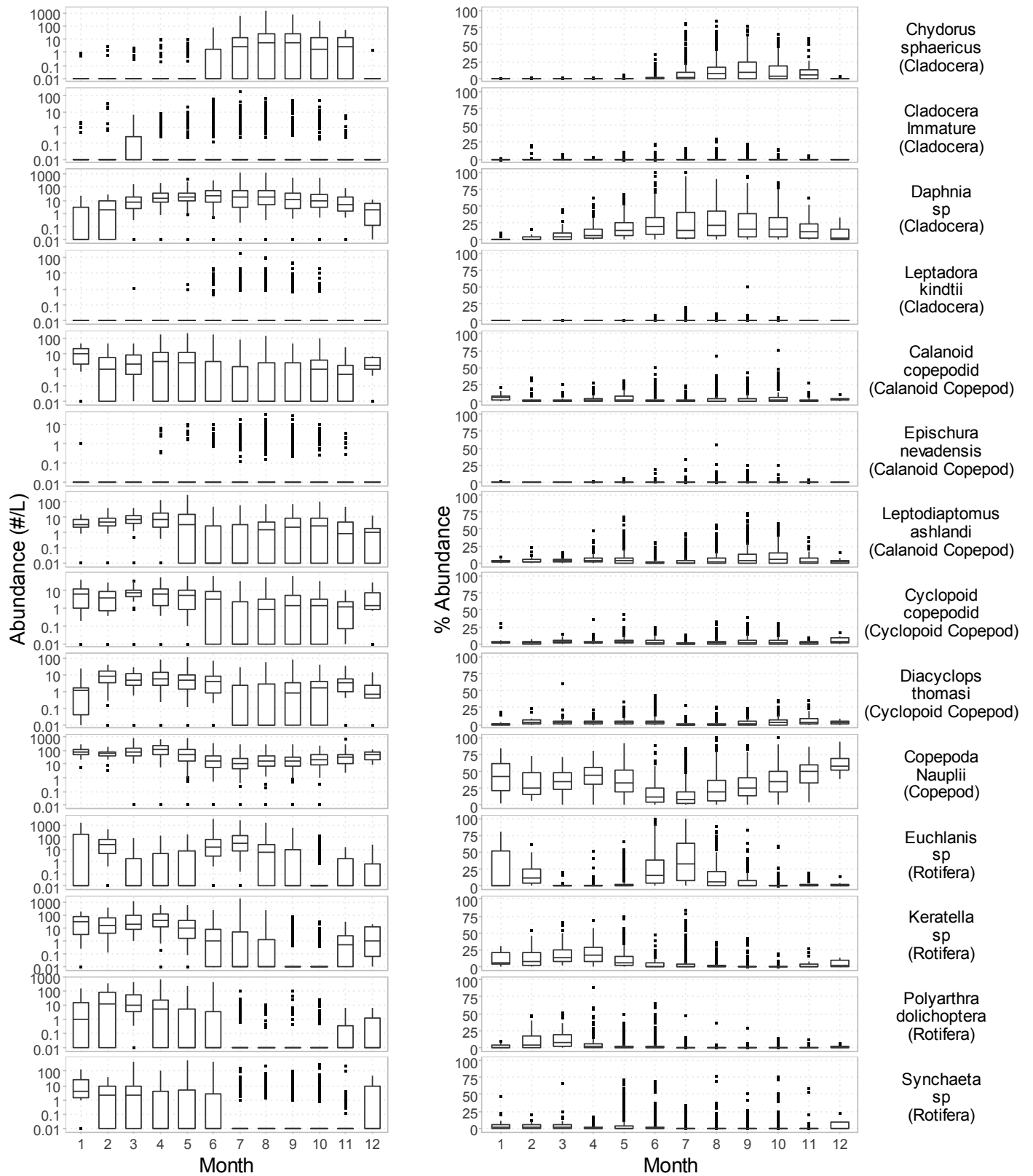


Figure 36. Monthly boxplots of abundance and percent abundance of dominant species and genera at all sites (except PB) in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

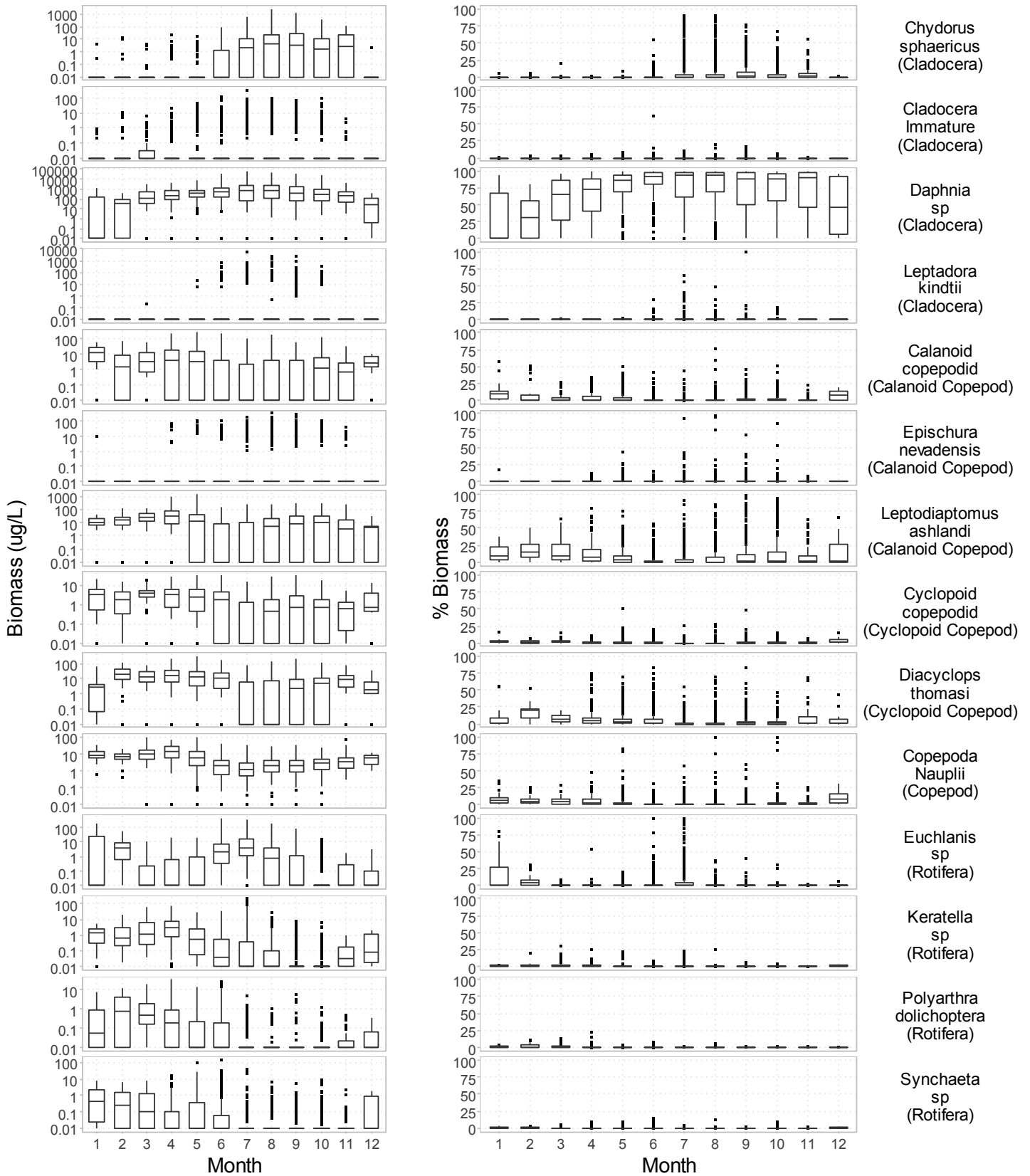


Figure 37. Monthly boxplots of biomass and percent biomass of dominant species and genera at all sites (except PB) in Upper Klamath and Agency lakes for months of January-December, 1990-2013.

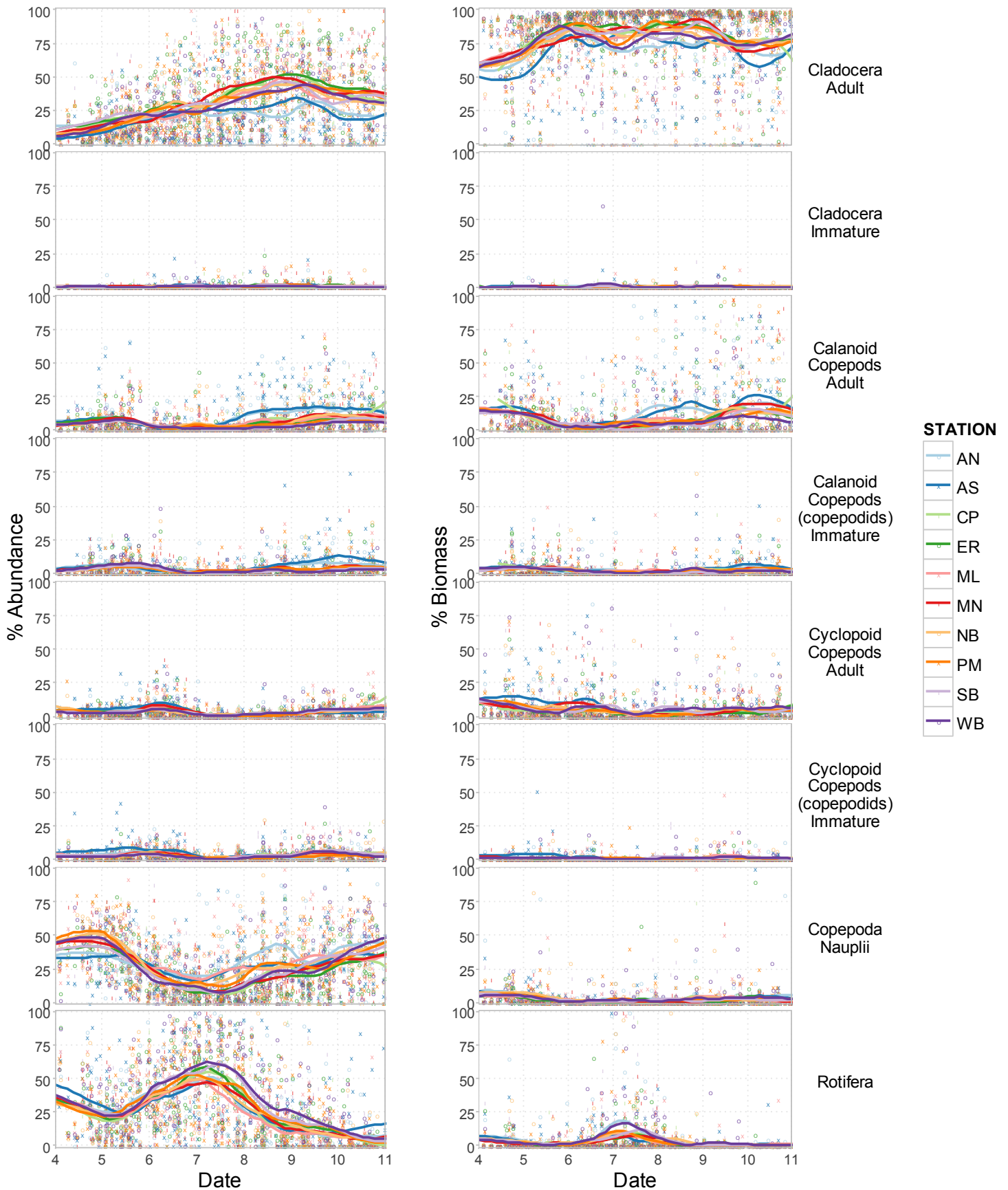


Figure 38. Percent abundance and percent biomass of zooplankton taxonomic groups at sites in Upper Klamath and Agency lakes for months of April-October, 1990-2013. Points are individual samples and lines are a LOESS (Local regrESSion) smoother.

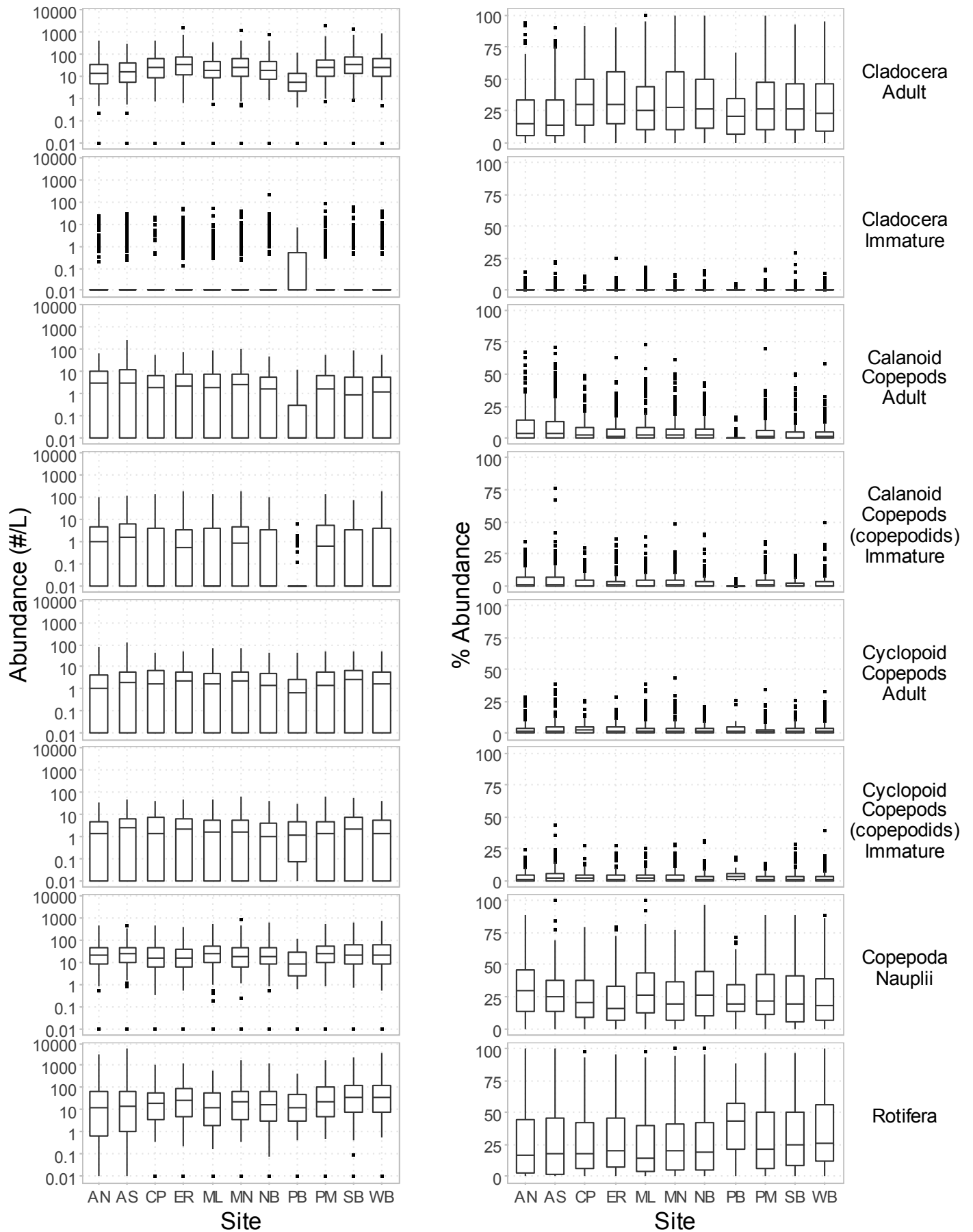


Figure 39. Boxplots of abundance and percent abundance of taxonomic groups at long-term stations and station PB in Upper Klamath and Agency lakes for April 15-October 30, 1990-2013.

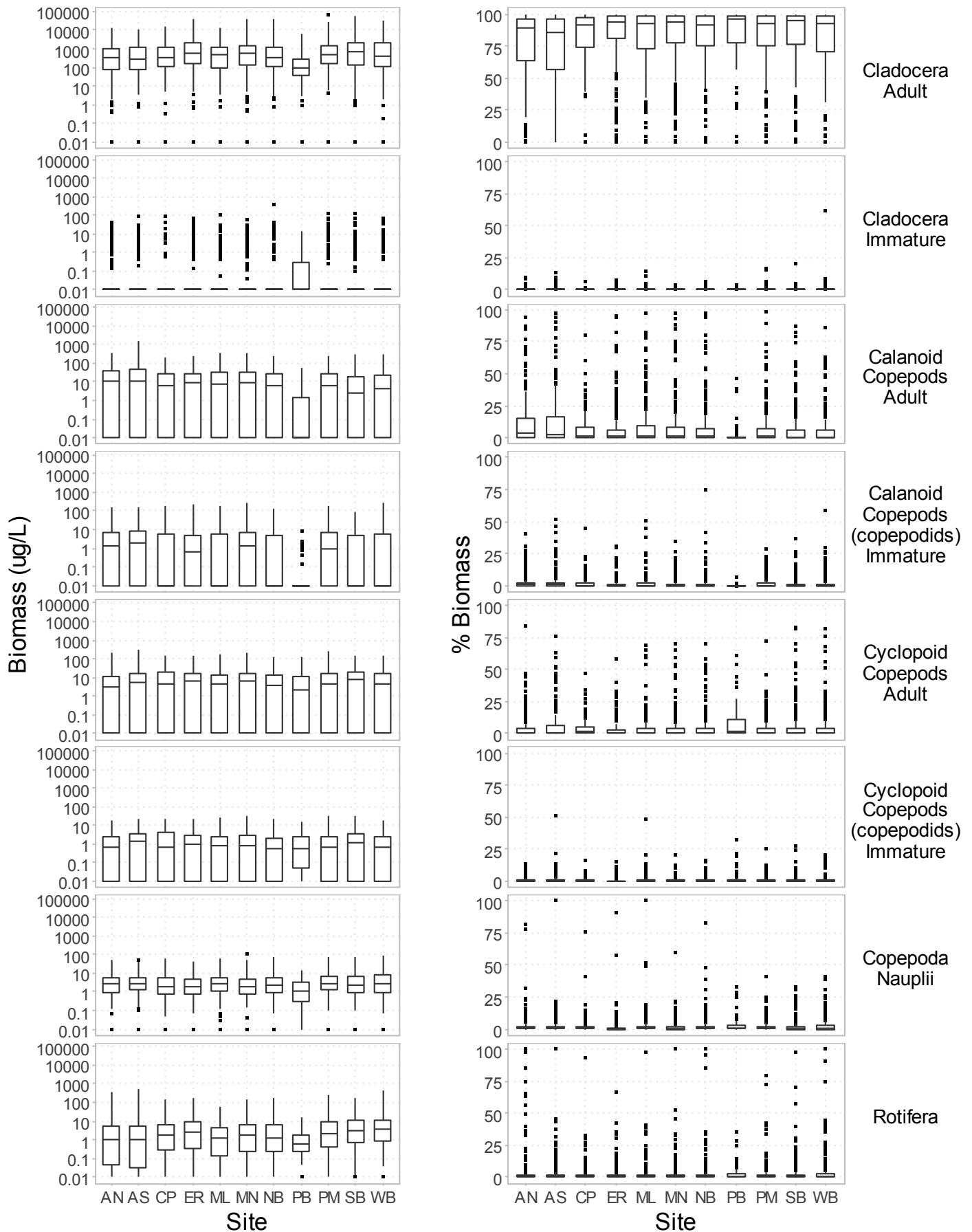


Figure 40. Boxplots of biomass and percent biomass of taxonomic groups at long-term stations and station PB in Upper Klamath and Agency lakes for April 15-October 30, 1990-2013.

Zooplankton Taxonomic Groups and Chl-a: Upper Klamath Lake Average, April-October

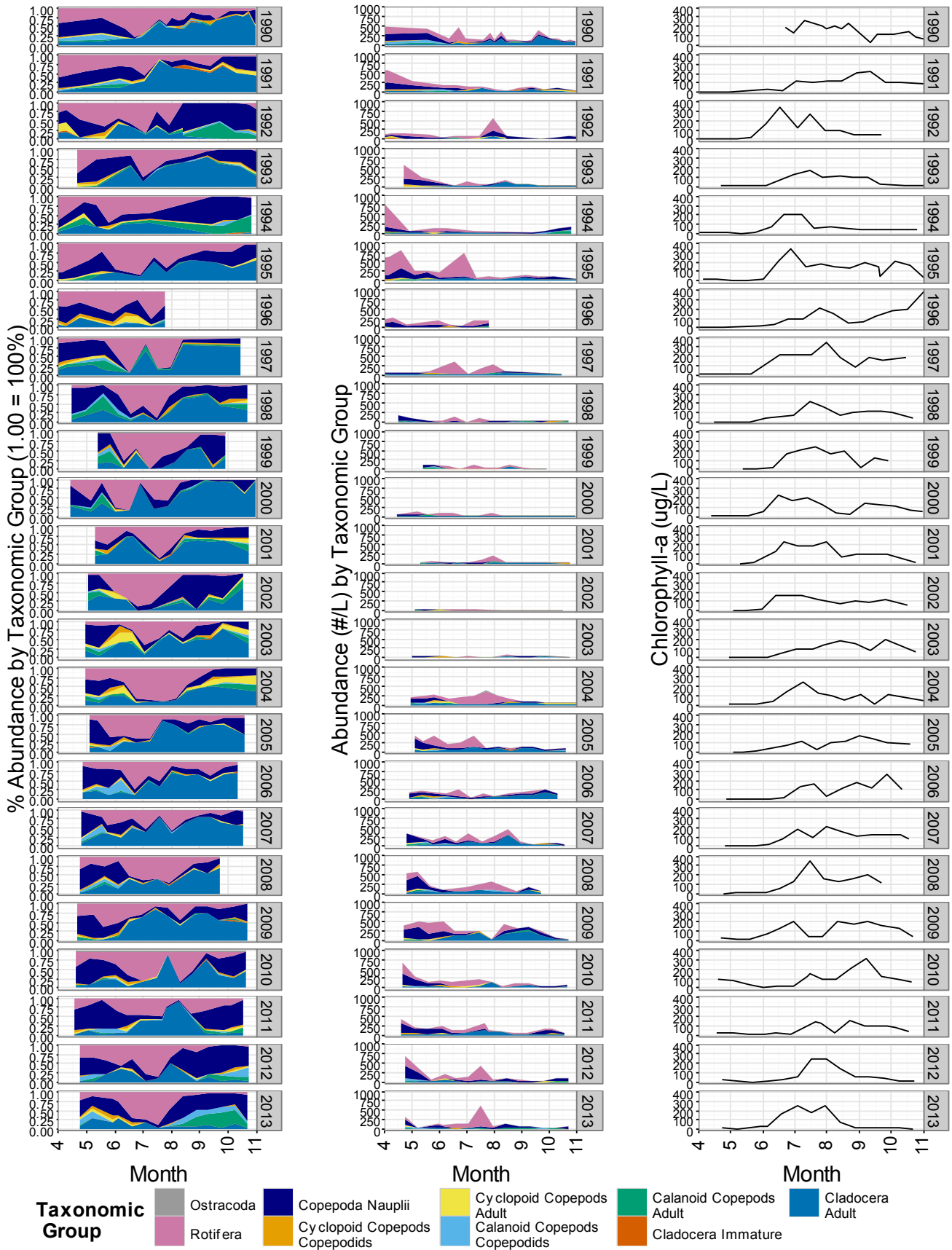


Figure 41. Percent abundance (left column) and abundance (middle column) of zooplankton taxonomic groups for average of Upper Klamath Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a.

Zooplankton Taxonomic Groups and Chl-a: Agency Lake Average, April-October

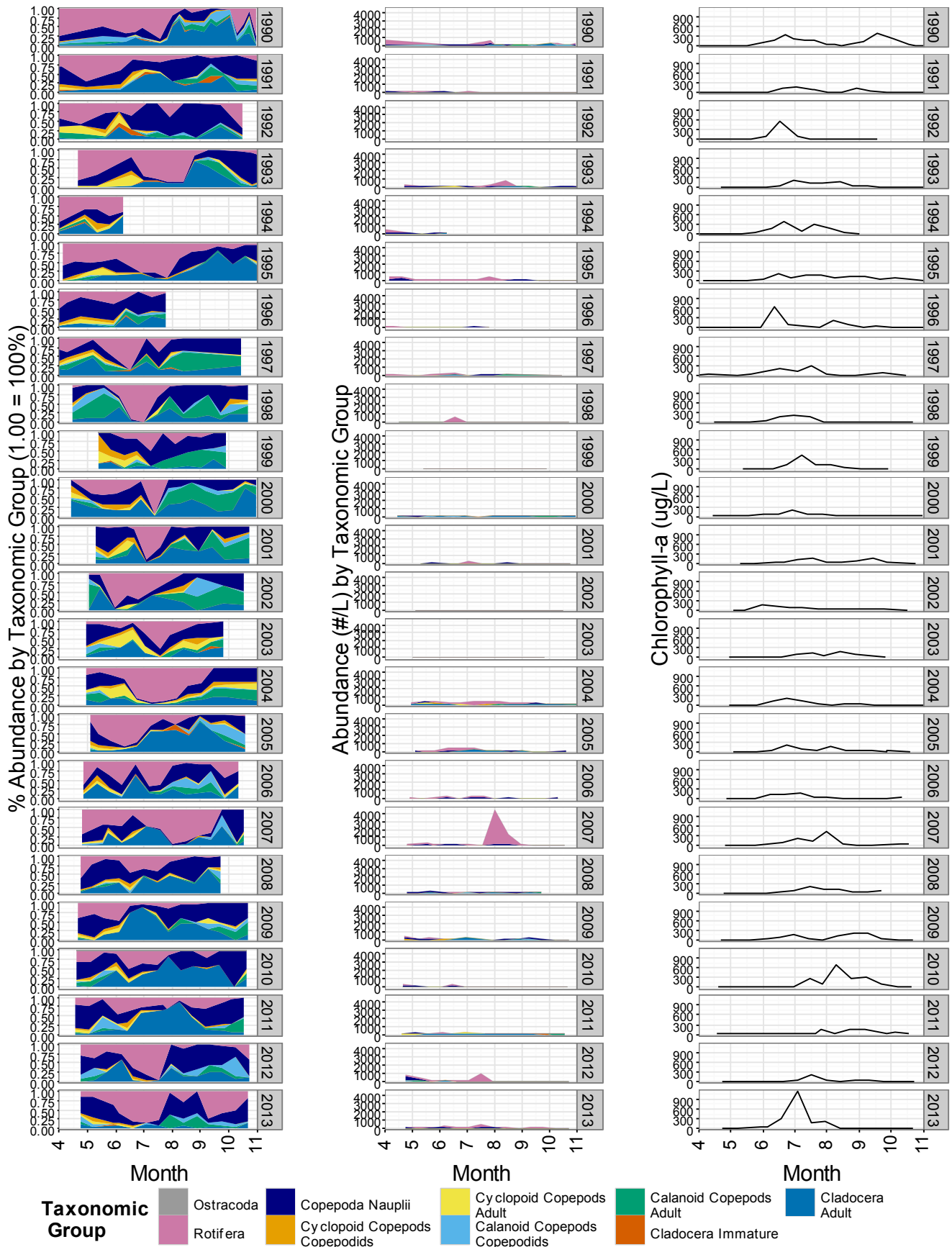


Figure 42. Percent abundance (left column) and abundance (middle columns) of zooplankton taxonomic groups for average of Agency Lake stations during the period April-October, 1990-2013. Right column is chlorophyll-*a*.

Zooplankton Taxonomic Groups and Chl-a: Upper Klamath Lake Average, April-October

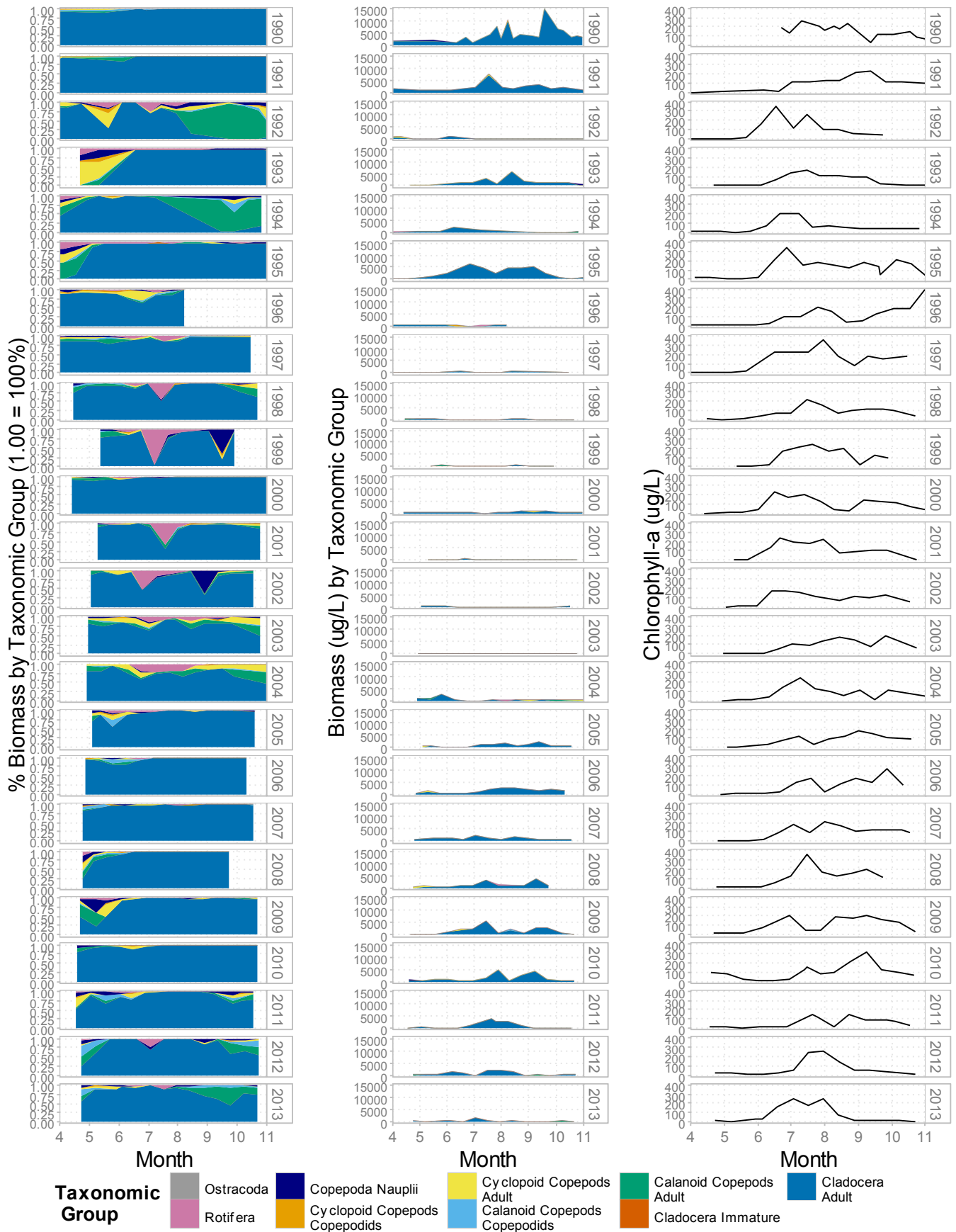


Figure 43. Percent biomass (left column) and biomass (middle column) of zooplankton taxonomic groups for average of Upper Klamath Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-*a*.

Zooplankton Taxonomic Groups and Chl-a: Agency Lake Average, April-October

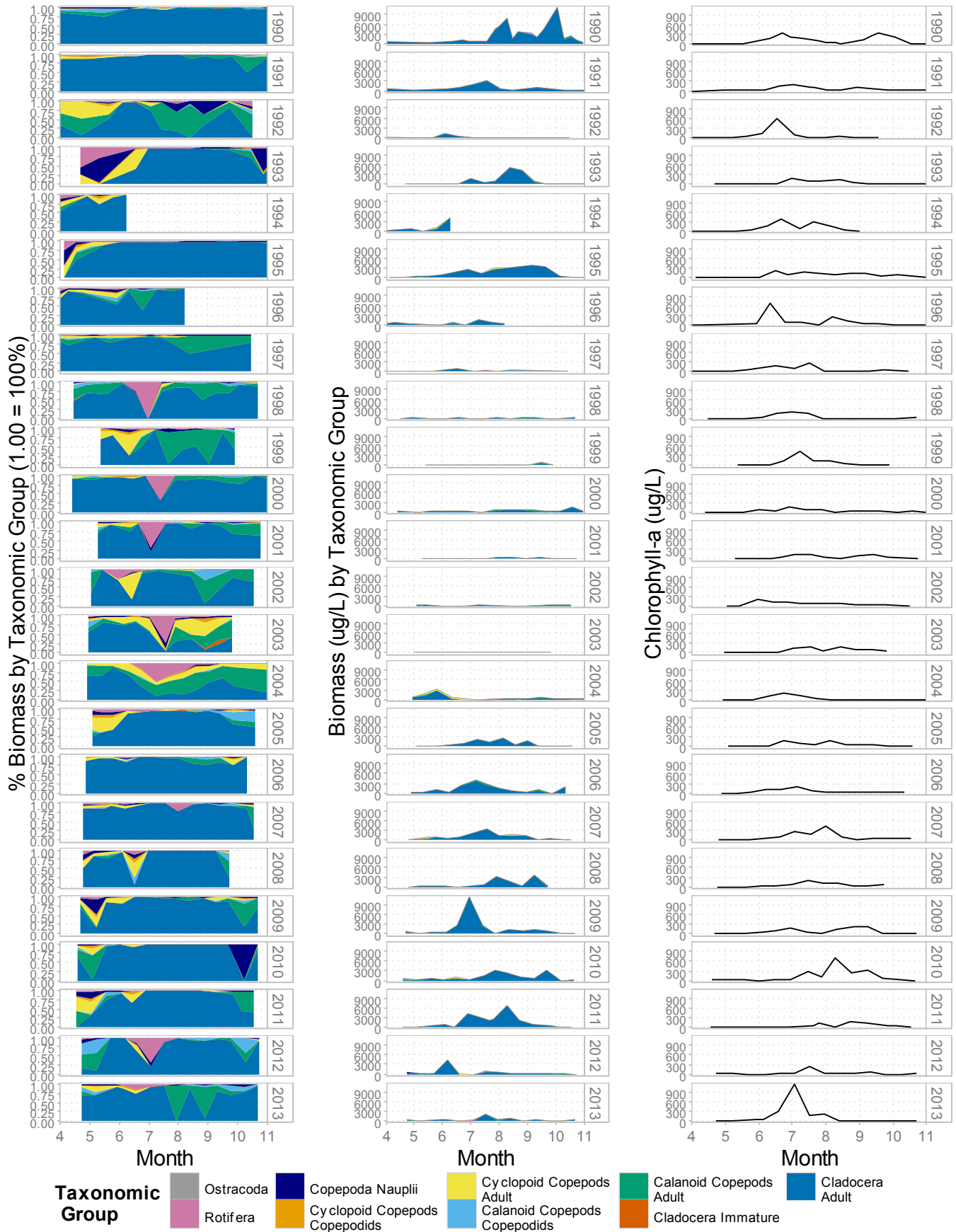


Figure 44. Biomass (left column) and percent biomass (middle columns) of zooplankton taxonomic groups for average of Agency Lake stations during the period April-October, 1990-2013. Right column is chlorophyll-*a*.

Zooplankton Genera/Species and Chl-a: Upper Klamath Lake Average, April-October

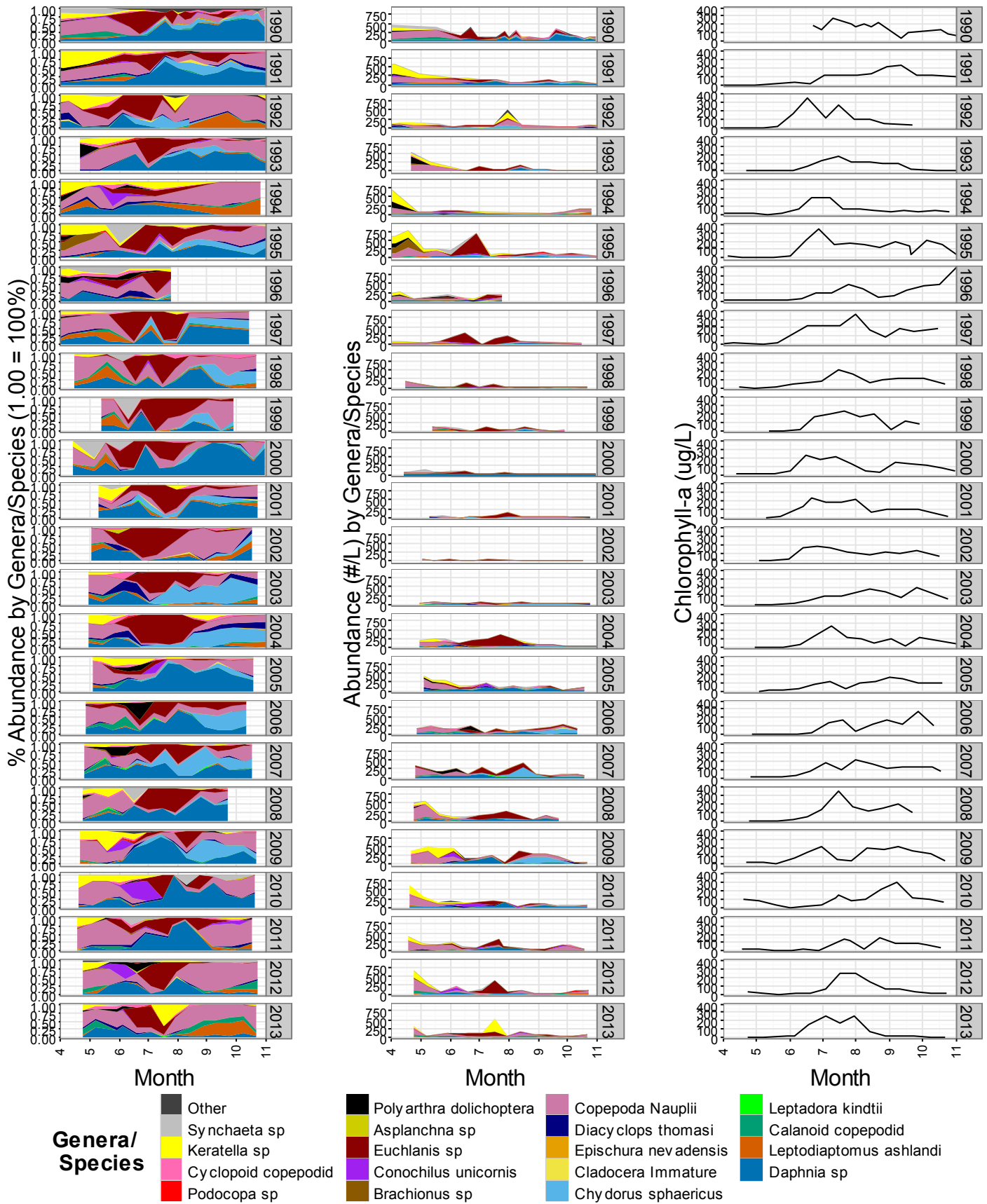


Figure 45. Abundance (left column) and percent abundance (middle columns) of dominant zooplankton genera /species for average of Upper Klamath Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a. "Other" is the sum of all taxa not otherwise included.

Zooplankton Genera/Species and Chl-a: Agency Lake Average, April-October

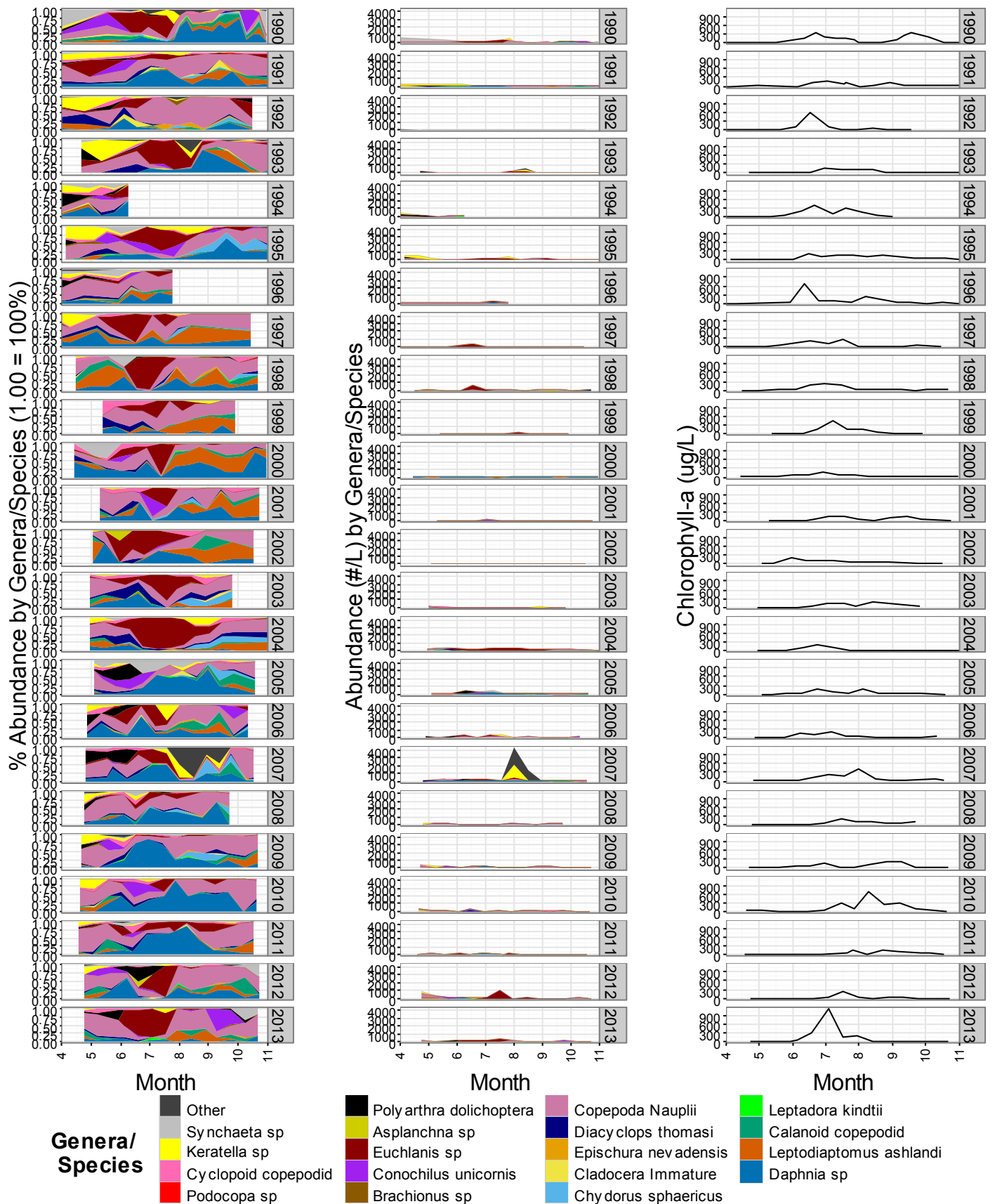


Figure 46. Abundance (left column) and percent abundance (middle columns) of dominant zooplankton genera /species for average of Agency Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a. "Other" is the sum of all taxa not otherwise included.

Zooplankton Genera/Species and Chl-a: Upper Klamath Lake Average, April-October

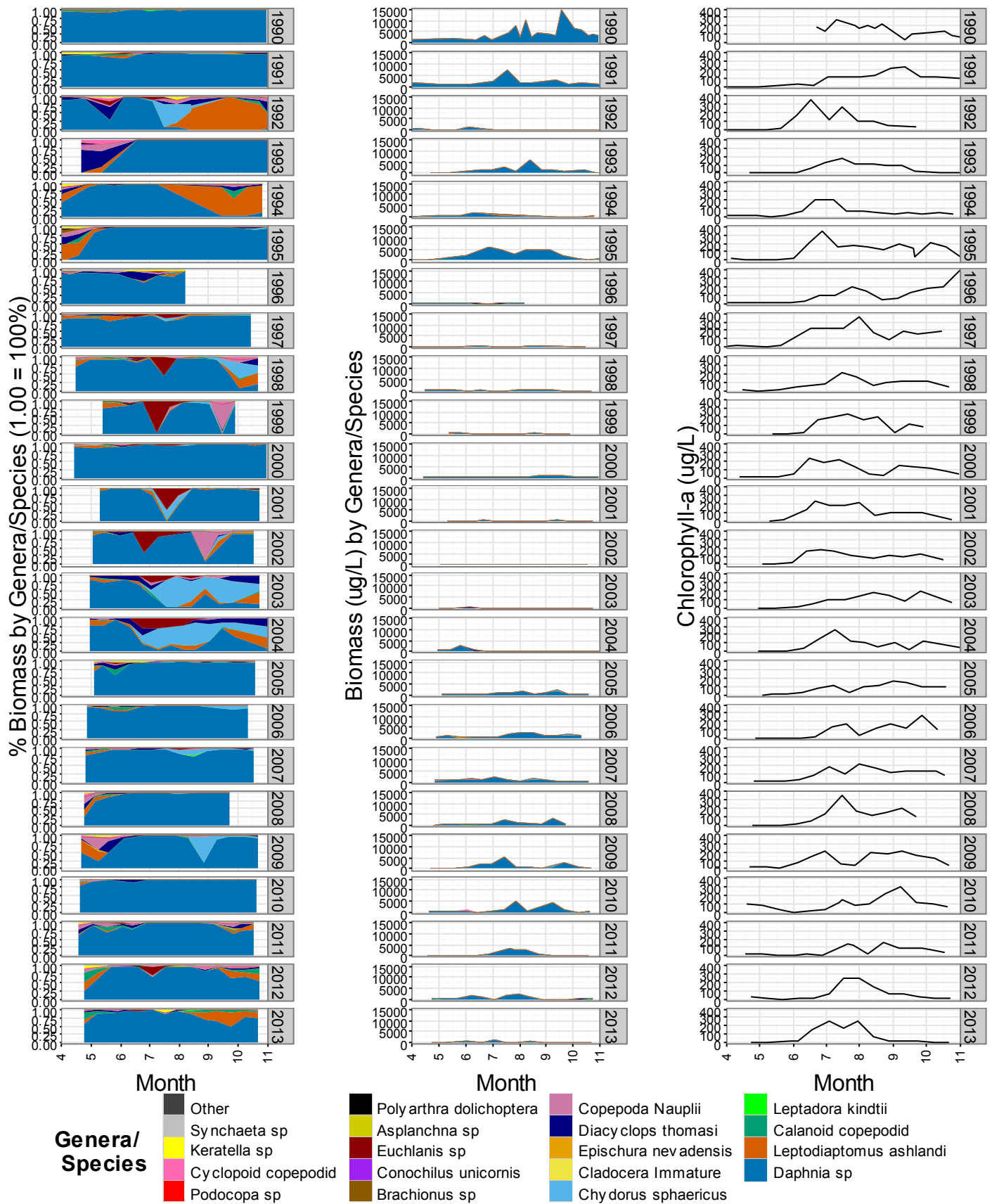


Figure 47. Biomass (left column) and percent biomass (middle columns) of dominant zooplankton genera /species for average of Agency Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-a. "Other" is the sum of all taxa not otherwise included.

Zooplankton Genera/Species and Chl-a: Agency Lake Average, April-October

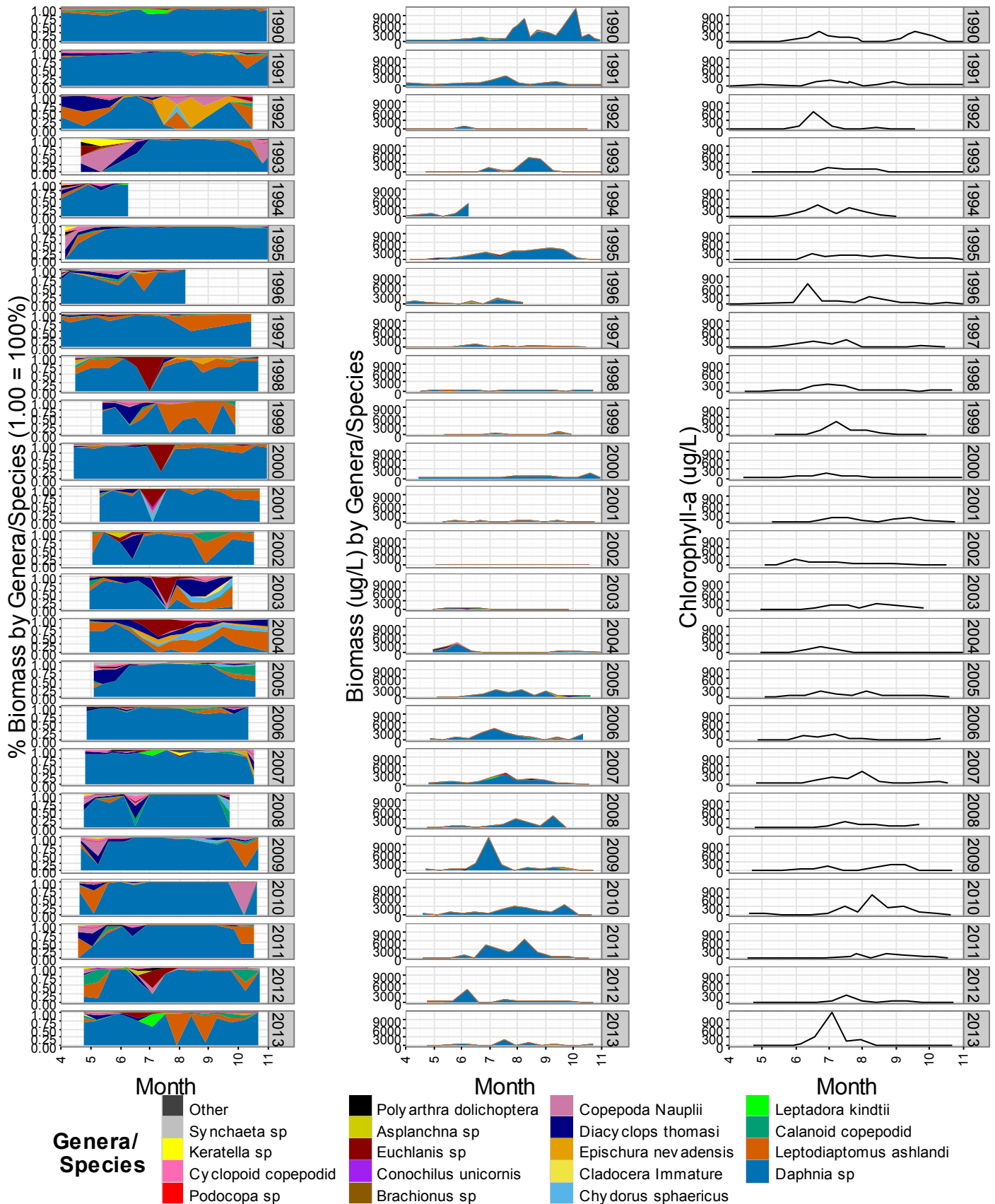


Figure 48. Biomass (left column) and percent biomass (middle columns) of dominant zooplankton genera /species for average of Agency Lake stations for months of April-October, 1990-2013. Right column is chlorophyll-*a*. “Other” is the sum of all taxa not otherwise included.

3.4.2 PRELIMINARY LONG-TERM TRENDS

Figure 49 and Figure 50 show annual time series for lake-wide averages of abundance, abundance percent, biomass, and biomass percent of zooplankton taxonomic groups in UKL and Agency Lake; similar figures with major species/genera are available in Appendix L. Full results of 1990-2013 Mann-Kendall trend tests for zooplankton taxonomic groups and major genera/species for lake-wide averages of UKL and Agency Lake are shown in Figure 51. Figures with site-level trends are available in Appendix K.

Notable trends include some spring increases of Copepods including Calanoid copepodids (May 1–31 abundance and biomass for UKL and Agency Lake, and May 1–31 percent biomass for UKL), Cyclopoid copepodids (June 1–30 abundance and biomass at UKL and Agency Lakes, and June 1–30 percent biomass at UKL), and Copepoda nauplii (April 15-30 biomass and abundance at UKL and Agency Lake, April 15-30 percent abundance at Agency Lake, and June 1–30 percent biomass at UKL), *Epischura nevadensis* (May 1-31 percent biomass at UKL), *Diatylops thomasi* (June 1–30 percent biomass at UKL and Agency Lake) (Figure 51).

The only statistically significant ($p < 0.05$) trends for *Daphnia* spp. or total adult Cladocerans are increased abundance at Agency Lake for May 1-31. The Cladoceran *Chydorus sphaericus* had decreasing abundance, percent abundance, biomass, and percent biomass for May 1-31 and June 1-30 at Agency Lake, and decreasing biomass and percent biomass for July 1-31 at UKL. Immature Cladocerans declined for several periods and parameters, including April 15 – October 30 abundance and percent abundance at Agency Lake and percent abundance at UKL.

The rotifers *Euchlanis* spp. and *Asplanchna* spp. showed some spring declines in UKL but not Agency Lake. The Rotifer *Synchaeta* spp. showed a mix of increases and decreases at both UKL and Agency Lake. The only significant trends for *Keratella* spp. and *Polyarthra dolichoptera* spp. (the other most common Rotifers), are increasing April 15 – October 30 biomass and percent biomass for *Keratella* spp. Trends in biomass and percent biomass for *Synchaeta* spp. and *Keratella* spp. are likely driven in part by the laboratories' use of different formulas for calculating average weight which caused larger weights in BSA and UW data than in the PhycoTech data (Table 10)³². There were no statistically significant trends for total zooplankton.

As with phytoplankton these results are considered preliminary and sensitivity analyses are to be performed in the Phase II effort, including differing frequency of stations sampled in some years, and differing counting resolution among labs. For example, trend analyses will be performed on a subset of stations that were consistently sampled among years.

³² Due to time/budgetary constraints we were unable to complete this standardization in the Phase I effort.

Lake-Wide Average of Taxonomic Groups by Season and Year

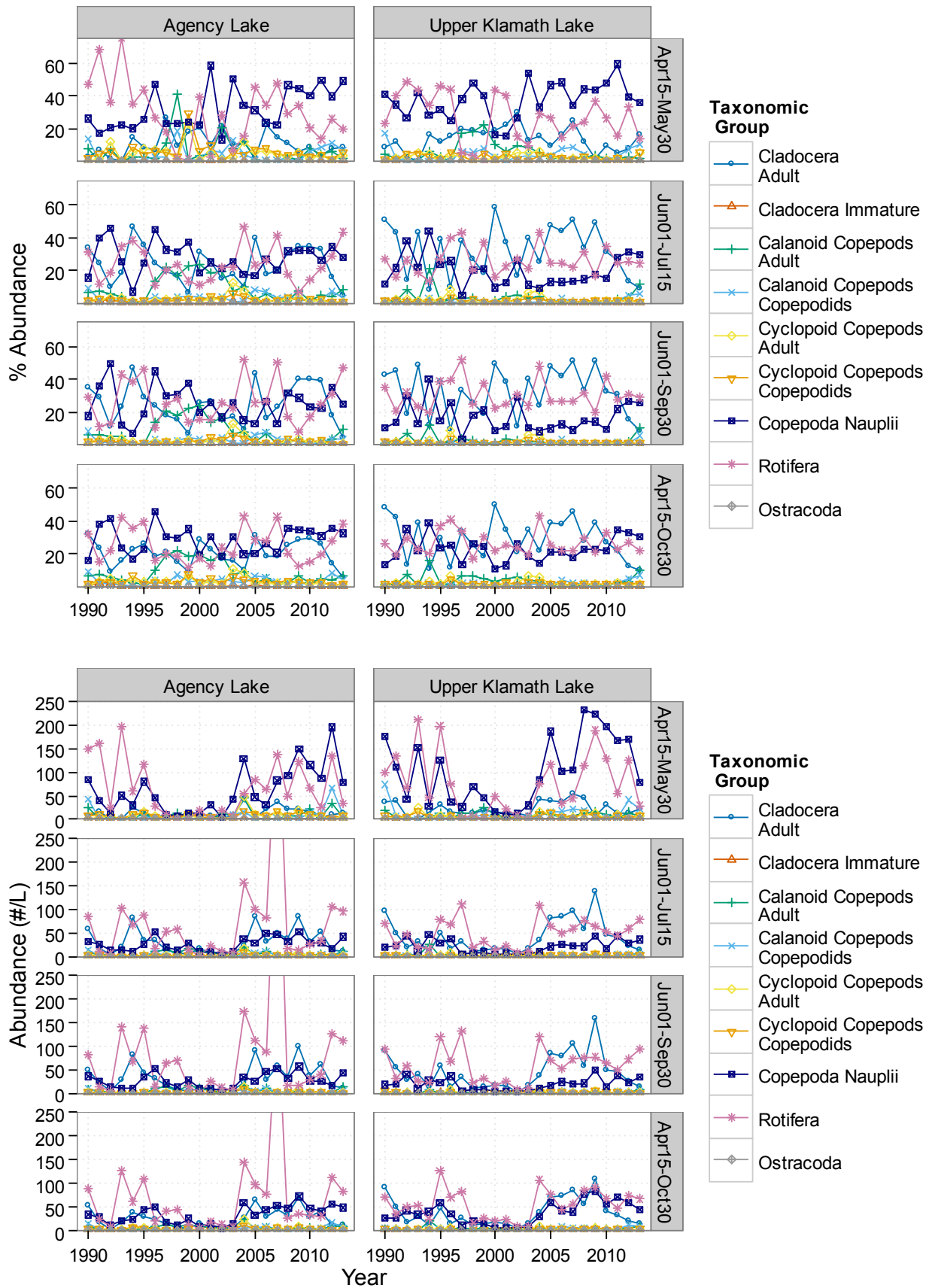


Figure 49. Lake-wide averages of percent abundance (top four panels) and abundance (bottom four panels) of zooplankton taxonomic groups in Agency (left panels) and Upper Klamath (right panels) lakes in four seasonal periods (April 15 - May 30, June 1 - July 15, June 1-September 30, and April 15 - October 31), 1990-2013.

Lake-Wide Average of Taxonomic Groups by Season and Year

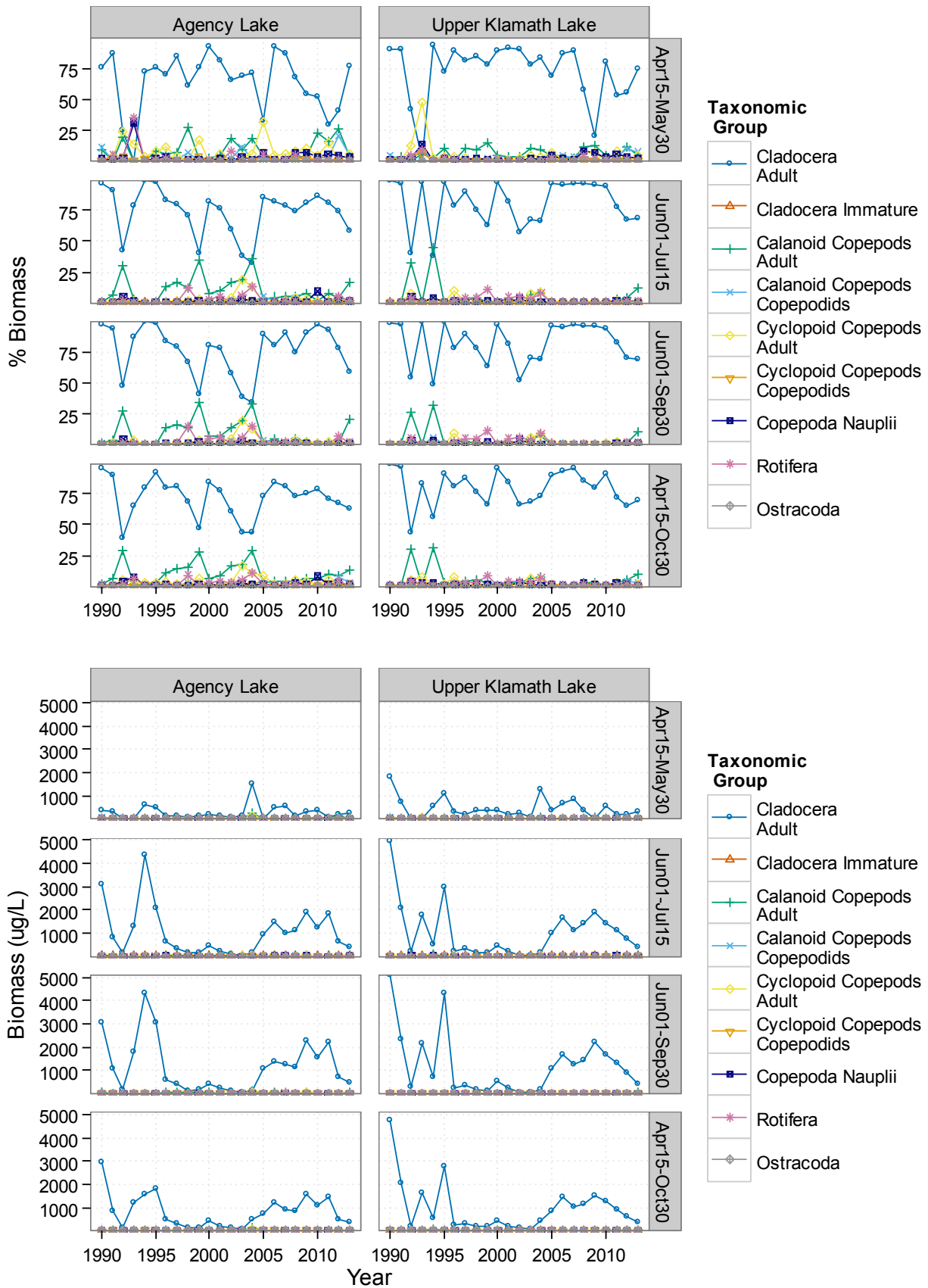


Figure 50. Lake-wide averages of percent biomass (top four panels) and biomass (bottom four panels) of zooplankton taxonomic groups in Agency (left panels) and Upper Klamath (right panels) lakes in four seasonal periods (April 15 - May 30, June 1- July 15, June 1-September 30, and April 15 - October 31), 1990-2013.

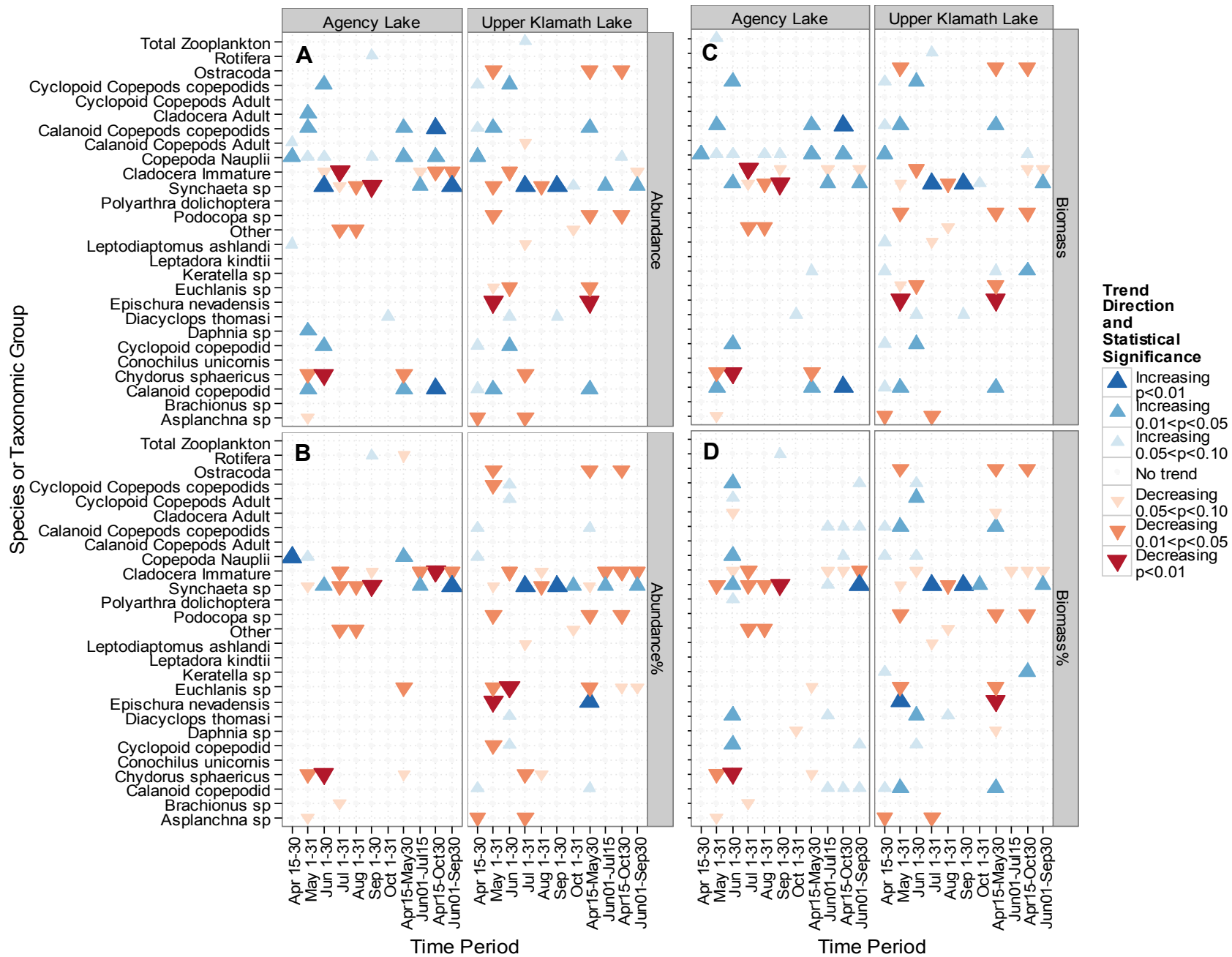


Figure 51. Summary of Mann-Kendall trend tests for zooplankton taxonomic groups and major genera/species, 1990-2013 for lake-wide averages of (A) abundance, (B) percent abundance, (C) biomass, (D) percent biomass in Upper Klamath and Agency Lakes. “Other” is the sum of all taxa not otherwise included.

4 SUMMARY AND RECOMMENDATIONS FOR FUTURE ANALYSIS/INVESTIGATION:

4.1 STANDARDIZATION

Given the importance of Upper Klamath and Agency Lakes in providing habitat for species of concern to the Klamath Tribes, as well as the algal bloom-driven water quality dynamics affecting those species (described above), the Klamath Tribes initiated a long-term water quality monitoring program for the lake system in 1990. The collection of phytoplankton and zooplankton species composition, abundance, and biomass data was considered especially important due to the role of algal blooms in water quality degradation associated with the decline of native endangered fish populations.

Although there were several early efforts to analyze the phytoplankton/zooplankton data, and the databases have been annually maintained and updated, beginning in 1998 multiple laboratories were utilized to analyze the phytoplankton and zooplankton data. Due to inter-lab issues that were outlined during annual quality assurance reviews of the data, it became apparent that analysis of the long-term database would be hampered by a lack of standardization among the labs over the entire 1990-2013 period. Thus this report provides the first comprehensive standardization of the phytoplankton/zooplankton databases on which further analyses can be performed. In addition, an initial analysis of seasonal, inter-annual, and spatial trends is provided, including preliminary statistical trend analyses. These databases will provide the basis for Phase II of this effort which will be a more comprehensive analysis of both time-series trends and interaction with environmental variables using multivariate techniques.

Inter-lab issues encountered during the standardization effort included: different means of calculating biomass (biovolume for phytoplankton and length/weight regressions for many of the zooplankton), different size classes used for zooplankton life stages, differing species identifications for both phytoplankton and zooplankton, differing counting units (e.g., enumeration of cells vs. algal units for some phytoplankton species), varying levels of taxonomic detail (aggregating to the genus level vs. species level), inconsistent assignment of species within a genus, outdated names and taxonomy updates, incorrect genus classification, and missing zooplankton biomass data.

Subsequent to careful review of the datasets that included: reviewing archived slides, number of detections by each lab/year, calculated mean cell/organism size, review of previous standardization efforts and interlab QA samples, and evaluation of seasonality, we created four versions of the database (four each [one original and three standardized versions] for phytoplankton and zooplankton). These are:

- 5) **“original database”** version retaining the original data as reported by the laboratories (without any taxonomic standardization/renaming or re-calculation of biovolume) for archival purposes.
- 6) **“partially standardized database”** version that includes a consistent density and biovolume/biomass time series based on taxonomic updates to modern conventions (e.g., species that have been reassigned a new genus), standardized naming for apparently misidentified taxa, and corrects misspellings.
- 7) **“analysis database”** version that combines taxa to emphasize long-term comparability. For example, in genera such as *Fragilaria* where species level identification varied

among labs, species were combined to the genus level. This is the version we recommend for data analyses. This is the version we recommend for data analyses.

- 8) **“supplemental analysis database”** version which is identical to the “analysis database” for most taxa but allows for a greater level of detail in a subset of years. For example, it includes picoplankton (only analyzed by PhycoTech during 2008-2013) as well as splitting taxa for three of the genera (*Fragilaria*, *Stephanodiscus*, and *Cymbella*) into respective morphological sub-groups rather than combining to the genus level (genus level aggregation was necessary for evaluation of the entire time period).

Although these standardized databases now provide the basis for analysis of the full 1990-2013 period for all major taxonomic groups as well as dominant species (particularly for the most dominant species such as *Aphanizomenon flos-aquae* and *Daphnia pulicaria*), the complexity of issues in the timeframe and budget allocated necessitated that further refinement be moved into the Phase II effort. Following are further recommendations to standardize the phytoplankton and zooplankton databases

4.1.1 PHYTOPLANKTON RECOMMENDATIONS

- Additional evaluation and adjustments to further improve long-term comparability for less common taxa
- Resolve outstanding taxonomic issues, including confirming the presence of *Pseudanabaena rutilus-viridis*, a toxin-producing filamentous cyanobacteria that grows in the fascicles of *Aphanizomenon flos-aquae* (Kling et al. 2012, Figure 7c). Kling confirmed the identification morphometrically in late fall 2014 material, but it needs to be confirmed genetically. Archival slides dating back to 2007 indicate that the taxa is the predominant *Pseudanabaena* species in the lake, and may be contributing to microcystin production.
- Confirmation of the relative abundance of both Cyanobacteria and Chlorophyte picoplankton back to 2007 needs to be re-evaluated as well.
- Further review of species where only algal units were enumerated and develop volume/cell density relationships (i.e., *Coelosphaerium naegelianum*, *Gloeotrichia echinulata*, *Coelosphaerium kuetzingianum*, and *Gomphosphaeria lacustris*)
- Evaluate and standardize biovolume calculations for genera such as *Rhodomonas* where different species identified over time were aggregated
- Evaluate and standardize chlorophyll-a due to a change in laboratory methods in 2008.
- Further filter the supplemental database to restrict time periods to only those species for which they are valid. In other words, if the valid time series for a particular species is 2008-2013, then do not include that species for the remaining years (see Section 3.3 for description of current usage for the supplemental database)

4.1.2 ZOOPLANKTON RECOMENDATIONS

- Further evaluate mean weight and length-weight regressions. As discussed in sections 3.3.2 and 3.3.3 we applied standardization to zooplankton weights where warranted; however, additional evaluation and adjustments could further improve long-term comparability. For example we calculated average weights from each lab for each taxa (Table 9, Table 10), but only were able to provide detailed evaluation of the common taxa, and not the rare ones. Evaluation of the weights and application of adjustments for

less common taxa (which we did not do due to time constraints), would improve the data but is not likely to affect overall trends.

- Further evaluation of among-lab length-weight regression differences and adjustment where necessary. For example, by modelling the effect of alternate length-weight regressions on predicted biomass within the PhycoTech dataset we were able to standardize biomass over the time period. Due to time constraints, we only applied that approach to taxa in the genus *Daphnia* (Figure 26 in section 3.3.2.2) but it would be beneficial to apply that same approach to other taxa where the labs also used different regressions equations, including but not limited to: Copepoda nauplii, the Calanoid Copepod *Epischura nevadensis*, Calanoid copepodids, the Cyclopoid Copepod *Diacyclops thomasi*, Cyclopoid copepodids, Cladocera immature, and all taxa in the rotifer genera *Asplanchna*, *Keratella*, and *Synchaeta*. We were not able to determine which regression equation BSA used for *Leptadora kindtii*, which merits further research because it was a relatively common species.
- Further filter the supplemental database to restrict time periods to only those species for which they are valid. In other words, if the valid time series for a particular species is 2008-2013, then do not include that species for the remaining years (see Section 3.3 for description of current usage for the supplemental database).

4.2 PRELIMINARY DATA ANALYSIS

Due to the considerable effort to standardize the database as described above (the initial complexity of standardizing the phytoplankton and zooplankton databases was far more than anticipated due to among-laboratory issues not initially foreseen), time and budgetary constraints limited the scope of the depth of analysis in this Phase I report. Thus, the analyses provided here are considered preliminary, with the main goal to provide graphical depictions of seasonal, spatial, and inter-annual patterns that allow evaluation of database structure, and to form the basis for Phase II comprehensive analyses.

4.2.1 PHYTOPLANKTON

Notable observations include the elucidation of clear seasonal and inter-annual differences over the period of record, as well as differences between UKL and Agency Lake. For example, although exact timing varies from year to year the general phytoplankton pattern is for diatoms (*Asterionella formosa* was most abundant during February through May peaking in March and April, and *Aulacoseira sp.* and *Fragilaria sp.* peaked in May and June) to dominate during late-winter and early-spring before they are replaced by Cyanobacteria (primarily *Aphanizomenon flos-aquae*), which rise to reach a peak of near 100% biovolume generally by early July. *Aphanizomenon* biovolume then declines mid-summer, and in many years increases (but usually not to early summer levels) to reach another peak in August or September. Aside from diatoms and Cyanobacteria, other taxonomic groups which sometimes reach high percent biovolume are Cryptophytes (*Cryptomonas sp.* and *Rhodomonas sp.*), Chlorophytes, and Xanthophytes (*Tribonema sp.*).

The relative biovolume of Cyanophyta (*Aphanizomenon*) tends to begin earlier and decline earlier in Agency Lake and the relative biovolume of diatoms tends to be lower in the spring but higher in the fall in Agency Lake, with the relative proportion of diatoms and Cyanophytes

showing an inverse pattern. Overall site differences are apparent, especially for the Pelican Bay site (PB) which is dominated by spring inflow and wetland plants and does not experience large Cyanophyte blooms. Another Cyanophyte, *Microcystis aeruginosa*, increases in prevalence in mid-summer, generally peaking in August, and is more prevalent in Agency Lake than in UKL.

During the years following dike breaching of the former wetlands between UKL and Agency Lake (described above), there was an apparent increase in the spring diatom bloom of *Asterionella*. In addition, secondary late-summer *Microcystis* increases were more apparent in Agency Lake than in UKL.

Mann-Kendall trend analyses indicate a potential long-term trend of increasing diatoms and decreasing cyanobacteria in the spring, which was particularly evident in Agency Lake, and the trend appeared to start in 2008. The declining Cyanophyta trend and increasing diatom trend was statistically significant ($p < 0.05$) for various spring and early-summer time periods, including April 15-May 30, May 1-30, and June 1-June 30. Trends suggest a delay in the timing of the onset and decline of the early summer *Aphanizomenon flos-aquae* bloom, and also included an increasing biovolume trend for some late-summer period for *Microcystis aeruginosa*.

Other statistically significant trends of note include an apparent spring to early-summer decrease in *Cryptomonas*, *Rhodomonas*, and *Nitzschia*, and increases in both *Fragilaria* and *Asterionella* (Figure 20). In addition, *Anabaena* sp. (group 2: potentially toxin producing forms) shows an increasing trend in early-summer.

4.2.2 ZOOPLANKTON

Due both to a combination of high abundance and large size, Cladocerans (*Daphnia* spp.) comprised a larger percent of zooplankton biomass than any other taxonomic group. Abundance, percent abundance, biomass, and percent biomass of adult *Daphnia* and other Cladocerans (*Chydorus sphaericus*, *Leptadora kindtii*, and immature Cladocera) peaks in summer or early fall and is markedly lower in December through February than in other months. Abundance and biomass of adult Calanoid and Cyclopoid Copepods were higher in the spring (through June) than in the summer (June-September), and Rotifer abundance and biomass tended to be higher through August and lower in the fall (*Euchlanis* spp., *Keratella* spp., *Polyarthra dolichoptera*, and *Synchaeta* spp. reach high abundance with a peak in June or July but due to their small size they typically showed low percent biomass abundance and biomass). Calanoid copepods (composed of two taxa: *Leptodiptomus ashlandi* and *Epischura nevadensis*) showed higher abundance, percent abundance, biomass, and percent biomass than Calanoid copepods (primarily *Diacyclops thomasi*).

Some site differences in timing and magnitude were evident where relative to UKL stations, Agency Lake (stations AN and AS) showed higher percent abundance and percent biomass of Calanoid Copepods later in the season, and overall lower percent abundance of adult Cladocerans. PB showed lower abundance, percent abundance, biomass, and percent biomass of adult Cladocerans and Calanoid copepods (both adults and copepodids), and lower biomass and percent biomass of Copepoda nauplii (as noted above, PB [only sampled through 2006] is dominated by spring inflow and wetland plants).

Notable Mann-Kendall trend tests for zooplankton taxonomic groups and major genera/species for lake-wide averages of UKL and Agency Lake included some spring increases of Copepods including Calanoid copepodids, Cyclopoid copepodids, Copepoda nauplii, *Epischura nevadensis* and *Diacyclops thomasi*. The only statistically significant ($p < 0.05$) trends for *Daphnia* spp. or

total adult Cladocerans was increased abundance in Agency Lake for May 1-31. The Cladoceran *Chydorus sphaericus* showed decreasing abundance, percent abundance, biomass, and percent biomass during the spring in Agency Lake, and decreasing biomass and percent biomass during July 1-31 in UKL. The Rotifers *Euchlanis* spp. and *Asplanchna* spp. showed some spring declines in UKL but not Agency Lake. The Rotifer *Synchaeta* spp. showed a mix of increases and decreases at both UKL and Agency Lake. There were no statistically significant trends for total zooplankton.

4.2.3 OVERALL RECOMMENDATIONS

The above seasonal, inter-annual, spatial, and trend patterns will be explored in further detail in Phase II, including additional seasonal trend testing (e.g., Mann-Kendall Trend Tests) and multivariate techniques (e.g., Non-metric Multidimensional Scaling, NMDS) to evaluate the effects of nutrients, climate, and other physical, chemical, and biological forcing factors on the observed seasonal, spatial, and inter-annual dynamics. A variety of techniques will be utilized, including the identification of natural groupings (e.g., cluster analysis), inter-site relationships defined by similarity coefficients, and NMDS to characterize spatial and seasonal variation in taxonomic groups and dominant species, as well as functional groups (e.g., nitrogen-fixers).

Follow-up Phase II analysis recommendations include:

- Evaluation of the effect of the missing four years (2000-2003) in the phytoplankton data due to inadequate preservation. Based on Helsel and Hirsch (2002), we assumed that a 4-year gap (17% of the 1990-2013 period) does not affect the results of the Mann-Kendall trend tests.
- Parse data into other year groupings for trend testing (e.g., 1990-1999; 2004-2013; 2008-2013).
- Compare seasonal Mann-Kendall trend tests to Regional Kendall tests (the Regional Kendall test is an expansion of the Seasonal M-K test applied to locations rather than seasons; Hirsch et al. 2006).
- Evaluate sensitivity to the minimum sample size used to compute the lake-wide means (differing frequency of stations sampled among years).
- Recompute trend analyses on a subset of stations that were consistently sampled among years.
- Evaluate sensitivity of trends to differing inter-lab methodological resolution (e.g., a greater number of algal units were counted per sample in 2008-2013 than in 2004-2007).

Further recommendations for refined standardization and analyses notwithstanding, the Phase I effort provides the first long-term comprehensive databases for both phytoplankton and zooplankton in Upper Klamath Lake. These databases are especially robust for dominant species, as well as groupings of species (consisting of lumping to the generic level or higher), and form the basis for further detailed multivariate and trend analyses to be undertaken in Phase II.

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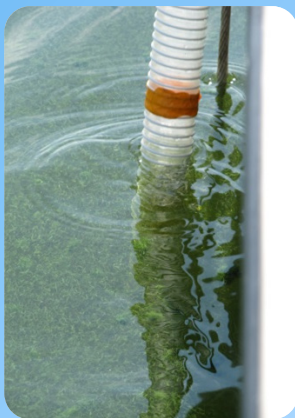


APPENDICES TO:
Standardization and
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for Upper Klamath Lake (Phase I)

Jacob Kann
Aquatic Ecosystem Sciences, LLC.

J. Eli Asarian
Riverbend Sciences

Ann St. Amand
PhycoTech, Inc.



Prepared for:
Klamath Tribes Natural Resources Department
April 2015

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Jacob Kann

Aquatic Ecosystem Sciences, LLC.
295 East Main St., Suite 7
Ashland, OR 97520

J. Eli Asarian

Riverbend Sciences
Weaverville, CA

Ann St. Amand

PhycoTech, Inc.
Saint Joseph, MI

Prepared for:

Klamath Tribes Natural Resources Department

PO Box 436
Chiloquin, OR

April 2015

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A. Upper Klamath Lake, 8/12/2013 (J. Kann); B. *Microcystis* bloom in Agency Lake, 8/12/2013 (J. Kann); C. *Aphanizomenon* bloom near Eagle Ridge, 8/12/2013 (J. Kann); D. *Aphanizomenon* and integrated tube sampler, 8/12/2013 (J. Kann); E. Sampling using integrated tube sampler, 8/12/2013 (J. Kann).

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APPENDIX A: PHYTOPLANKTON SPECIES LIST AND TAXONOMIC/BIOVOLUME STANDARDIZATION

Table A1. List of Phytoplankton taxa in the “original database” for Upper Klamath and Agency Lakes, sorted by taxa group and showing species standardization, cell size standardization (Std), median size calculated from each laboratory’s data (calc med), and detections per year. Key to taxa codes: Chl = Chlorophyta, Chr = Chrysophyta, Cry = Cryptophyta, Cya = Cyanophyta, Dia = Diatoms, Eug = Euglenophyta, Hap = Haptophyta, Pyr = Pyrrhophyta, Misc = Miscellaneous microflagellate, Xan = Xanthophyta. Anal = Analysis Database, PSDB = Partially Standardized Database, and Orig. = Original Database.

Division			Species Name					Cell Size (um^3)					Detections Per Lab-Year																									
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Std	AA lookup	AID calc med	BSA calc med	PT calc med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013		
							Total Phytoplankton						130	136	129	56	138	177	95	113	8	129	107	131	220	134	168	15	30	48	142	168	167	172	195	198		
Chl	Chl	Chl	Actinastrum hantzschii	Actinastrum hantzschii	Actinastrum hantzschii	Actinastrum hantzschii	Actinastrum hantzschii	24.1	240	15.5		20.1				4	2	12	4								1			1			16	1				
Chl	Chl	Chl	Botryococcus braunii	Botryococcus braunii	Botryococcus braunii	Botryococcus braunii	Botryococcus braunii	105				116																	1				1	5	2			
Chl	Chl	Chl	Botryococcus braunii	Botryococcus braunii	Botryococcus braunii	Botryococcus braunii	Botryococcus sp	105			18.0											2																
Chl	Chl	Chl	Characium sp.	Characium sp.	Characium ambiguum	Characium ambiguum	Characium ambiguum	60.3				60.3																		1		2						
Chl	Chl	Chl	Characium sp.	Characium sp.	Characium limneticum	Characium limneticum	Characium limneticum	429				529																	1		1	1	1	1	5			
Chl	Chl	Chl	Characium sp.	Characium sp.	Characium sp.	Characium sp.	Characium sp.	38.7			100											3																
Chl	Chl	Chl	Chlamydomonas sp	Chlamydomonas sp	Chlamydomonas sp	Chlamydomonas globosa	Chlamydomonas globosa	262				268															1		3	7	1	1						
Chl	Chl	Chl	Chlamydomonas sp	Chlamydomonas sp	Chlamydomonas sp	Chlamydomonas sp	Chlamydomonas sp	126	325	63.5	384	110	35	49	71	23	80	45	21	27	3	44	55	28	18	32	30	3	6	11	58	68	86	102	116	180		
Chl	Chl	Chl	Chlorogonium sp	Chlorogonium sp	Chlorogonium fusiforme	Chlorogonium fusiforme	Chlorogonium fusiforme	80.3				67.0																	2			1						
Chl	Chl	Chl	Chlorogonium sp	Chlorogonium sp	Chlorogonium sp	Chlorogonium sp	Chlorogonium sp	155				128																			1	1	1	17				
Chl	Chl	Chl	Chloromonas sp	Chloromonas sp	Chloromonas prona	Chloromonas prona	Chloromonas prona	17.9				17.6																							1	1		
Chl	Chl	Chl	Chloromonas sp	Chloromonas sp	Chloromonas pumilio	Chloromonas pumilio	Chloromonas pumilio	105				105																						1				
Chl	Chl	Chl	Cladophora sp	Cladophora sp	Cladophora sp	Cladophora sp	Cladophora sp	205887				205893																								1		
Chl	Chl	Chl	Closterium sp	Closterium sp	Closterium sp (lunate)	Closterium sp (lunate)	Closterium sp (lunate)	182818																													1	
Chl	Chl	Chl	Closterium sp	Closterium sp	Closterium sp (straight)	Closterium sp (straight)	Closteriopsis longissima	10873	356														1			1	2											
Chl	Chl	Chl	Closterium sp	Closterium sp	Closterium sp (straight)	Closterium sp (straight)	Closterium gracile	10873			830												1															
Chl	Chl	Chl	Closterium sp	Closterium sp	Closterium sp (straight)	Closterium sp (straight)	Closterium sp	10873		131716	230	5898		1		2					2	15	17															
Chl	Chl	Chl	Closterium sp	Closterium sp	Closterium sp (straight)	Closterium sp (straight)	Closterium sp (straight)	10873																									1		1	1	8	
Chl	Chl	Chl	Coelastrum sp	Coelastrum sp	Coelastrum cambricum	Coelastrum cambricum	Coelastrum cambricum	503				503																			1							
Chl	Chl	Chl	Coelastrum sp	Coelastrum sp	Coelastrum microporum	Coelastrum microporum	Coelastrum microporum	105				113																					2	4	4	4		
Chl	Chl	Chl	Coelastrum sp	Coelastrum sp	Coelastrum proboscideum	Coelastrum proboscideum	Coelastrum proboscideum	30.2				30.2																								1		
Chl	Chl	Chl	Coelastrum sp	Coelastrum sp	Coelastrum pseudomicroporum	Coelastrum pseudomicroporum	Coelastrum pseudomicroporum	65.4				65.5																										1
Chl	Chl	Chl	Coelastrum sp	Coelastrum sp	Coelastrum sp	Coelastrum sp	Coelastrum sp	105			84.0												1															
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia crucifera	Crucigenia crucifera	Crucigenia crucifera	6.28	21															1														
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia fenestrata	Crucigenia fenestrata	Crucigenia fenestrata	6.28		56.5	91.0		4									2	3															
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia quadrata	Crucigenia quadrata	Crucigenia quadrata	11.8	21			12.1												2								1	3	2				
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia rectangularis	Crucigenia rectangularis	Crucigenia rectangularis	25.1		37.6	96.0		4		1		1					5	1															
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia tetrapedia	Crucigenia tetrapedia	Crucigenia tetrapedia	54.0		2.25		54.0	11	5	6	3	8	7	5	11																		
Chl	Chl	Chl	Crucigenia sp	Crucigenia sp	Crucigenia truncata	Crucigenia truncata	Crucigenia truncata	1244				1244																									1	
Chl	Chl	Chl	Diacanthos belanophorus	Diacanthos belanophorus	Diacanthos belanophorus	Diacanthos belanophorus	Diacanthos belanophorus	804				804																									1	
Chl	Chl	Chl	Diacanthos sp	Diacanthos sp	Diacanthos sp	Diacanthos sp	Diacanthos sp	804				3665																						1				
Chl	Chl	Chl	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium chlorelloides	Dictyosphaerium chlorelloides	Dictyosphaerium chlorelloides	44.5				30.2																				1	2		1		1	
Chl	Chl	Chl	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium pulchellum	Dictyosphaerium pulchellum	Dictyosphaerium pulchellum	6.04	15	28.2	40.0		3		6		16	4				3	1				1	3										
Chl	Chl	Chl	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium pulchellum	Dictyosphaerium pulchellum	Dictyosphaerium pulchellum	6.04		18.8		4.11		1	5	5	5	7													1	8	3	4	22	11	119	
Chl	Chl	Chl	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium sp	Dictyosphaerium smithii	28.7			52.0												1															

Division			Species Name				Cell Size (um^3)				Detections Per Lab-Year																												
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc med	BSA calc med	PT calc med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013			
Chl	Chl	Chl	Dispora sp	Dispora sp	Dispora sp	Dispora sp	Dispora sp	263				263																									1		
Chl	Chl	Chl	Eudorina elegans	Eudorina elegans	Eudorina elegans	Eudorina elegans	Eudorina elegans	533				259																									8		
Chl	Chl	Chl	Eudorina elegans	Eudorina elegans	Eudorina elegans	Eudorina elegans	Eudorina sp	533			41.0											1											3	3					
Chl	Chl	Chl	Gloeococcus minor	Gloeococcus minor	Gloeococcus minor	Gloeococcus minor	Gloeococcus minor	79.7				113																				1	1			1			
Chl	Chl	Chl	Gloeocystis sp	Gloeocystis sp	Gloeocystis sp	Gloeocystis sp	Gloeocystis ampla	1936	64																			2											
Chl	Chl	Chl	Gloeocystis sp	Gloeocystis sp	Gloeocystis sp	Gloeocystis sp	Gloeocystis sp	1936	260			1936															1									1			
Chl	Chl	Chl	Golenkinia sp	Golenkinia sp	Golenkinia paucispina	Golenkinia paucispina	Golenkinia paucispina	905				905																								1			
Chl	Chl	Chl	Golenkinia sp	Golenkinia sp	Golenkinia radiata	Golenkinia radiata	Golenkinia radiata	340				524																				3				1			
Chl	Chl	Chl	Gonium sp	Gonium sp	Gonium sp	Gonium sp	Gonium sp	45.2			36.0	47.3										1													2				
Chl	Chl	Chl	Kirchneriella sp	Kirchneriella sp	Kirchneriella lunaris	Kirchneriella lunaris	Kirchneriella lunaris	10.0				10.0																							1	1			
Chl	Chl	Chl	Kirchneriella sp	Kirchneriella sp	Kirchneriella sp	Kirchneriella sp	Kirchneriella subsalsa	7.81		18.4	62.0		1		8	2	8				3	1	1																
Chl	Chl	Chl	Lobomonas sp	Lobomonas sp	Lobomonas sp	Lobomonas sp	Lobomonas sp	131				131																						1					
Chl	Chl	Chl	Micractinium pusillum	Micractinium pusillum	Micractinium pusillum	Micractinium pusillum	Micractinium pusillum	29.3				30.2																							5				
Chl	Chl	Chl	Monoraphidium sp	Monoraphidium sp	Ankistrodesmus braunii	Ankistrodesmus braunii	Ankistrodesmus braunii	20.1				20.1																								1			
Chl	Chl	Chl	Monoraphidium sp	Monoraphidium sp	Ankistrodesmus convolutus	Ankistrodesmus convolutus	Ankistrodesmus convolutus	21.8			14.1	84.0	35.0	6	2			4					5						1			1				2			
Chl	Chl	Chl	Monoraphidium sp	Monoraphidium sp	Ankistrodesmus falcatus	Ankistrodesmus falcatus	Ankistrodesmus falcatus	31.6	25	38.5	91.5	22.6	36	19	37	11	69	42	4	16		15	5	73	114	74	67	1	1	4	7	4	6	2	11				
Chl	Chl	Chl	Monoraphidium sp	Monoraphidium sp	Monoraphidium arcuatum	Monoraphidium arcuatum	Ankistrodesmus falcatus var. mirabilis	29.4			16.5			38	3	19		46	48	7	13																		
Chl	Chl	Chl	Monoraphidium sp	Monoraphidium sp	Monoraphidium arcuatum	Monoraphidium arcuatum	Monoraphidium arcuatum	29.4				22.7																	1	1			4	4	15	24	29	52	
Chl	Chl	Chl	Mougeotia sp	Mougeotia sp	Mougeotia sp	Mougeotia sp	Mougeotia sp	3016		242480		3016	2																										
Chl	Chl	Chl	Nephrocytium agardhianum	Nephrocytium agardhianum	Nephrocytium agardhianum	Nephrocytium agardhianum	Nephrocytium agardhianum	84.6			36.4		1		1		1																						
Chl	Chl	Chl	Nephroselmis sp	Nephroselmis sp	Nephroselmis sp	Nephroselmis sp	Nephroselmis sp	146				146																									1		
Chl	Chl	Chl	Oedogonium sp	Oedogonium sp	Oedogonium sp	Oedogonium sp	Oedogonium sp	2056				1932																									4		
Chl	Chl	Chl	Oocystis sp	Oocystis sp	Oocystis lacustris	Oocystis lacustris	Oocystis lacustris	2792	308			2681											1	2			1	1							1	2	2		
Chl	Chl	Chl	Oocystis sp	Oocystis sp	Oocystis parva	Oocystis parva	Oocystis parva	103	10			85.9																											
Chl	Chl	Chl	Oocystis sp	Oocystis sp	Oocystis pusilla	Oocystis pusilla	Oocystis pusilla	8.38	54			8.38																											
Chl	Chl	Chl	Oocystis sp	Oocystis sp	Oocystis solitaria	Oocystis solitaria	Oocystis solitaria	733			1355	108	3										1														2		
Chl	Chl	Chl	Oocystis sp	Oocystis sp	Oocystis sp	Oocystis sp	Oocystis sp	28.3	75	226	134		3		1	3	6	14	2	3		4		2															
Chl	Chl	Chl	Pandorina morum	Pandorina morum	Pandorina morum	Pandorina morum	Pandorina morum	186			71.9	41.0	112	1	1	5		1					8	10									1	2	3	2	1		
Chl	Chl	Chl	Paulschulzia tenera	Paulschulzia tenera	Paulschulzia tenera	Paulschulzia tenera	Paulschulzia tenera	254				183																											
Chl	Chl	Chl	Pediastrum sp	Pediastrum sp	Pediastrum boryanum	Pediastrum boryanum	Pediastrum boryanum	495			52.0		204										4												3	3	6	11	
Chl	Chl	Chl	Pediastrum sp	Pediastrum sp	Pediastrum duplex	Pediastrum duplex	Pediastrum duplex	543	17	209	43.0	274	15	1	4	1	1	15	1			1	4	3	1	3		1					2	1	4	7			
Chl	Chl	Chl	Pediastrum sp	Pediastrum sp	Pediastrum simplex	Pediastrum simplex	Pediastrum simplex	62.5			51.5												2																
Chl	Chl	Chl	Phacotus sp	Phacotus sp	Phacotus sp	Phacotus sp	Phacotus sp	229				248																											
Chl	Chl	Chl	Pyramichlamys dissecta	Pyramichlamys dissecta	Pyramichlamys dissecta	Pyramichlamys dissecta	Pyramichlamys dissecta	419				419																											
Chl	Chl	Chl	Quadrigula sp	Quadrigula sp	Quadrigula closterioides	Quadrigula closterioides	Quadrigula closterioides	11.3			37.6	96.0		2	1		1						2																
Chl	Chl	Chl	Quadrigula sp	Quadrigula sp	Quadrigula lacustris	Elakatothrix viridis	Elakatothrix viridis	121			37.6	104						2	4			6	4																
Chl	Chl	Chl	Quadrigula sp	Quadrigula sp	Quadrigula lacustris	Elakatothrix viridis	Elakatothrix viridis	121					938																										
Chl	Chl	Chl	Quadrigula sp	Quadrigula sp	Quadrigula lacustris	Quadrigula lacustris	Quadrigula lacustris	11.3				40.2																	1										
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus abundans	Scenedesmus abundans	Scenedesmus abundans	16.0				11.3																											
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus acuminatus	Scenedesmus acuminatus	Scenedesmus acuminatus	17.8	60																														
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus acutus	Scenedesmus acutus	Scenedesmus acutus	17.8				25.2																											
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus acutus alternans	Scenedesmus acutus alternans	Scenedesmus acutus alternans	21.9				20.9																							1		13	2	3
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus bijuga	Scenedesmus bijuga	Scenedesmus bijuga	13.3			47.0	88.0	13.0																										
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus dimorphus	Scenedesmus dimorphus	Scenedesmus dimorphus	20.3			20.8	66.0	44.6	1	11	4	26	1		1		1													3				
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus intermedius	Scenedesmus intermedius	Scenedesmus intermedius	18.6				18.6																								1			
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus opoliensis	Scenedesmus opoliensis	Scenedesmus opoliensis	32.9				41.9																									1	1	

Division			Species Name					Cell Size (um^3)					Detections Per Lab-Year																												
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc med	BSA calc med	PT calc med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013					
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus quadricauda	Scenedesmus quadricauda	Scenedesmus quadricauda	16.6	65	23.4	84.0	18.6	2	4	19	12	46	22	2	3		1		2	1	3	3					1	8	3	1						
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus semipulcher	Scenedesmus semipulcher	Scenedesmus semipulcher	28.3				28.3																						1							
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus serratus	Scenedesmus serratus	Scenedesmus serratus	4.42				4.19																						1							
Chl	Chl	Chl	Scenedesmus sp	Scenedesmus sp	Scenedesmus sp	Scenedesmus sp	Scenedesmus sp	16.6		47.0	69.5		10	1	4		1	3					1	1								3	1	2	1						
Chl	Chl	Chl	Schroderia sp	Schroderia sp	Schroderia sp	Schroderia sp	Schroderia sp	24.6	45		210												1	1	1	13															
Chl	Chl	Chl	Schroderia sp	Schroderia sp	Schroderia judayi	Schroderia judayi	Schroderia judayi	24.6				19.7																					4	15	19	73	57	58	105	101	151
Chl	Chl	Chl	Schroderia sp	Schroderia sp	Schroderia setigera	Schroderia setigera	Schroderia setigera	245		58.2		190	31	23	33	16	25	32	18	35													3	4	5	15	10	13	9	19	20
Chl	Chl	Chl	Selenastrum minutum	Selenastrum minutum	Selenastrum minutum	Selenastrum minutum	Selenastrum minutum	27.2	20			106													1	1	4					1	2								
Chl	Chl	Chl	Selenastrum sp	Selenastrum sp	Selenastrum sp	Selenastrum sp	Selenastrum sp	55.3		9.41										1																					
Chl	Chl	Chl	Sorastrum sp	Sorastrum sp	Sorastrum sp	Sorastrum sp	Sorastrum sp	428				801																													
Chl	Chl	Chl	Sorastrum sp	Sorastrum sp	Sorastrum sp	Sorastrum sp	Sorastrum spinulosum	428			72.0													1																	
Chl	Chl	Chl	Spermatozopsis exsultans	Spermatozopsis exsultans	Spermatozopsis exsultans	Spermatozopsis exsultans	Spermatozopsis exsultans	9.98				6.70																													
Chl	Chl	Chl	Sphaerocystis schroeteri	Sphaerocystis schroeteri	Sphaerocystis schroeteri	Sphaerocystis schroeteri	Sphaerocystis schroeteri	82.4	35	151	43.5	62.7	19	13	8	1	3	12	1	4		10	12	11	29	14	20	1	7	5	22	3	16	16	23	23					
Chl	Chl	Chl	Spirogyra sp	Spirogyra sp	Spirogyra sp	Spirogyra sp	Spirogyra sp	227709	227709			216770																													
Chl	Chl	Chl	Staurastrum sp	Staurastrum sp	Staurastrum sp	Staurastrum sp	Staurastrum sp	19623		23532	1385	28811											3																		
Chl	Chl	Chl	Tetraedron sp	Tetraedron sp	Tetraedron caudatum	Tetraedron caudatum	Tetraedron caudatum	64.2		41.1			1	1																											
Chl	Chl	Chl	Tetraedron sp	Tetraedron sp	Tetraedron minimum	Tetraedron minimum	Tetraedron minimum	40.8		71.9	104	23.6	11	1	9	2	20	3	1			2												1	1	1	3				
Chl	Chl	Chl	Tetraedron sp	Tetraedron sp	Tetraedron minimum	Tetraedron minimum	Tetraedron regulare	40.8	115																1																
Chl	Chl	Chl	Tetrastrum	Tetrastrum	Tetrastrum	Tetrastrum	Tetrastrum	9.50	216			8.22																													
Chl	Chl	Chl	staurigeniaeforme	staurigeniaeforme	staurigeniaeforme	staurigeniaeforme	staurigeniaeforme																																		
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Chlorococcaceae sp 1 (2-9.9 um spherical)	Chlorococcaceae sp 1 (2-9.9 um spherical)	Chlorella sp	25.3	60															4	6	6															
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Chlorococcaceae sp 1 (2-9.9 um spherical)	Chlorococcaceae sp 1 (2-9.9 um spherical)	Chlorococcaceae sp 1 (2-9.9 um spherical)	25.3				33.5																													
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Chlorococcaceae sp 2 (> 10 um spherical)	Chlorococcaceae sp 2 (> 10 um spherical)	Chlorococcaceae sp 2 (> 10 um spherical)	4189				3167																													
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Chlorococcaceae sp 3 (> 1 um ovoid)	Chlorococcaceae sp 3 (> 1 um ovoid)	Chlorococcaceae sp 3 (> 1 um ovoid)	15.6				7.33																													
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Deasonia Gigantica	Deasonia Gigantica	Deasonia Gigantica	1846				1968																													
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Stichococcus bacillaris	Stichococcus bacillaris	Stichococcus bacillaris	3.64				3.53																													
Chl	Chl	Chl	Trebouxiophyceae sp	Trebouxiophyceae sp	Trebouxiophyceae sp	Trebouxiophyceae sp	Unident green alga	30.2	150	151			24	31	3	1	3	6		20																					
Chl	Chl	Chl	Ulothrix sp	Ulothrix sp	Ulothrix sp	Ulothrix sp	Ulothrix sp	571	80		125	558																													
Chl	Chl	Chl	Unident Chlorophyta cyst	Unident Chlorophyta cyst	Unident Chlorophyta cyst	Unident Chlorophyta cyst	Unident Chlorophyta cyst	78.5				78.5																													
Chl	Chl	Chl	Volvox sp	Volvox sp	Volvox sp	Volvox sp	Volvox sp	65.4	10			65.5																													
Chl	Chl	Chl	Xanthidium sp	Xanthidium sp	Xanthidium sp	Xanthidium sp	Xanthidium sp	261				261																													
Chl	Chl	Chl	Monoraphidium capricornutum	Monoraphidium capricornutum	Monoraphidium capricornutum	Monoraphidium capricornutum	Monoraphidium capricornutum	7.81				7.81																													
Chl	Cya	Cya	Picoplankton	Picoplankton	Chroococcaceae (<1 um spherical)	Chroococcaceae (<1 um spherical)	Chroococcaceae (<1 um spherical)	0.52				0.52																													
Chl	Cya	Cya	Picoplankton	Picoplankton	Synechococcus elongatus	Synechococcus elongatus	Synechococcus elongatus	1.56				1.57																													
Chl	Cya	Cya	Picoplankton	Picoplankton	Synechococcus leopoliensis	Synechococcus leopoliensis	Synechococcus leopoliensis	1.39				1.57																													
Chl	Cya	Cya	Picoplankton	Picoplankton	Synechocystis sp 1 (>1 um spherical)	Synechocystis sp 1 (>1 um spherical)	Synechocystis sp 1 (>1 um spherical)	2.07				1.77																													
Chl	Cya	Cya	Picoplankton	Picoplankton	Synechocystis sp 2 (>=2 um spherical)	Synechocystis sp 2 (>=2 um spherical)	Synechocystis sp 2 (>=2 um spherical)	29.2				33.5																													
Chl	Chl	Chl	Cosmarium regnesi	Cosmarium regnesi	Cosmarium regnesi	Cosmarium regnesi	Cosmarium regnesi	335		75.3																															
Chl	Chl	Chl	Cosmarium sp	Cosmarium sp	Cosmarium sp	Cosmarium sp	Cosmarium sp	335		183			3	3	1		1	2																							
Chr	Chr	Chr	Chrysocapsaceae sp	Chrysocapsaceae sp	Chrysocapsaceae sp	Chrysocapsaceae sp	Chrysocapsaceae sp	113				113																													
Chr	Chr	Chr	Chrysococcus sp	Chrysococcus sp	Chrysococcus minutus	Chrysococcus minutus	Chrysococcus minutus	23.4				30.2																													

Division			Species Name			Cell Size (um^3)					Detections Per Lab-Year																																						
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc	BSA calc	PT calc	med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013												
Cya	Cya	Cya	akinetes	akinetes	akinetes	akinetes	akinetes	66.0		63.5	5.00			11	12	9	9	9	11	4	7		20	31	7	36	14	40																					
Cya	Cya	Cya	Anabaena sp. Group 2 - heterocysts	Anabaena sp. Group 2 - heterocysts	Anabaena lemmermannii - heterocysts	Anabaena lemmermannii - heterocysts	Anabaena lemmermannii - heterocysts	66.0				64.9																		8	3			3	13	24													
Cya	Cya	Cya	Anabaena sp. Group 2 - heterocysts	Anabaena sp. Group 2 - heterocysts	Anabaena mendotae - heterocysts	Anabaena mendotae - heterocysts	Anabaena mendotae - heterocysts	67.3				64.9																			30	30	21	22	8	3													
Cya	Cya	Cya	Aphanizomenon flos-aquae	Aphanizomenon flos-aquae	Aphanizomenon flos-aquae	Aphanizomenon flos-aquae	Aphanizomenon flos-aquae	119	63	95.8	1.11	118		118	131	87	48	85	138	78	92	8	129	106	126	166	116	133	15	28	43	114	149	120	128	129	142												
Cya	Cya	Cya	Aphanizomenon flos-aquae - akinetes	Aphanizomenon flos-aquae - akinetes	Aphanizomenon flos-aquae - akinetes	Aphanizomenon flos-aquae - akinetes	Aphanizomenon flos-aquae - akinetes	1205		1126	31.0	1244		55	43	8	20	9	42	25	18	8	111	74	61	74	28	59	3	7	24	34	62	65	33	30	64												
Cya	Cya	Cya	Aphanizomenon flos-aquae - heterocysts	Aphanizomenon flos-aquae - heterocysts	Aphanizomenon flos-aquae - heterocysts	Aphanizomenon flos-aquae - heterocysts	Aphanizomenon flos-aquae - heterocysts	192		146	8.00	196		91	104	53	36	61	104	68	67	1	48	76	114	152	108	132			42	110	127	113	104	115	120												
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa delicatissima	Aphanocapsa delicatissima	Aphanocapsa delicatissima	0.56				0.52																		5	2		7	19	14	25	36												
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa elachista	Aphanocapsa elachista	Aphanocapsa elachista	5.42				1.77																	1		1	1	4		1														
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa holsatica	Aphanocapsa holsatica	Aphanocapsa holsatica	0.52				0.52																								1	2	9											
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa incerta	Aphanocapsa incerta	Aphanocapsa incerta	24.4				4.19																	1										1										
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa koordersi	Aphanocapsa koordersi	Aphanocapsa koordersi	4.19				4.19																	1																				
Cya	Cya	Cya	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa sp	Aphanocapsa sp (<1 um spherical)	Aphanocapsa sp (<1 um spherical)	0.52				0.52												9	7												1	2											
Cya	Cya	Cya	Aphanothece sp	Aphanothece sp	Aphanothece clathrata	Aphanothece clathrata	Aphanothece clathrata	0.98				1.05																											10										
Cya	Cya	Cya	Aphanothece sp	Aphanothece sp	Aphanothece nidulans	Aphanothece nidulans	Aphanothece nidulans	1.07				1.05																	1									11	21	12									
Cya	Cya	Cya	Aphanothece sp	Aphanothece sp	Aphanothece sp	Aphanothece sp	Aphanothece sp	1.57			4.00												4																										
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus dispersus	Chroococcus dispersus	Chroococcus dispersus	16.8			11.0												3	3																									
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus dispersus	Chroococcus dispersus	Chroococcus dispersus var. minor	16.8		2.35	12.0			33	5	19	9	46	27	4	12		14	8																									
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus limneticus	Chroococcus limneticus	Chroococcus limneticus	56.5															7	5																									
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus minimus	Chroococcus minimus	Chroococcus minimus	4.58				4.19																											1	12	1	2	1	6	1	3			
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus minutus	Chroococcus minutus	Chroococcus minutus	22.3				16.8																		1	4	3	2	1	2	4	1												
Cya	Cya	Cya	Chroococcus sp	Chroococcus sp	Chroococcus sp	Chroococcus minutus	Chroococcus minutus	22.3		7.94	11.0						13	4					31	11																									
Cya	Cya	Cya	Cuspidothrix issatschenkoi	Cuspidothrix issatschenkoi	Cuspidothrix issatschenkoi	Cuspidothrix issatschenkoi	Cuspidothrix issatschenkoi	51.9				42.4																		1										1									
Cya	Cya	Cya	Cyanodictyon planctonicum	Cyanodictyon planctonicum	Cyanodictyon planctonicum	Cyanodictyon planctonicum	Cyanodictyon planctonicum	1.05				1.05																														2							
Cya	Cya	Cya	Cyanonephron styloides	Cyanonephron styloides	Cyanonephron styloides	Cyanonephron styloides	Cyanonephron styloides	0.33				0.59																													1	19							
Cya	Cya	Cya	Cylindrospermopsis raciborskii	Cylindrospermopsis raciborskii	Cylindrospermopsis raciborskii	Cylindrospermopsis raciborskii	Cylindrospermopsis raciborskii	17.7				17.7																															1						
Cya	Cya	Cya	Dactylococcopsis irregularis	Dactylococcopsis irregularis	Dactylococcopsis irregularis	Dactylococcopsis irregularis	Dactylococcopsis irregularis	7.93				14.7																															1	1					
Cya	Cya	Cya	Gloeotrichia echinulata	Gloeotrichia echinulata	Gloeotrichia echinulata	Gloeotrichia echinulata	Gloeotrichia echinulata	82.7		Inf	8.00	75.4		2	1						1		2																			6	2	6	7	1			
Cya	Cya	Cya	Gomphosphaeria sp	Gomphosphaeria sp	Gomphosphaeria lacustris	Gomphosphaeria lacustris	Gomphosphaeria lacustris	10.9		Inf	10.0	10.6						1					6	3					1																				
Cya	Cya	Cya	Lyngbya sp	Lyngbya sp	Lyngbya sp	Lyngbya sp	Lyngbya sp	2.65		176	8.00			1									1																										
Cya	Cya	Cya	Lyngbya subtilissima	Lyngbya subtilissima	Lyngbya subtilissima	Lyngbya subtilissima	Lyngbya subtilissima	21.2				21.2																	1																				
Cya	Cya	Cya	Merismopedia sp	Merismopedia sp	Merismopedia punctata	Merismopedia punctata	Merismopedia punctata	1.05				1.05																																	1				
Cya	Cya	Cya	Merismopedia sp	Merismopedia sp	Merismopedia sp	Merismopedia sp	Merismopedia sp	1.05		2.35												1																											
Cya	Cya	Cya	Merismopedia sp	Merismopedia sp	Merismopedia tenuissima	Merismopedia tenuissima	Merismopedia tenuissima	0.89		0.20		1.05		1	4	33	3	28	38	1	6																							6	4	3	8	2	1
Cya	Cya	Cya	Merismopedia sp	Merismopedia sp	Merismopedia trolleri	Merismopedia trolleri	Merismopedia trolleri	19.8				28.3																																					
Cya	Cya	Cya	Merismopedia sp	Merismopedia sp	Merismopedia warmingiana	Merismopedia warmingiana	Merismopedia warmingiana	0.13				0.13																																					

Division			Species Name				Cell Size (um^3)					Detections Per Lab-Year																										
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc med	BSA calc med	PT calc med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013		
Cya	Cya	Cya	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa (single cell)	Microcystis aeruginosa (single cell)	44.4	8	1.00		33.5	19	7	5		5	18	11	33		20	5	13	8	23	21		7	13	22	40	12	17	19	29		
Cya	Cya	Cya	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa	Microcystis aeruginosa (single cell)	Microcystis aeruginosa (single cell)	44.4																					3	1	8	17	16		1			
Cya	Cya	Cya	Microcystis sp	Microcystis sp	Microcystis novacekii	Microcystis novacekii	Microcystis novacekii	56.5				65.5																		3				1				
Cya	Cya	Cya	Microcystis sp	Microcystis sp	Microcystis sp	Microcystis sp	Microcystis sp	44.4		433													3															
Cya	Cya	Cya	Oscillatoria sp	Oscillatoria sp	Oscillatoria amphibia	Oscillatoria amphibia	Oscillatoria amphibia	23.4				29.9																	2									
Cya	Cya	Cya	Oscillatoria sp	Oscillatoria sp	Oscillatoria sp	Oscillatoria sp	Oscillatoria sp	158	62	10.0		113											2	5	1			1							3			
Cya	Cya	Cya	Phormidium sp	Phormidium sp	Phormidium sp	Phormidium sp	Phormidium sp	3.53				3.53																	1									
Cya	Cya	Cya	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena limnetica	Pseudanabaena limnetica	Pseudanabaena limnetica	6.26				7.07																	9	22	6	65	96	55	92	62	84	
Cya	Cya	Cya	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena mucicola	Pseudanabaena mucicola	Pseudanabaena mucicola	2.82				2.74																	1	2	21	20	41	28	22	19	12	
Cya	Cya	Cya	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	6.26		3.53				31		37	29	71	91	62	68																	
Cya	Cya	Cya	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	4.81		3.53				38	80	33	1			6																		
Cya	Cya	Cya	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	Pseudanabaena sp	4.81			1.00	5.30										8	76	33						16	20	4	1	1	6	24		
Cya	Cya	Cya	Rhabdoderma lineare	Rhabdoderma lineare	Rhabdoderma lineare	Rhabdoderma lineare	Rhabdoderma lineare	1.05				1.05																							2	2	2	
Cya	Cya	Cya	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	20.6			Inf 10.0												2															
Cya	Cya	Cya	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana (single cell)	Woronichinia naegeliana (single cell)	22.7			Inf	23.6		3	1																							
Cya	Cya	Cya	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana (single cell)	Woronichinia naegeliana (single cell)	22.7				23.6																		3	11	4	10		1	1	1	
Cya	Cya	Cya	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana	Woronichinia naegeliana (single cell)	Woronichinia naegeliana (single cell)	22.7																						2	2	6	5	8	8	5	2	1
Cya	Cya	Cya			Gloeothece sp	Gloeothece sp	Gloeothece sp	1.05		10594	12.0			2	2	7	1	1	2		1		6															
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes delicatula hauckiana	Achnanthes delicatula hauckiana	Achnanthes hauckiana	109	48																1													
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes exigua	Achnanthes exigua	Achnanthes exigua	141				785																										
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes flexella	Achnanthes flexella	Achnanthes flexella	283				283																										
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes lanceolata	Achnanthes lanceolata	Achnanthes lanceolata	127	180																4	4	4	2									1	
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes linearis	Achnanthes linearis	Achnanthes linearis	105	132																1													
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes minutissima	Achnanthes minutissima	Achnanthes minutissima	144	50			119														1	1		1	2	1	1	5			2		
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes peragalli	Achnanthes peragalli	Achnanthes peragalli	101	140																													
Dia	Dia	Dia	Achnanthes sp	Achnanthes sp	Achnanthes sp	Achnanthes sp	Achnanthes sp	118			132	118											1	4												1		
Dia	Dia	Dia	Amphora 1	Amphora 1	Amphora 1	Amphora 1	Amphora 1	219				219																										
Dia	Dia	Dia	Amphora 1	Amphora 1	Amphora ovalis	Amphora ovalis	Amphora ovalis	5415	578			6568																										
Dia	Dia	Dia	Amphora 1	Amphora 1	Amphora pediculus	Amphora pediculus	Amphora pediculus	253																														
Dia	Dia	Dia	Amphora 1	Amphora 1	Amphora perpusilla	Amphora perpusilla	Amphora perpusilla	94.1	166																1	2			1							1		
Dia	Dia	Dia	Amphora 1	Amphora 1	Amphora veneta	Amphora veneta	Amphora veneta	1806				1917																										
Dia	Dia	Dia	Anomoeoneis vitrea	Anomoeoneis vitrea	Anomoeoneis vitrea	Anomoeoneis vitrea	Anomoeoneis vitrea	339				339																										
Dia	Dia	Dia	Asterionella formosa	Asterionella formosa	Asterionella formosa	Asterionella formosa	Asterionella formosa	805	220	898	415	738	26	45	32	13	27	44	19	30		20	26	17	79	30	19	7	8	8	52	64	67	48	58	47		
Dia	Dia	Dia	Asterionella formosa	Asterionella formosa	Asterionella formosa	Asterionella formosa	Asterionella sp	805		1294							1	1																				
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira ambigua	Aulacoseira ambigua	Aulacoseira ambigua	1072				922																		5	5	1	4	9		9	9	
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira ambigua	Aulacoseira ambigua	Melosira ambigua	1072	589																	14	8	4	1									
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira canadensis	Aulacoseira canadensis	Aulacoseira canadensis	402																														
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira distans	Aulacoseira distans	Aulacoseira distans	1357				1357																									1	
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira distans	Aulacoseira distans	Melosira distans alpigena	1357	175																													
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira granulata	Aulacoseira granulata	Aulacoseira granulata	873				854																										
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira granulata	Aulacoseira granulata	Melosira granulata	873	550	8467	913		9	7	3	5	3	8	1	3				22	30	11	14	12	30									
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira sp	Aulacoseira islandica 1	Melosira islandica	1072																														
Dia	Dia	Dia	Aulacoseira sp	Aulacoseira sp	Aulacoseira sp	Aulacoseira granulata	Melosira sp.	873	500		432																											

Division			Species Name				Cell Size (um^3)					Detections Per Lab-Year																											
Anal.	PSDB	Orig.	Analysis	Analysis Supplemental	Partially Standardized Database	Cell Size	Original	Stnd	AA lookup	AID calc	BSA calc	PT calc	med	AID_1990	AID_1991	AID_1992	AID_1993	AID_1994	AID_1995	AID_1996	AID_1997	BSA_1997	BSA_1998	BSA_1999	AA_2004	AA_2005	AA_2006	AA_2007	PT_2005	PT_2006	PT_2007	PT_2008	PT_2009	PT_2010	PT_2011	PT_2012	PT_2013		
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis bacillum	Caloneis bacillum	Caloneis bacillaris	679					2011																								1		
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis bacillum	Caloneis bacillum	Caloneis bacillum	679					679																									1	
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis hyalina	Caloneis hyalina	Caloneis hyalina	412	220																1														
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis lewisii	Caloneis lewisii	Caloneis lewisii	4072					4072																									1	
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis sp	Caloneis sp	Caloneis sp	4608	240				5429												1	2		1				1	1			1	1	1	
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis ventricosa	Caloneis ventricosa	Caloneis ventricosa	4608	245																			1											
Dia	Dia	Dia	Caloneis sp	Caloneis sp	Caloneis ventricosa	Caloneis ventricosa	Caloneis ventricosa minuta	4608	280																			2											
Dia	Dia	Dia	Cocconeis sp	Cocconeis sp	Cocconeis pediculus	Cocconeis pediculus	Cocconeis pediculus	2851					2909																					1	1				
Dia	Dia	Dia	Cocconeis sp	Cocconeis sp	Cocconeis placentula	Cocconeis placentula	Cocconeis placentula	580	460		516		565											2	2	2	2	8	1	1	5	3	6	6	3	2	2		
Dia	Dia	Dia	Cocconeis sp	Cocconeis sp	Cocconeis sp	Cocconeis sp	Cocconeis sp	580		1270	520			19	12	5	4	13	7	1	2	2	34	20													1		
Dia	Dia	Dia	Cyclostephanos sp	Cyclostephanos sp	Cyclostephanos damasii	Cyclostephanos damasii	Cyclostephanos damasii	3142					3142																									1	
Dia	Dia	Dia	Cyclostephanos sp	Cyclostephanos sp	Cyclostephanos tholiformis	Cyclostephanos tholiformis	Cyclostephanos tholiformis	201					201																	1									
Dia	Dia	Dia	Cyclostephanos sp	Cyclostephanos sp	Cyclostephanos tholiformis (>8 um)	Cyclostephanos tholiformis (>8 um)	Cyclostephanos tholiformis (>8 um)	201																						1									
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella atomus	Cyclotella atomus	Cyclotella atomus	59.6					61.0																						1				
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella meneghiniana	Cyclotella meneghiniana	Cyclotella meneghiniana	1036	380				679													3	1	2		2		2				2		1	
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella ocellata	Cyclotella ocellata	Cyclotella ocellata	108	125				84.8													1								1		2		1	
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella pseudostelligera	Cyclotella pseudostelligera	Cyclotella pseudostelligera	99.8	65				84.8												1		3		1	2	6	2	14	4			9		
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella sp 1	Cyclotella sp 1	Cyclotella sp 1	52.5																						1	1	1	4	1					
Dia	Dia	Dia	Cyclotella sp	Cyclotella sp	Cyclotella stelligera	Cyclotella stelligera	Cyclotella stelligera	306	55				393												4						1	2			2				
Dia	Dia	Dia	Cymatopleura sp	Cymatopleura sp	Cymatopleura solea	Cymatopleura solea	Cymatopleura solea	56297	16200		775		54086											1	2							1				1			
Dia	Dia	Dia	Cymatopleura sp	Cymatopleura sp	Cymatopleura sp	Cymatopleura sp	Cymatopleura sp	205887			775		205887												1								1						
Dia	Dia	Dia	Cymbella sp	Cymbella silesiaca species group	Cymbella minuta	Cymbella minuta	Cymbella minuta	710	370																	5	6	1	3										
Dia	Dia	Dia	Cymbella sp	Cymbella silesiaca species group	Cymbella silesiaca	Cymbella silesiaca	Cymbella silesiaca	710					614																				1	2	1		1		
Dia	Dia	Dia	Cymbella sp	Cymbella sp	Cymbella affinis	Cymbella affinis	Cymbella affinis	4659	1800				4659													2			1										
Dia	Dia	Dia	Cymbella sp	Cymbella sp	Cymbella lanceolata	Cymbella lanceolata	Cymbella lanceolata	3240			790													2	1														
Dia	Dia	Dia	Cymbella sp	Cymbella sp	Cymbella microcephala	Cymbella microcephala	Cymbella microcephala	140	53				140													1									1				
Dia	Dia	Dia	Cymbella sp	Cymbella sp	Cymbella naviculiformis	Cymbella naviculiformis	Cymbella naviculiformis	721	1200																	3													
Dia	Dia	Dia	Cymbella sp	Cymbella sp	Cymbella sp	Cymbella sp	Cymbella sp	1351		2995	221		675	16	5		1	4	6				2	23	21						1	1		3			1		
Dia	Dia	Dia	Cymbellonitzschia sp	Cymbellonitzschia sp	Cymbellonitzschia diluviana	Cymbellonitzschia diluviana	Cymbellonitzschia diluviana	128	125																	1			1										
Dia	Dia	Dia	Denticula kuetzingii	Denticula kuetzingii	Denticula kuetzingii	Denticula kuetzingii	Denticula kuetzingii	314					314																										
Dia	Dia	Dia	Diatoma sp	Diatoma sp	Diatoma sp	Diatoma sp	Diatoma sp	1005			7277	165		11	4			2	1	2		1			7	6													
Dia	Dia	Dia	Diatoma sp	Diatoma sp	Diatoma tenuis	Diatoma tenuis	Diatoma tenue elongatum	1085	720																1		1												
Dia	Dia	Dia	Diatoma sp	Diatoma sp	Diatoma tenuis	Diatoma tenuis	Diatoma tenuis	1085					1005																					1			2		
Dia	Dia	Dia	Diatoma sp	Diatoma sp	Diatoma vulgaris	Diatoma vulgaris	Diatoma vulgare	6434	1960																	1		1											
Dia	Dia	Dia	Diploneis sp	Diploneis sp	Diploneis elliptica	Diploneis elliptica	Diploneis elliptica	1571	260																			1	2										
Dia	Dia	Dia	Diploneis sp	Diploneis sp	Diploneis puella	Diploneis puella	Diploneis puella	1257					1433																								2		
Dia	Dia	Dia	Diploneis sp	Diploneis sp	Diploneis smithii	Diploneis smithii	Diploneis smithii	1963			522													1	1														
Dia	Dia	Dia	Diploneis sp	Diploneis sp	Diploneis sp	Diploneis sp	Diploneis sp	1810					1810																									1	
Dia	Dia	Dia	Epithemia sp	Epithemia sp	Epithemia sorex	Epithemia sorex	Epithemia sorex	1467	1140																														
Dia	Dia	Dia	Epithemia sp	Epithemia sp	Epithemia sp	Epithemia sp	Epithemia sp	1467			260		1467												4	3									1				
Dia	Dia	Dia	Epithemia sp	Epithemia sp	Epithemia turgida	Epithemia turgida	Epithemia turgida	6972	4250				7467													1	1	2	2			1		1					
Dia	Dia	Dia	Epithemia sp	Epithemia sp	Epithemia turgida westermanni	Epithemia turgida westermanni	Epithemia turgida westermanni	31200																											1				
Dia	Dia	Dia	Eunotia sp	Eunotia sp	Eunotia pectinalis	Eunotia pectinalis	Eunotia pectinalis	6627	720																				1										
Dia	Dia	Dia	Eunotia sp	Eunotia sp	Eunotia sp	Eunotia sp	Eunotia sp	979			327		384																						9	1	2		2
Dia	Dia	Dia	Fragilaria sp	Fragilaria sp Group 2, small	Fragilaria construens	Fragilaria construens	Fragilaria construens	296					275																				2	5	5	3	2		

**APPENDIX B: LIST OF KEYS AND TAXONOMIC REFERENCES USED BY PHYCOTECH
TO IDENTIFY PHYTOPLANKTON AND ZOOPLANKTON**



Keys & Taxonomic References (exclusive of primary and on-line references)

Algae | Macroinvertebrates | Macrophytes | Zooplankton

Algae

Note: List does not include all primary and on-line references.

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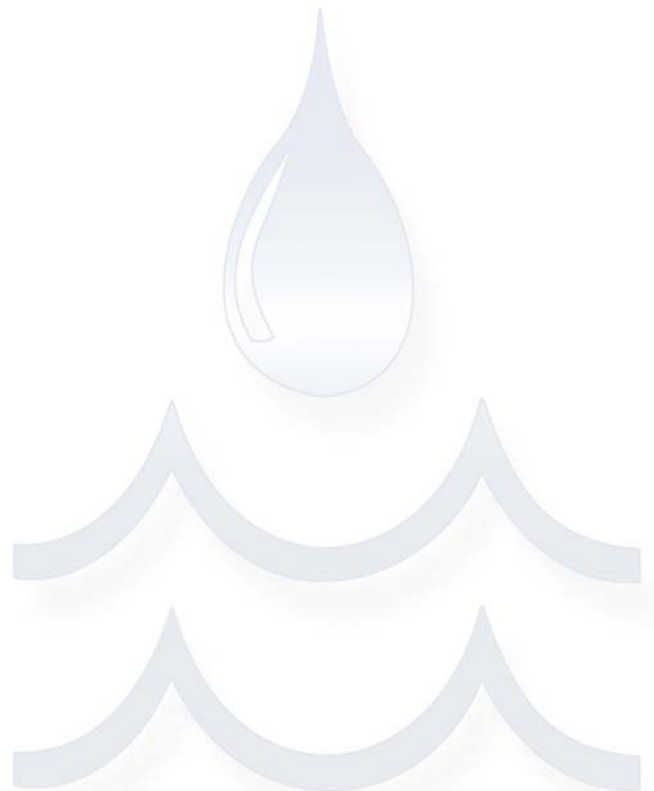
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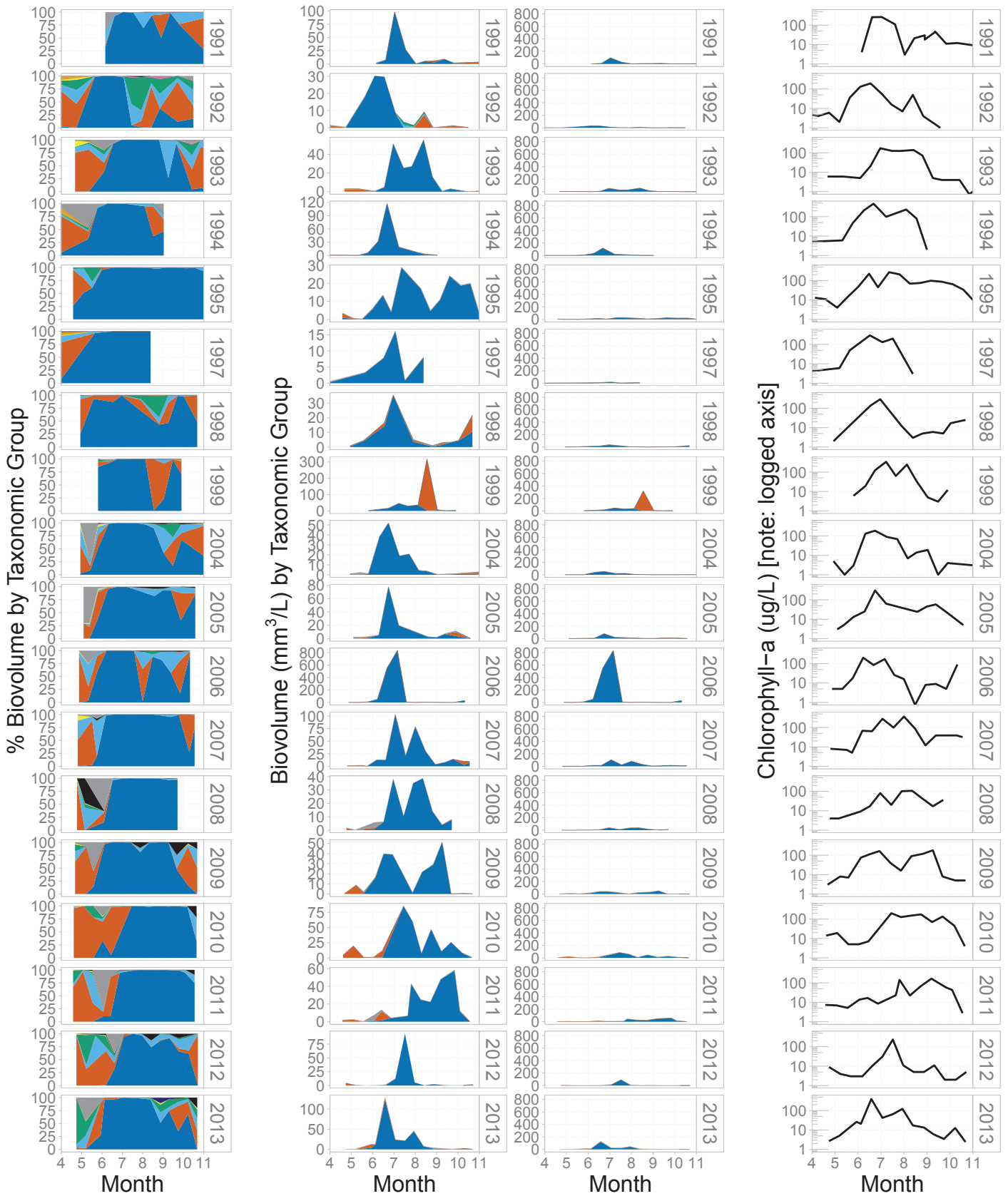
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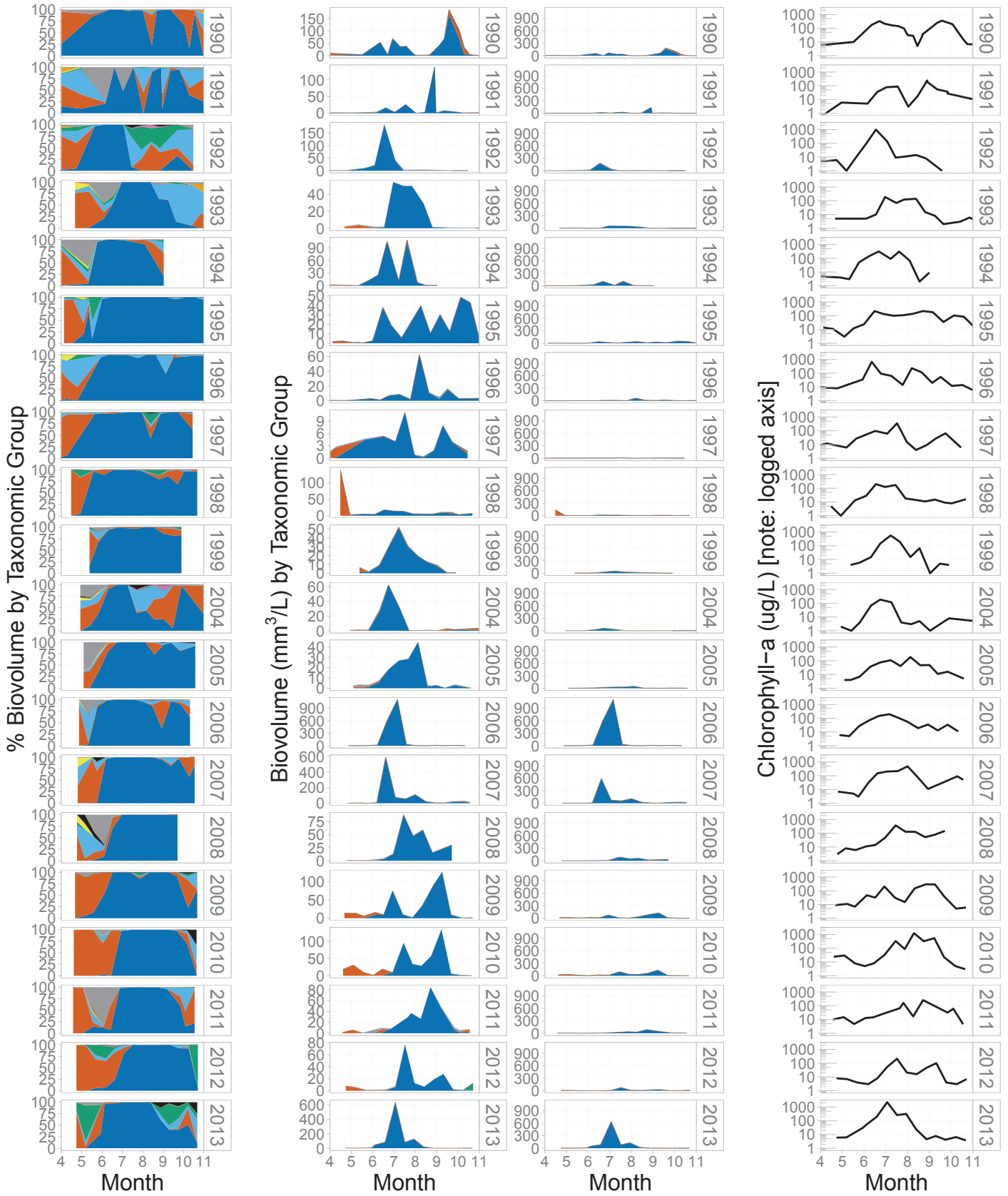
APPENDIX C: DETAILED TIME SERIES CHARTS OF BIOVOLUME FOR PHYTOPLANKTON TAXONOMIC GROUPS FOR EACH SITE

Note: the group labelled as "Unknown" in the graphs is composed entirely of miscellaneous microflagellates.

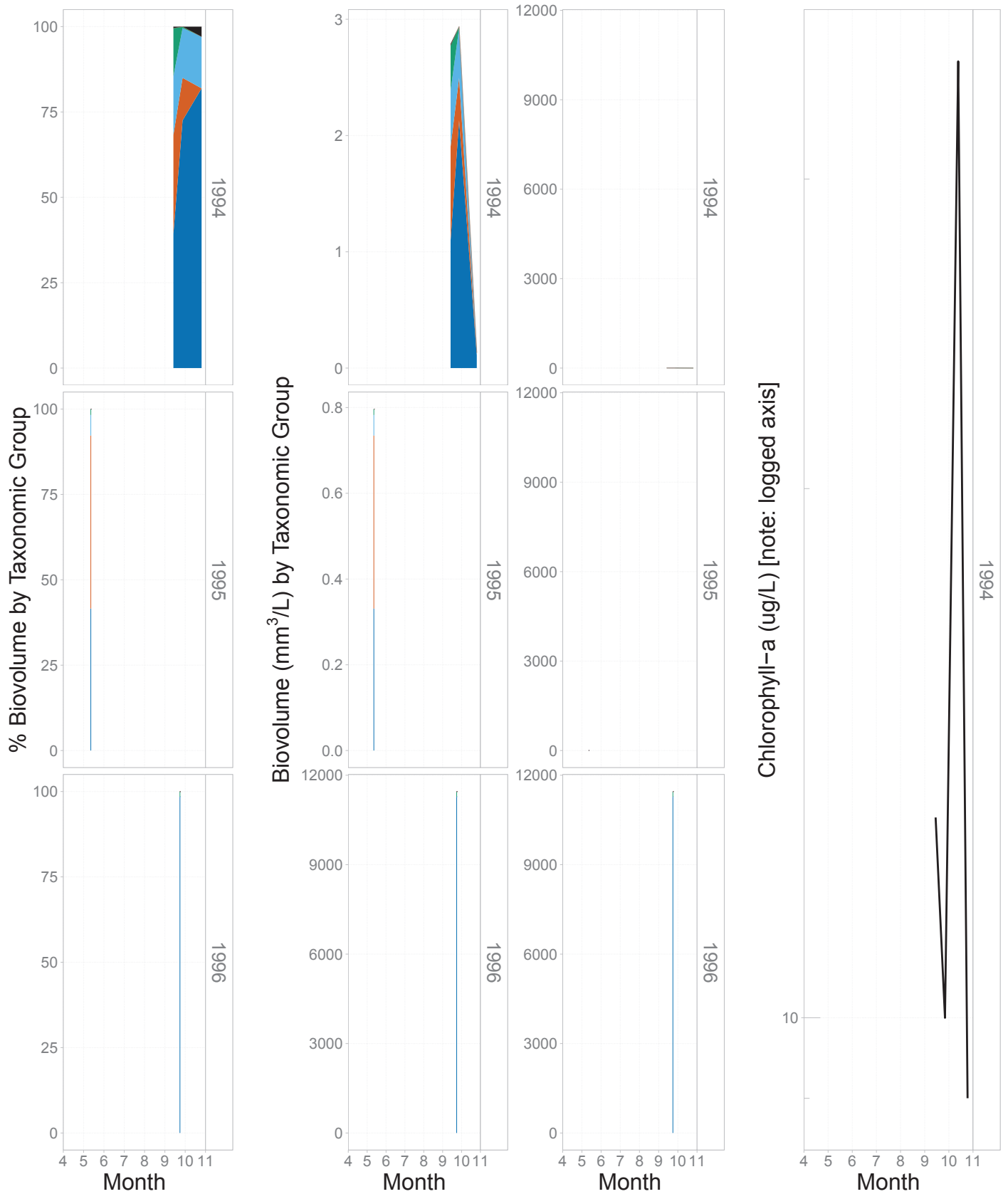
Phyto Taxonomic Groups and Chlorophyll-a: AN (UKL @ Agency Lake North), April-October



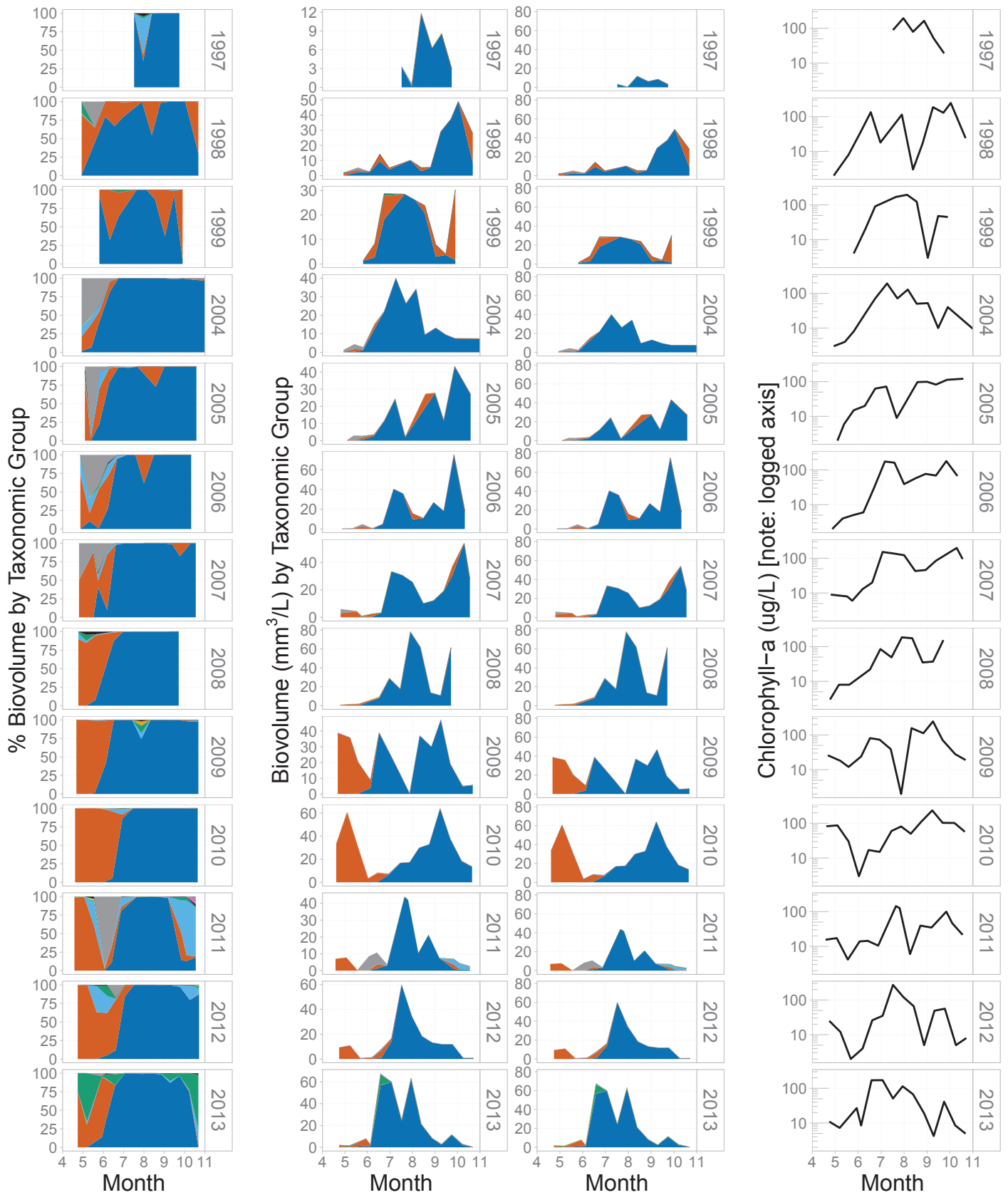
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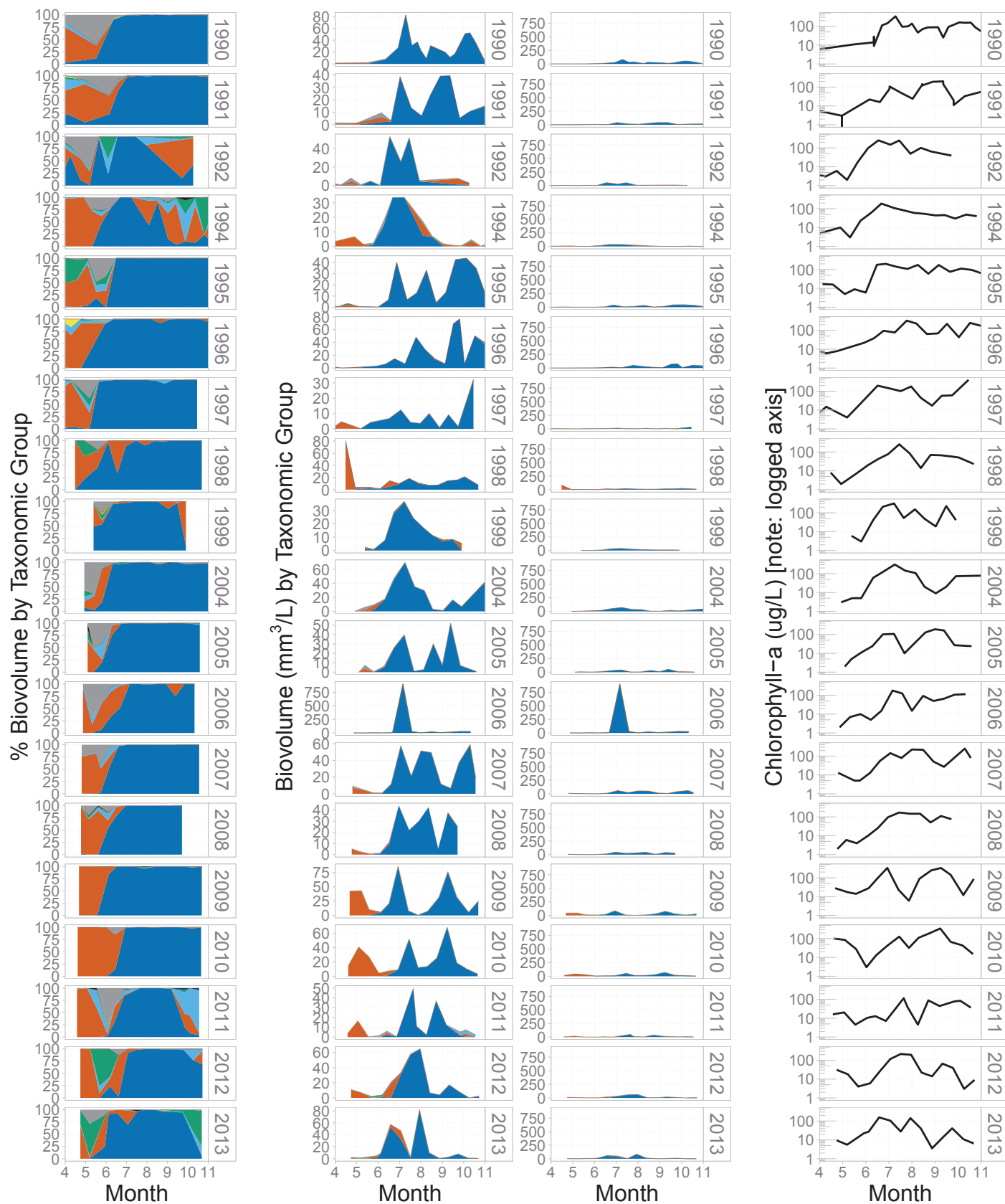
Phyto Taxonomic Groups & Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), Apr-Oct



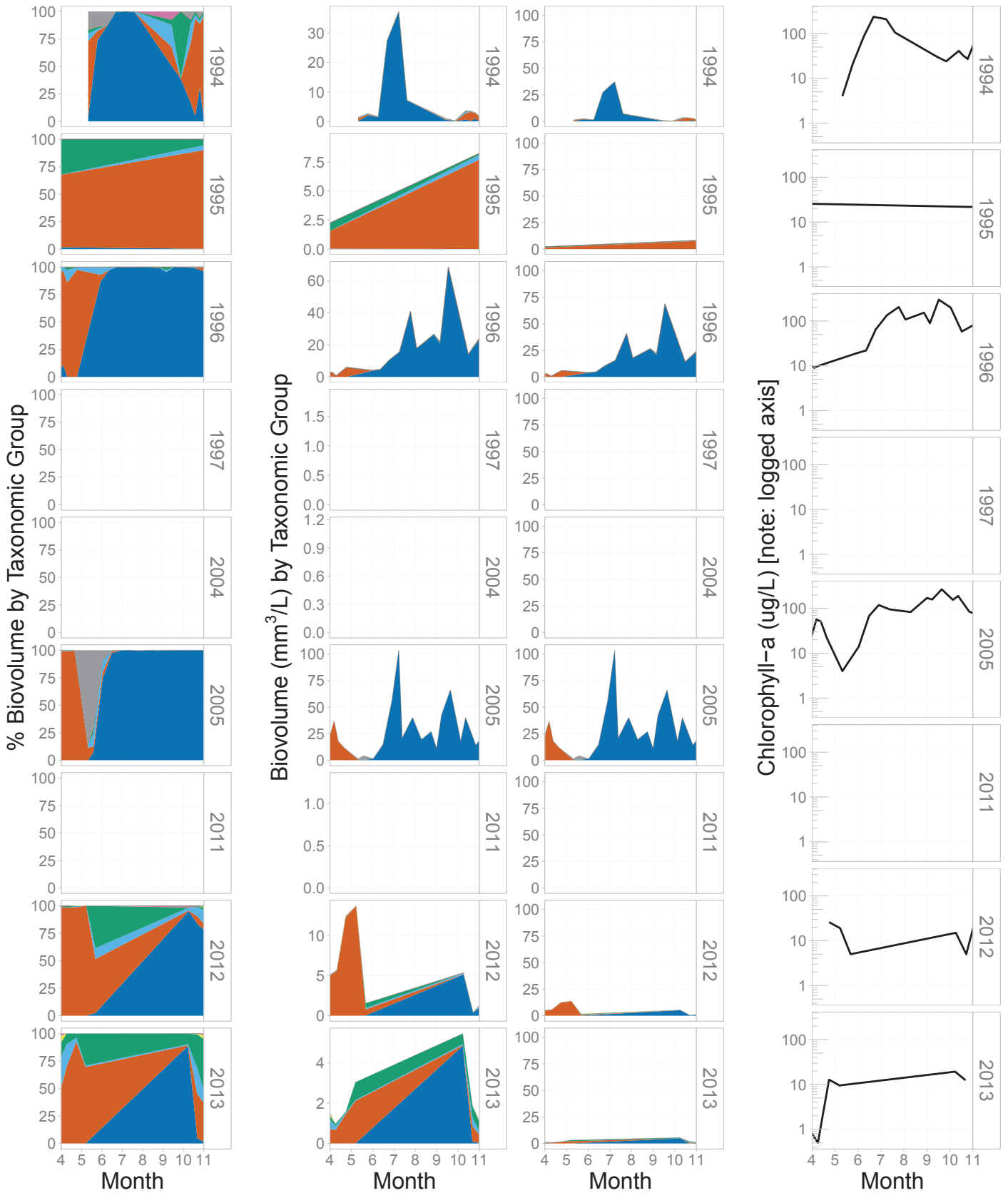
Phyto Taxonomic Groups and Chlorophyll-a: CP (UKL @ Coon Point), April-October



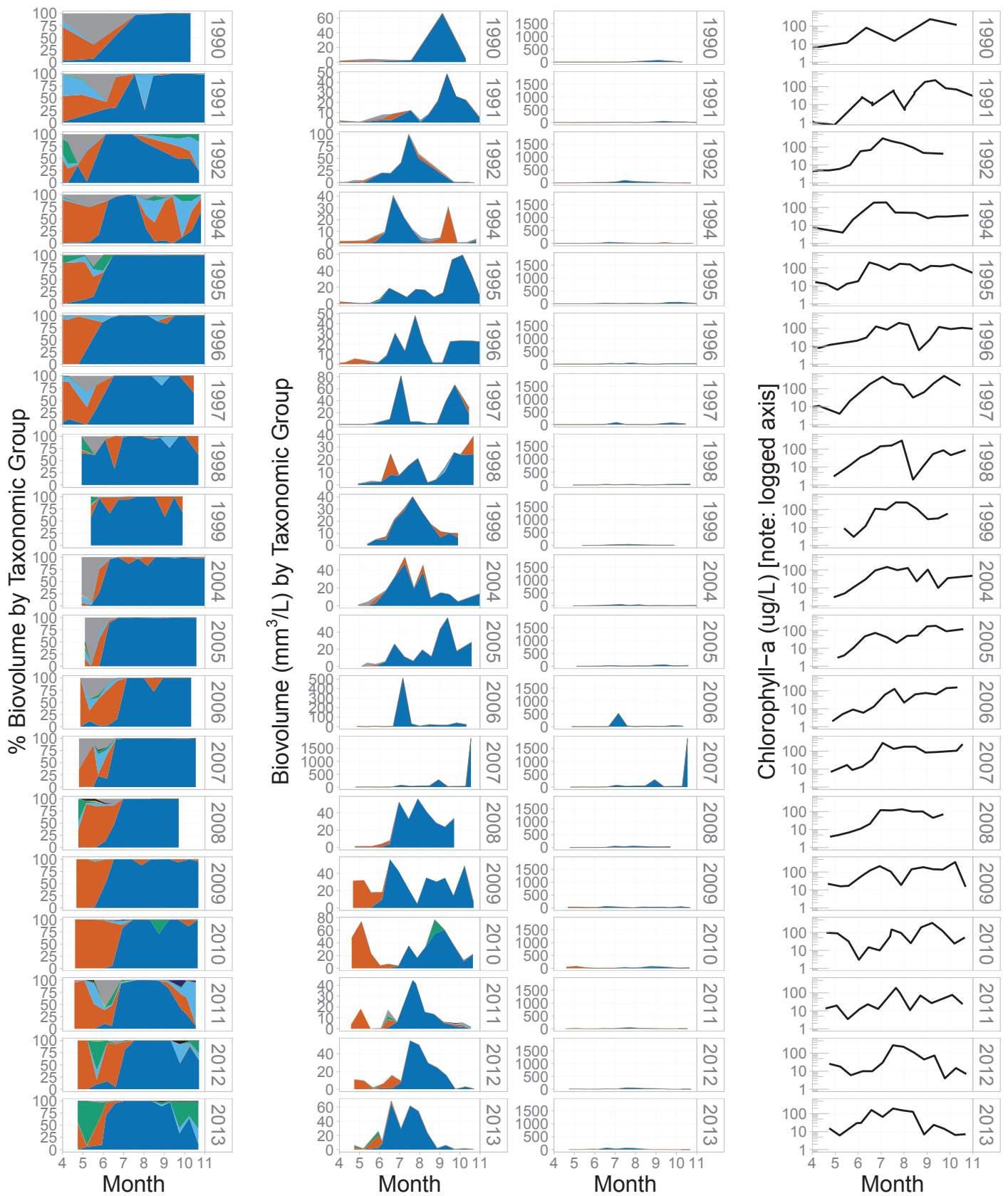
Phyto Taxonomic Groups and Chlorophyll-a: ER (UKL @ Eagle Ridge), April-October



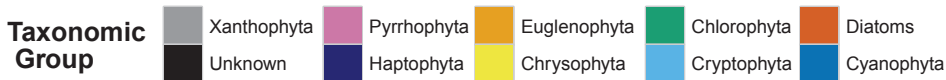
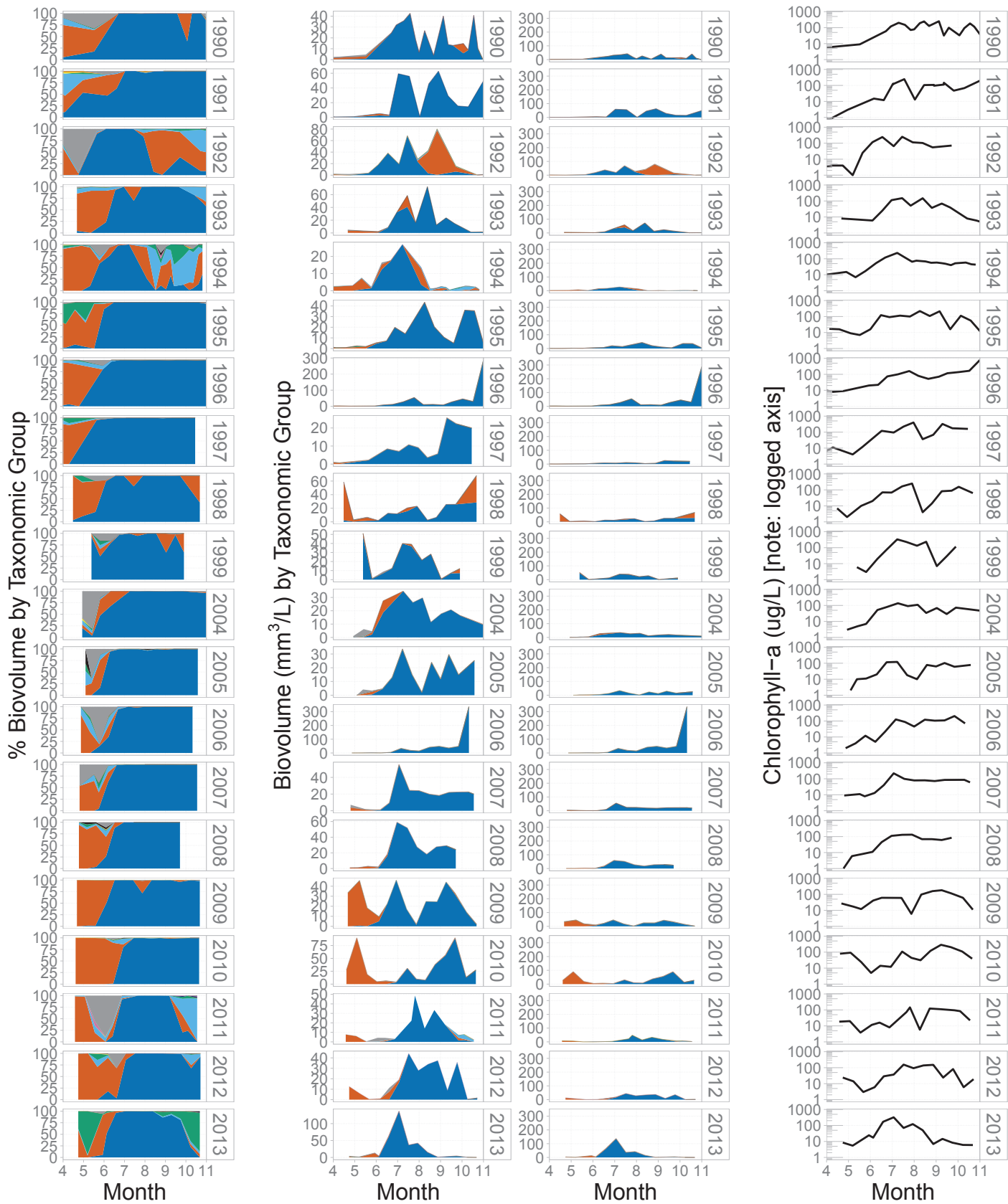
Phyto Taxonomic Groups and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), April-October



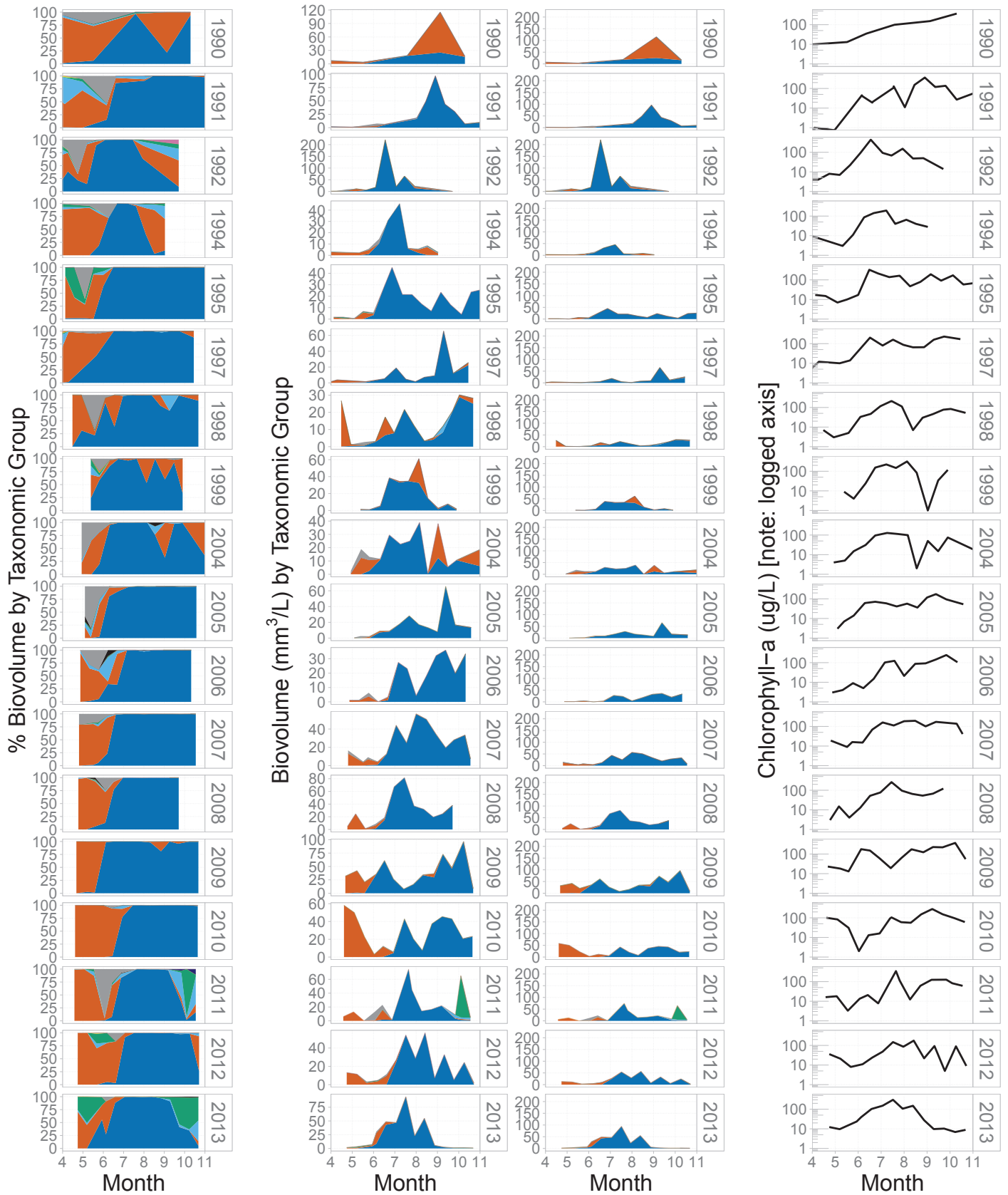
Phyto Taxonomic Groups and Chlorophyll-a: ML (UKL @ Mid-Lake), April-October



Phyto Taxonomic Groups and Chlorophyll-a: MN (UKL @ Mid-Lake North), April-October



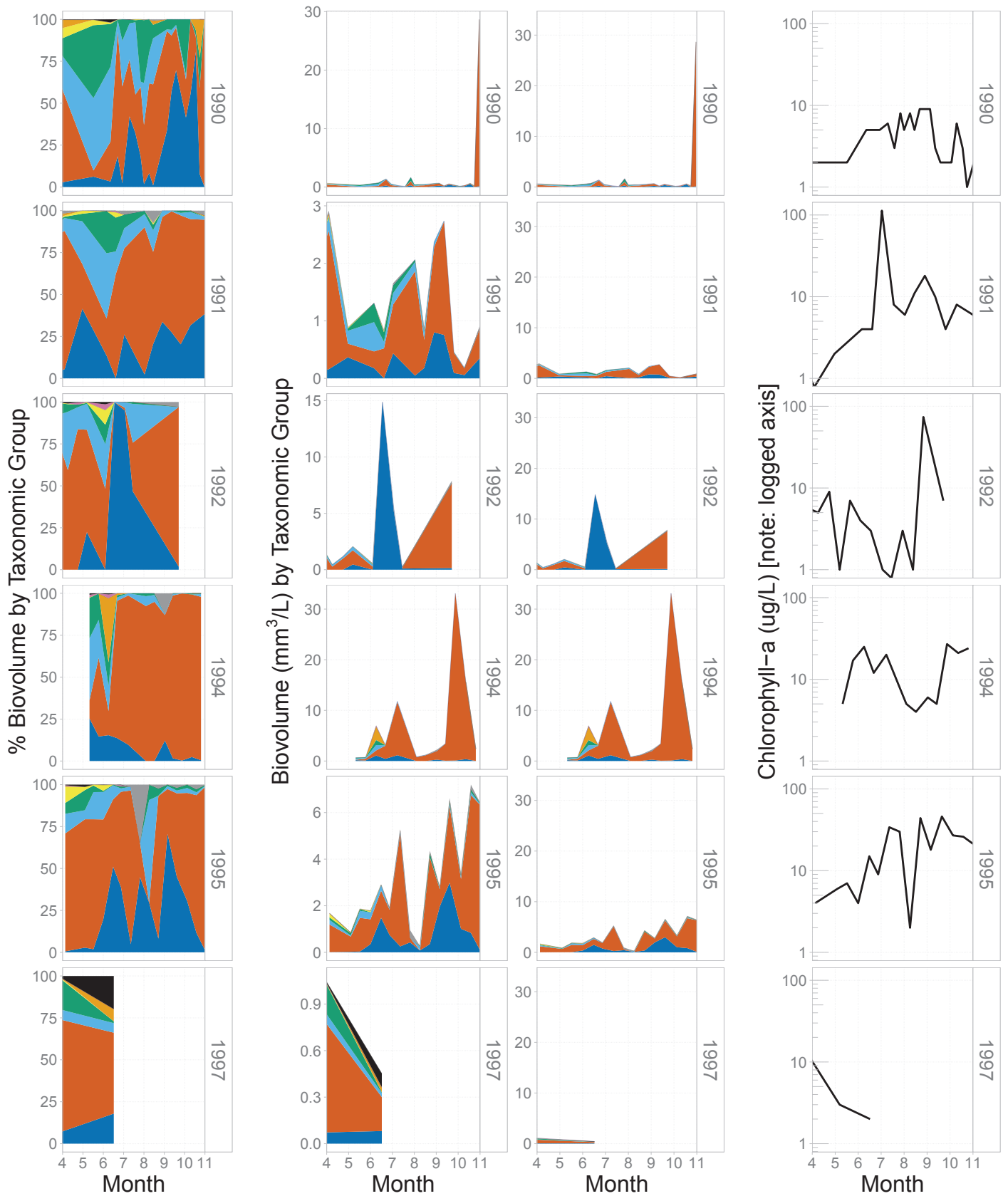
Phyto Taxonomic Groups and Chlorophyll-a: NB (UKL @ North Buck Island), April-October



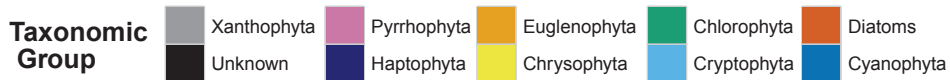
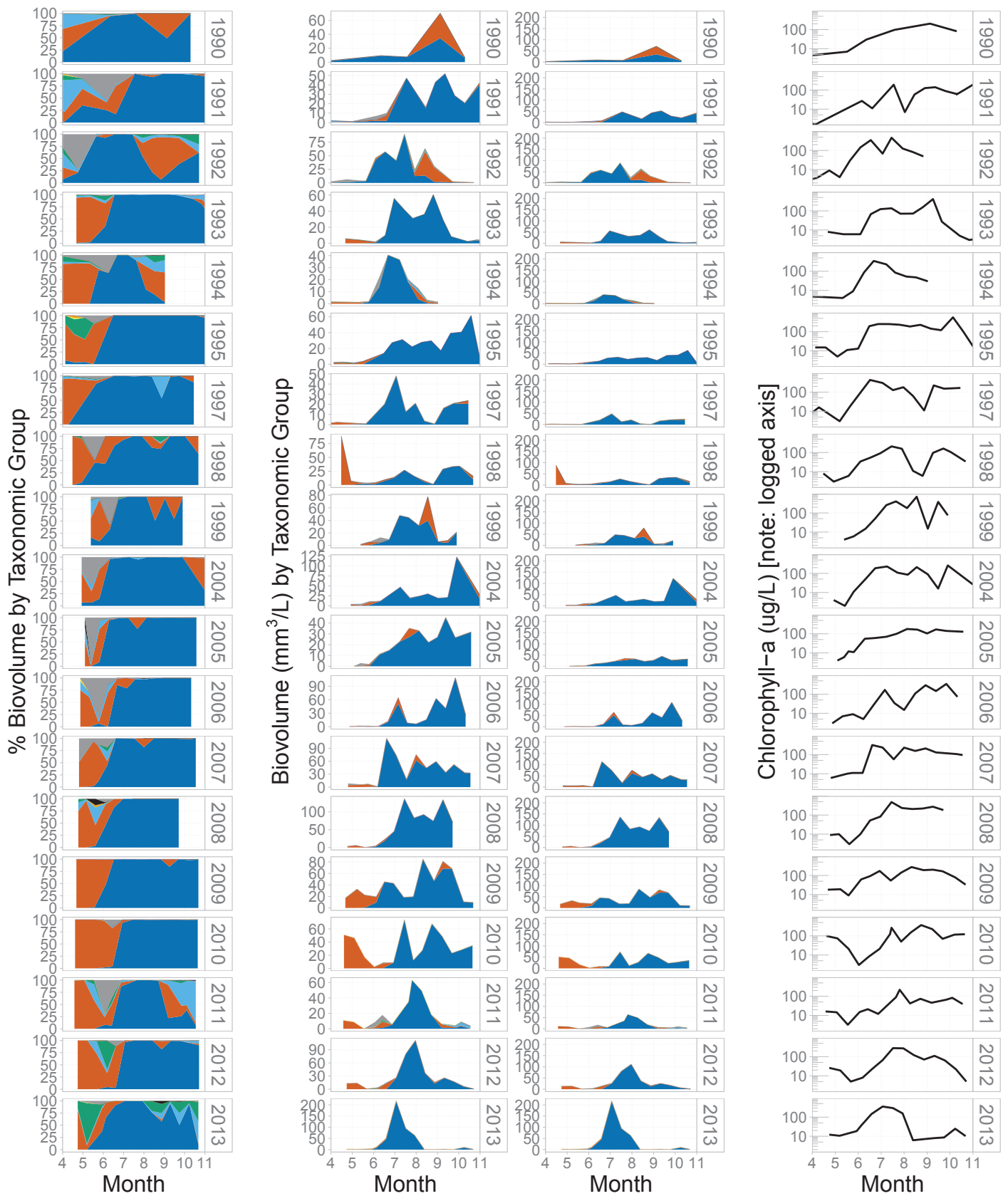
Taxonomic Group

Xanthophyta	Pyrrhophyta	Euglenophyta	Chlorophyta	Diatoms
Unknown	Haptophyta	Chrysophyta	Cryptophyta	Cyanophyta

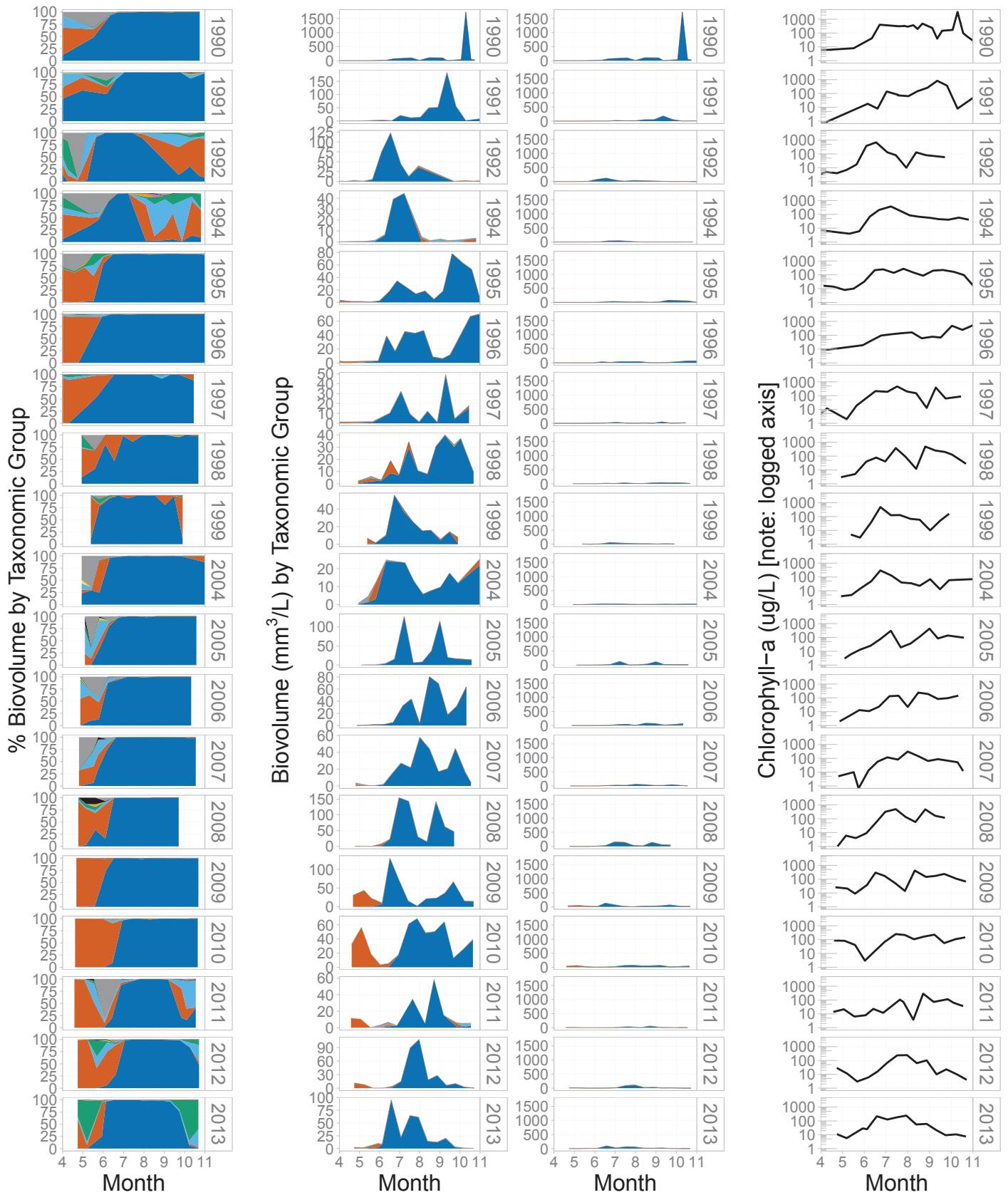
Phyto Taxonomic Groups and Chlorophyll-a: PB (UKL @ Pelican Bay), April-October



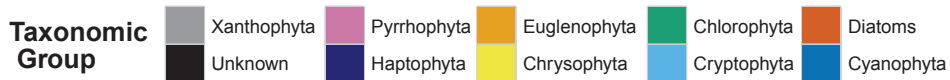
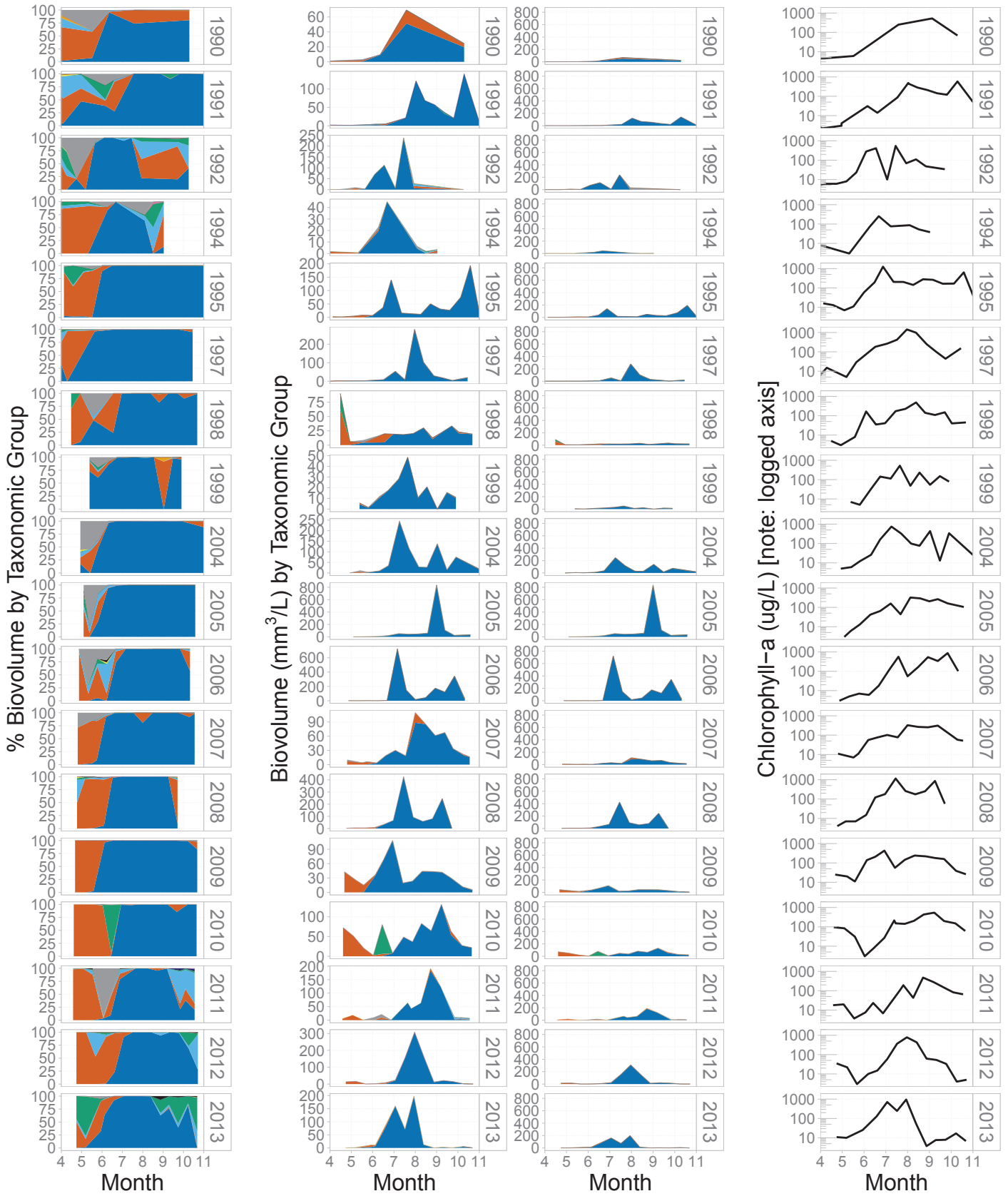
Phyto Taxonomic Groups and Chlorophyll-a: PM (UKL @ Pelican Marina), April-October



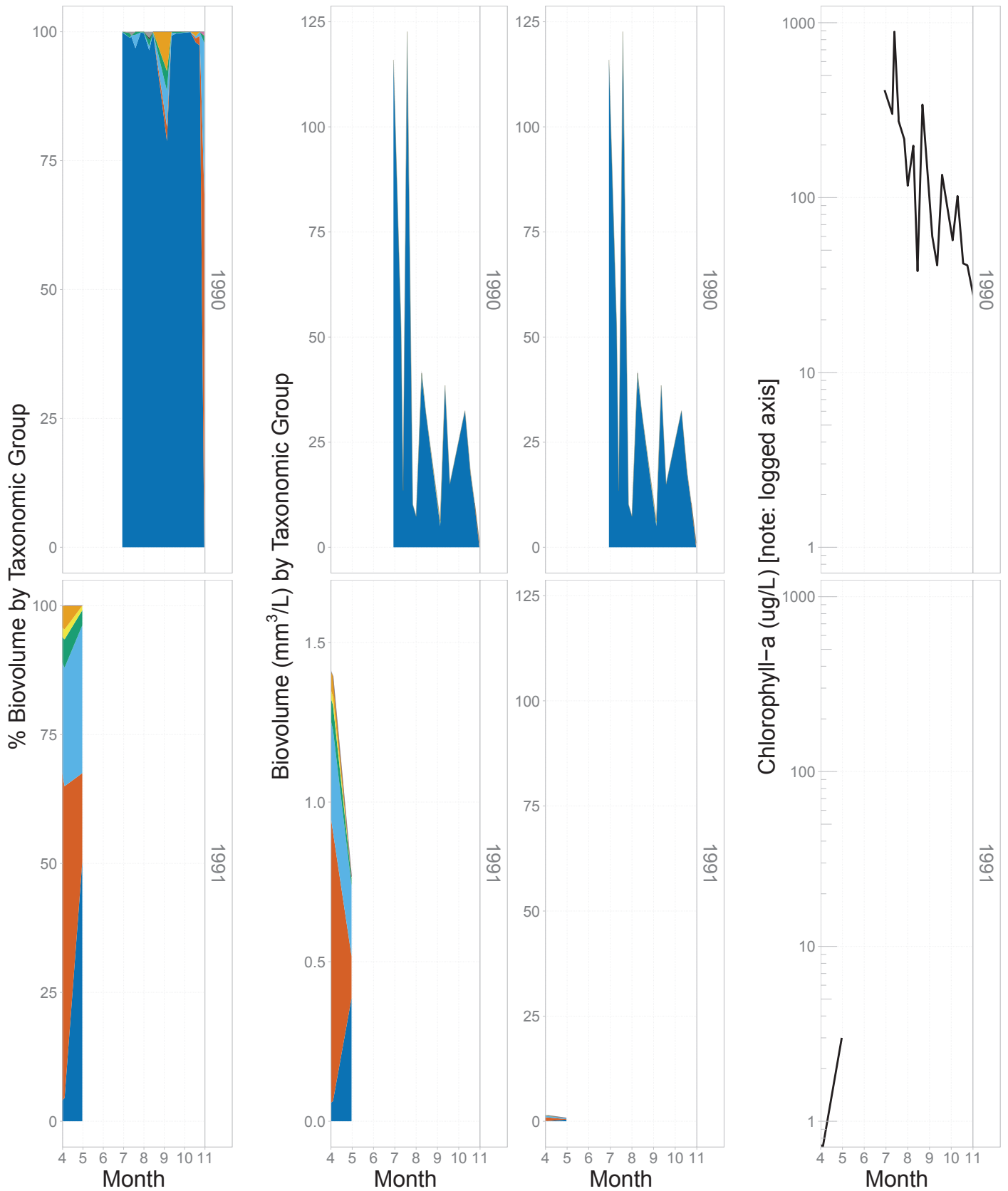
Phyto Taxonomic Groups and Chlorophyll-a: SB (UKL @ Shoal Water Bay), April-October



Phyto Taxonomic Groups and Chlorophyll-a: WB (UKL @ Wocus Bay), April-October

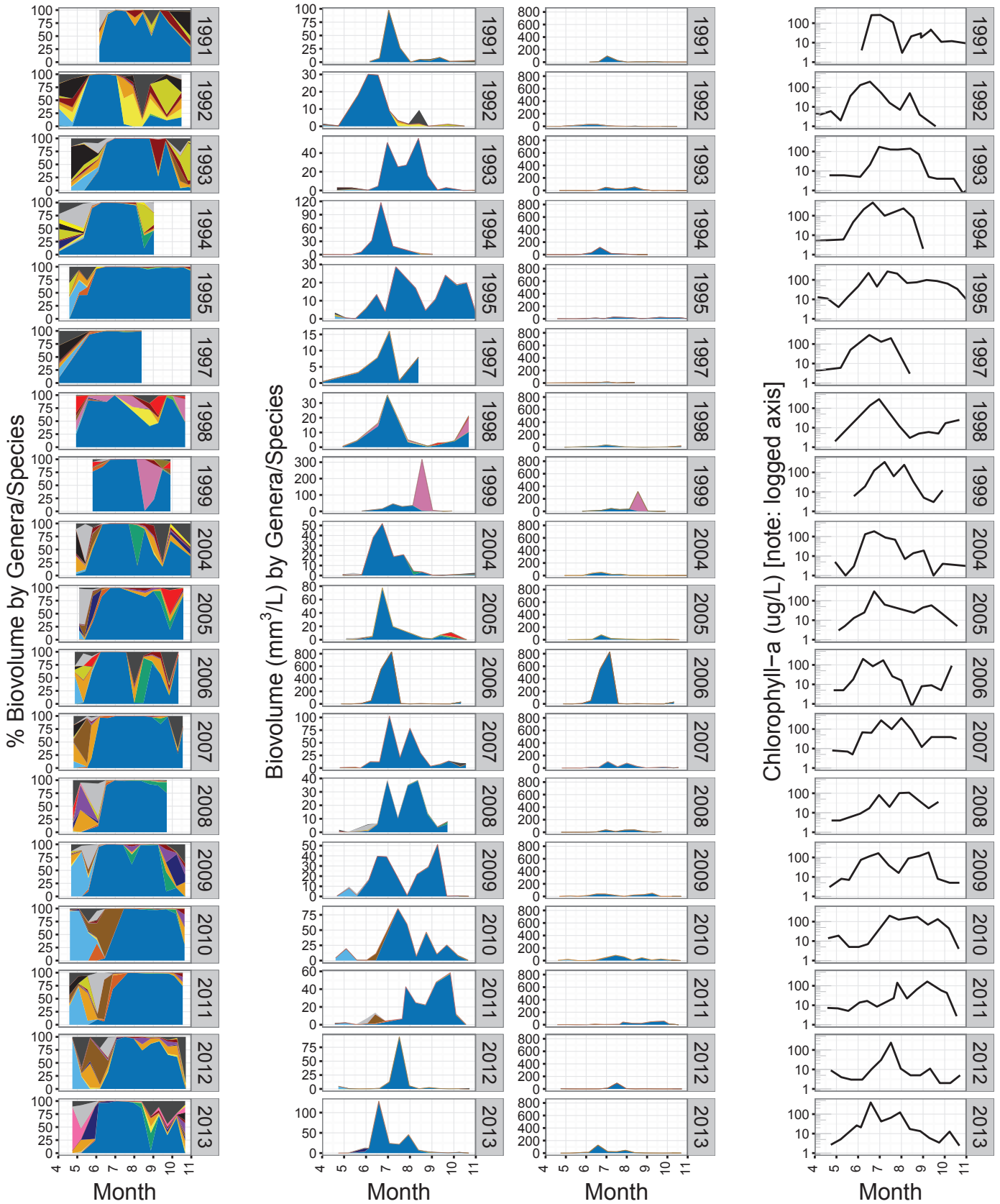


Phyto Taxonomic Groups & Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct



**APPENDIX D: DETAILED TIME SERIES CHARTS OF BIOVOLUME FOR
PHYTOPLANKTON MAJOR GENERA/SPECIES FOR EACH SITE**

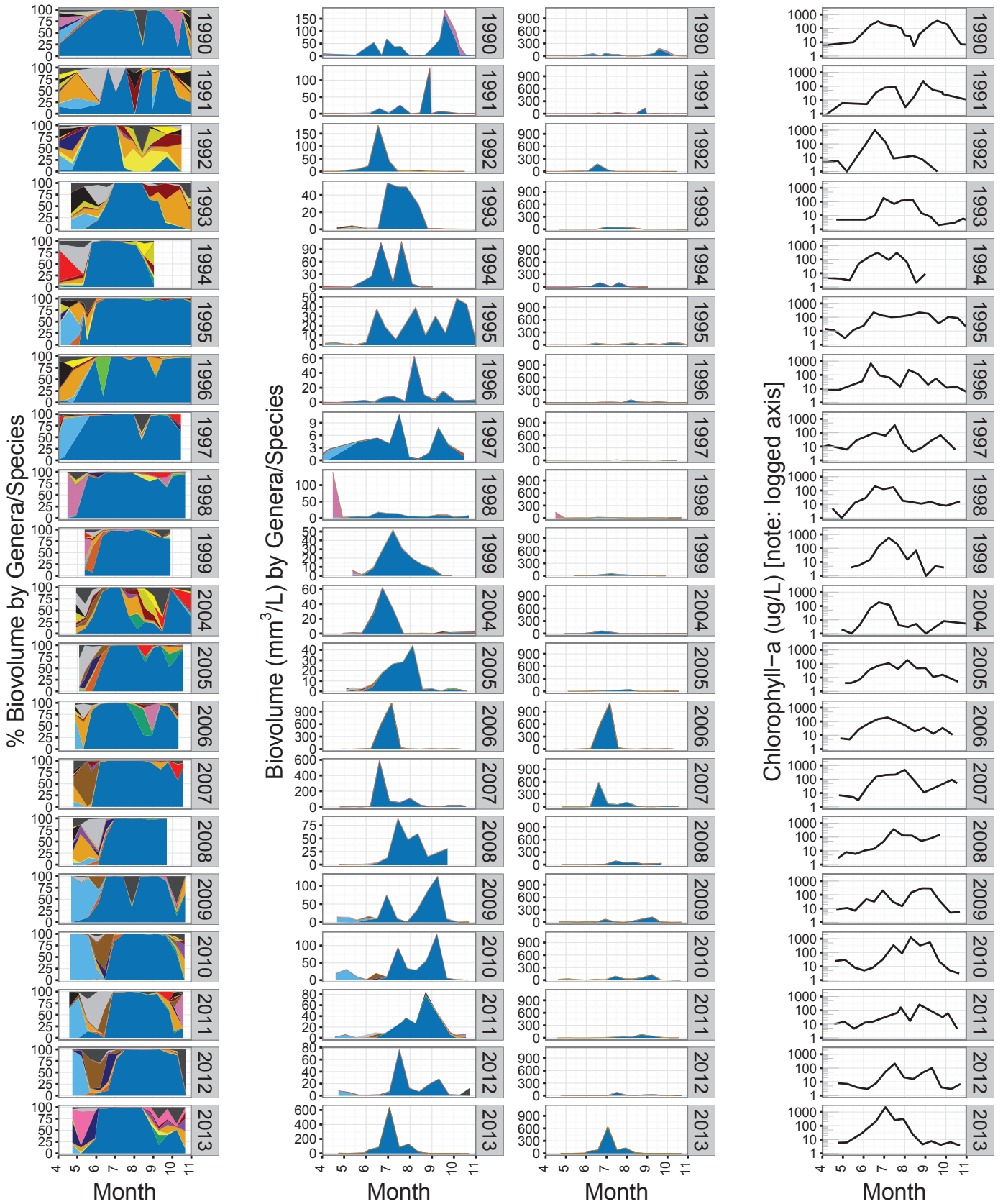
Phyto Genera/Species and Chlorophyll-a: AN (UKL @ Agency Lake North), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

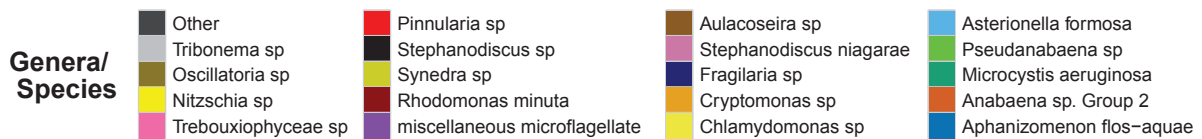
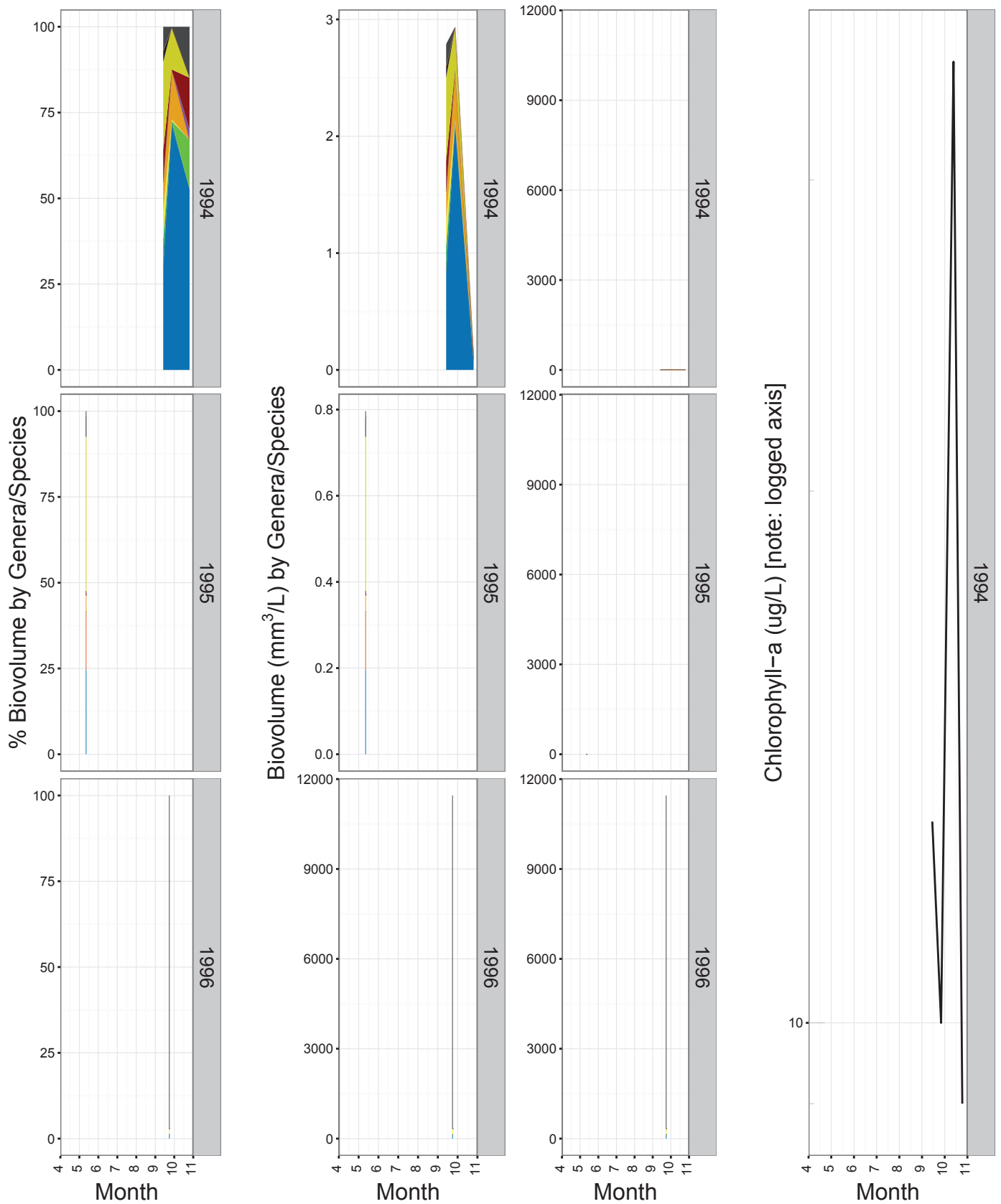
Phyto Genera/Species and Chlorophyll-a: AS (UKL @ Agency Lake South), Apr-Oct



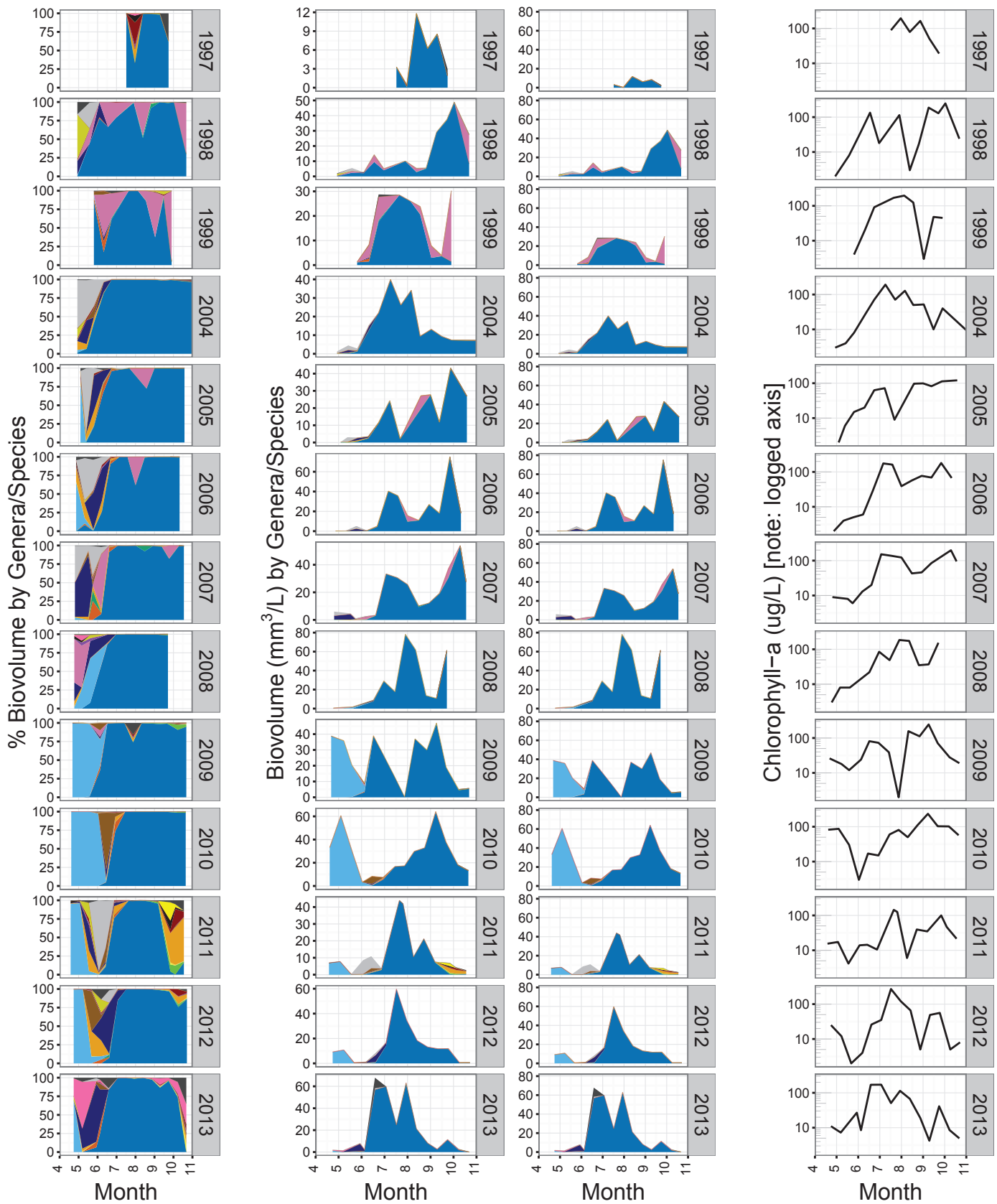
General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

Phyto Genera/Species and Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), Apr-Oct



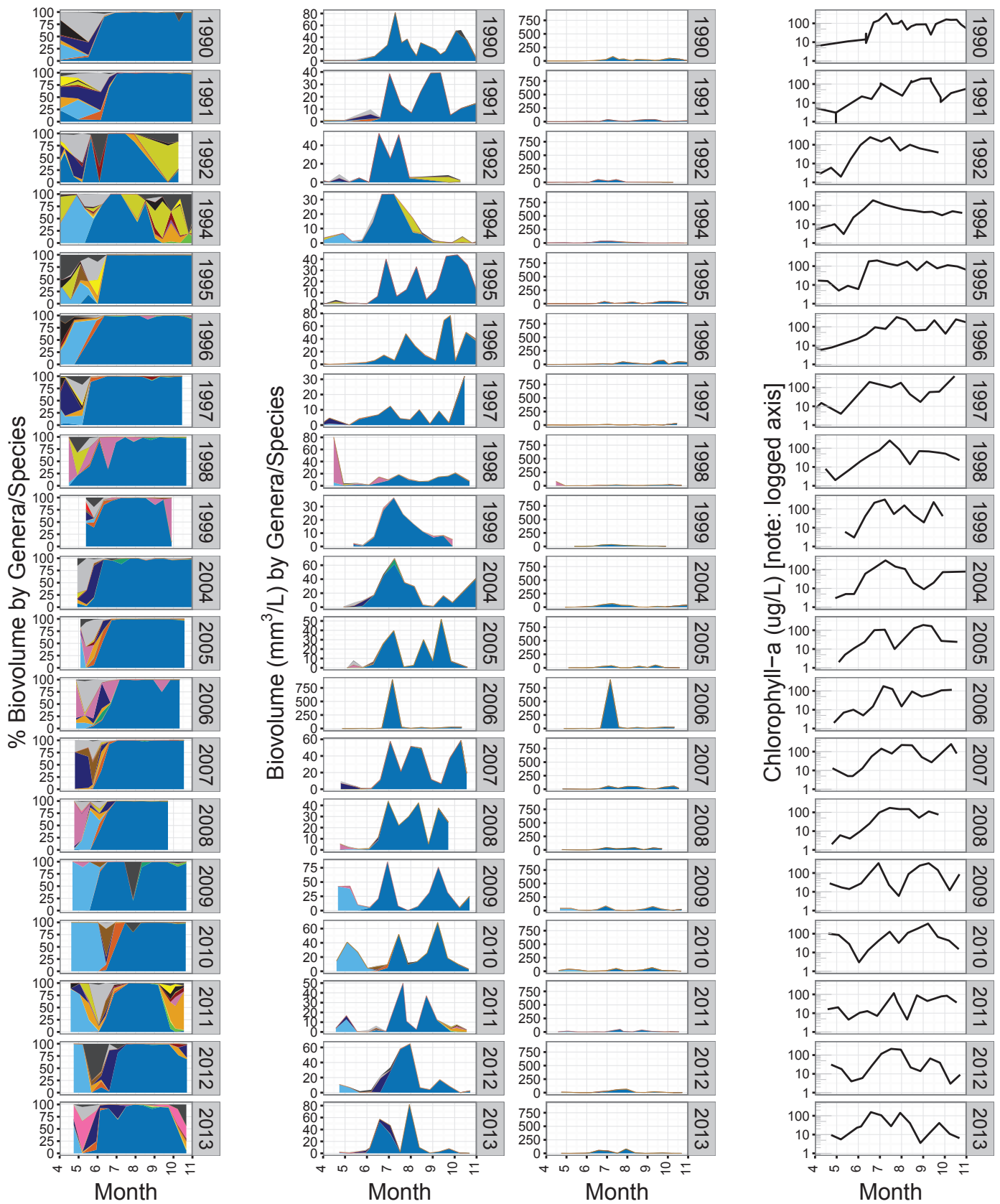
Phyto Genera/Species and Chlorophyll-a: CP (UKL @ Coon Point), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

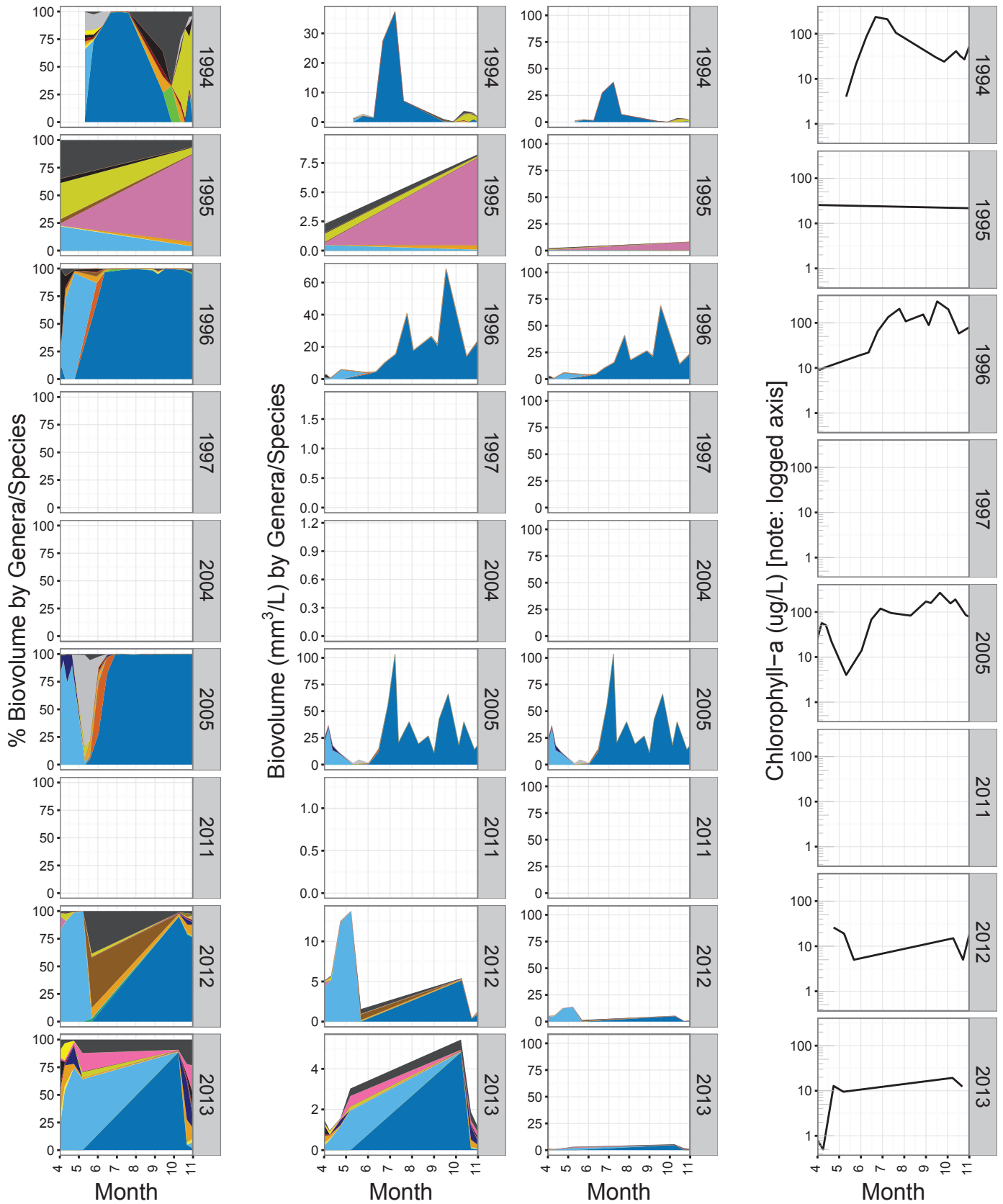
Phyto Genera/Species and Chlorophyll-a: ER (UKL @ Eagle Ridge), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

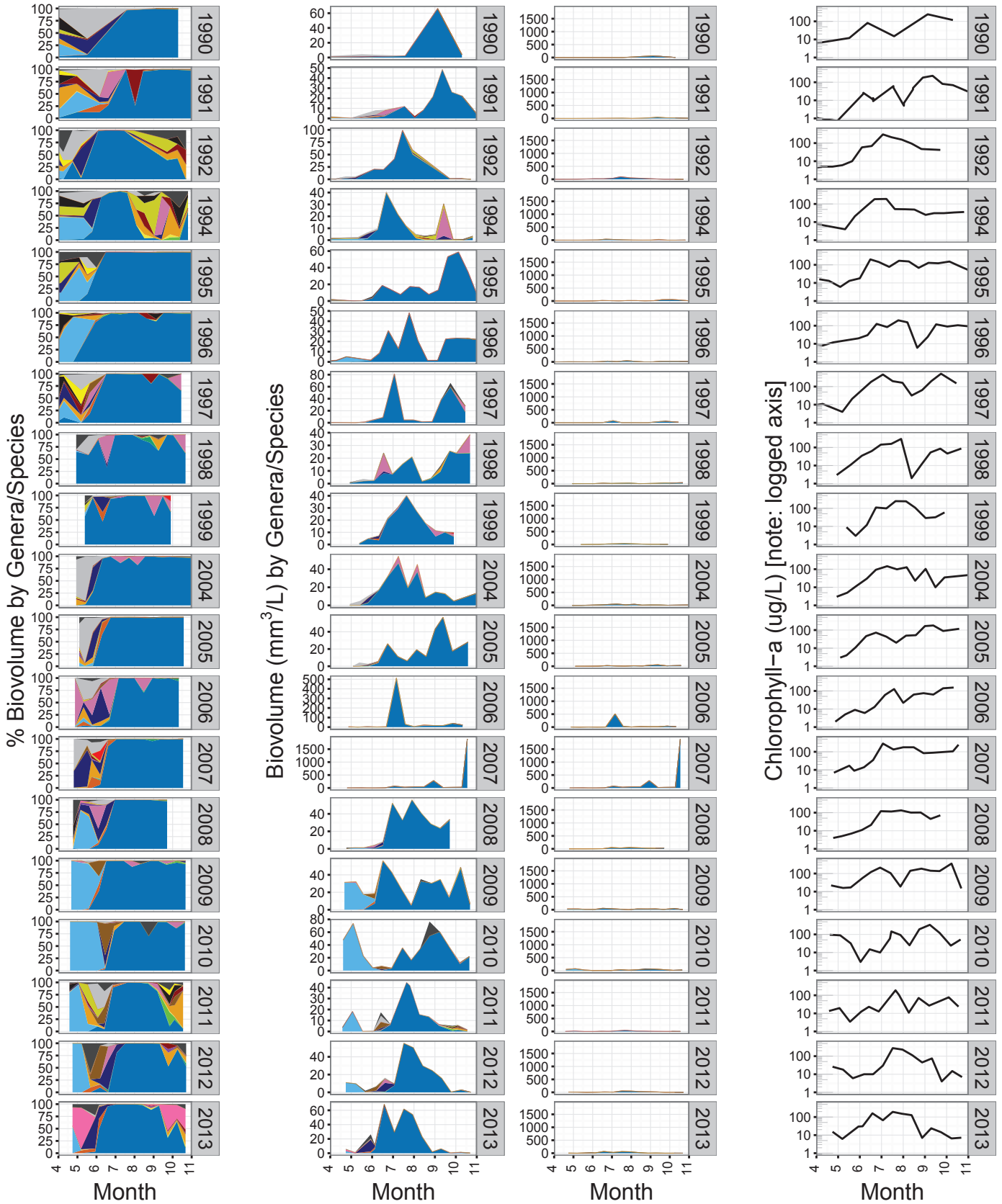
Phyto Genera/Species and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), Apr-Oct



General/Species

- Other
- Pinnularia sp
- Aulacoseira sp
- Asterionella formosa
- Tribonema sp
- Stephanodiscus sp
- miscellaneous microflagellate
- Pseudanabaena sp
- Oscillatoria sp
- Stephanodiscus niagarae
- Synedra sp
- Fragilaria sp
- Microcystis aeruginosa
- Nitzschia sp
- Rhodomonas minuta
- Cryptomonas sp
- Anabaena sp. Group 2
- Trebouxiophyceae sp
- Chlamydomonas sp
- Aphanizomenon flos-aquae

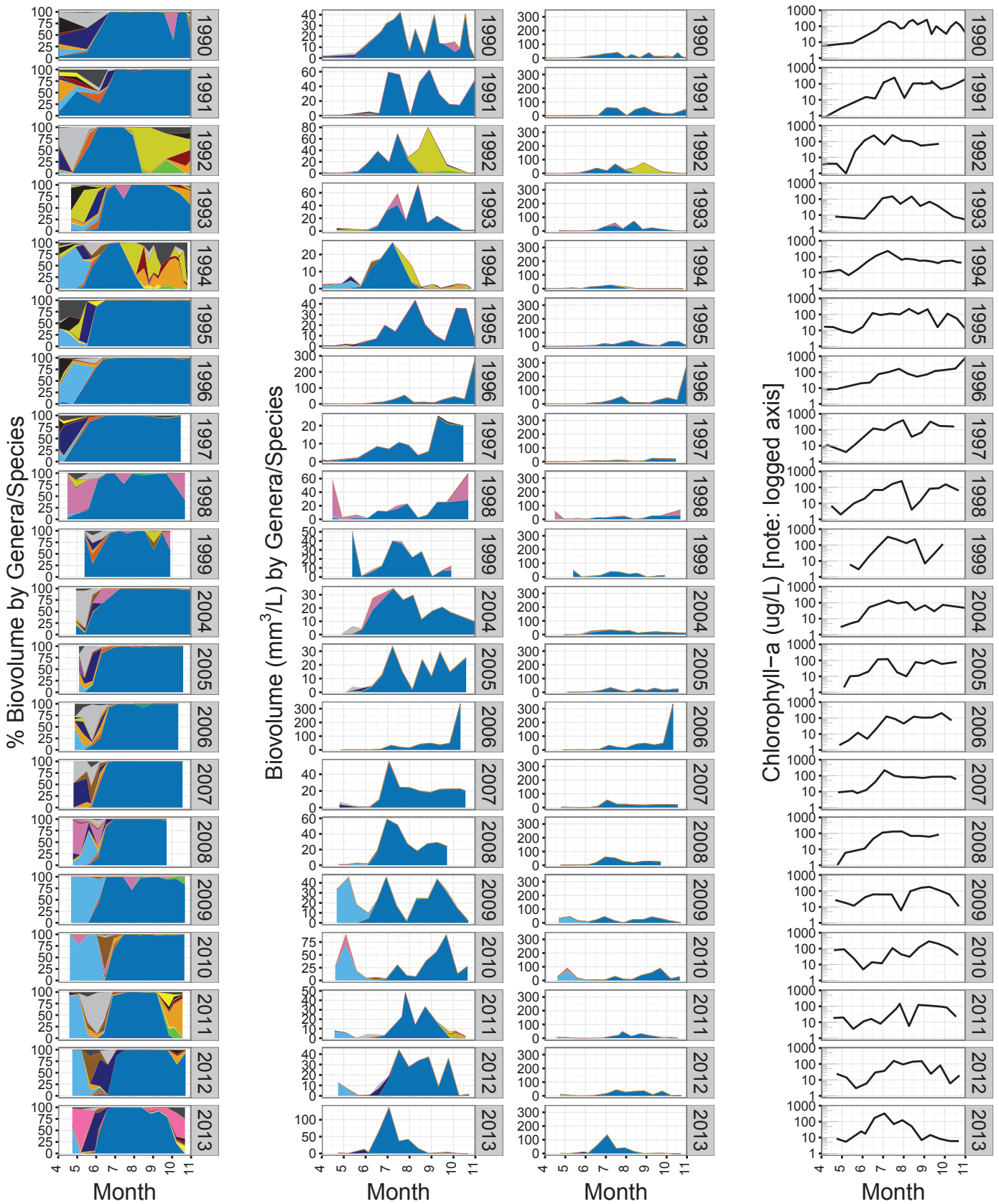
Phyto Genera/Species and Chlorophyll-a: ML (UKL @ Mid-Lake), Apr-Oct



General/Species

- Other
- Pinnularia sp
- Aulacoseira sp
- Asterionella formosa
- Tribonema sp
- Stephanodiscus sp
- Stephanodiscus niagarae
- Pseudanabaena sp
- Oscillatoria sp
- Synedra sp
- Fragilaria sp
- Microcystis aeruginosa
- Nitzschia sp
- Rhodomonas minuta
- Cryptomonas sp
- Anabaena sp. Group 2
- Trebouxiophyceae sp
- miscellaneous microflagellate
- Chlamydomonas sp
- Aphanizomenon flos-aquae

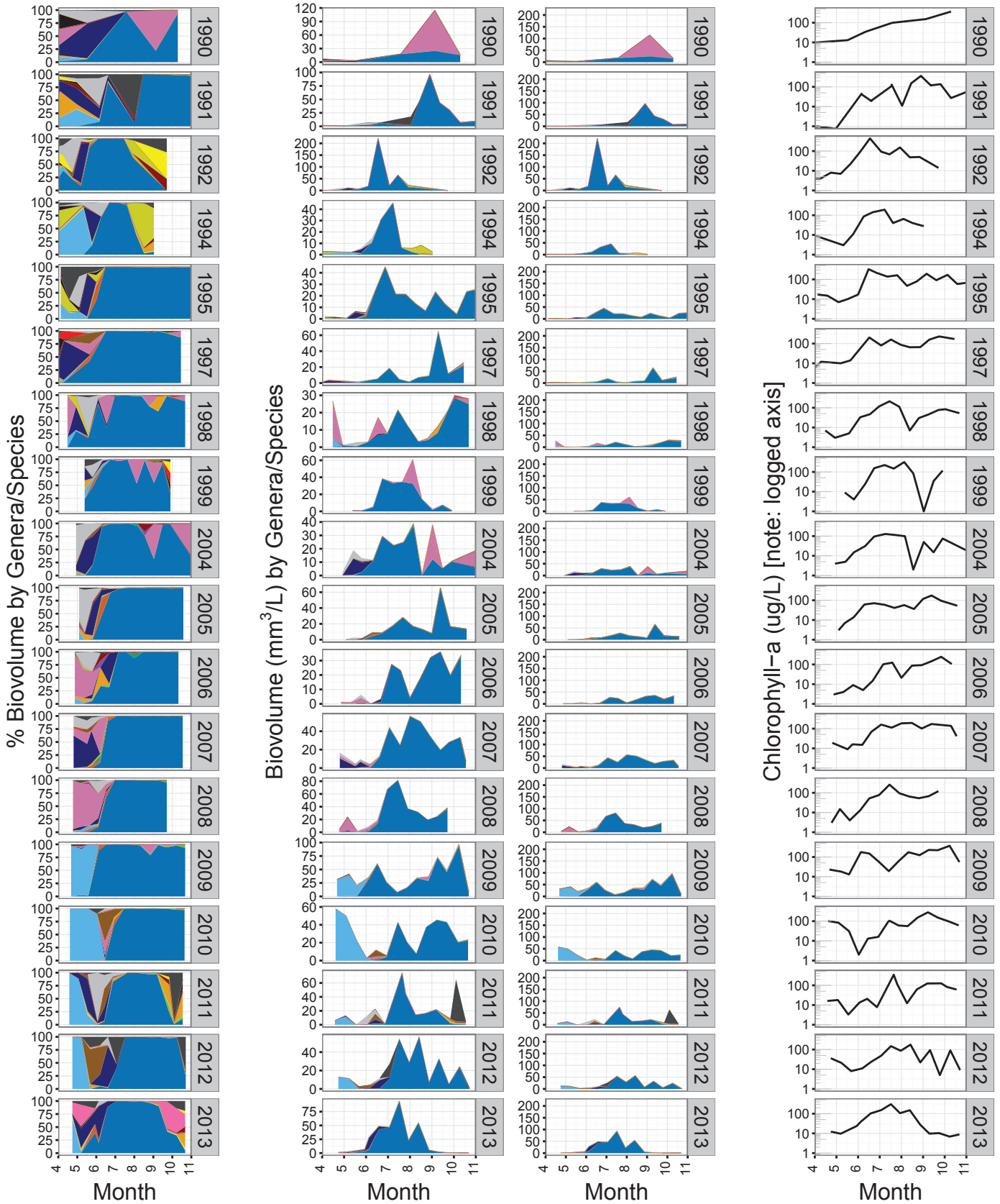
Phyto Genera/Species and Chlorophyll-a: MN (UKL @ Mid-Lake North), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

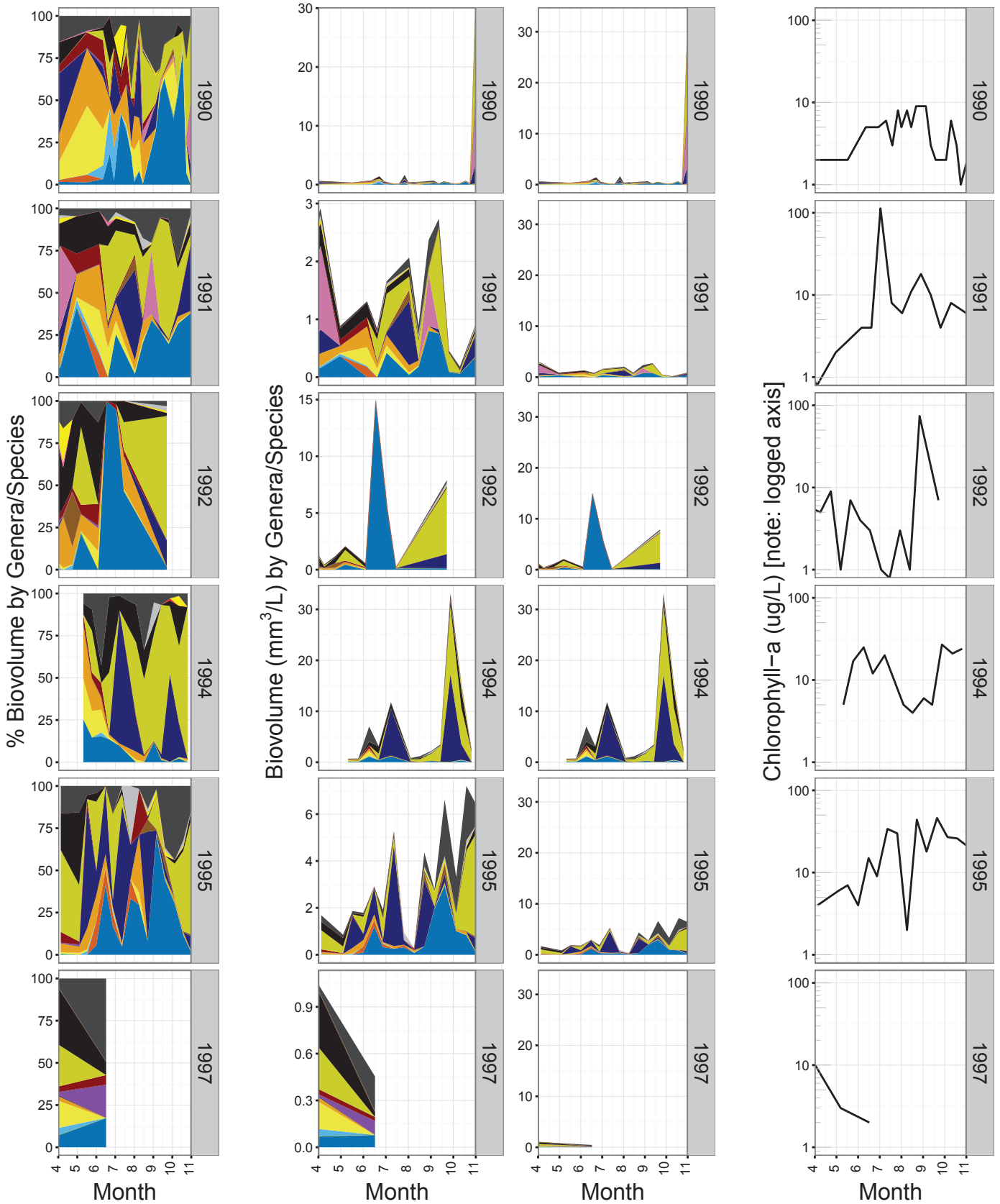
Phyto Genera/Species and Chlorophyll-a: NB (UKL @ North Buck Island), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

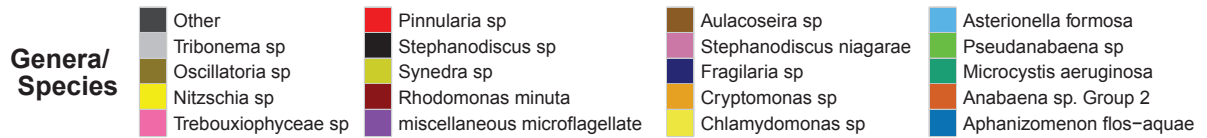
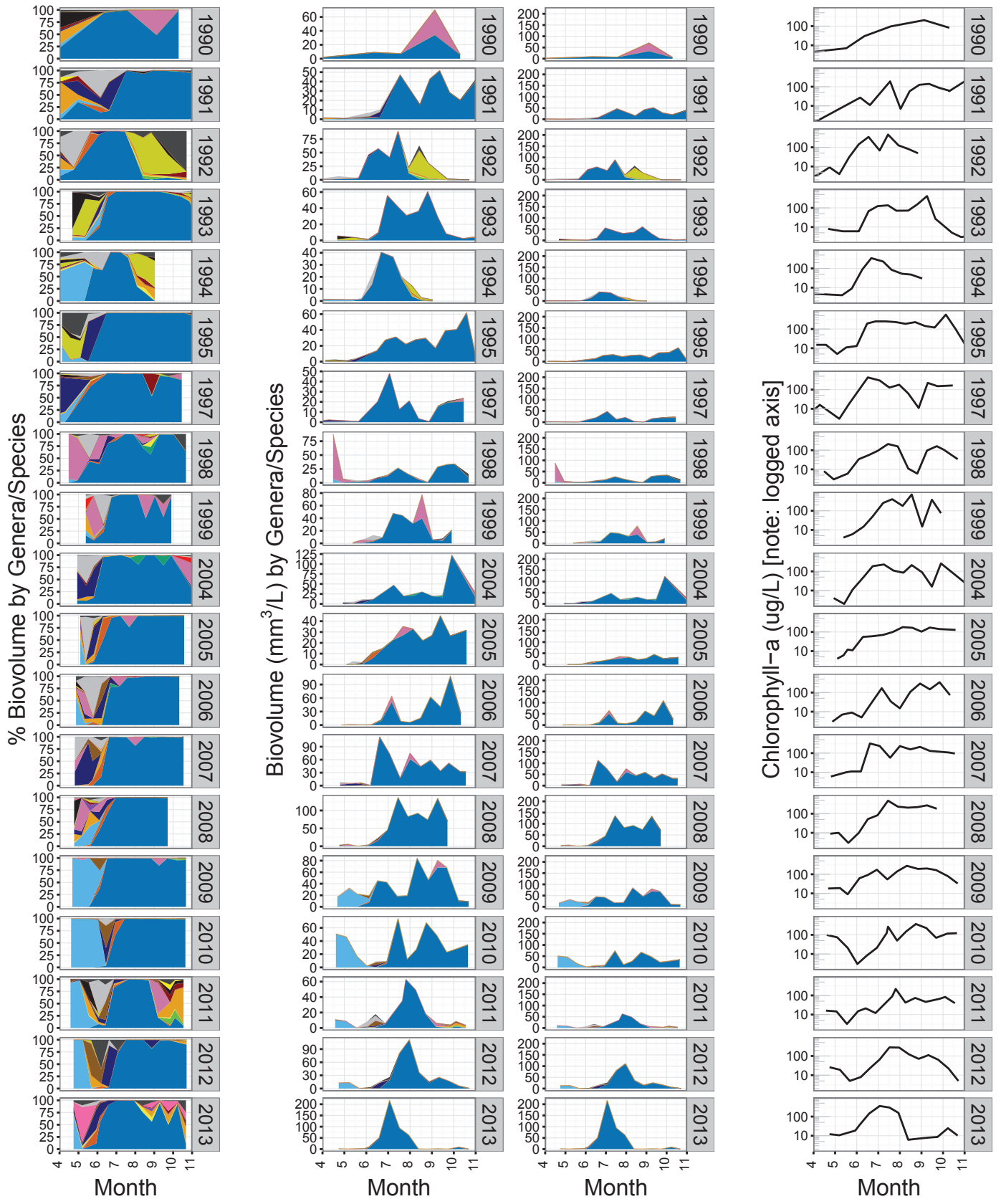
Phyto Genera/Species and Chlorophyll-a: PB (UKL @ Pelican Bay), Apr-Oct



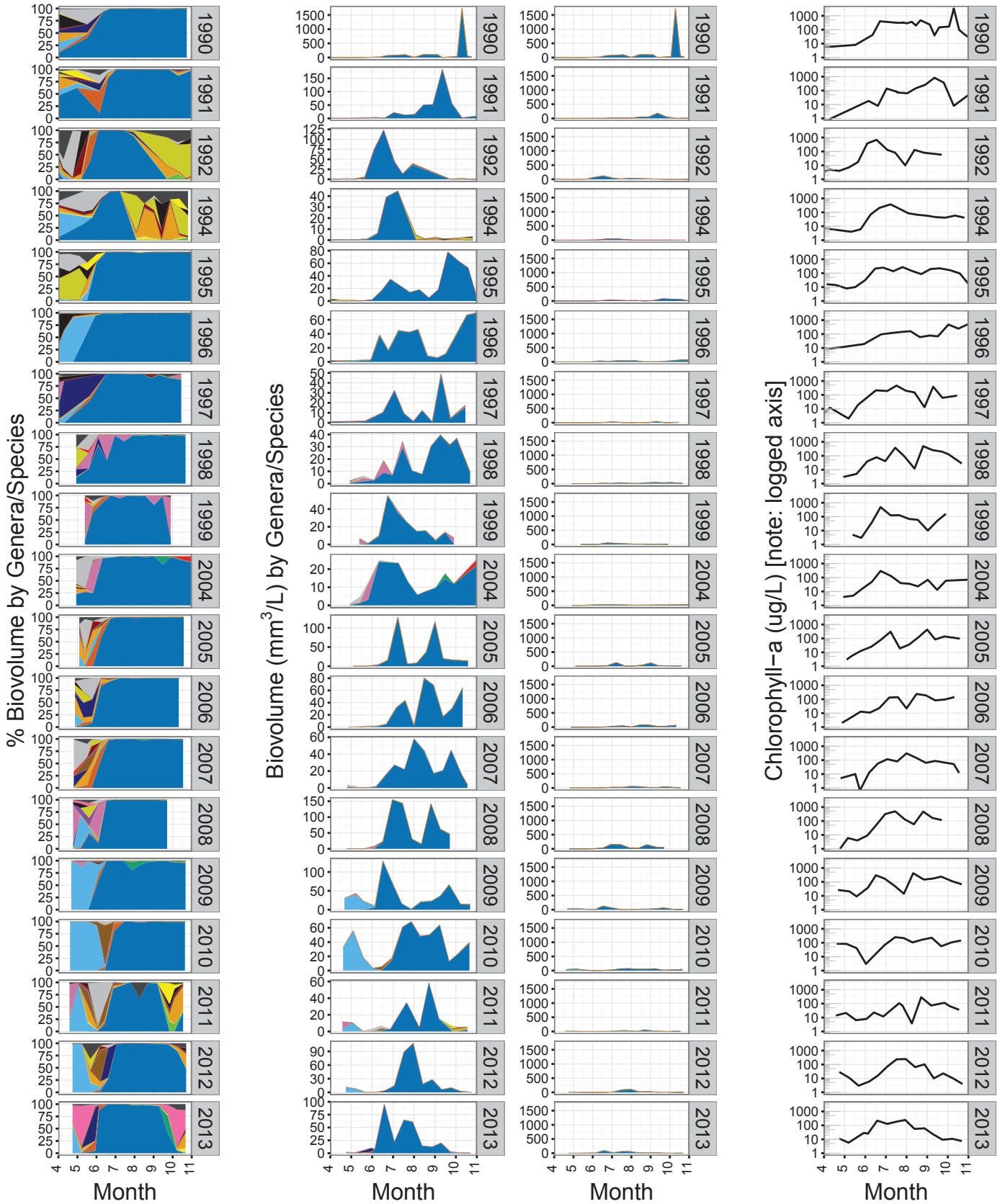
General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

Phyto Genera/Species and Chlorophyll-a: PM (UKL @ Pelican Marina), Apr-Oct



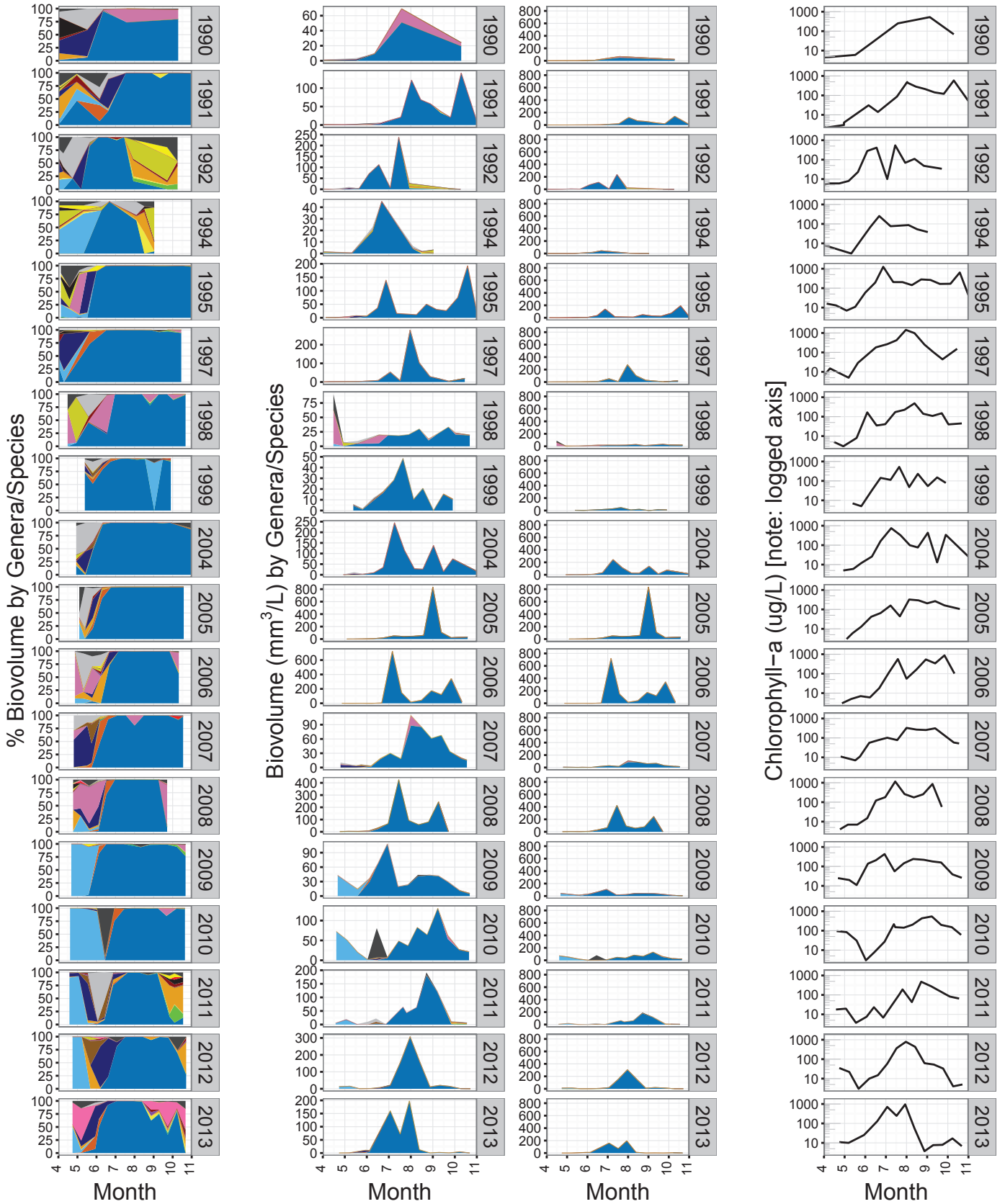
Phyto Genera/Species and Chlorophyll-a: SB (UKL @ Shoal Water Bay), Apr-Oct



General/Species

- | | | | |
|---------------------|-------------------------------|-------------------------|--------------------------|
| Other | Pinnularia sp | Aulacoseira sp | Asterionella formosa |
| Tribonema sp | Stephanodiscus sp | Stephanodiscus niagarae | Pseudanabaena sp |
| Oscillatoria sp | Synedra sp | Fragilaria sp | Microcystis aeruginosa |
| Nitzschia sp | Rhodomonas minuta | Cryptomonas sp | Anabaena sp. Group 2 |
| Trebouxiophyceae sp | miscellaneous microflagellate | Chlamydomonas sp | Aphanizomenon flos-aquae |

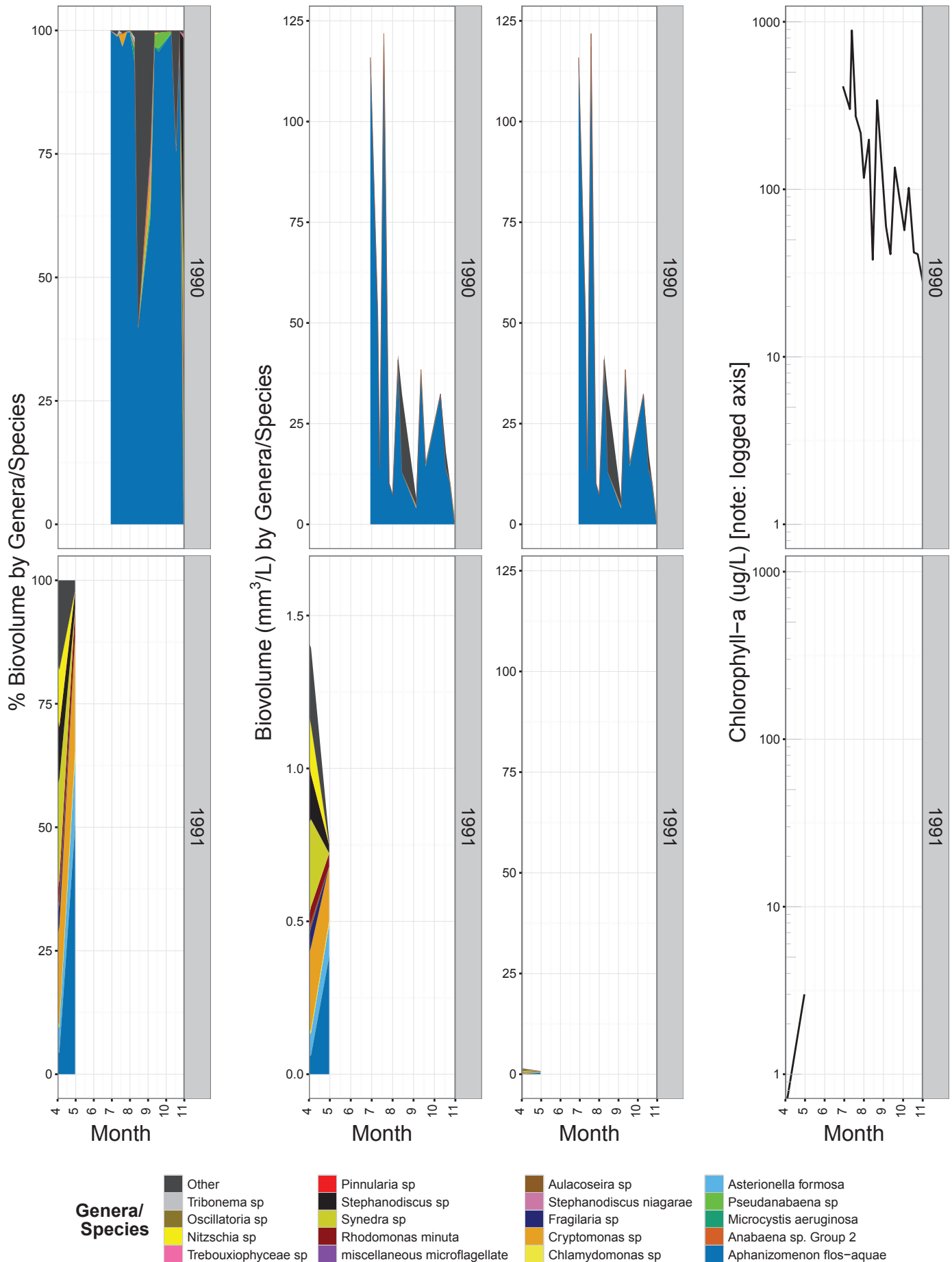
Phyto Genera/Species and Chlorophyll-a: WB (UKL @ Wocus Bay), Apr-Oct



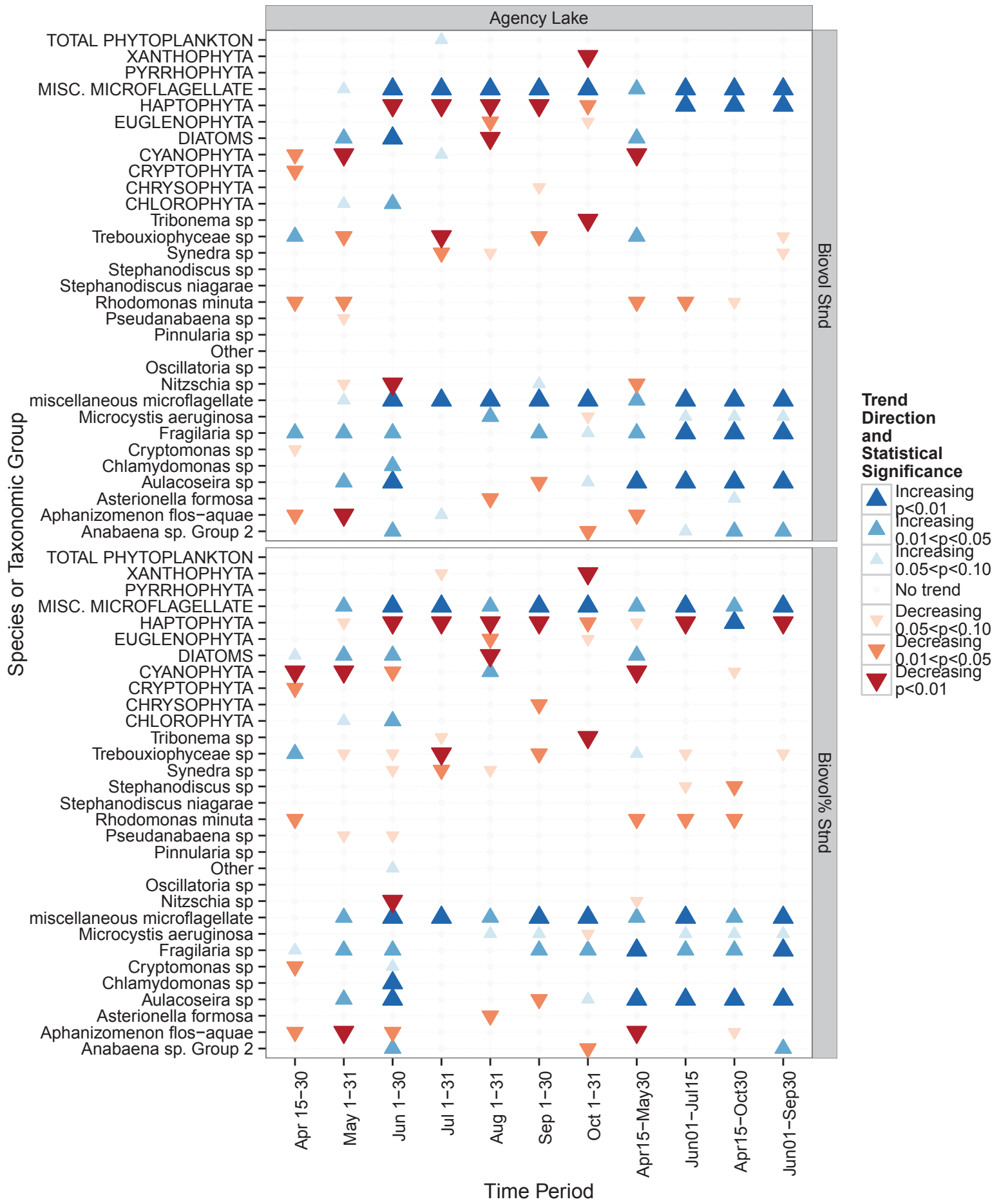
General/Species

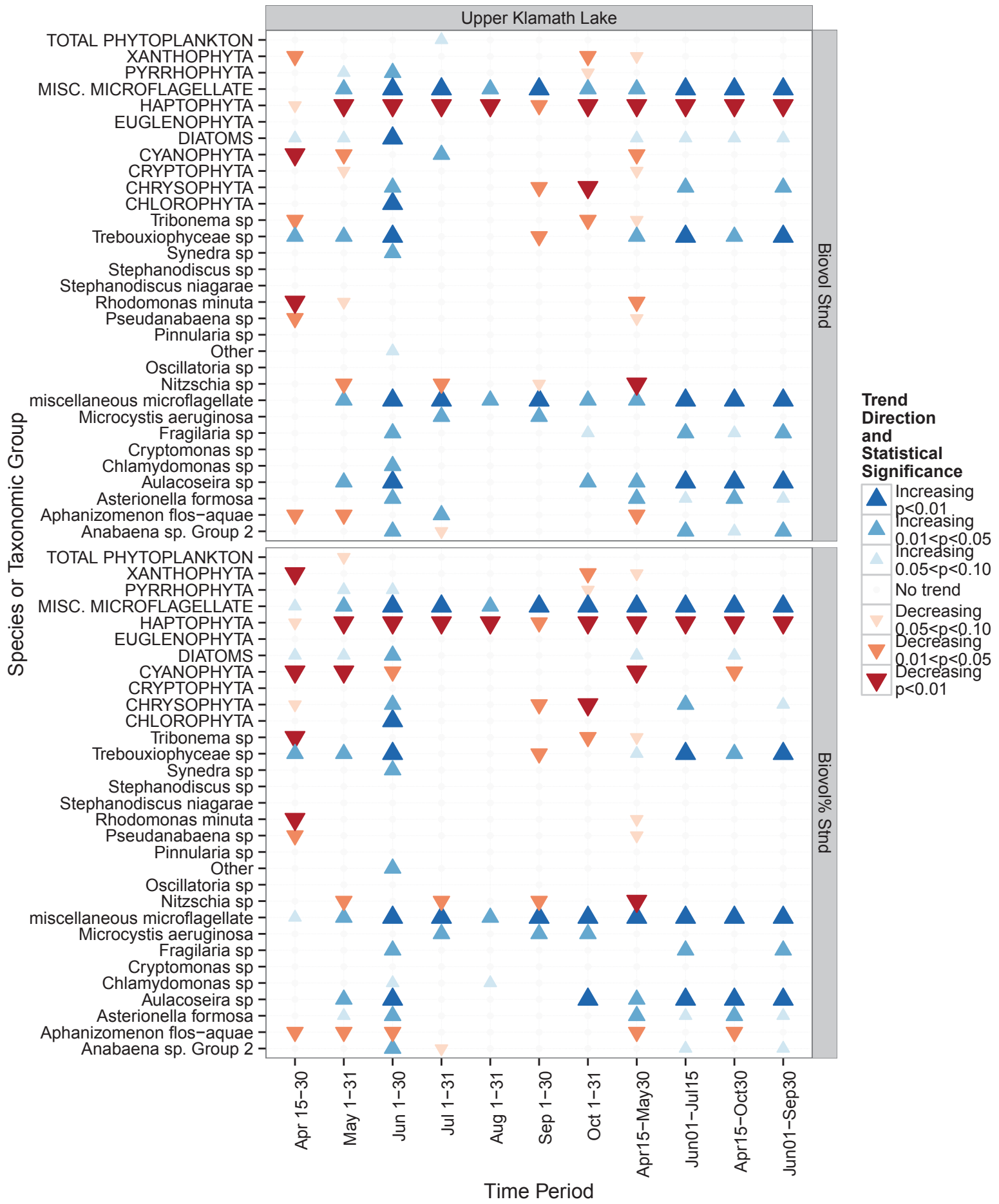
- Other
- Pinnularia sp
- Aulacoseira sp
- Asterionella formosa
- Tribonema sp
- Stephanodiscus sp
- Stephanodiscus niagarae
- Pseudanabaena sp
- Oscillatoria sp
- Synedra sp
- Fragilaria sp
- Microcystis aeruginosa
- Nitzschia sp
- Rhodomonas minuta
- Cryptomonas sp
- Anabaena sp. Group 2
- Trebouxiophyceae sp
- miscellaneous microflagellate
- Chlamydomonas sp
- Aphanizomenon flos-aquae

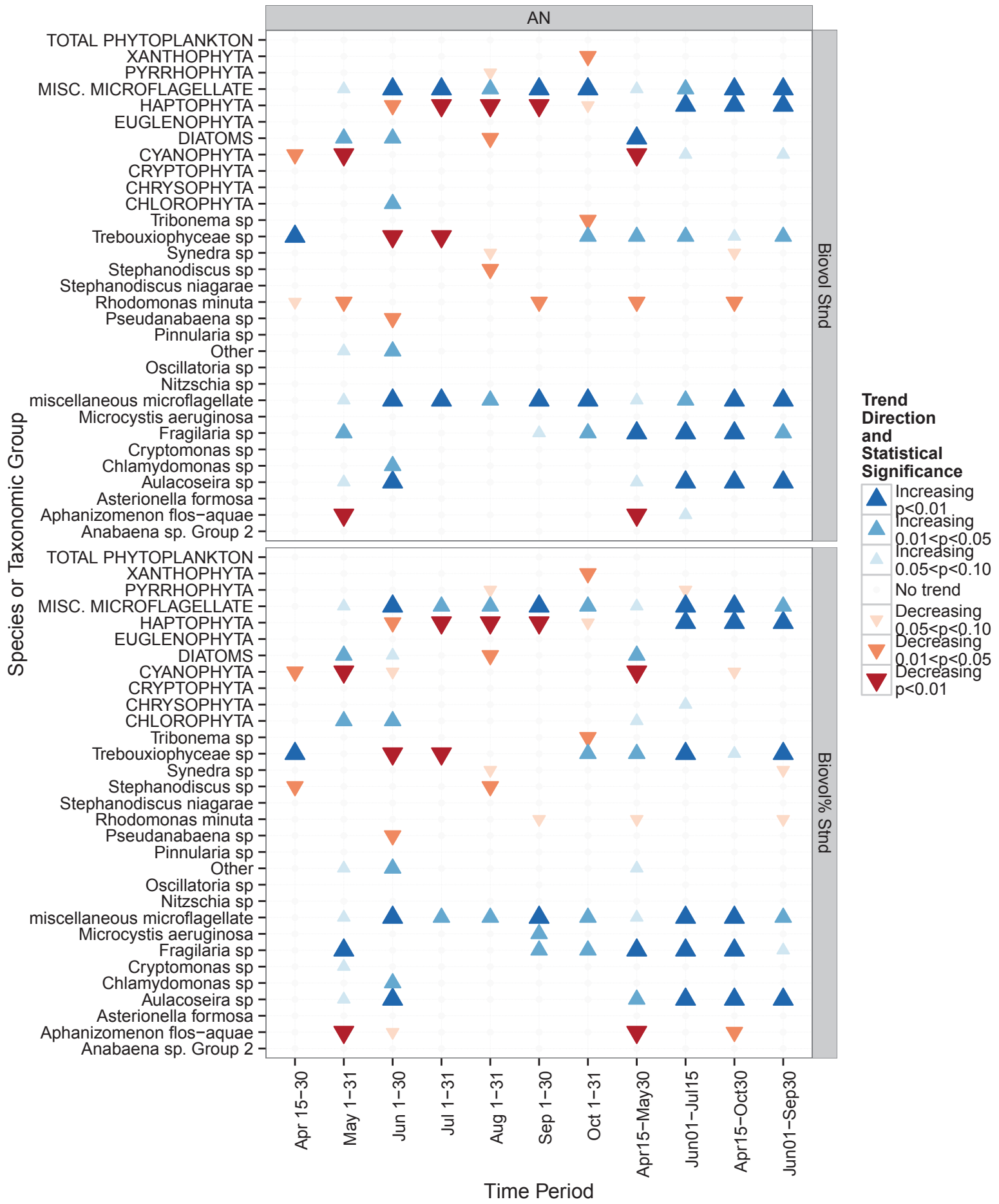
Phyto Genera/Species and Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct

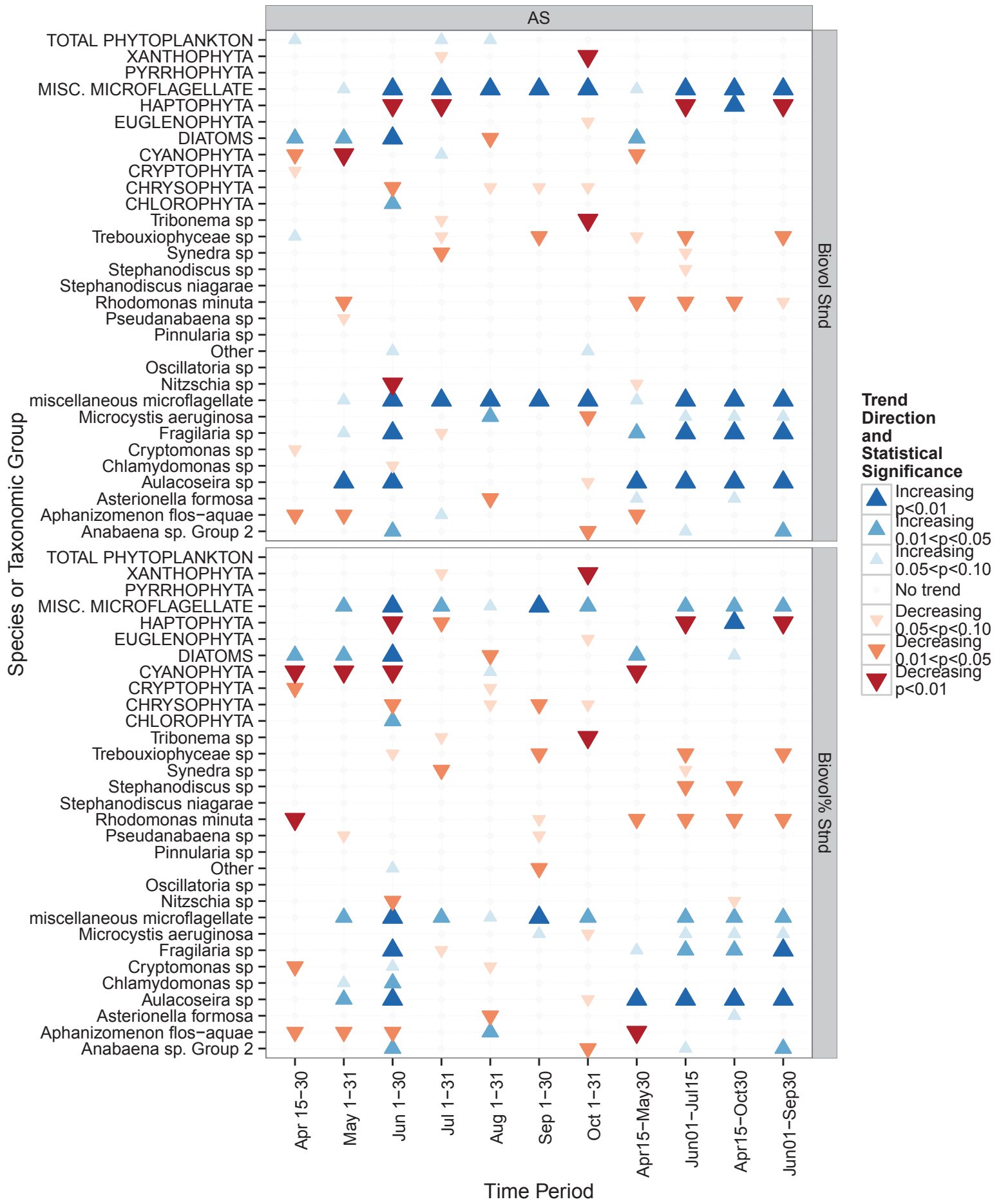


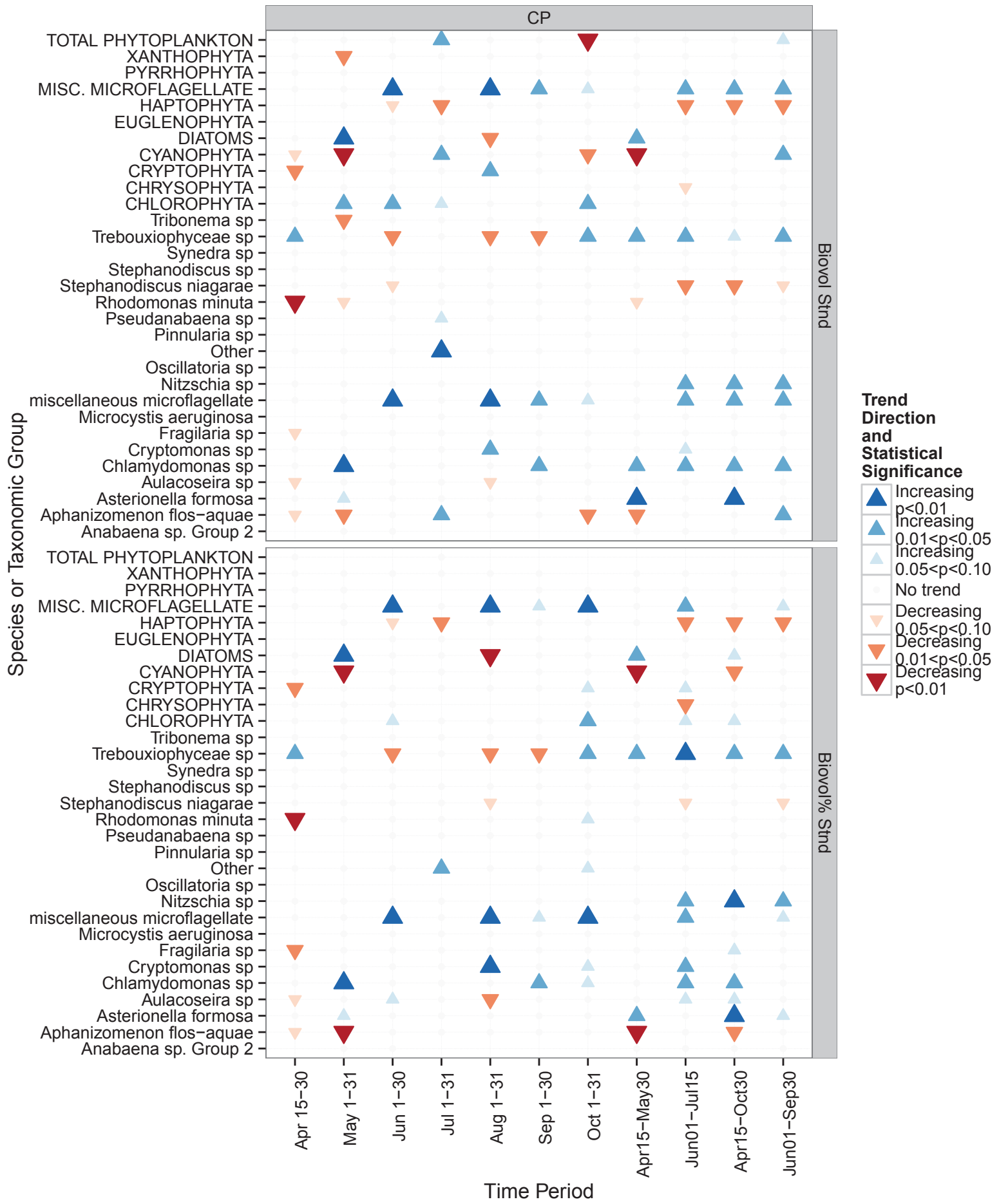
**APPENDIX E: LONG TERM TRENDS TESTS FOR PHYTOPLANKTON TAXONOMIC
GROUPS AND MAJOR GENERA/SPECIES FOR EACH SITE**

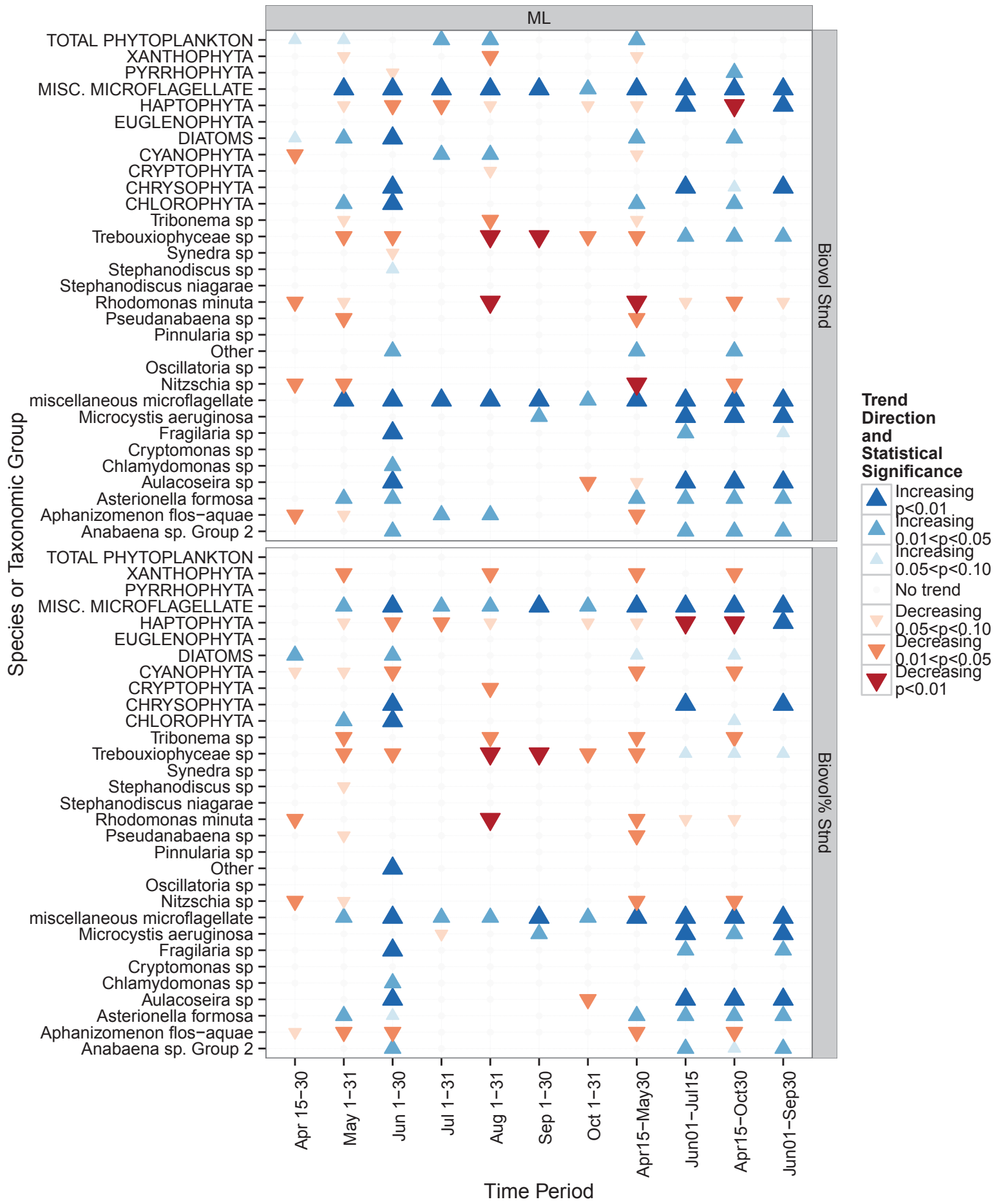


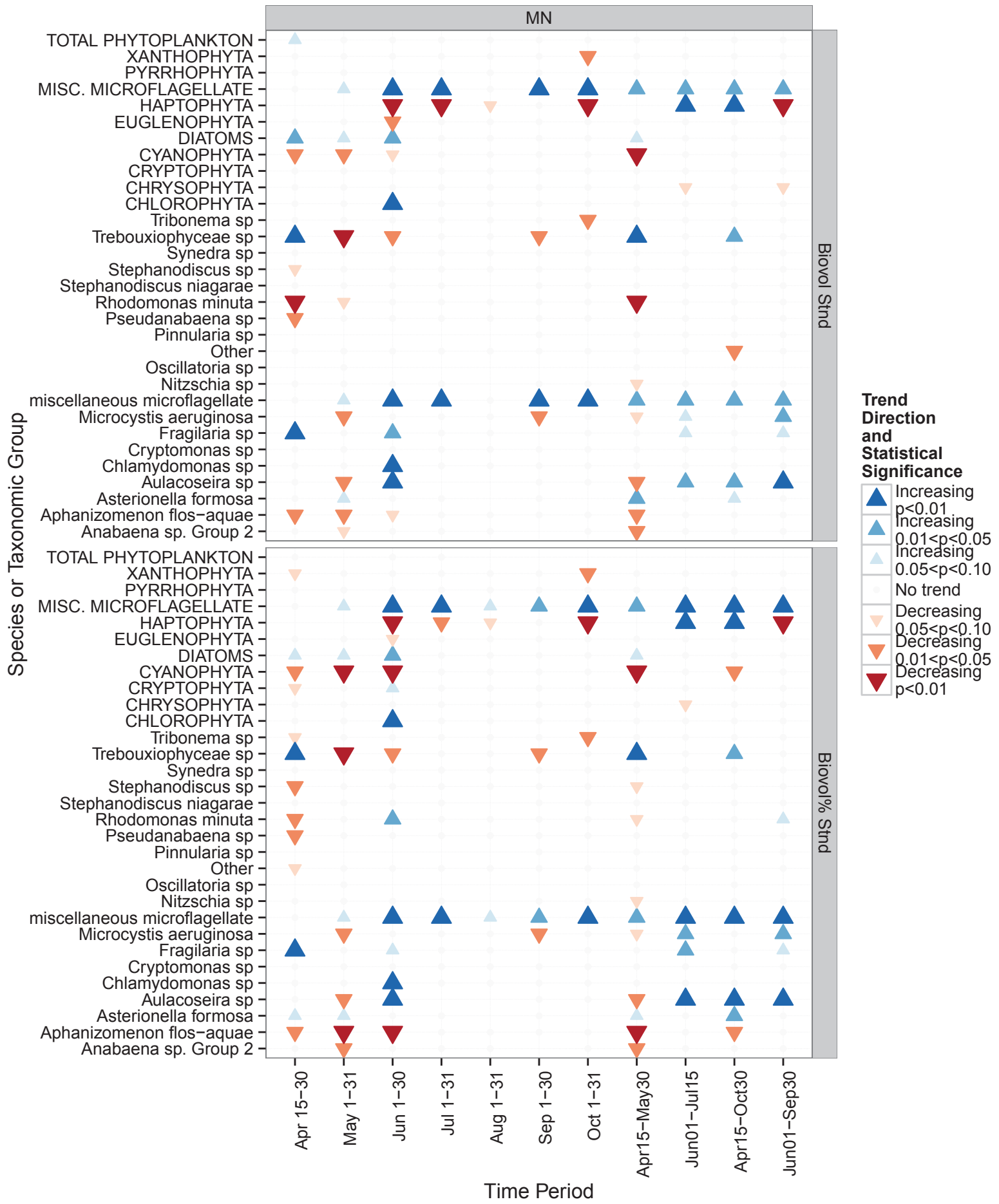


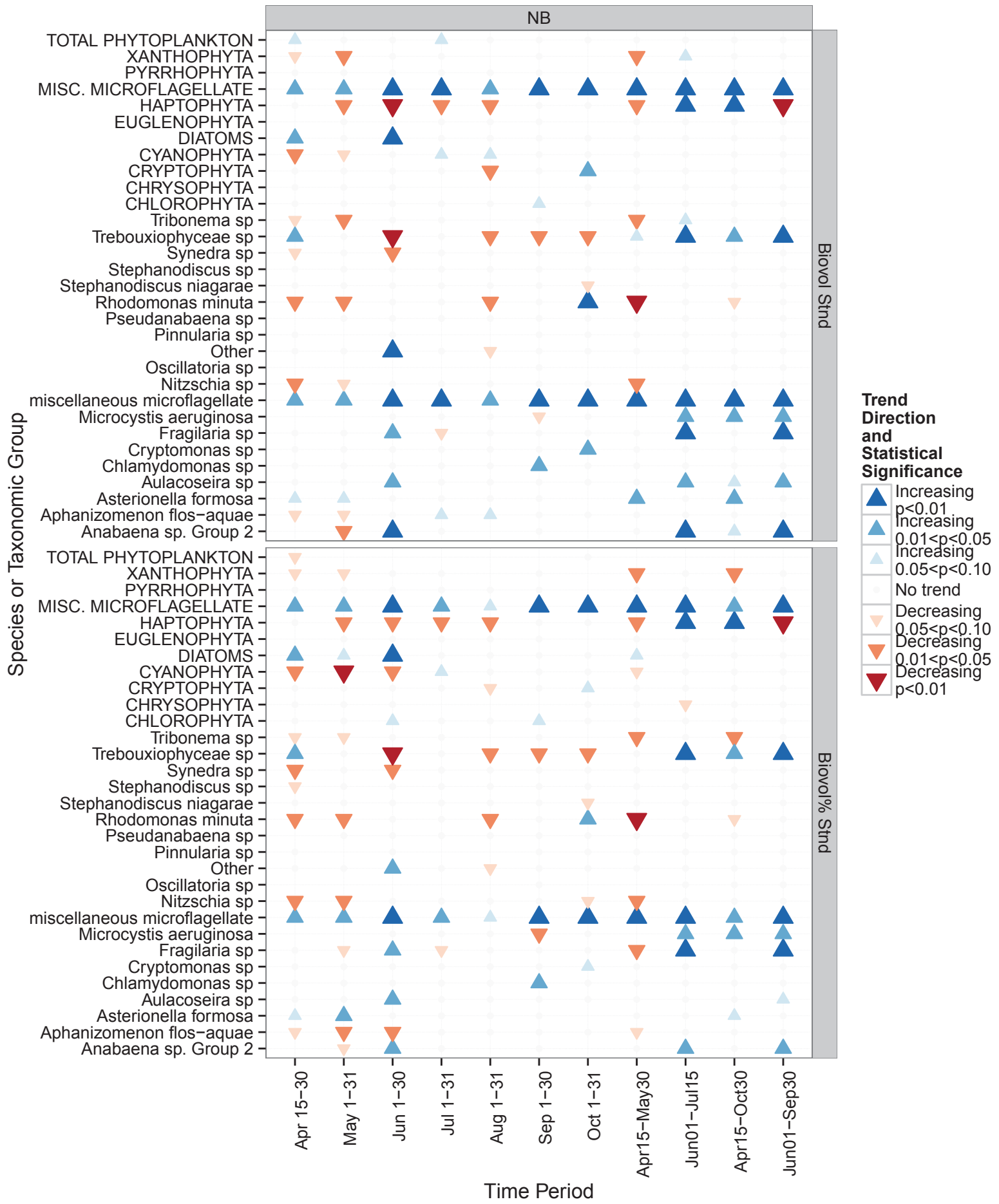


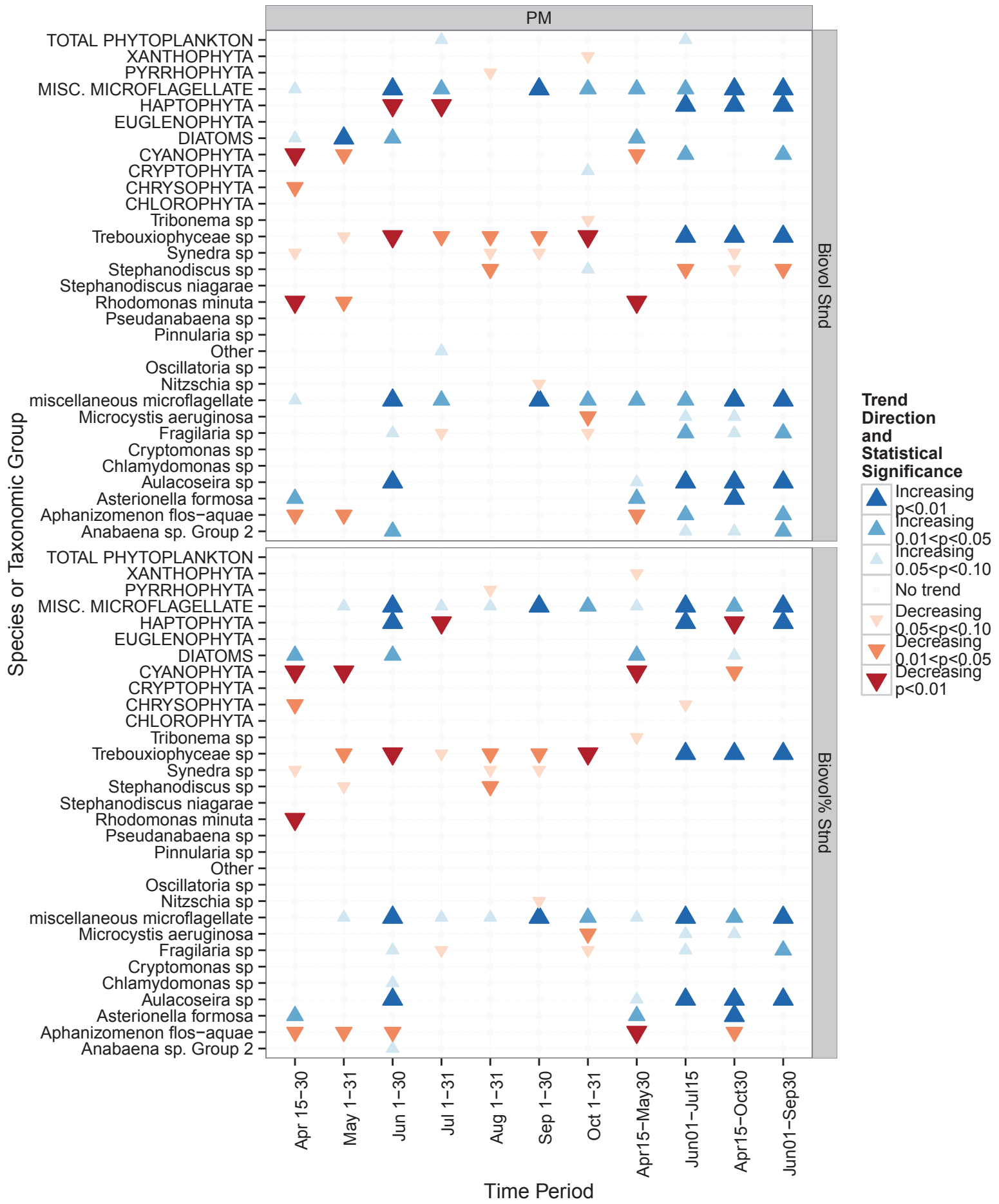


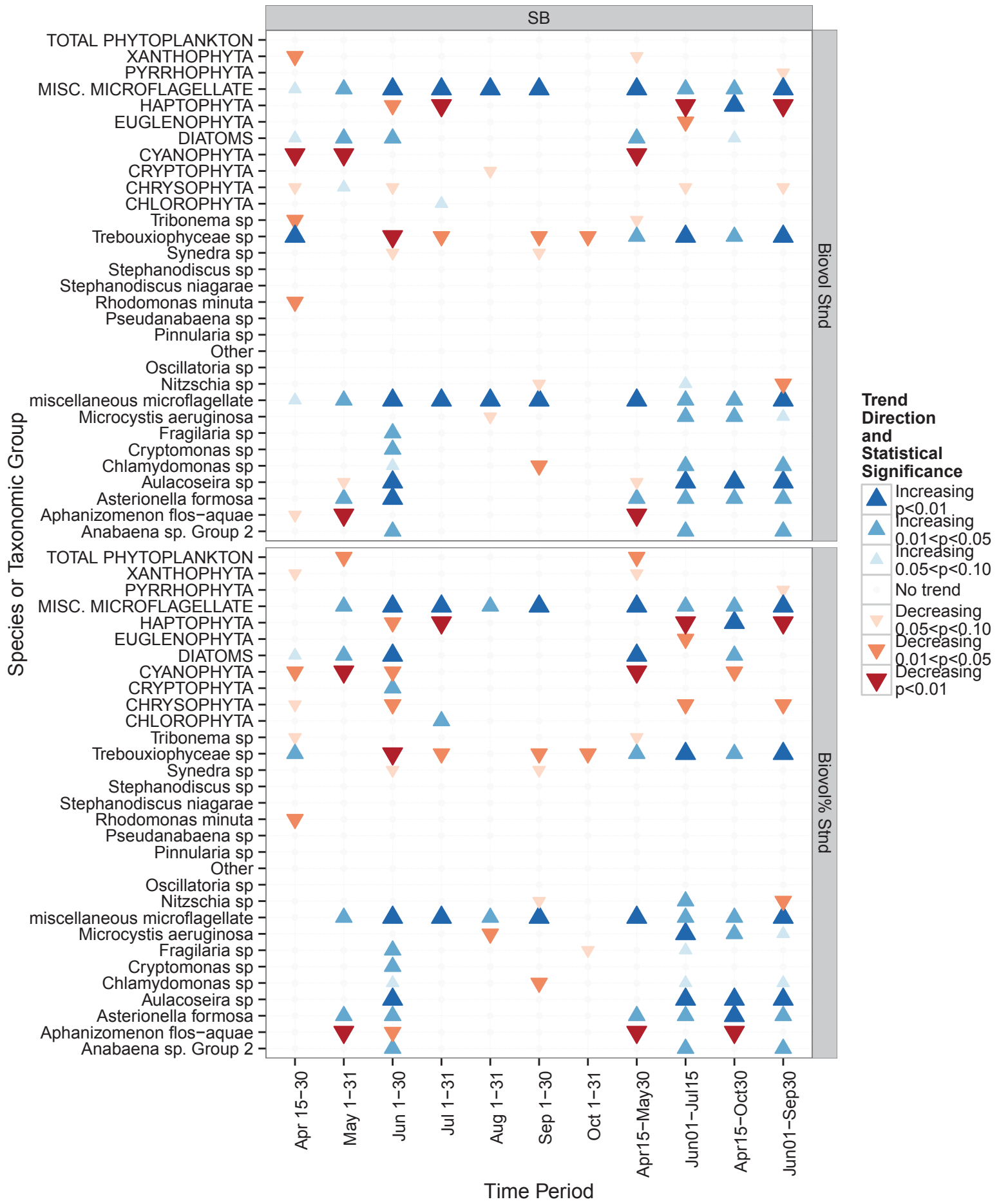


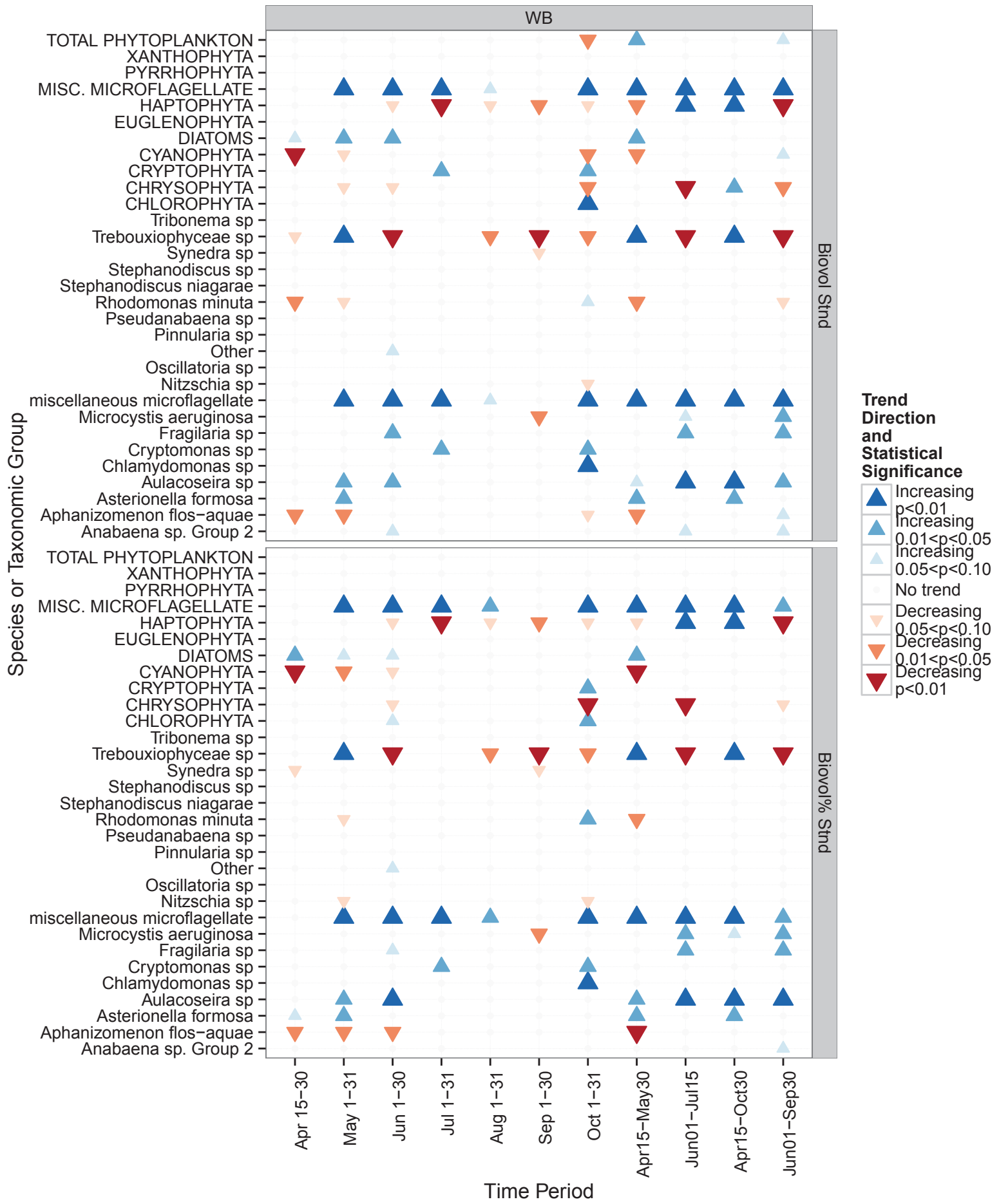






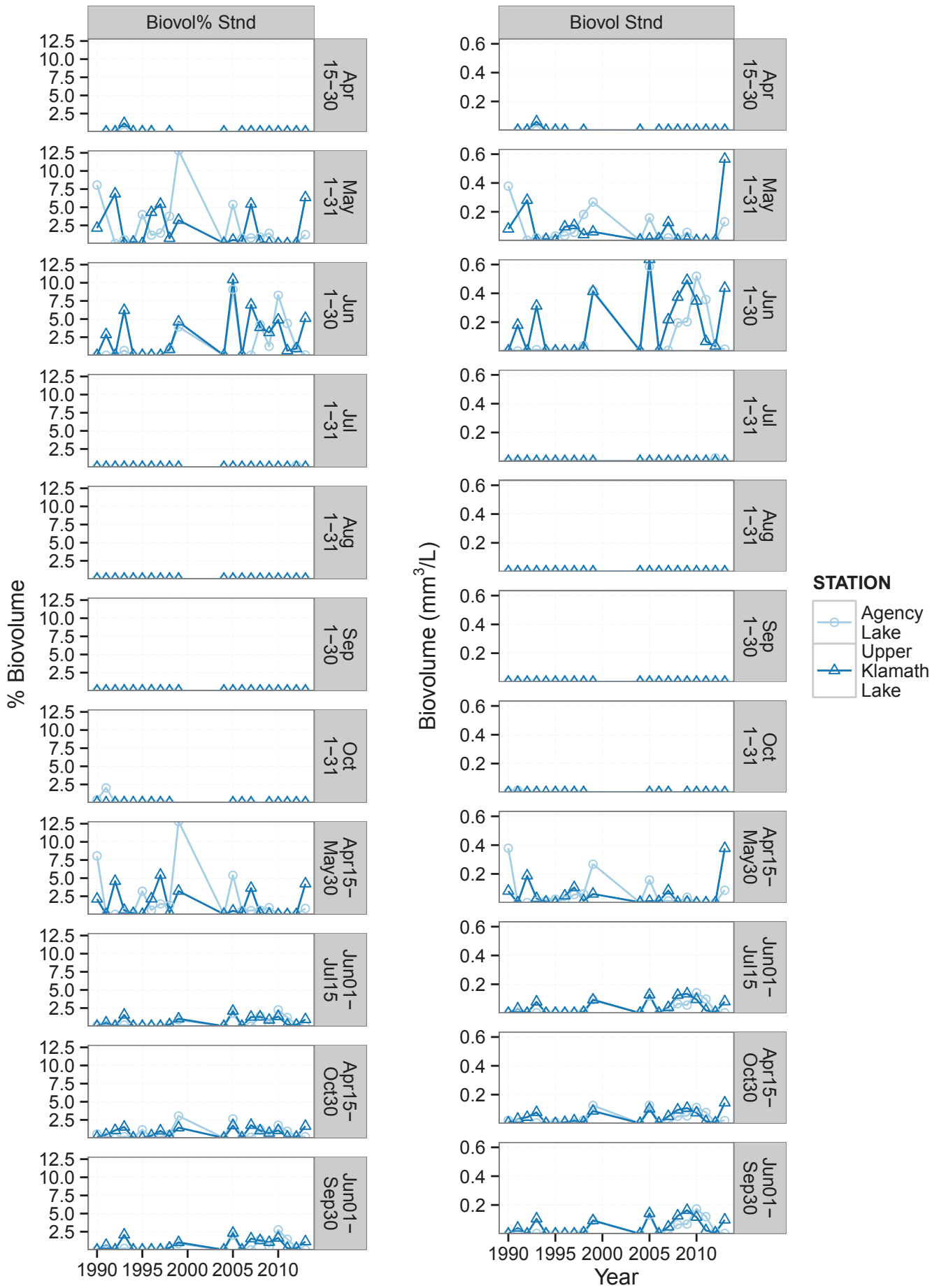




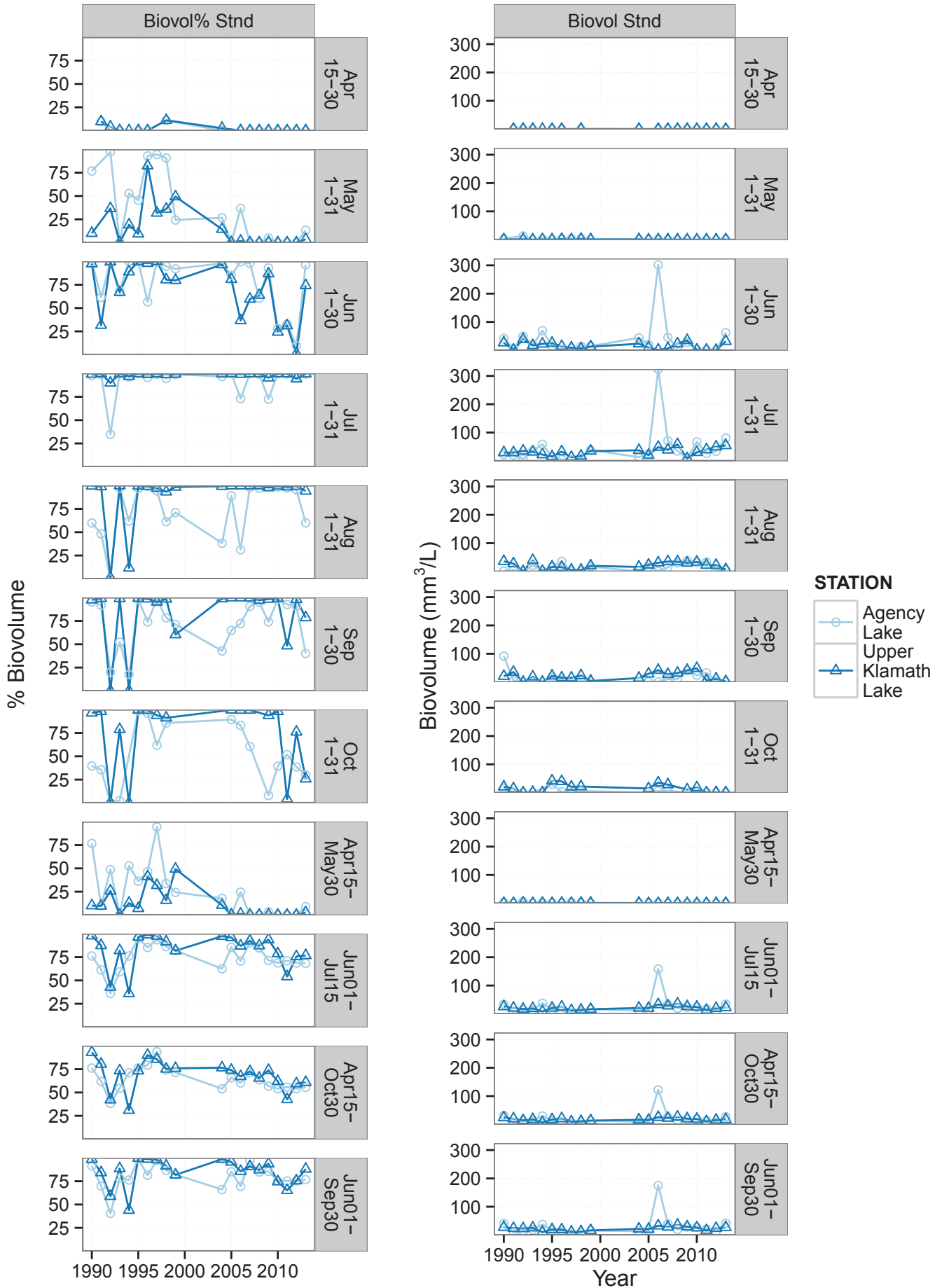


**APPENDIX F: ANNUAL TIME SERIES CHARTS OF LAKE-WIDE BIOVOLUME FOR
PHYTOPLANKTON MAJOR GENERA/SPECIES**

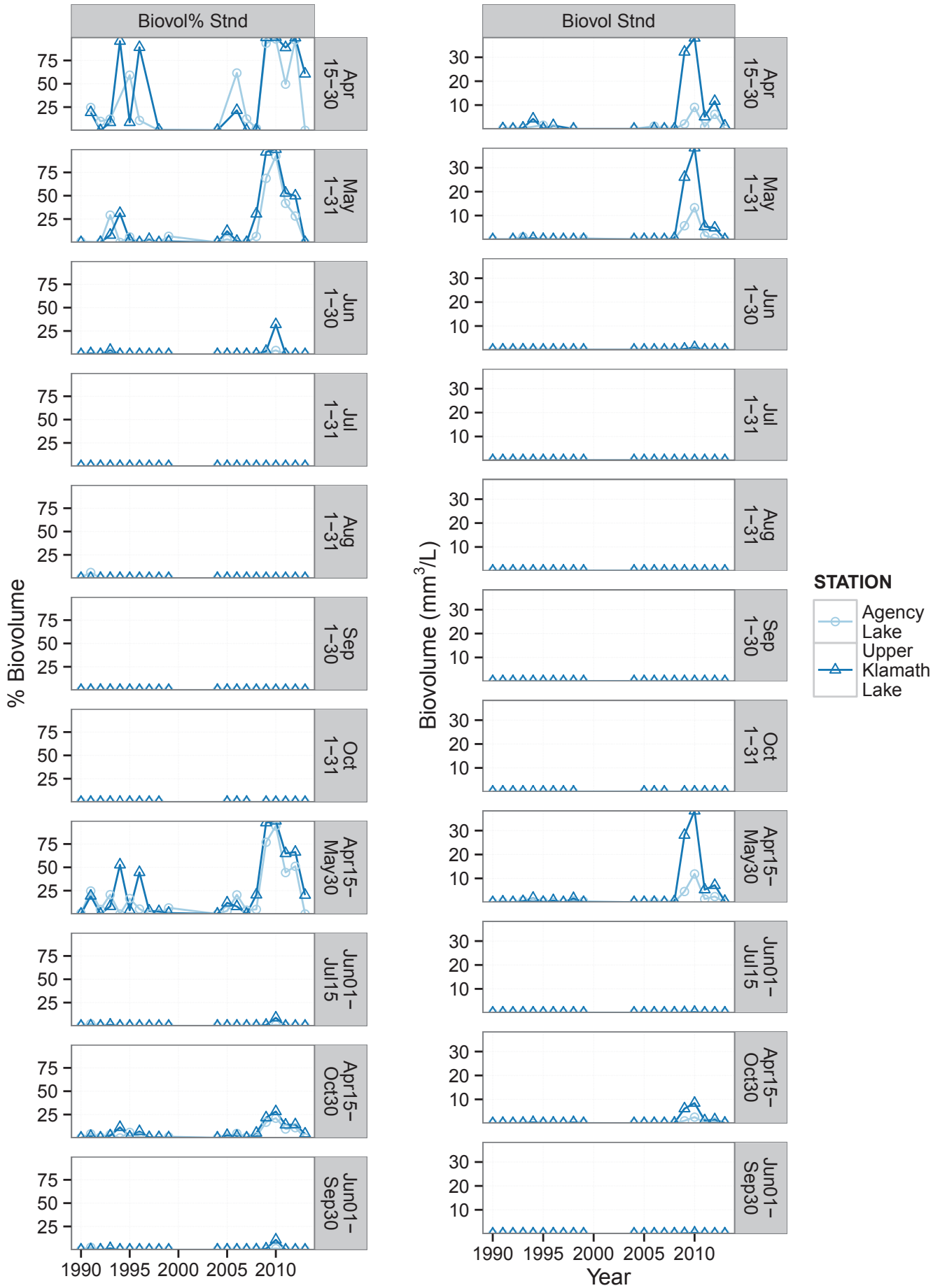
Average by Seasonal Periods and Year: Anabaena sp. Group 2



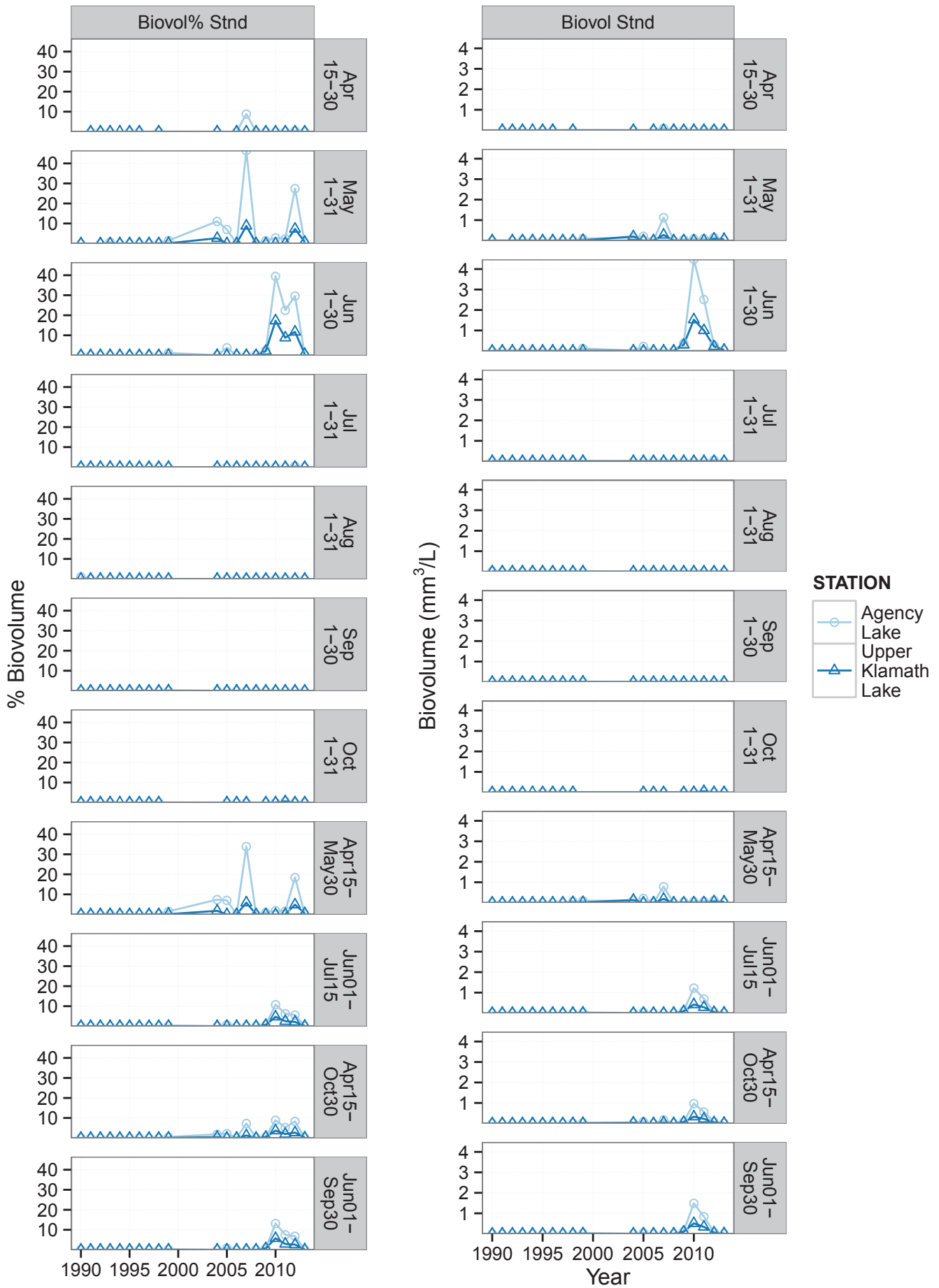
Average by Seasonal Periods and Year: *Aphanizomenon flos-aquae*



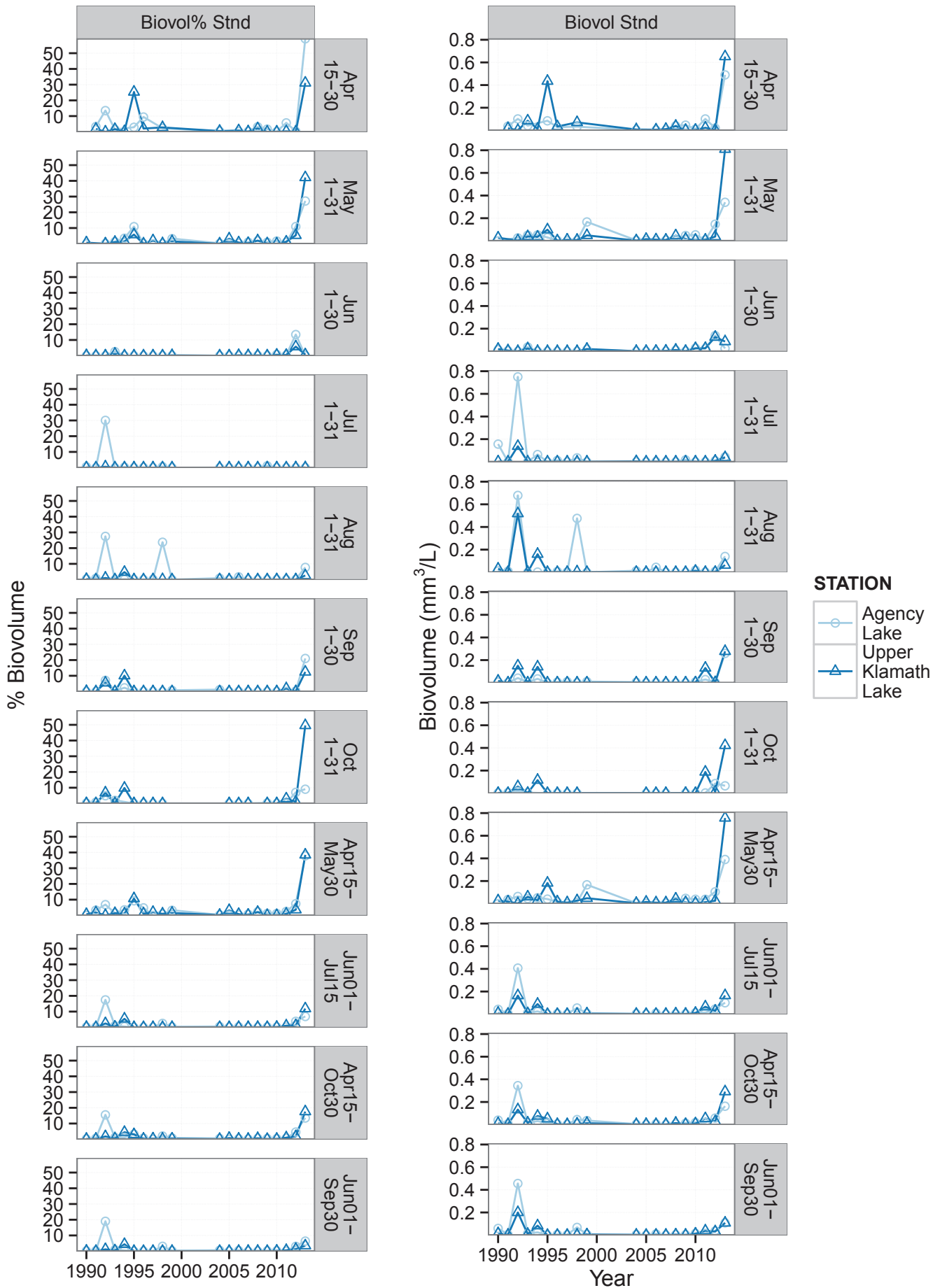
Average by Seasonal Periods and Year: *Asterionella formosa*



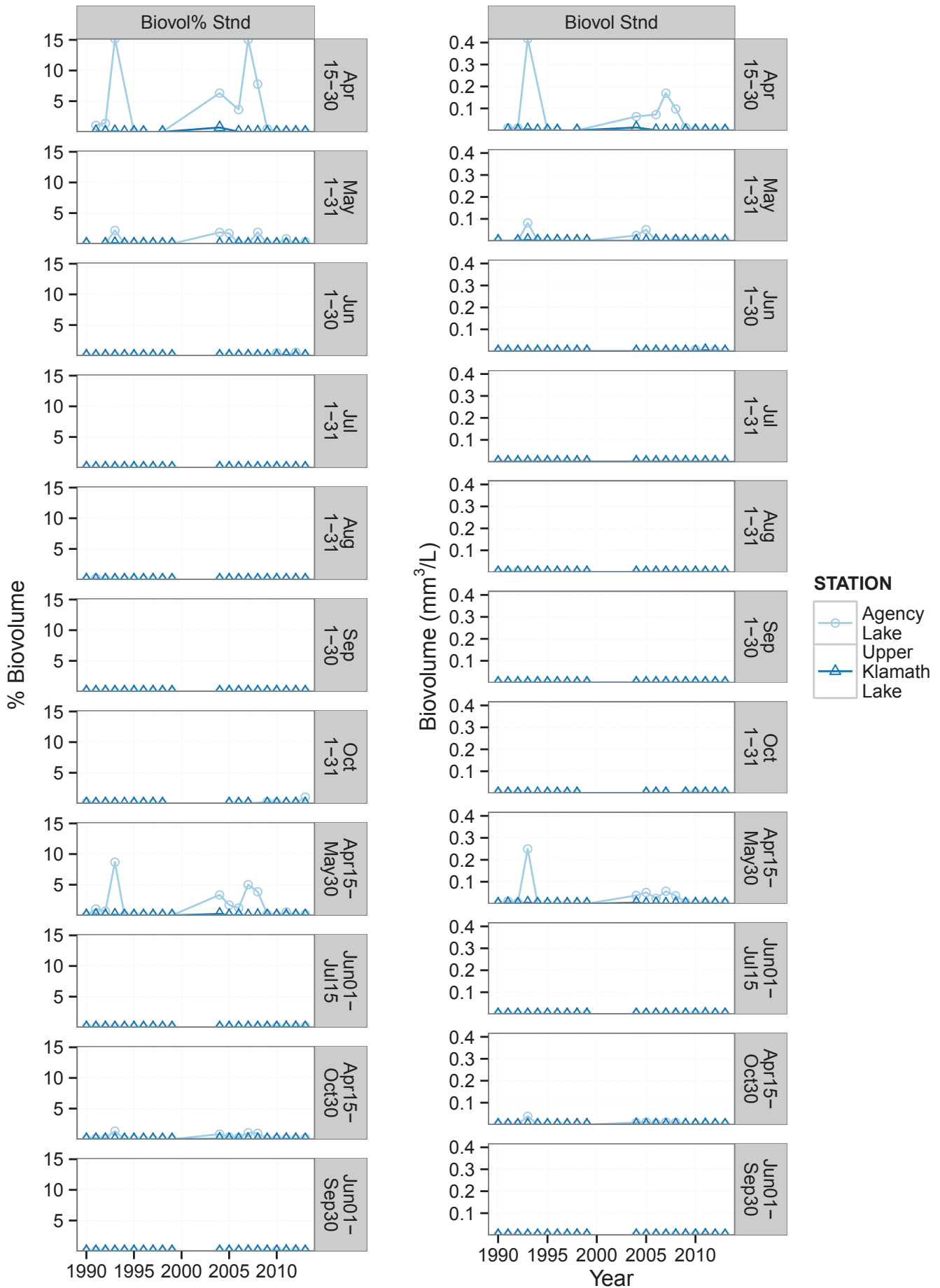
Average by Seasonal Periods and Year: Aulacoseira sp



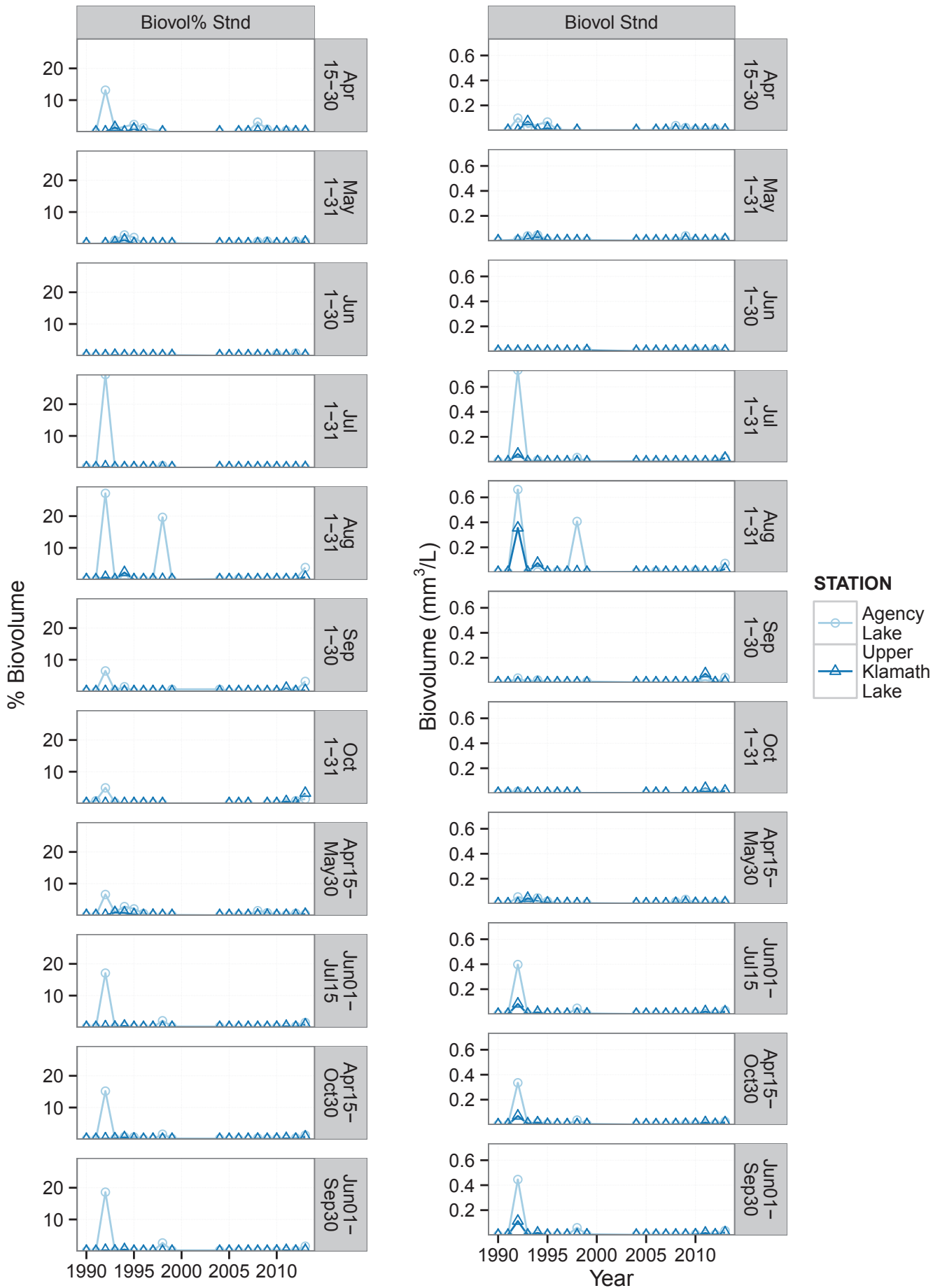
Average by Seasonal Periods and Year: CHLOROPHYTA



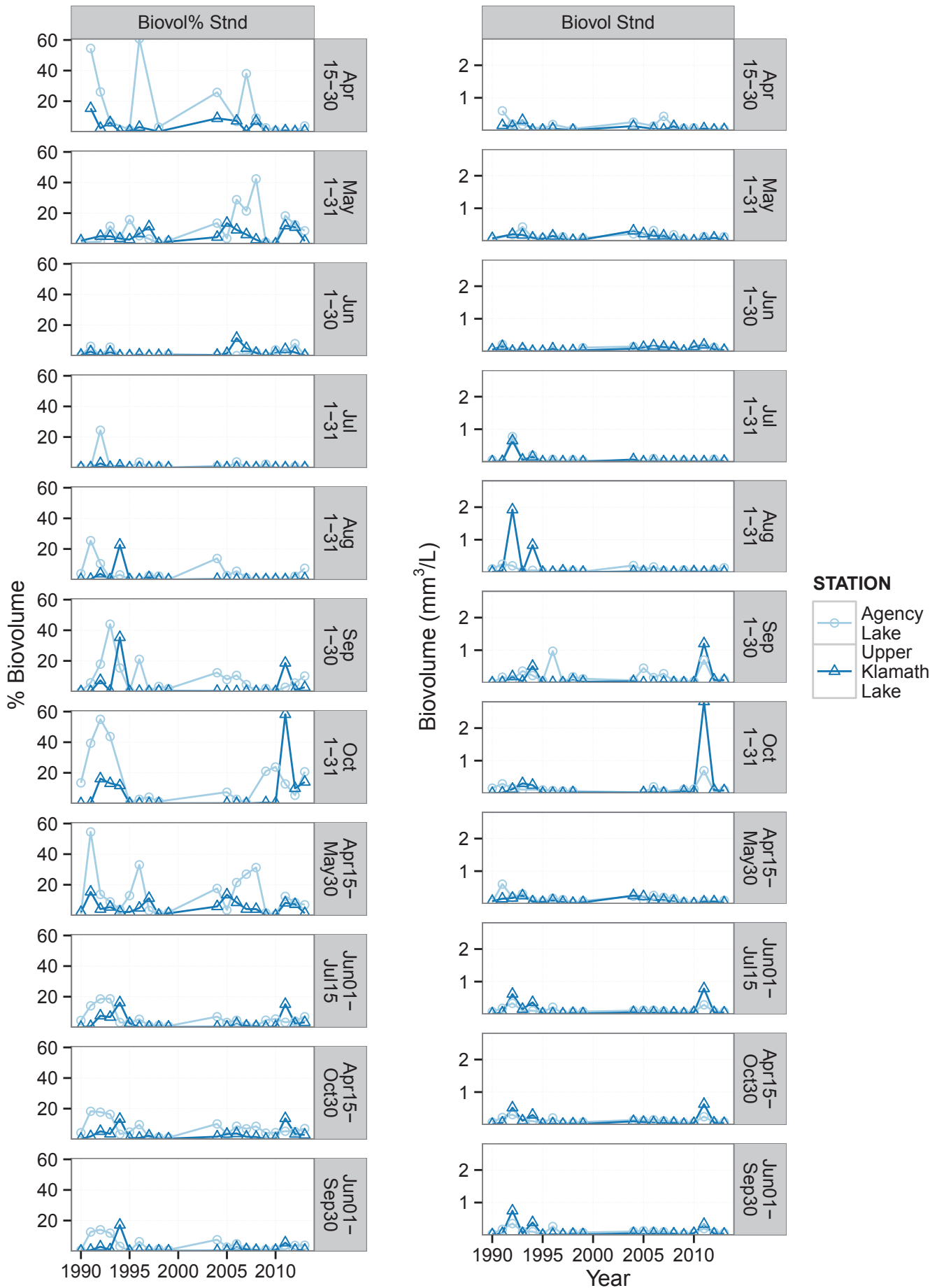
Average by Seasonal Periods and Year: CHRYSOPHYTA



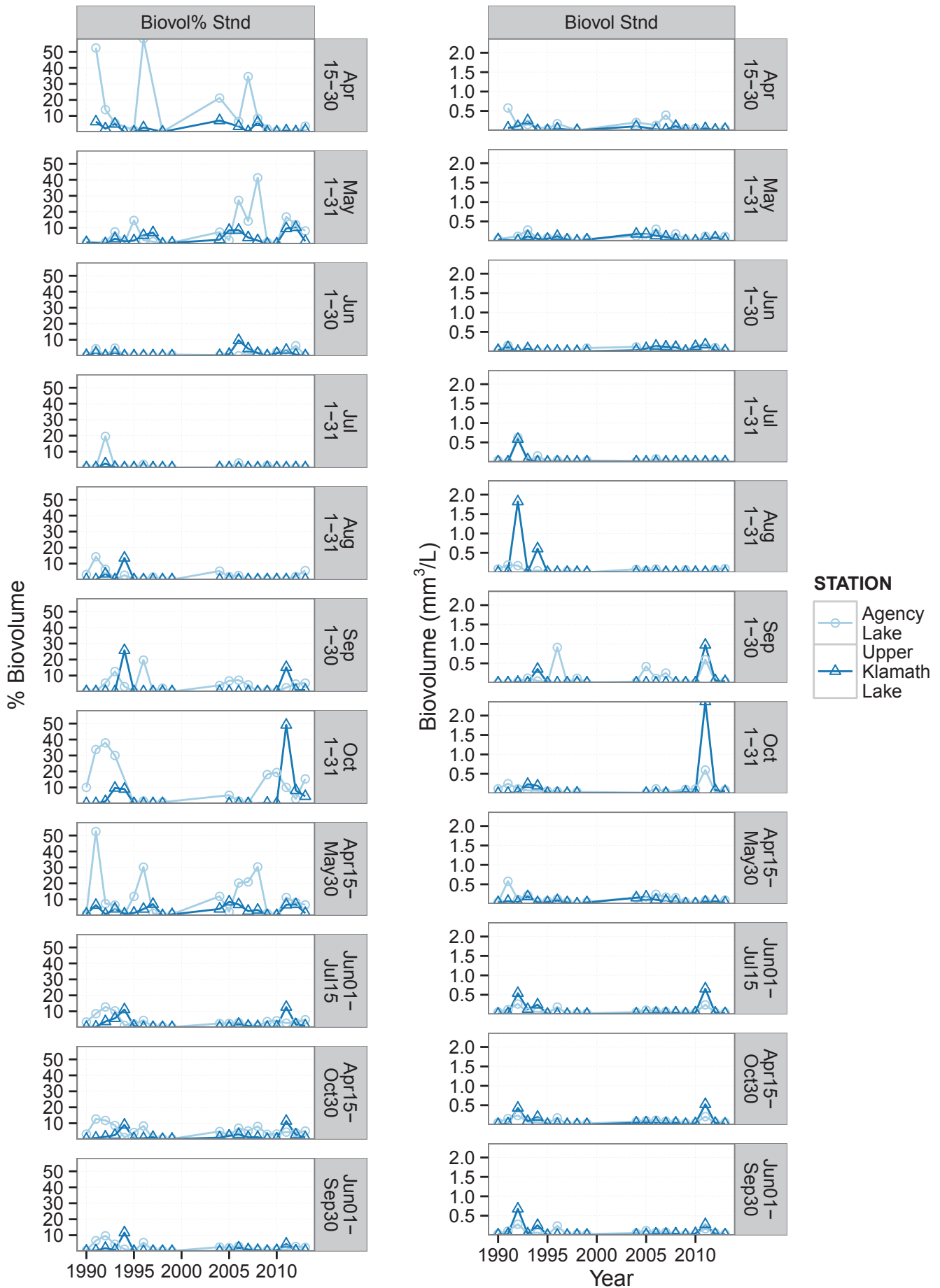
Average by Seasonal Periods and Year: Chlamydomonas sp



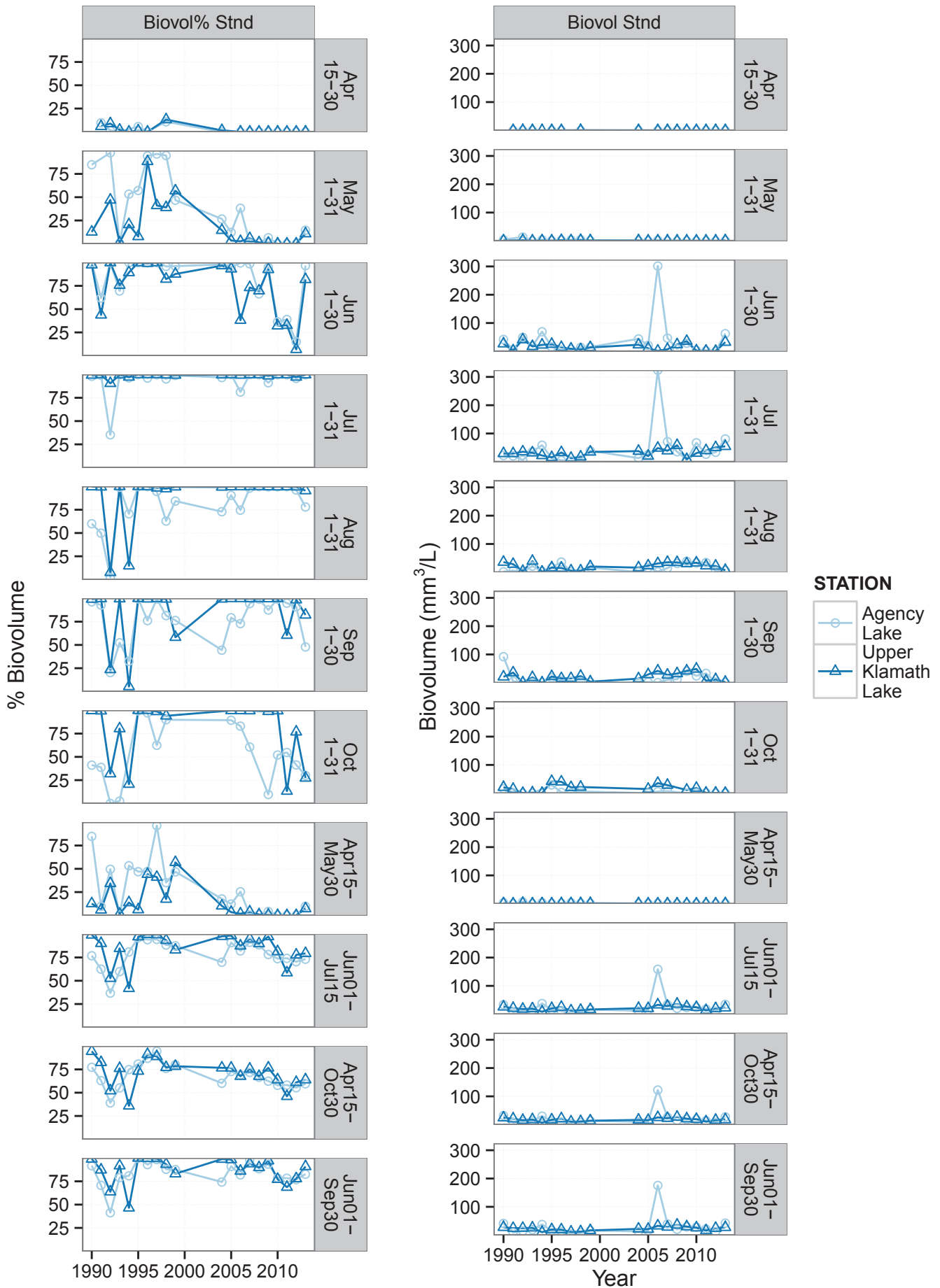
Average by Seasonal Periods and Year: CRYPTOPHYTA



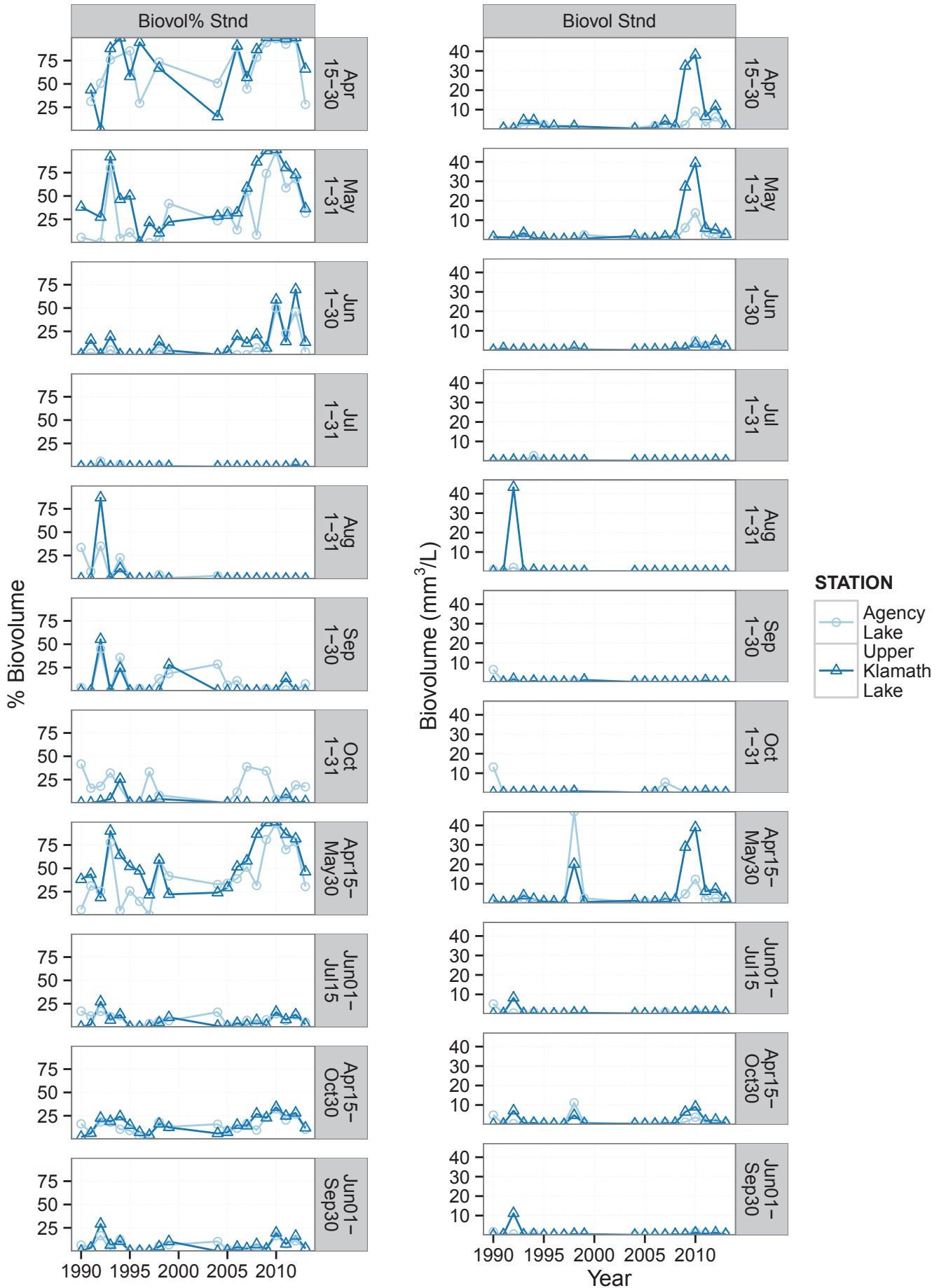
Average by Seasonal Periods and Year: Cryptomonas sp



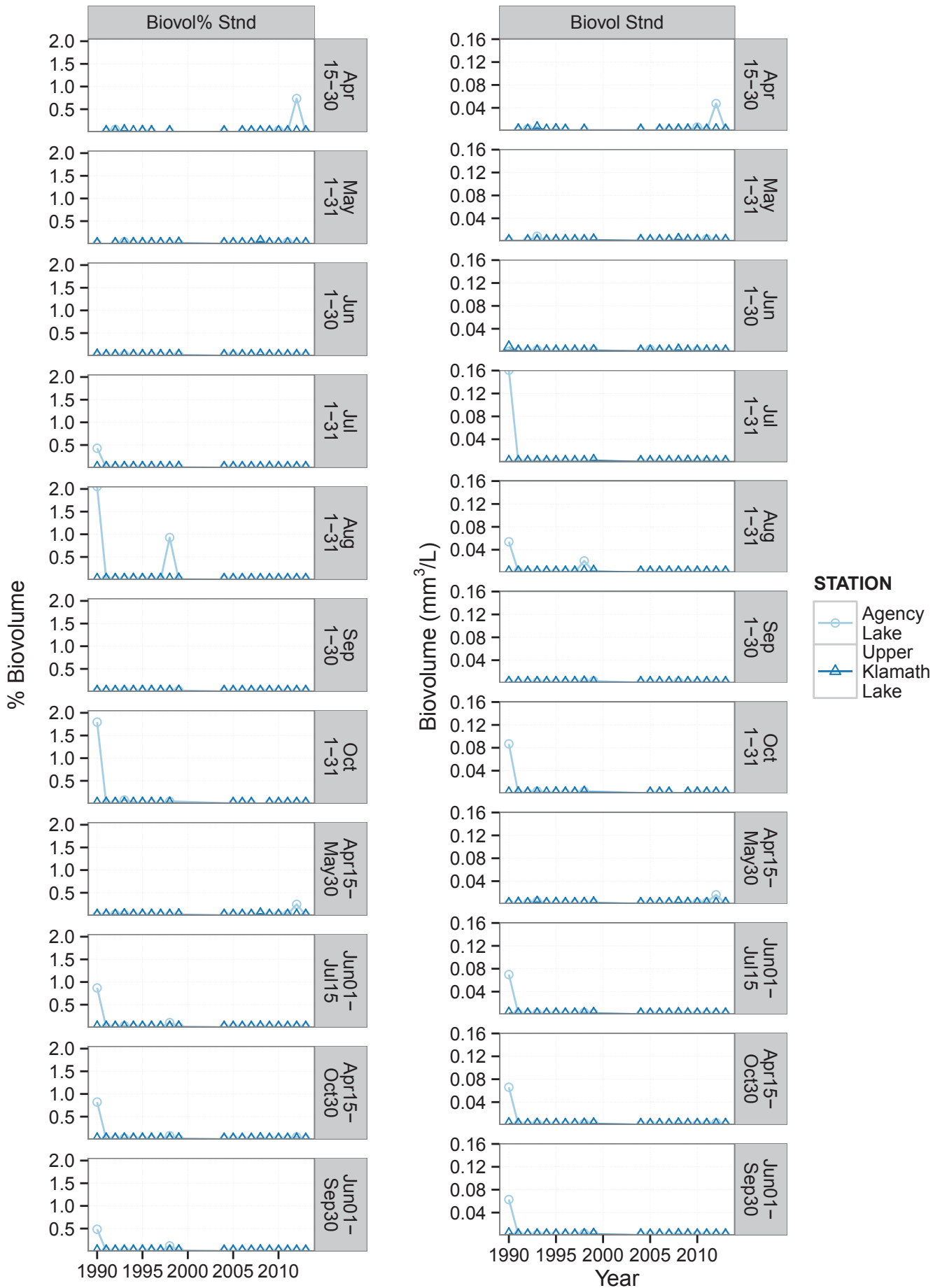
Average by Seasonal Periods and Year: CYANOPHYTA



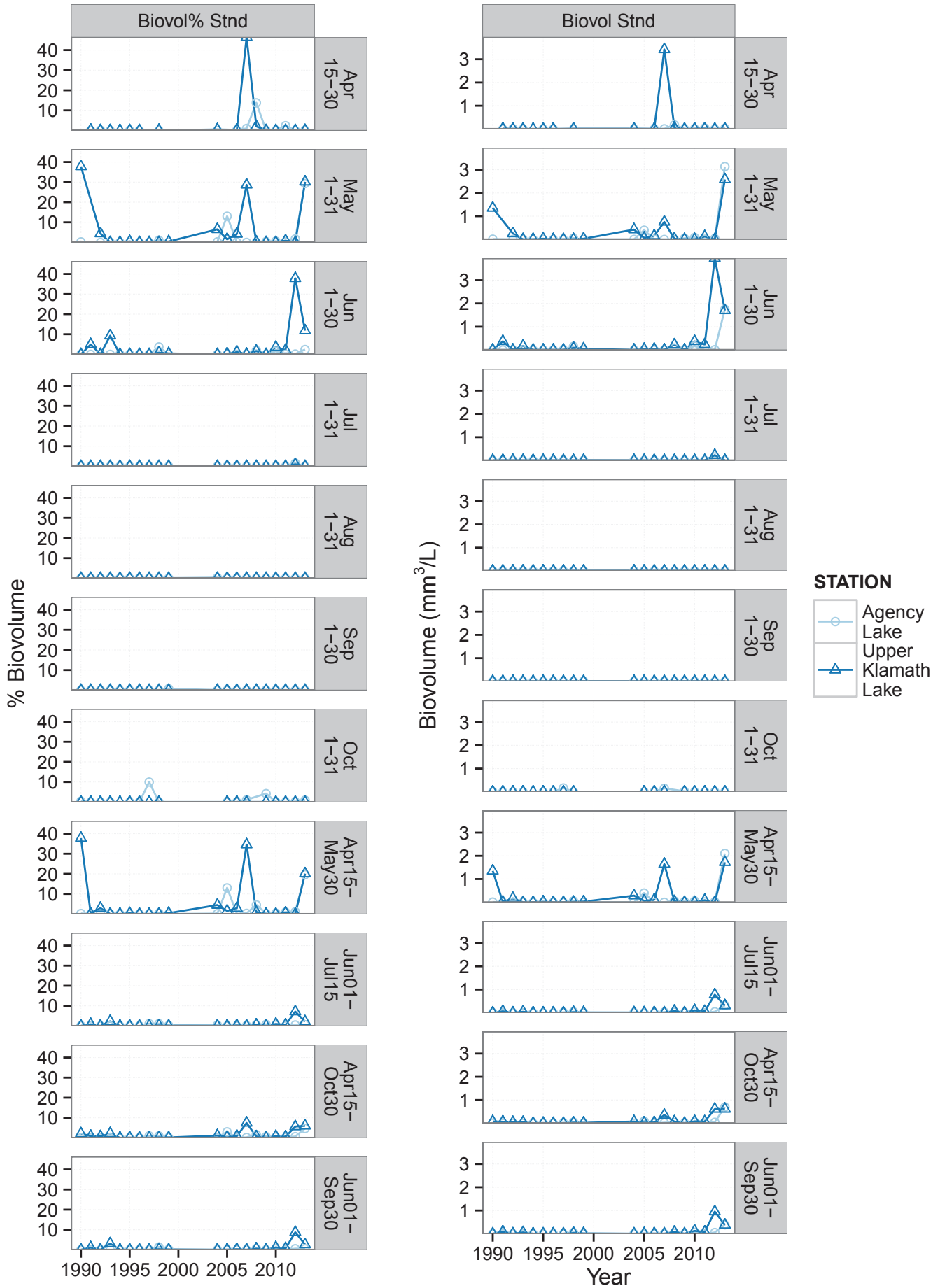
Average by Seasonal Periods and Year: DIATOMS



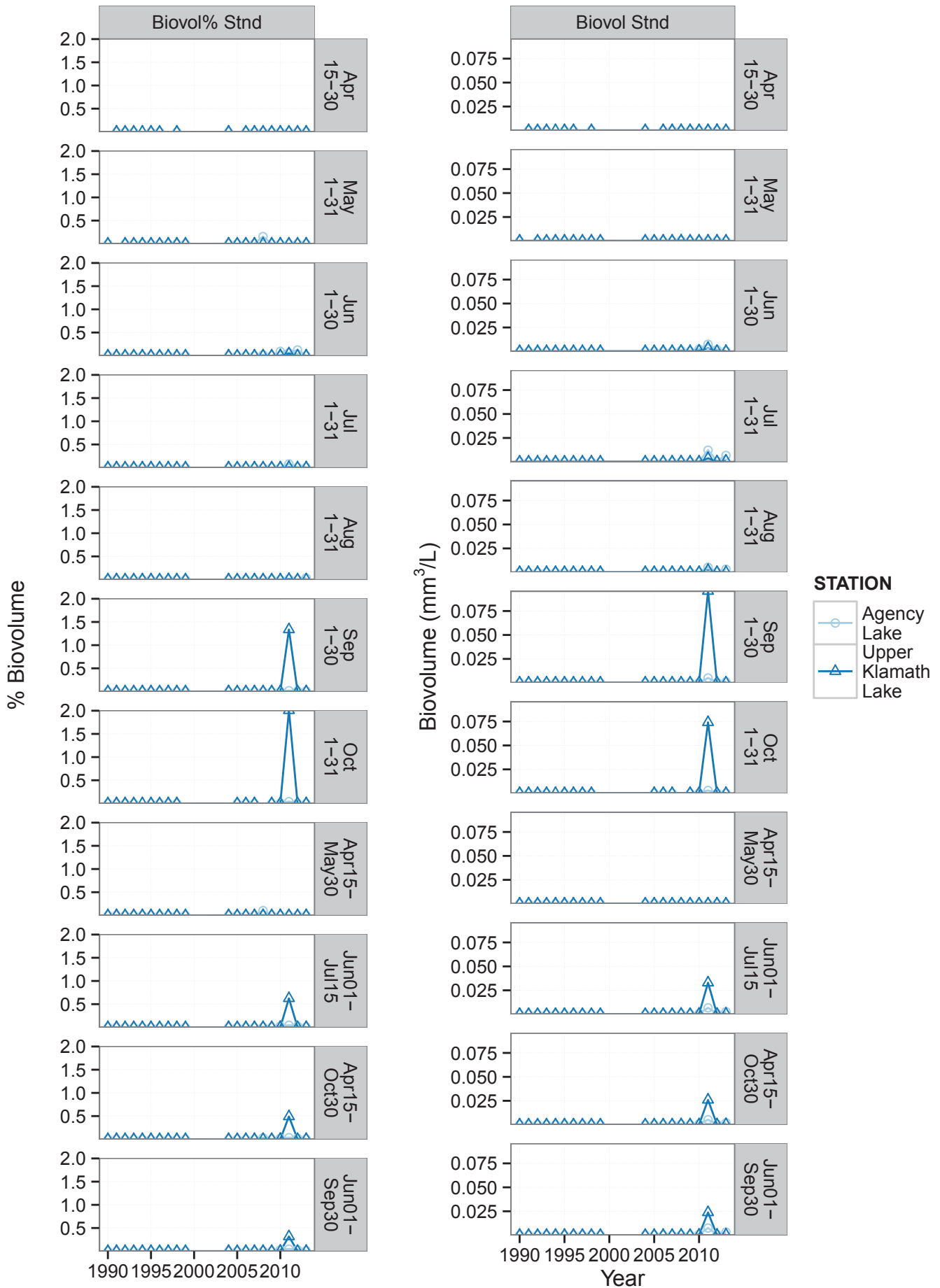
Average by Seasonal Periods and Year: EUGLENOPHYTA



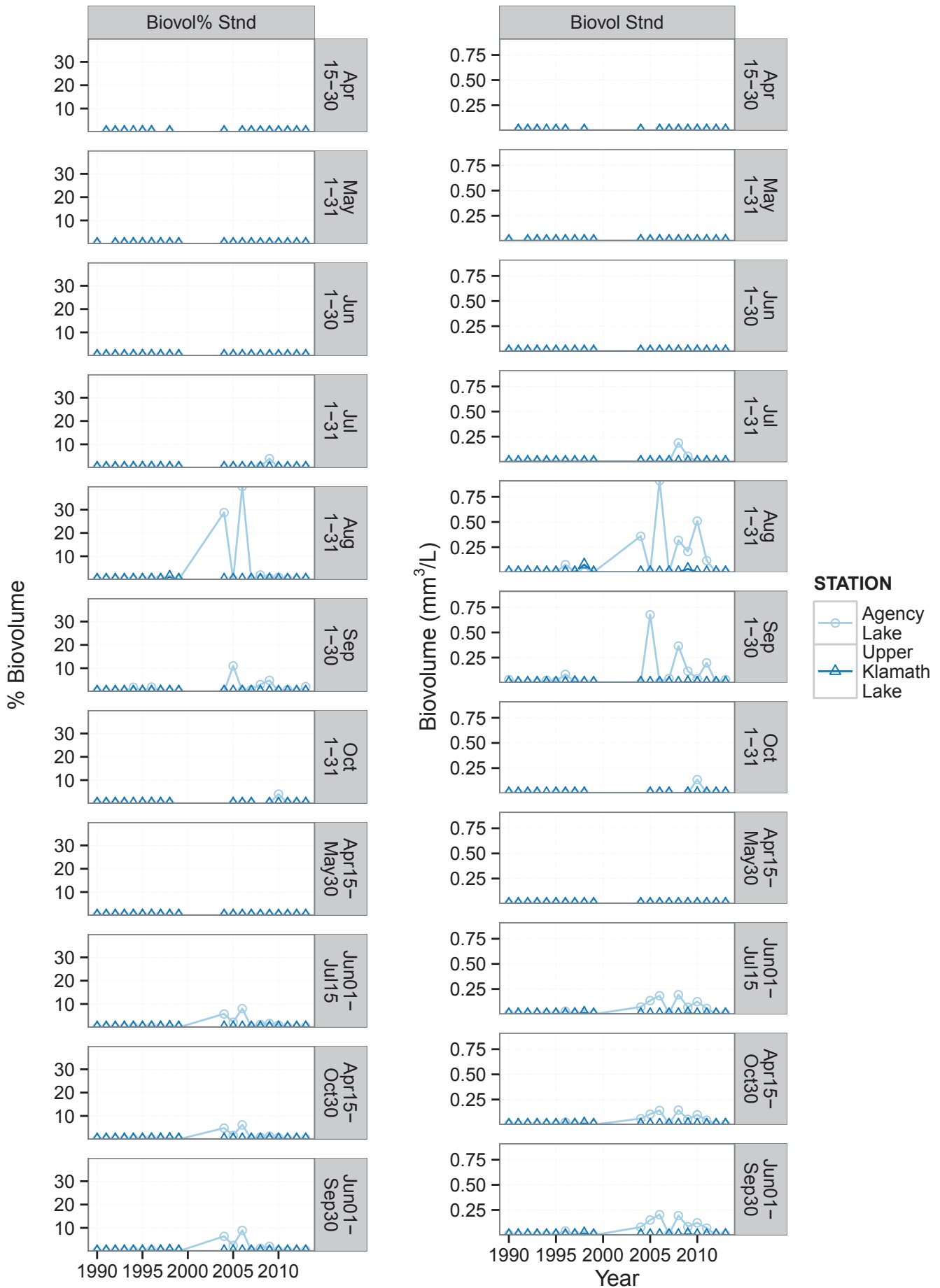
Average by Seasonal Periods and Year: *Fragilaria* sp



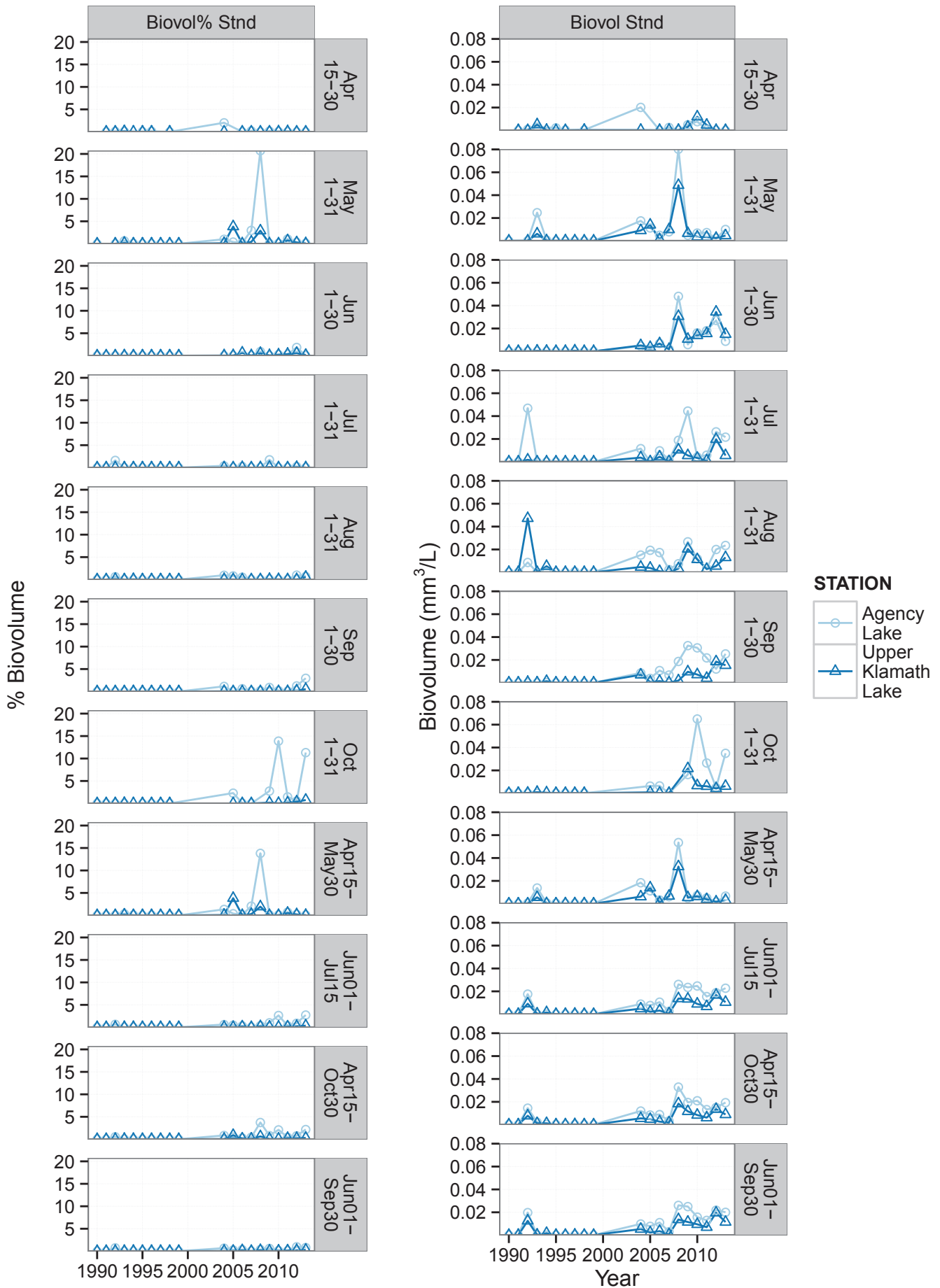
Average by Seasonal Periods and Year: HAPTOPHYTA



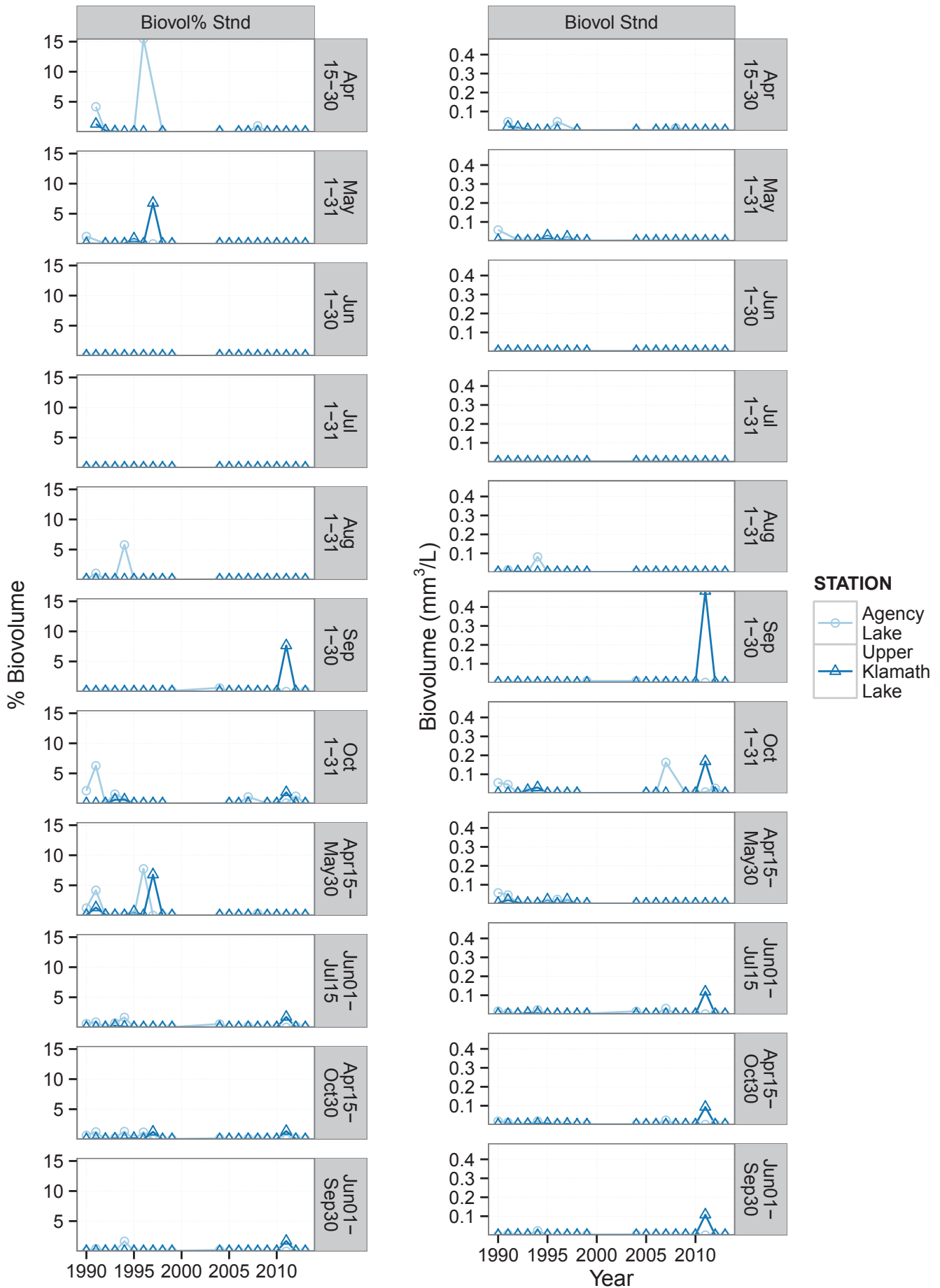
Average by Seasonal Periods and Year: *Microcystis aeruginosa*



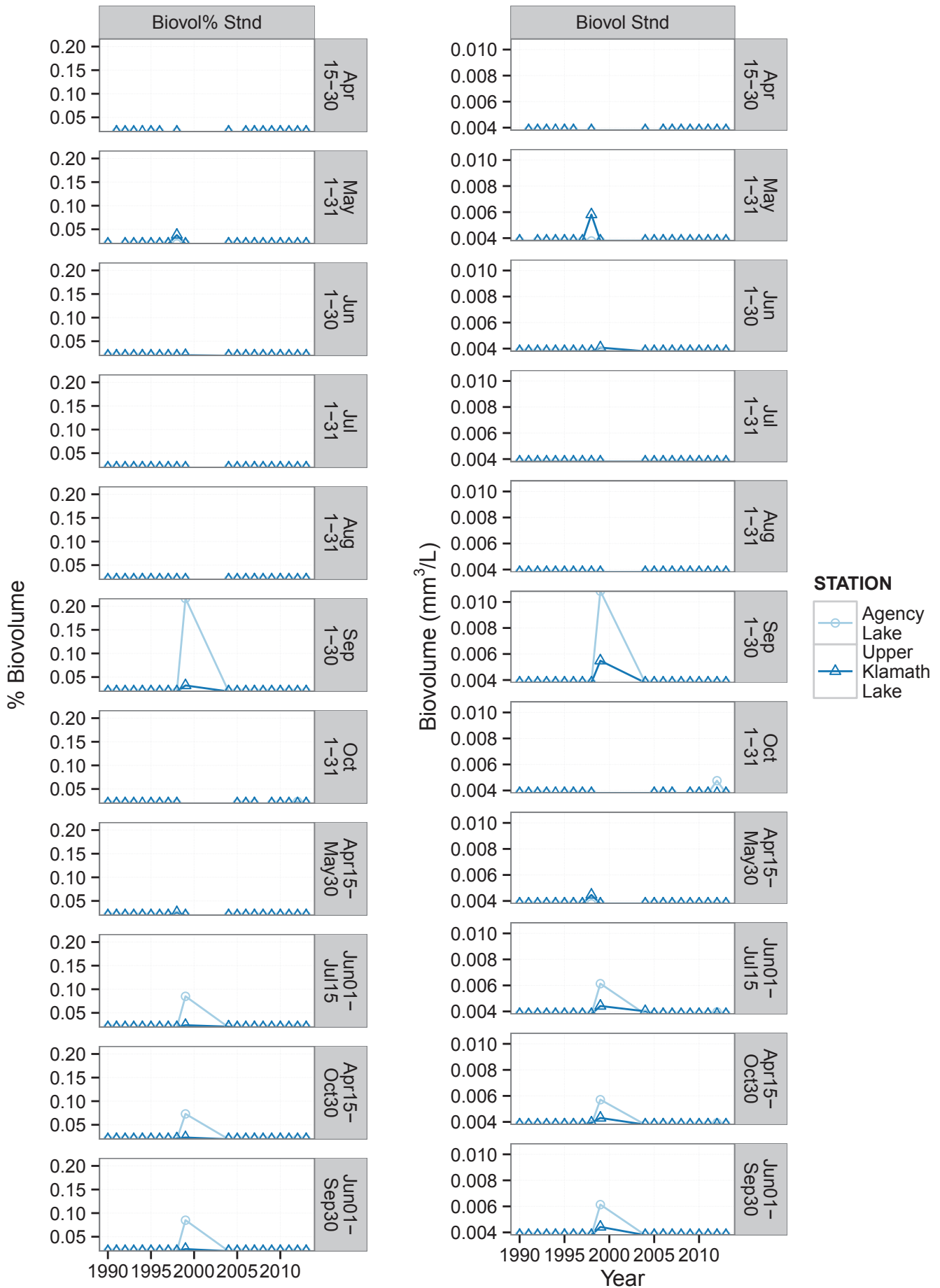
Average by Seasonal Periods and Year: miscellaneous microflagellate



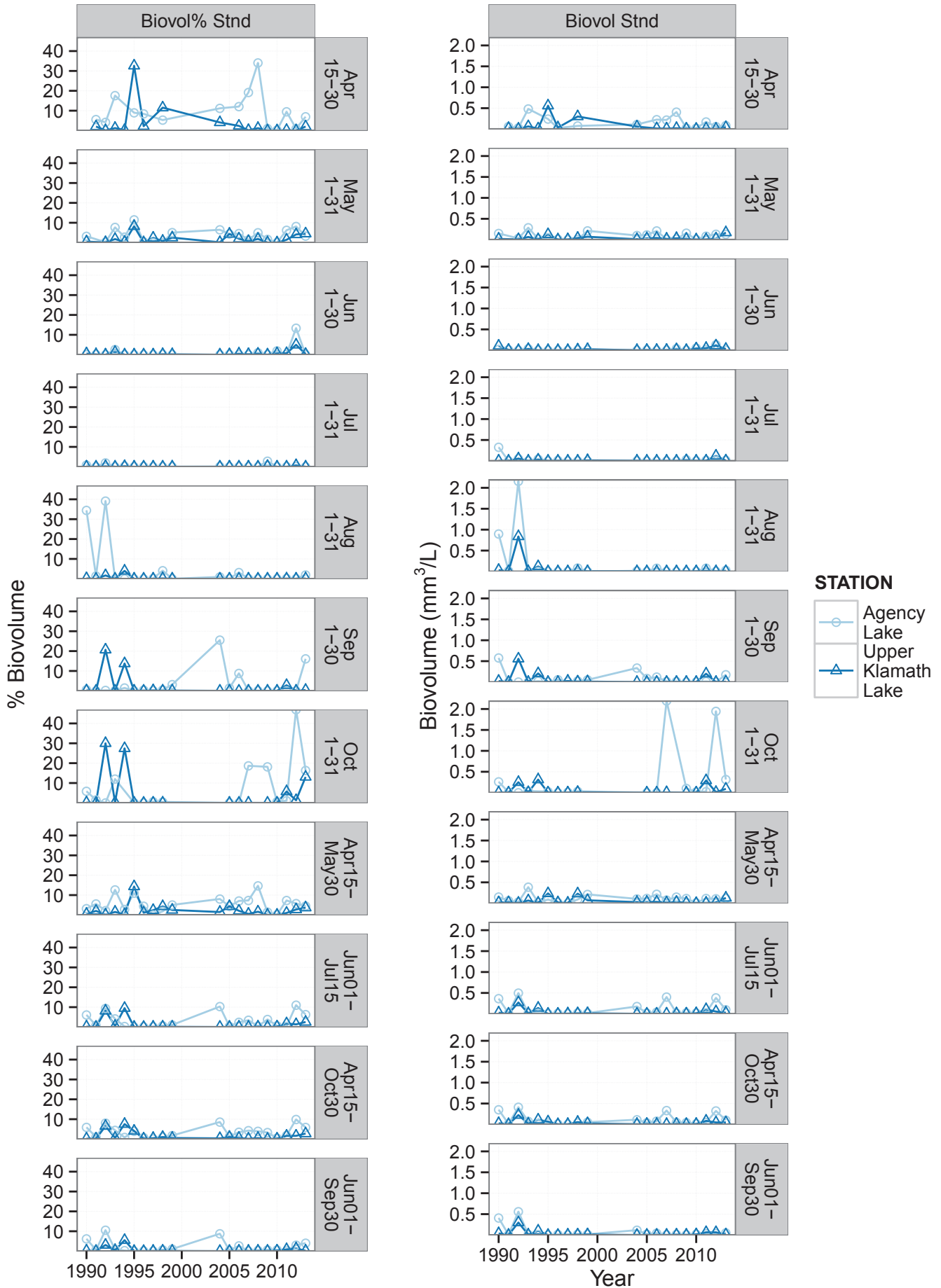
Average by Seasonal Periods and Year: Nitzschia sp



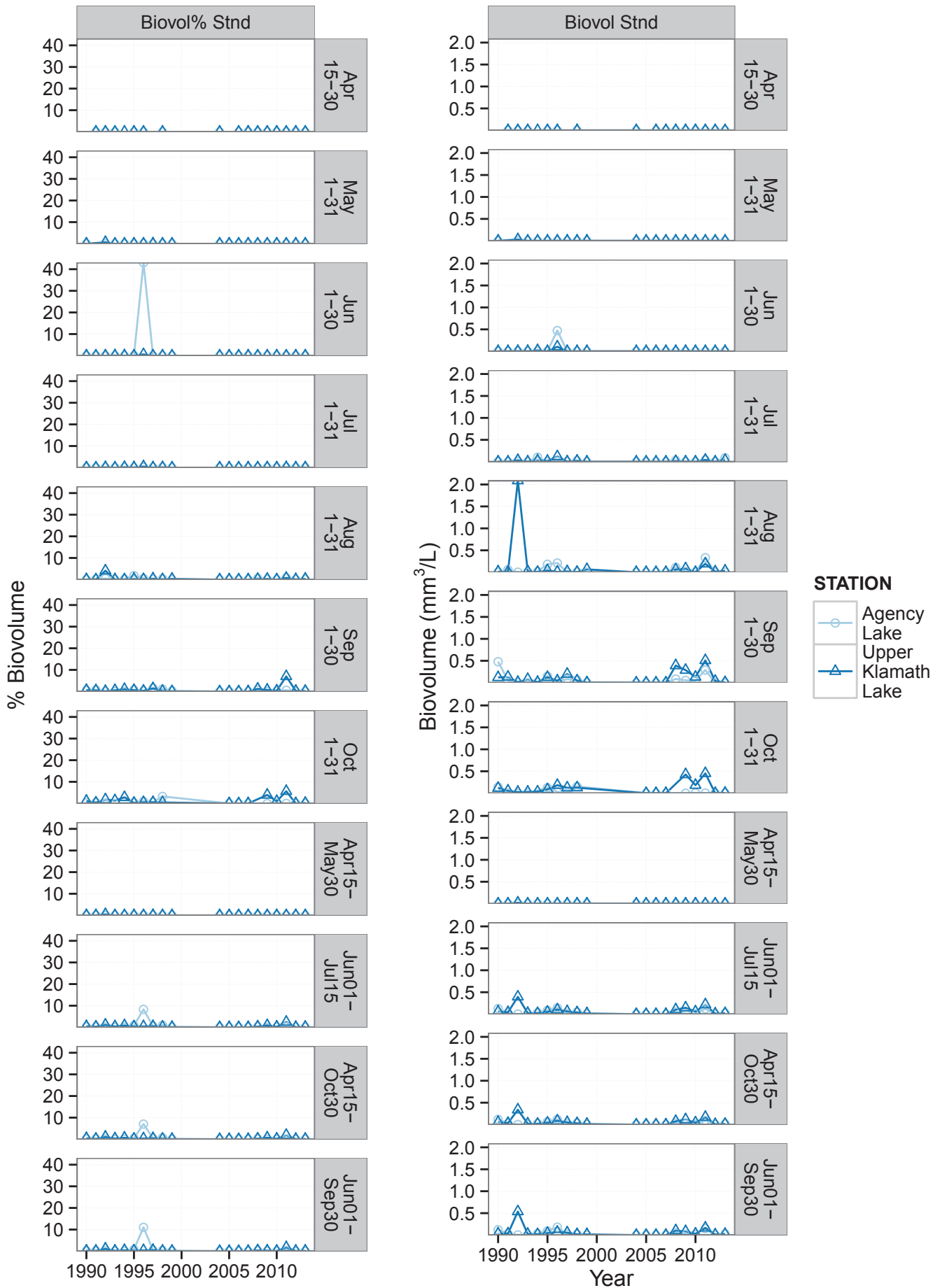
Average by Seasonal Periods and Year: Oscillatoria sp



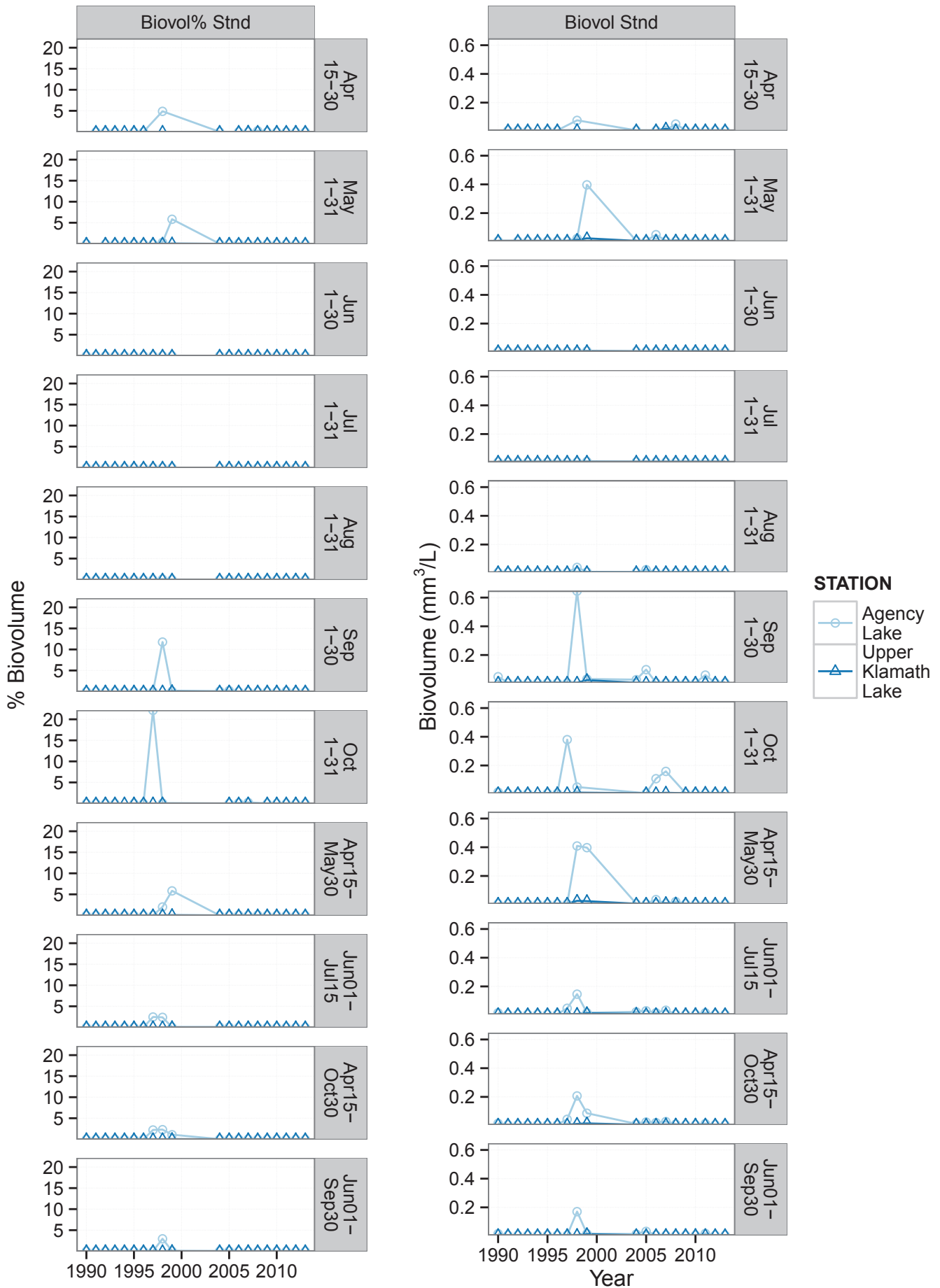
Average by Seasonal Periods and Year: Other



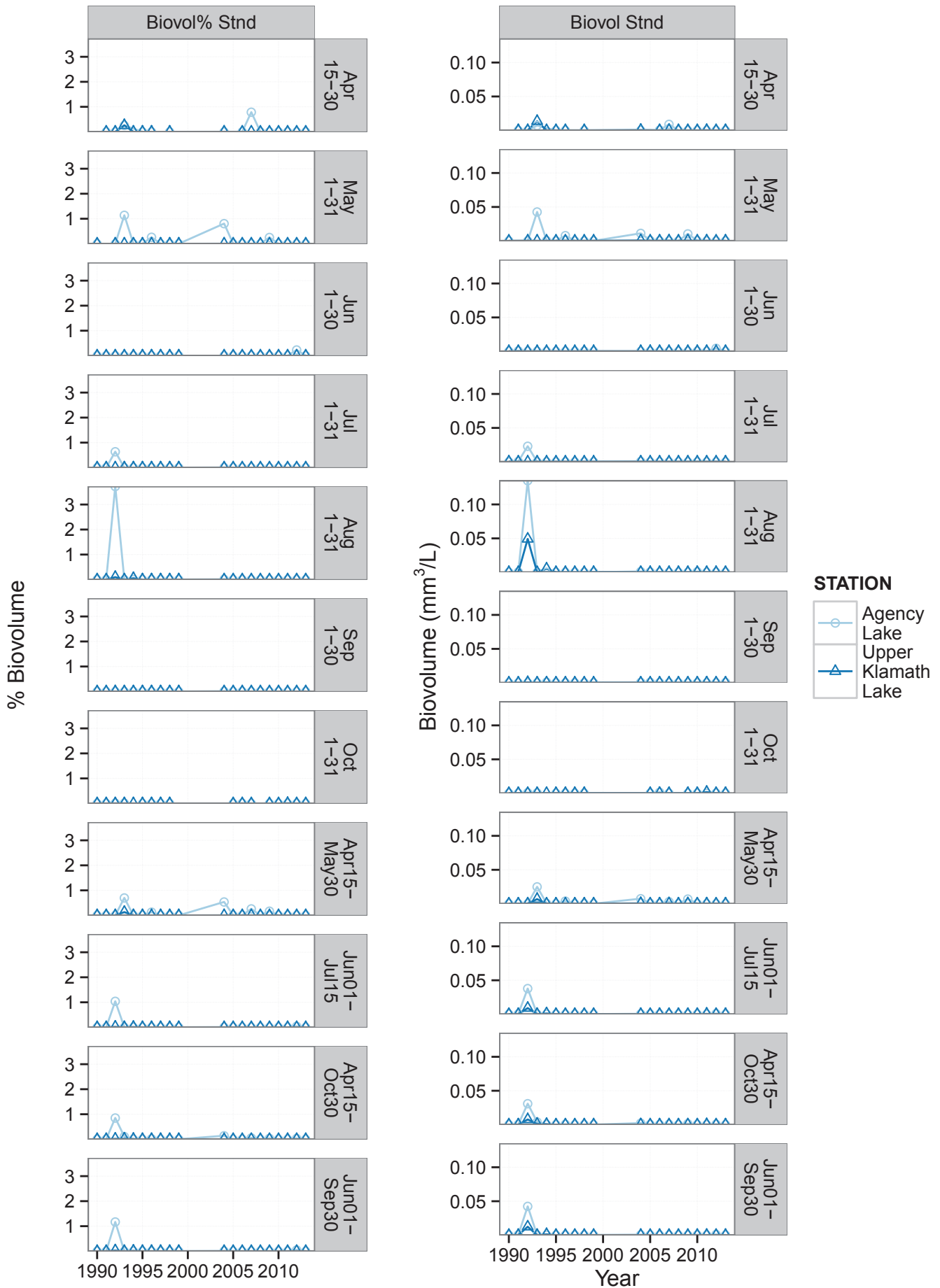
Average by Seasonal Periods and Year: Pseudanabaena sp



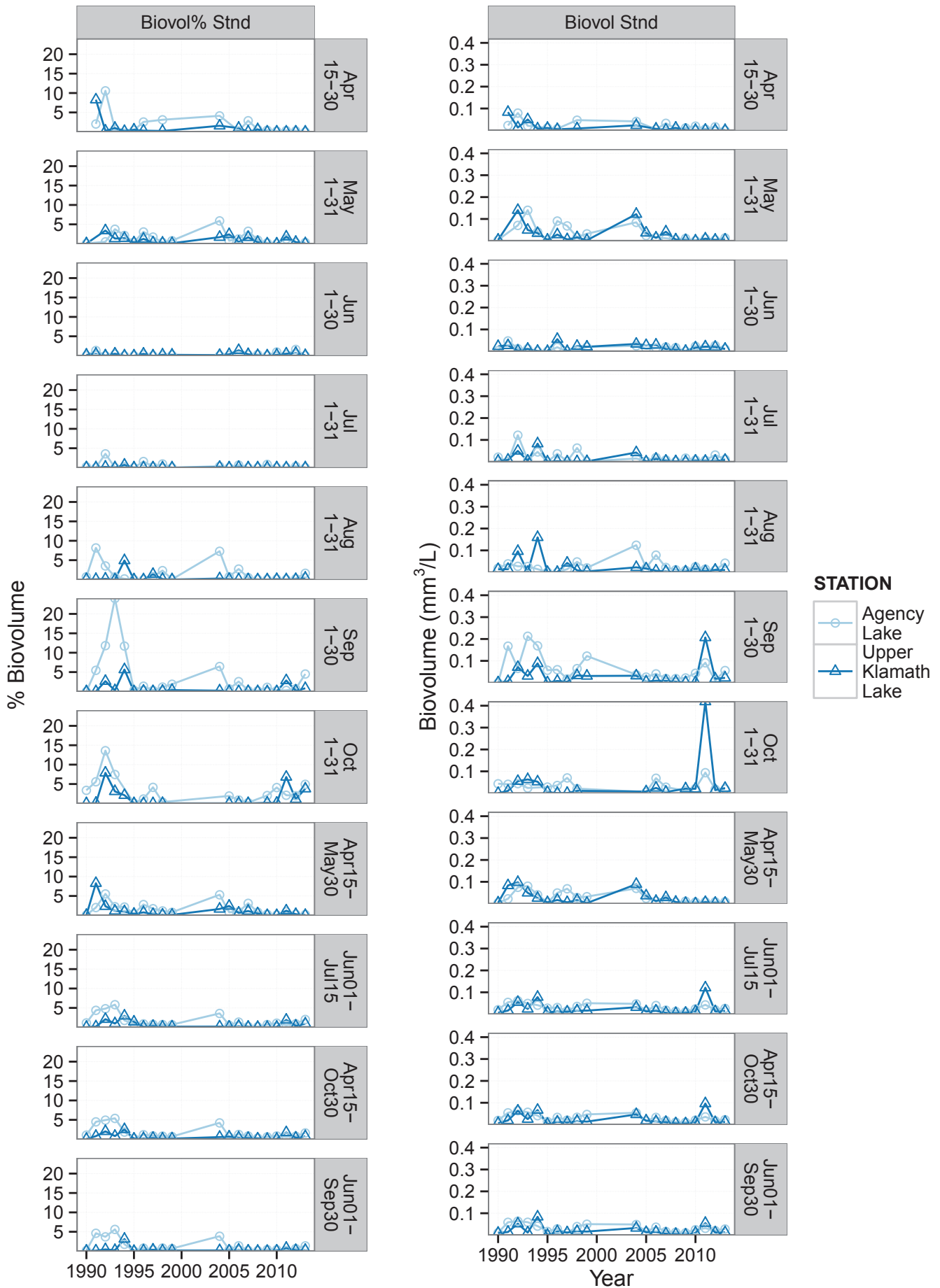
Average by Seasonal Periods and Year: Pinnularia sp



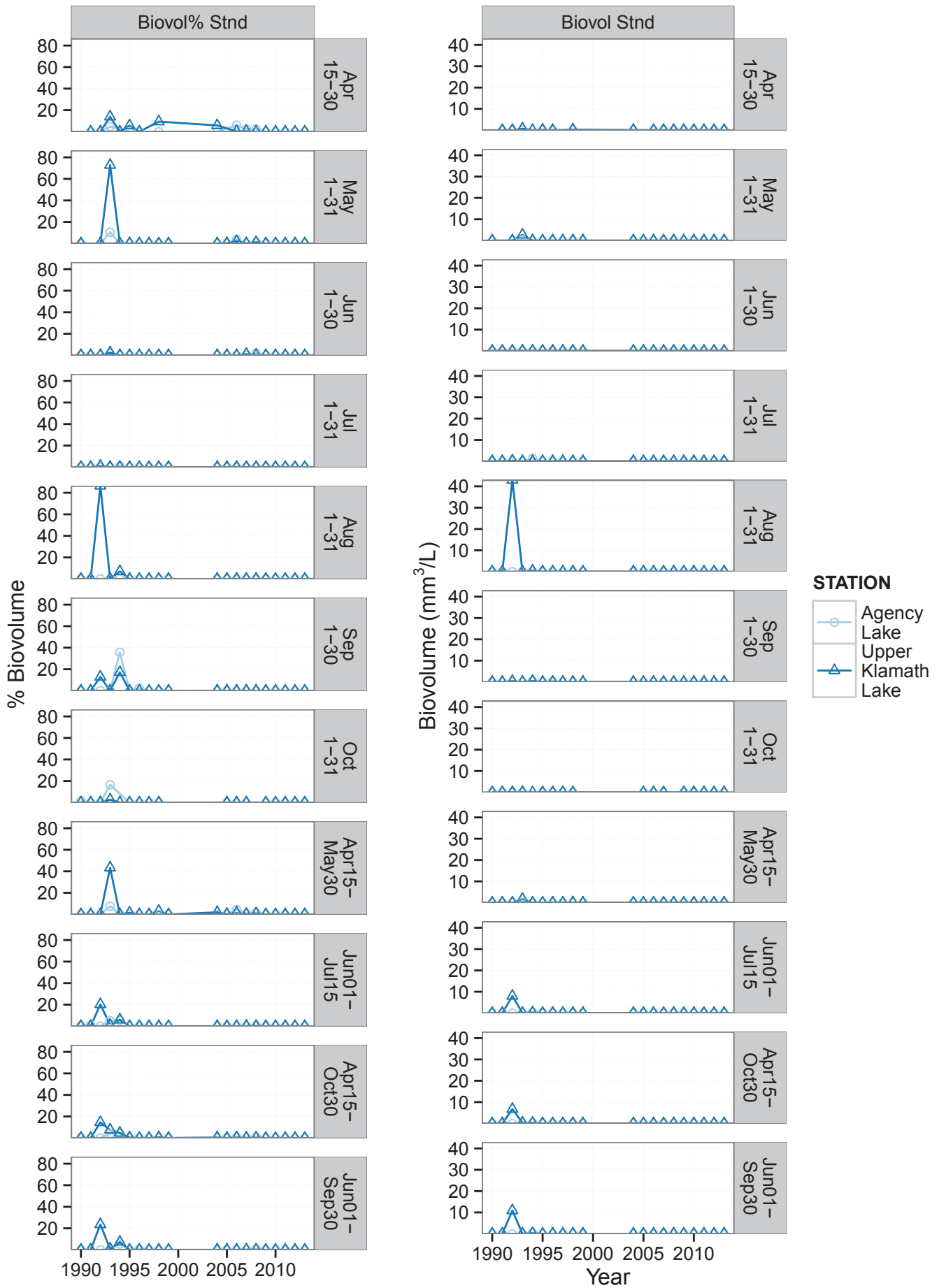
Average by Seasonal Periods and Year: PYRRHOPHYTA



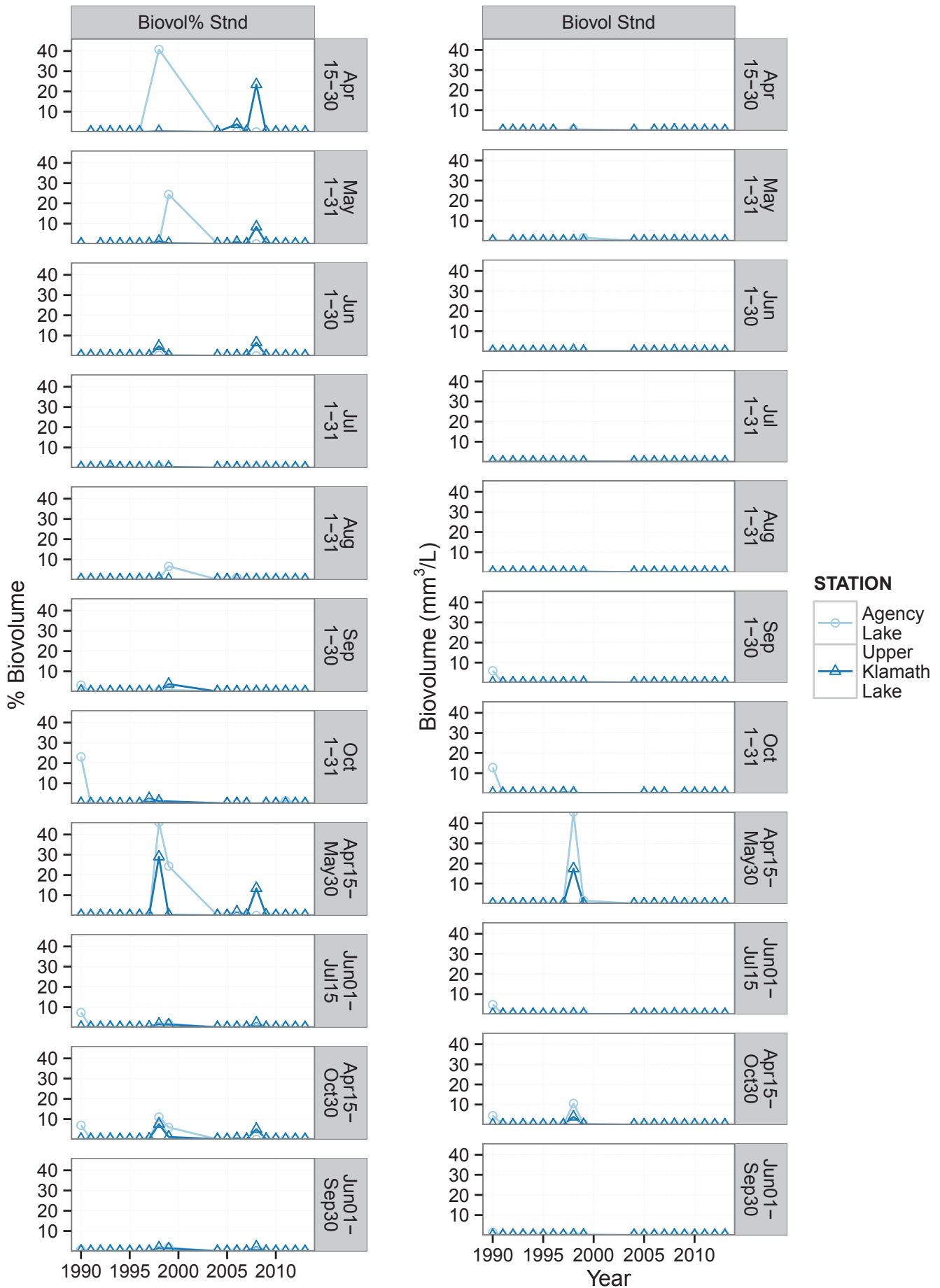
Average by Seasonal Periods and Year: *Rhodomonas minuta*



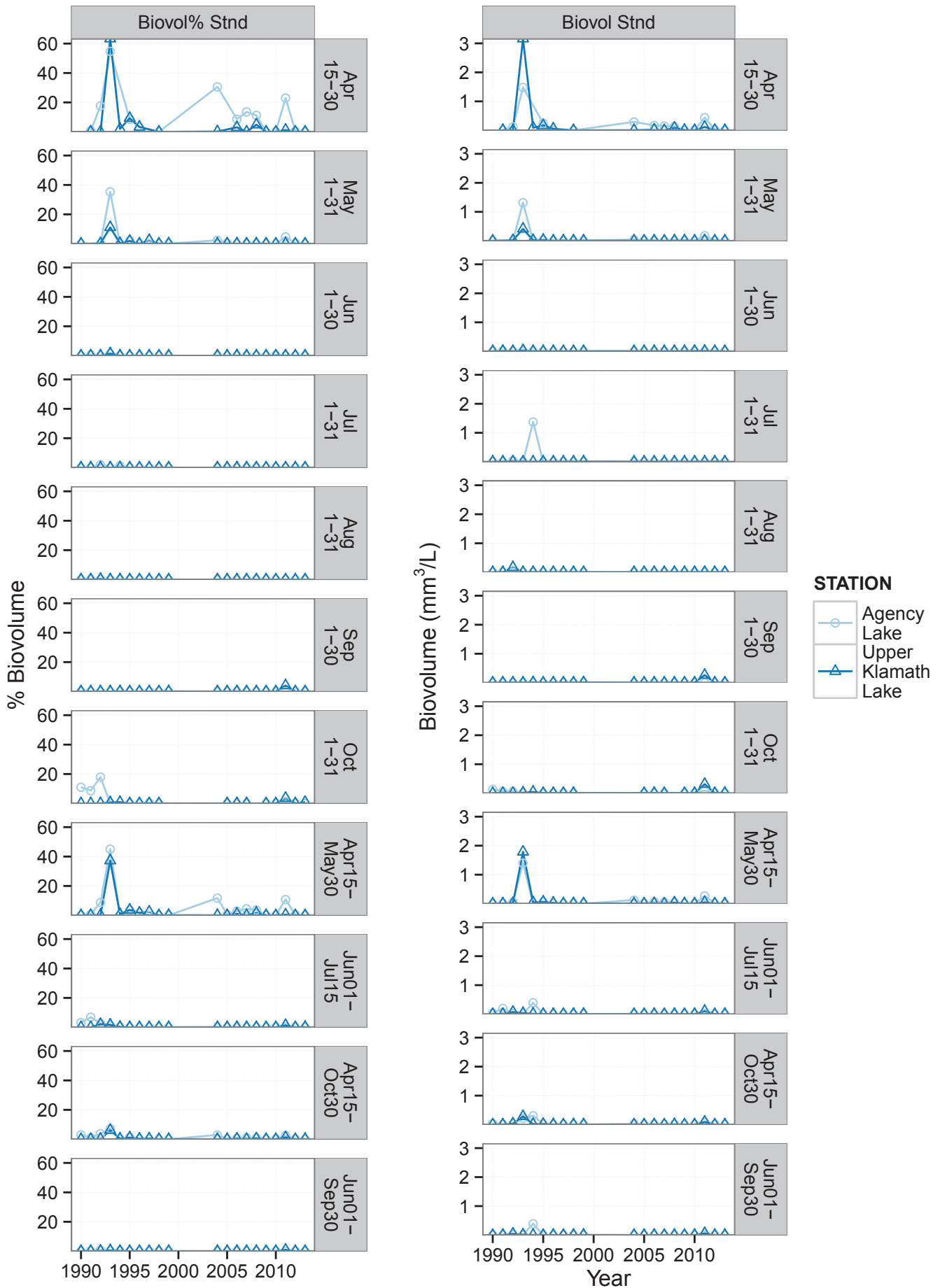
Average by Seasonal Periods and Year: *Synedra* sp



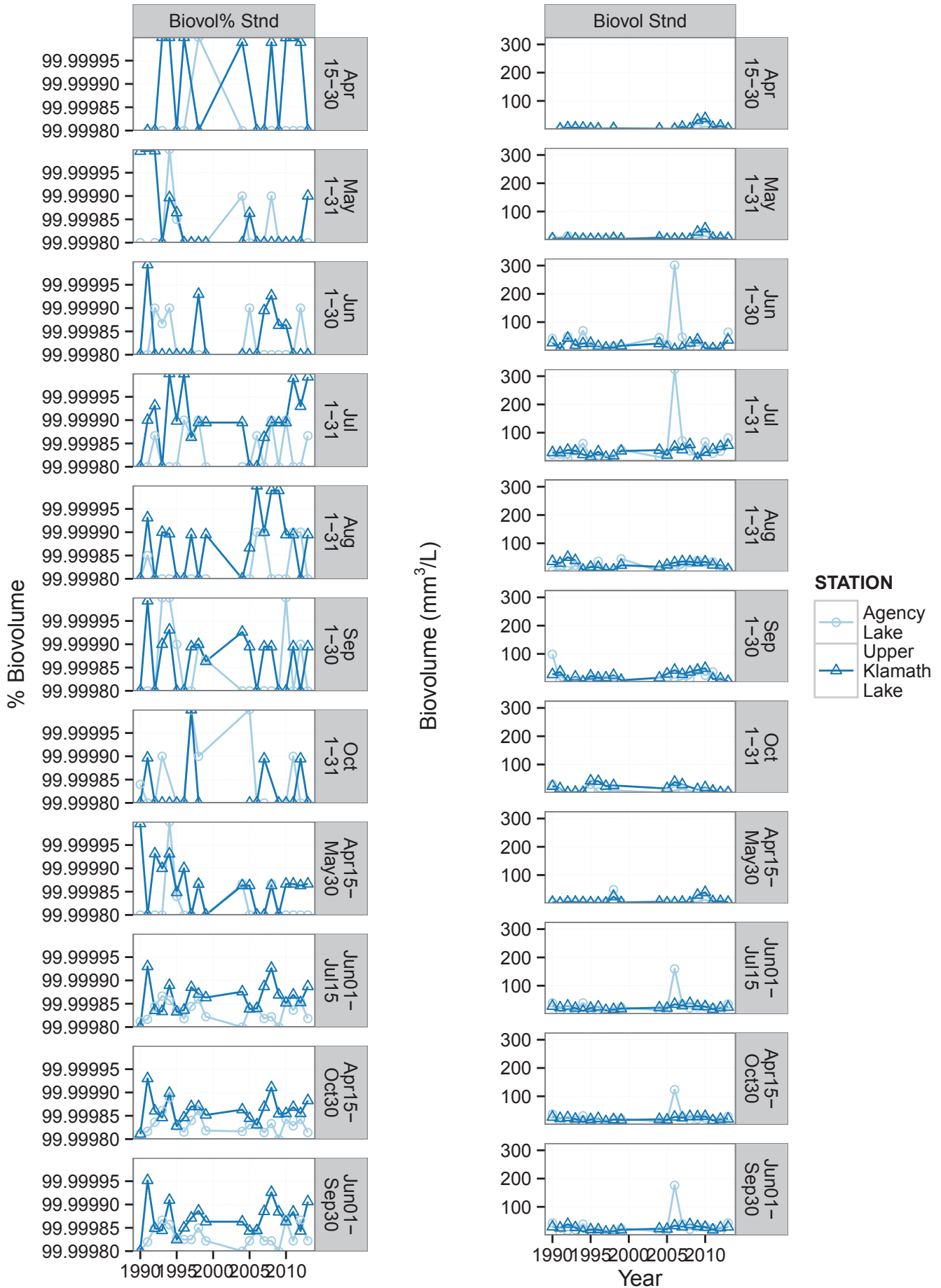
Average by Seasonal Periods and Year: *Stephanodiscus niagarae*



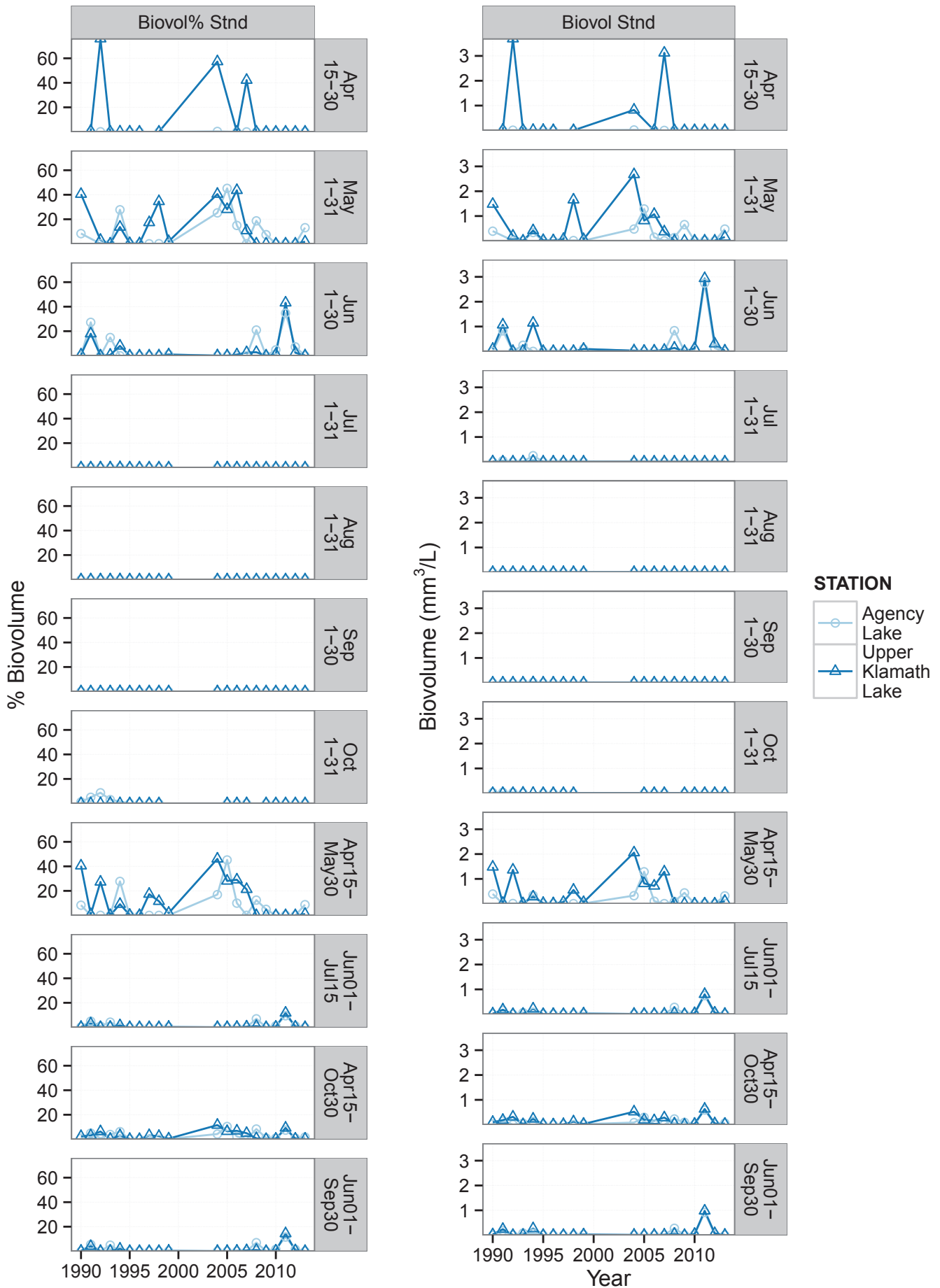
Average by Seasonal Periods and Year: *Stephanodiscus* sp



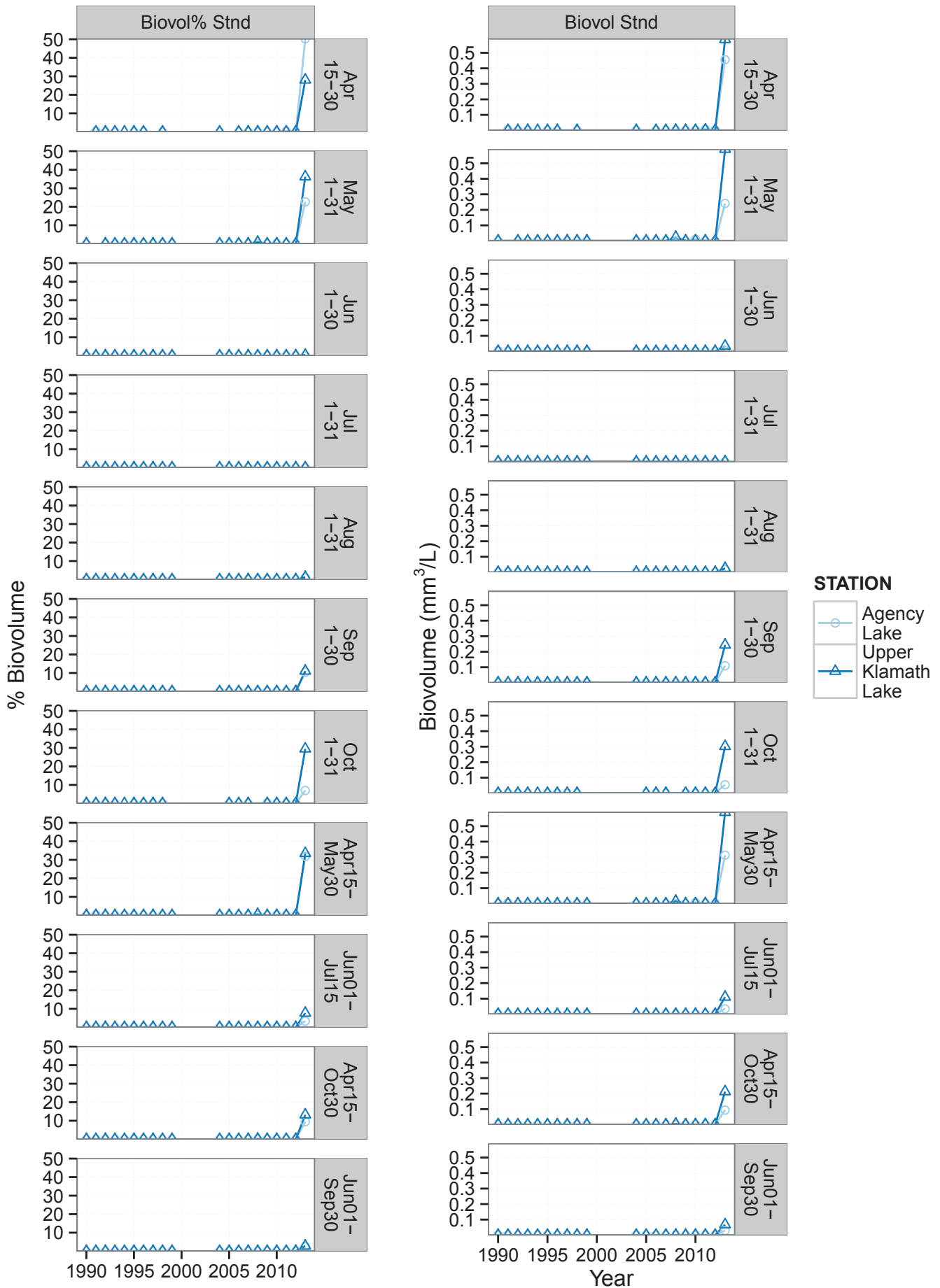
Average by Seasonal Periods and Year: Total Zooplankton



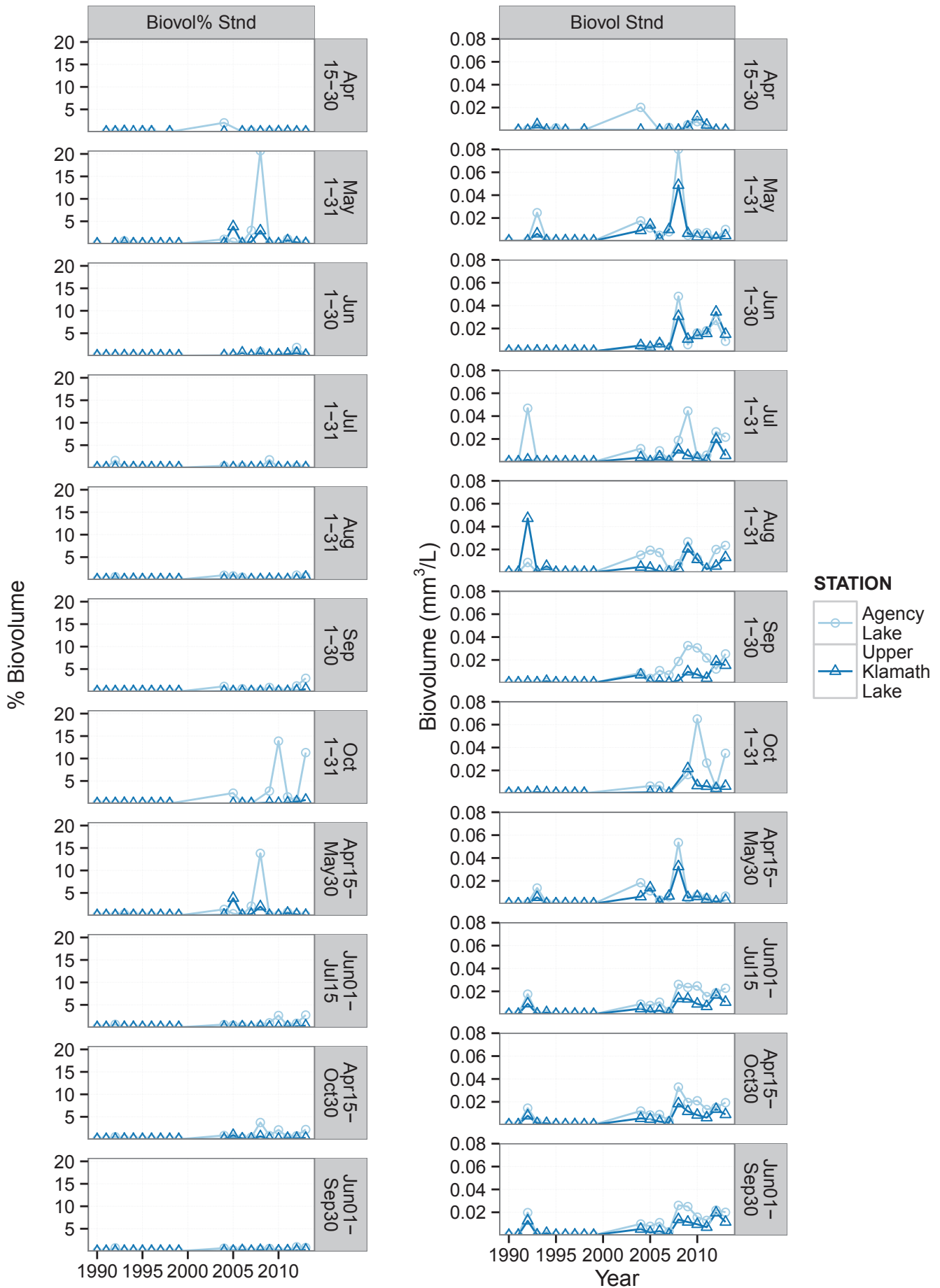
Average by Seasonal Periods and Year: Tribonema sp



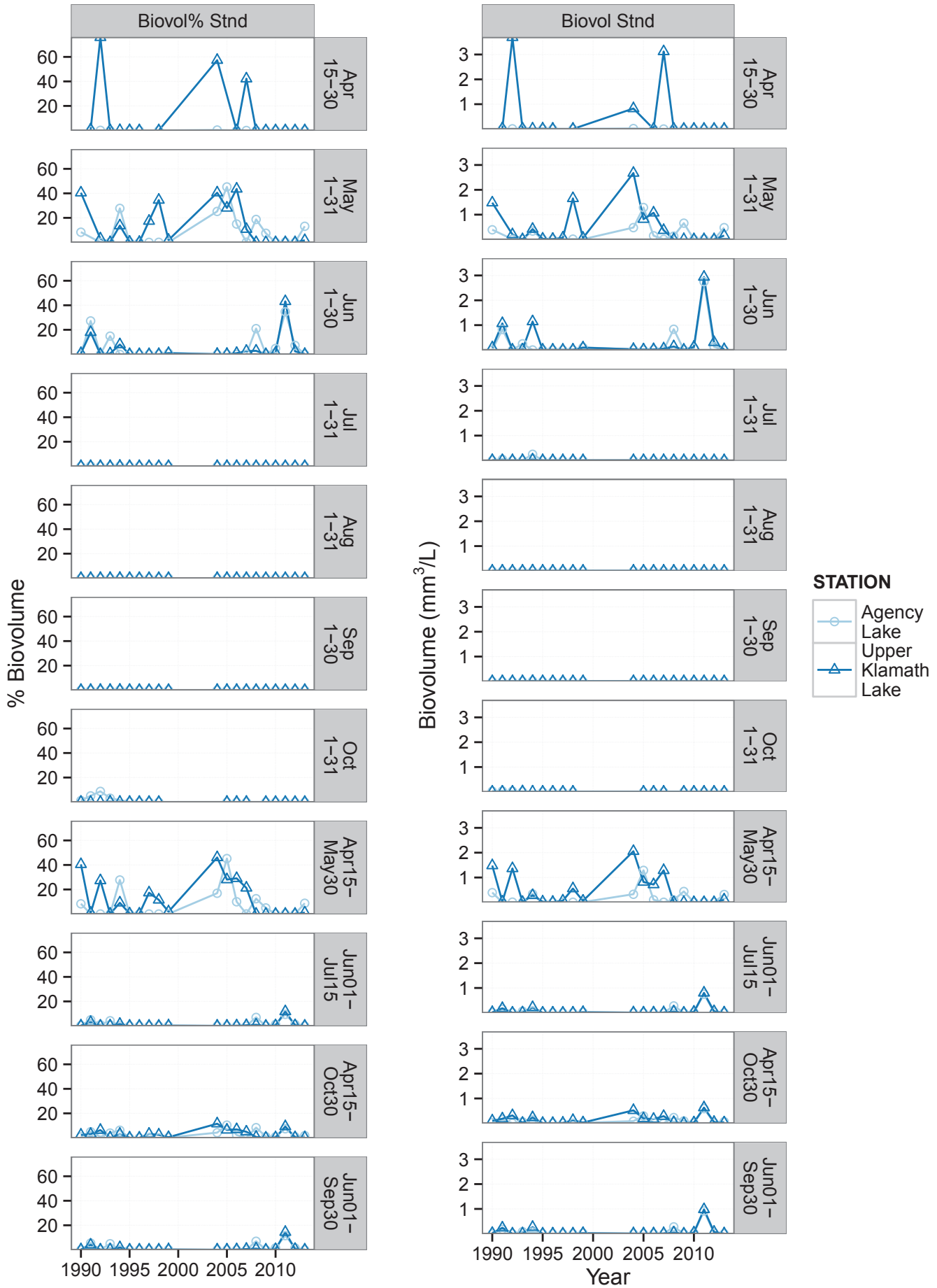
Average by Seasonal Periods and Year: Trebouxiophyceae sp



Average by Seasonal Periods and Year: Misc. Microflagellate

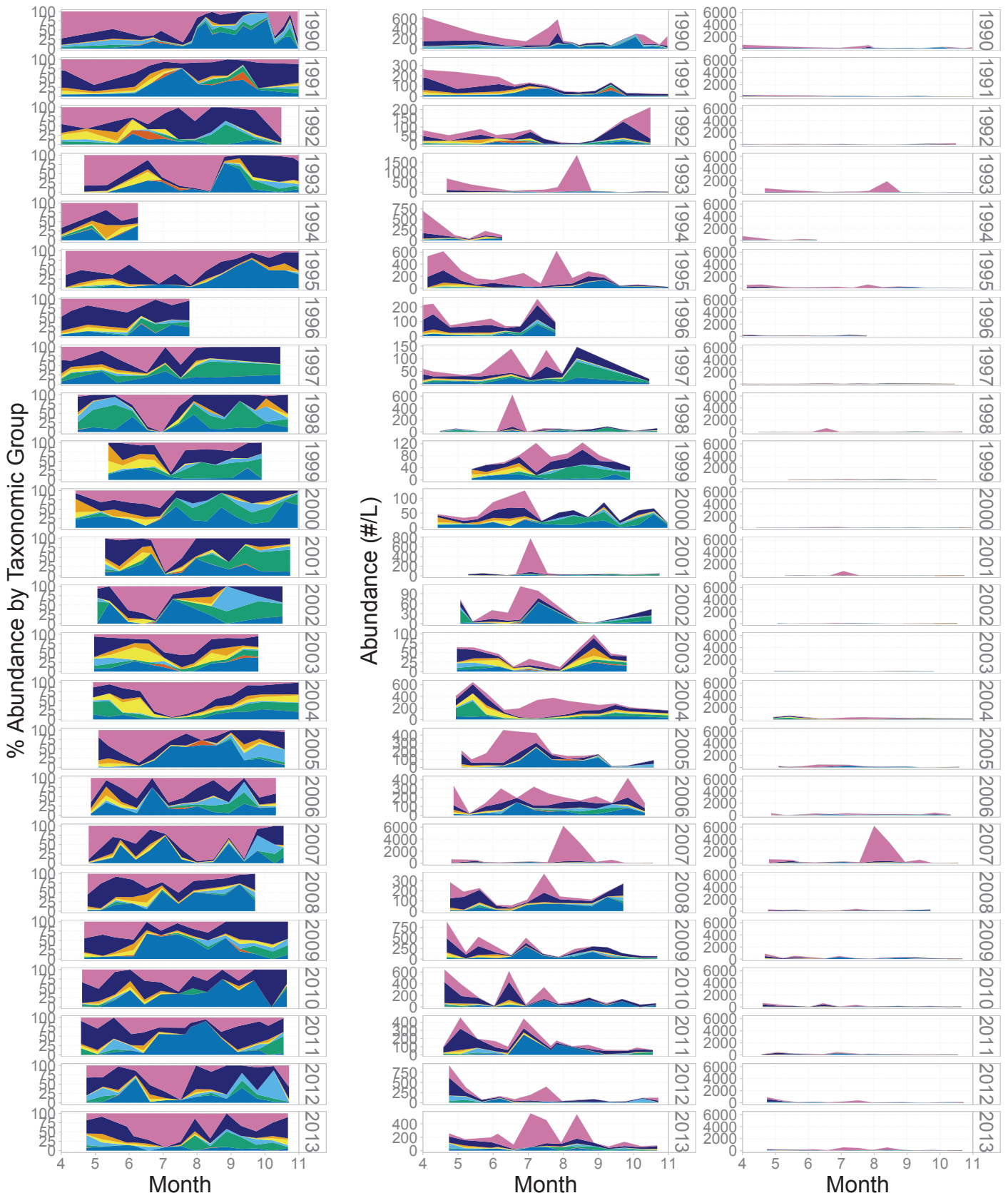


Average by Seasonal Periods and Year: XANTHOPHYTA



**APPENDIX G: DETAILED TIME SERIES CHARTS OF ABUNDANCE FOR ZOOPLANKTON
TAXONOMIC GROUPS FOR EACH SITE**

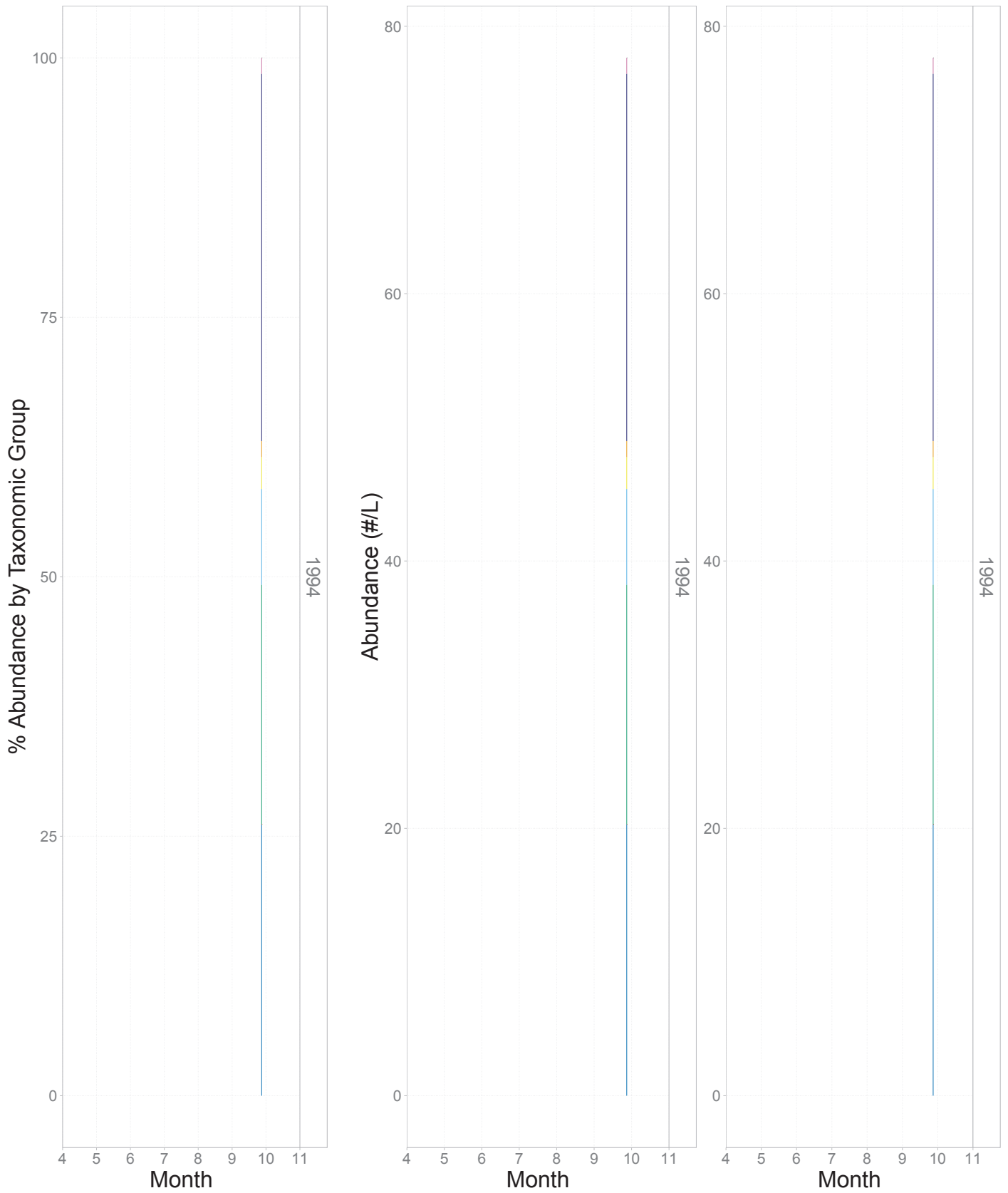
Phyto Taxonomic Groups and Chlorophyll-a: AS (UKL @ Agency Lake South), April–October



Taxonomic Group

- Ostracoda
- Rotifera
- Copepoda Nauplii
- Cyclopoid Copepods Copepodids
- Cyclopoid Copepods Adult
- Calanoid Copepods
- Cladocera Adult
- Cladocera Immature
- Calanoid Copepods Adult

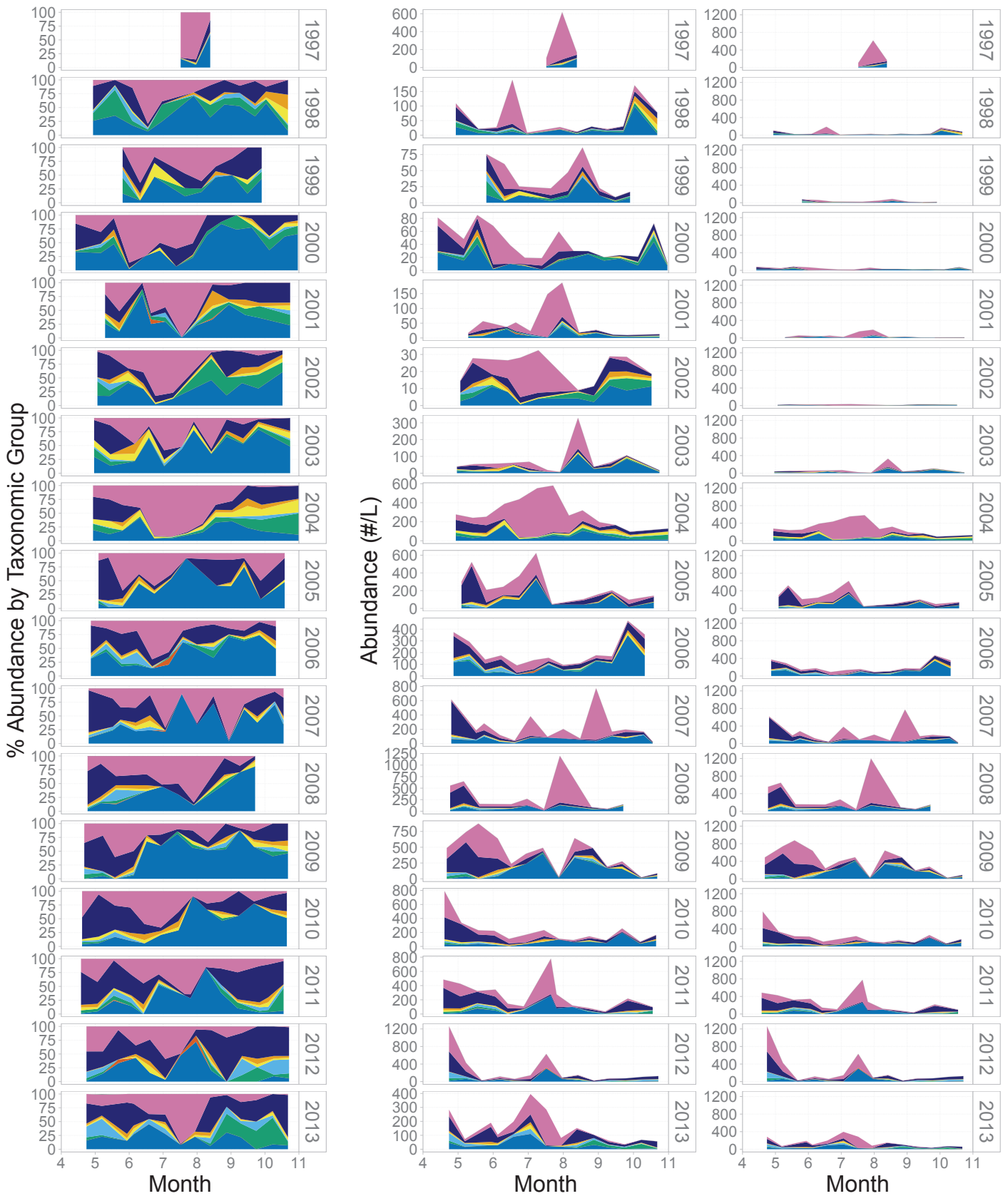
Phyto Taxonomic Groups & Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), Apr.-Oct.



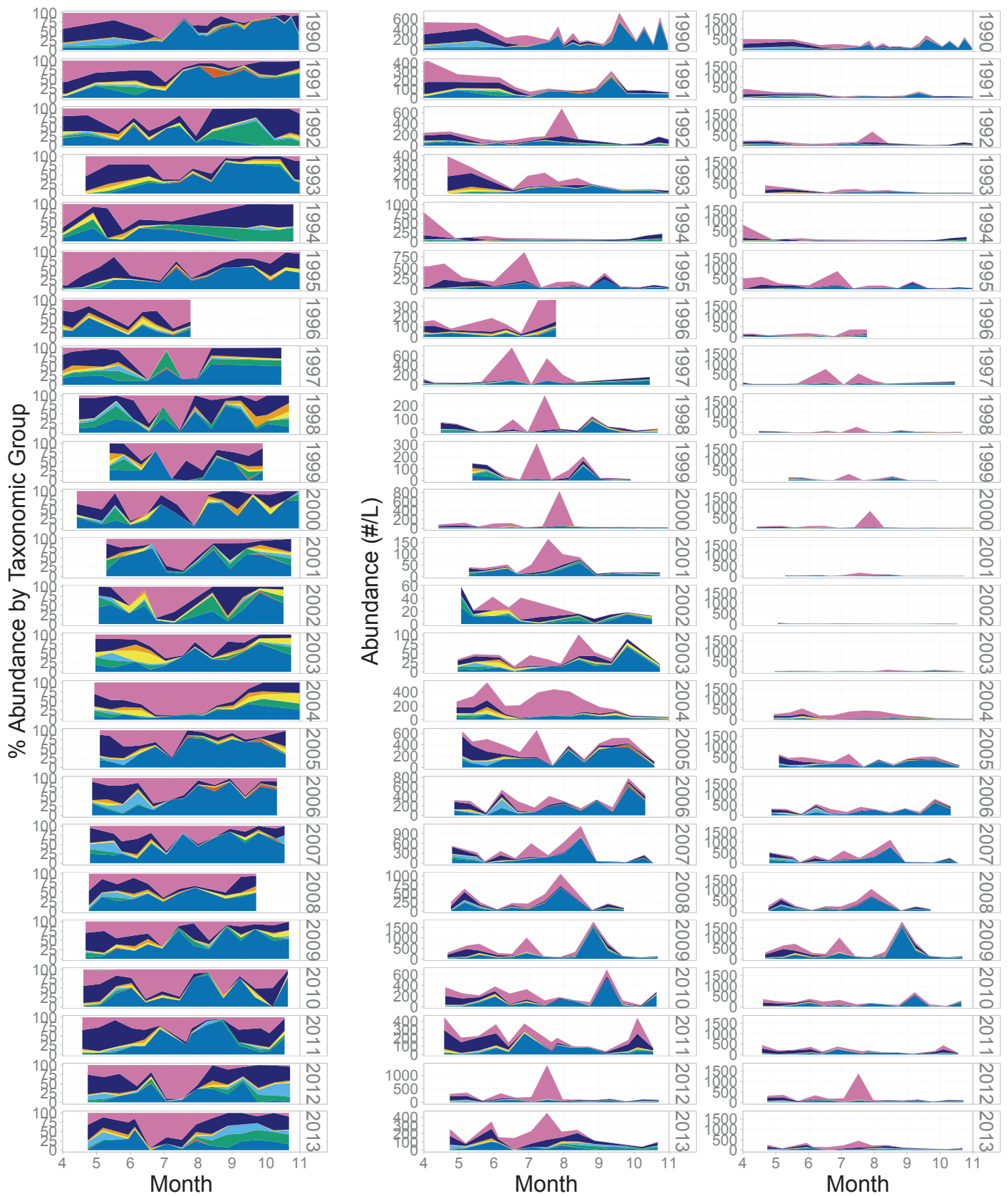
Taxonomic Group

- Ostracoda
- Copepoda Nauplii
- Cyclopoid Copepods Adult
- Calanoid Copepods Adult
- Cladocera Adult
- Rotifera
- Cyclopoid Copepods Copepodids
- Calanoid Copepods Copepodids
- Cladocera Immature

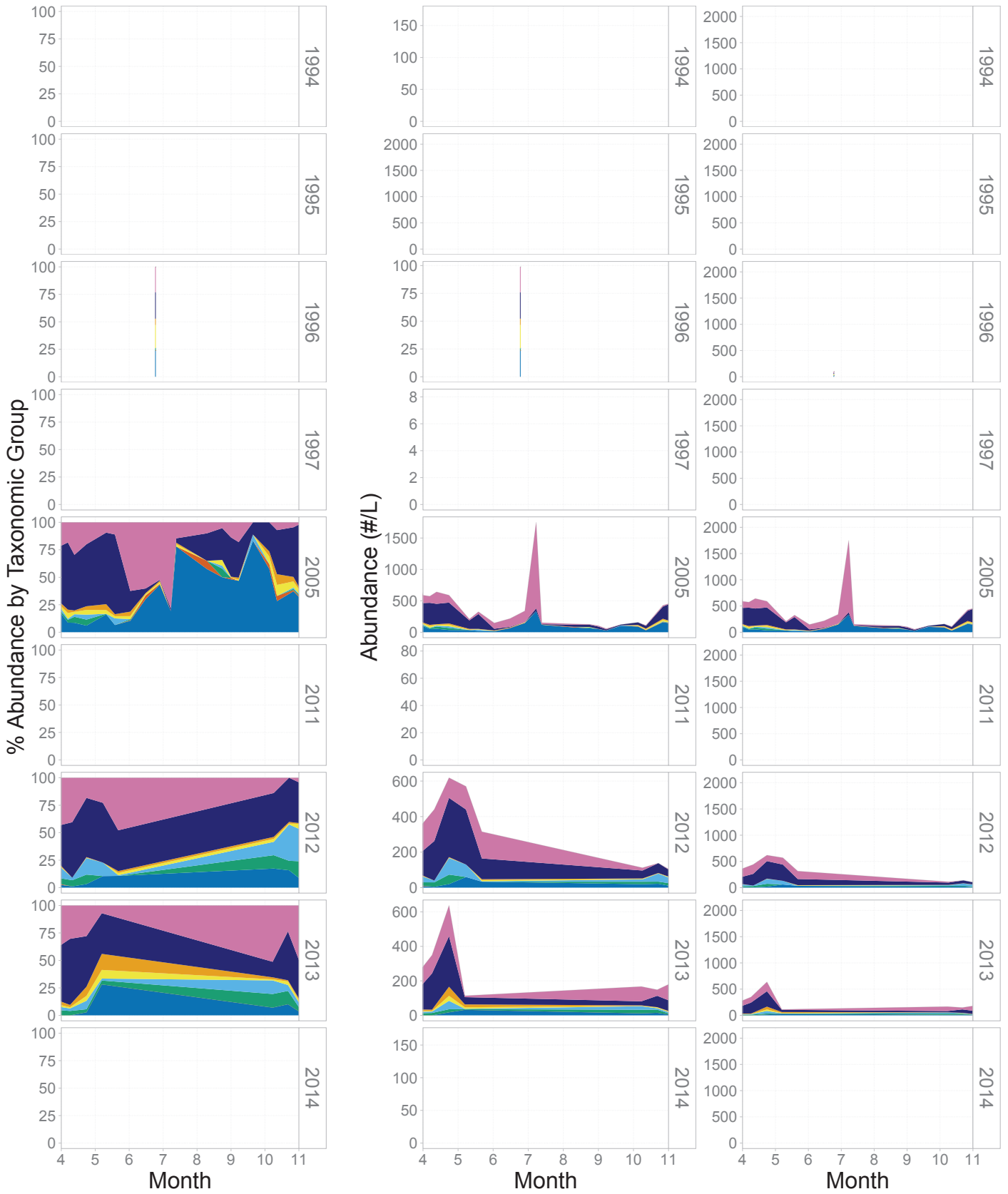
Phyto Taxonomic Groups and Chlorophyll-a: CP (UKL @ Coon Point), April–October



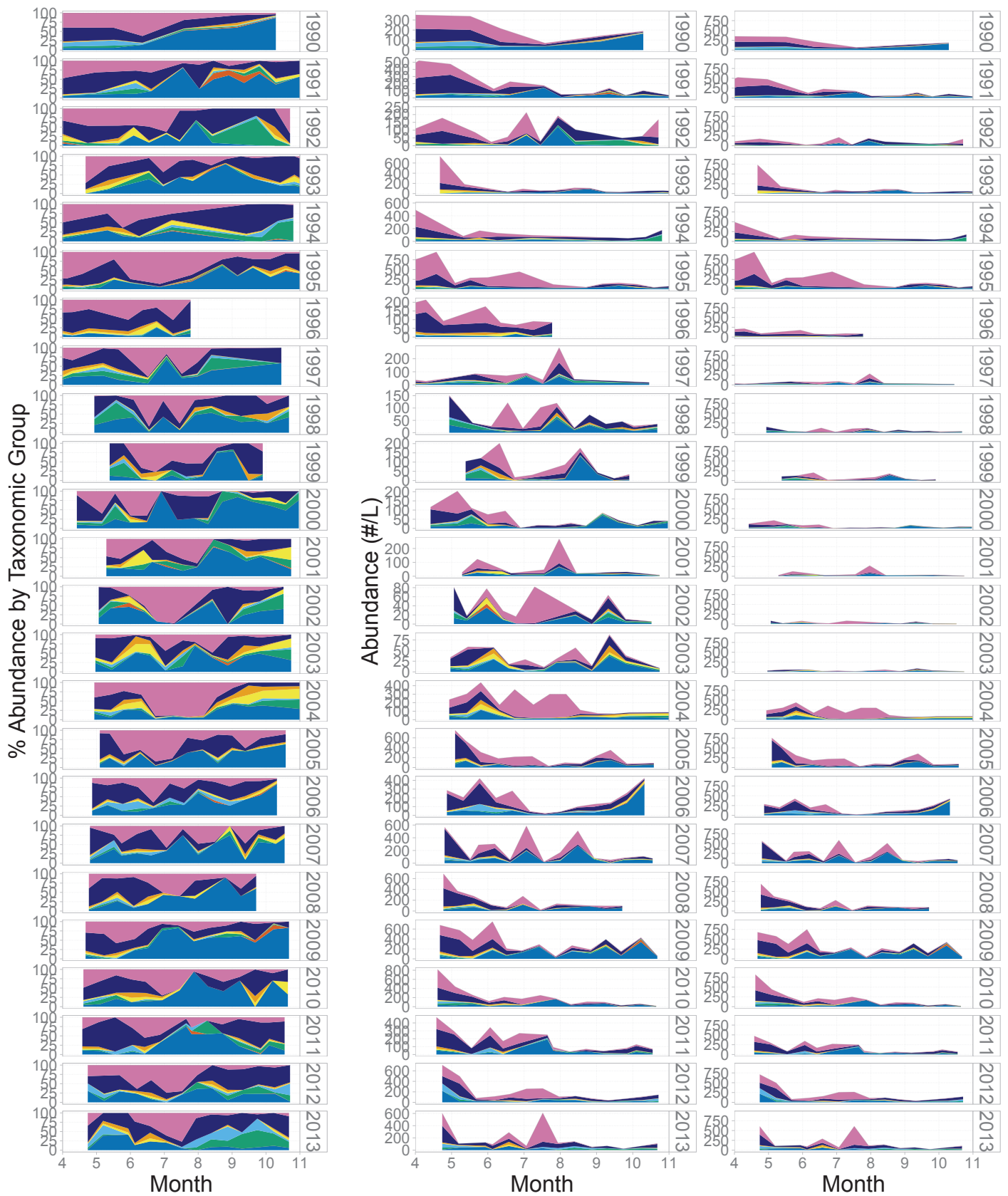
Phyto Taxonomic Groups and Chlorophyll-a: ER (UKL @ Eagle Ridge), April–October



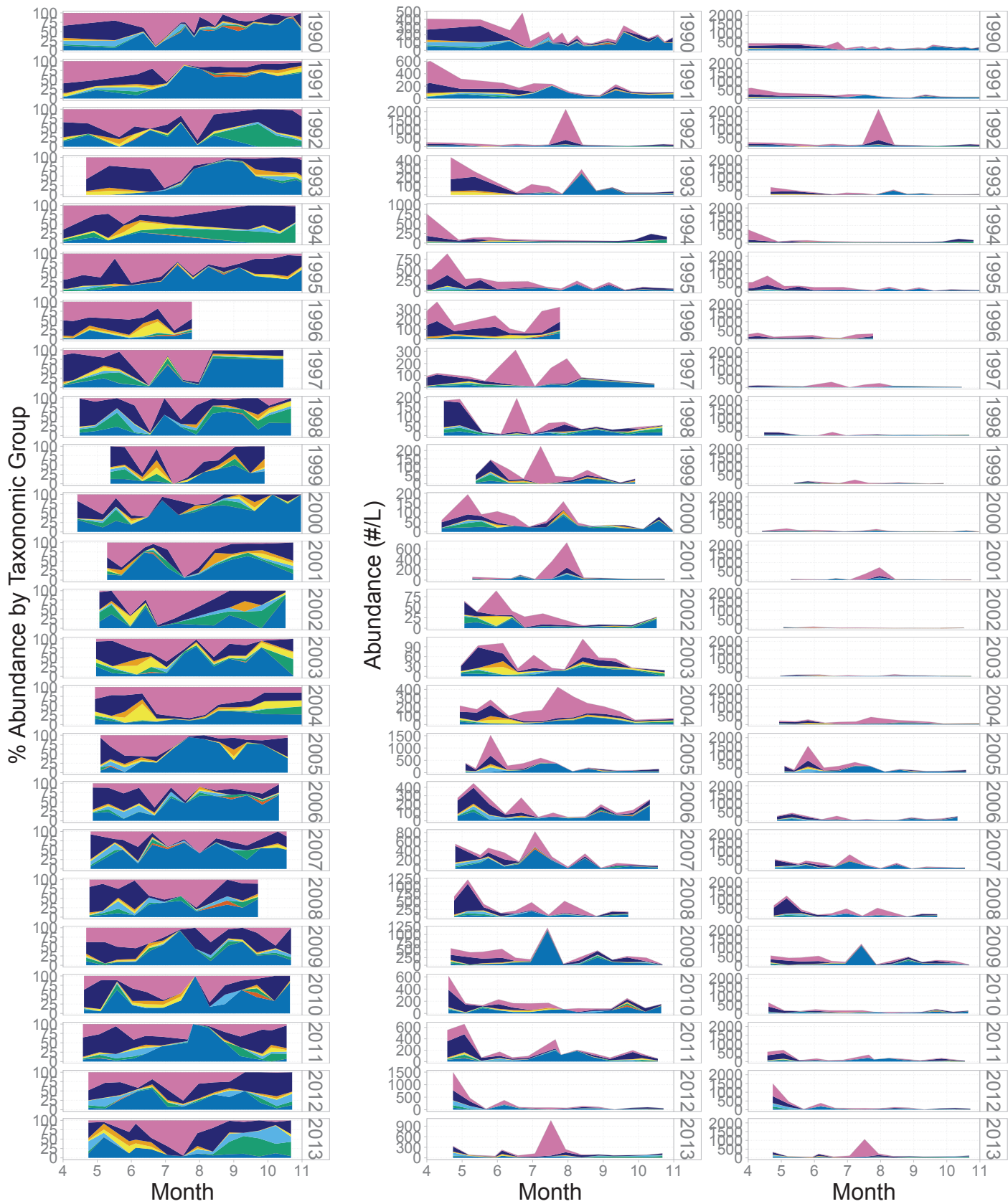
Phyto Taxonomic Groups and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), April-October



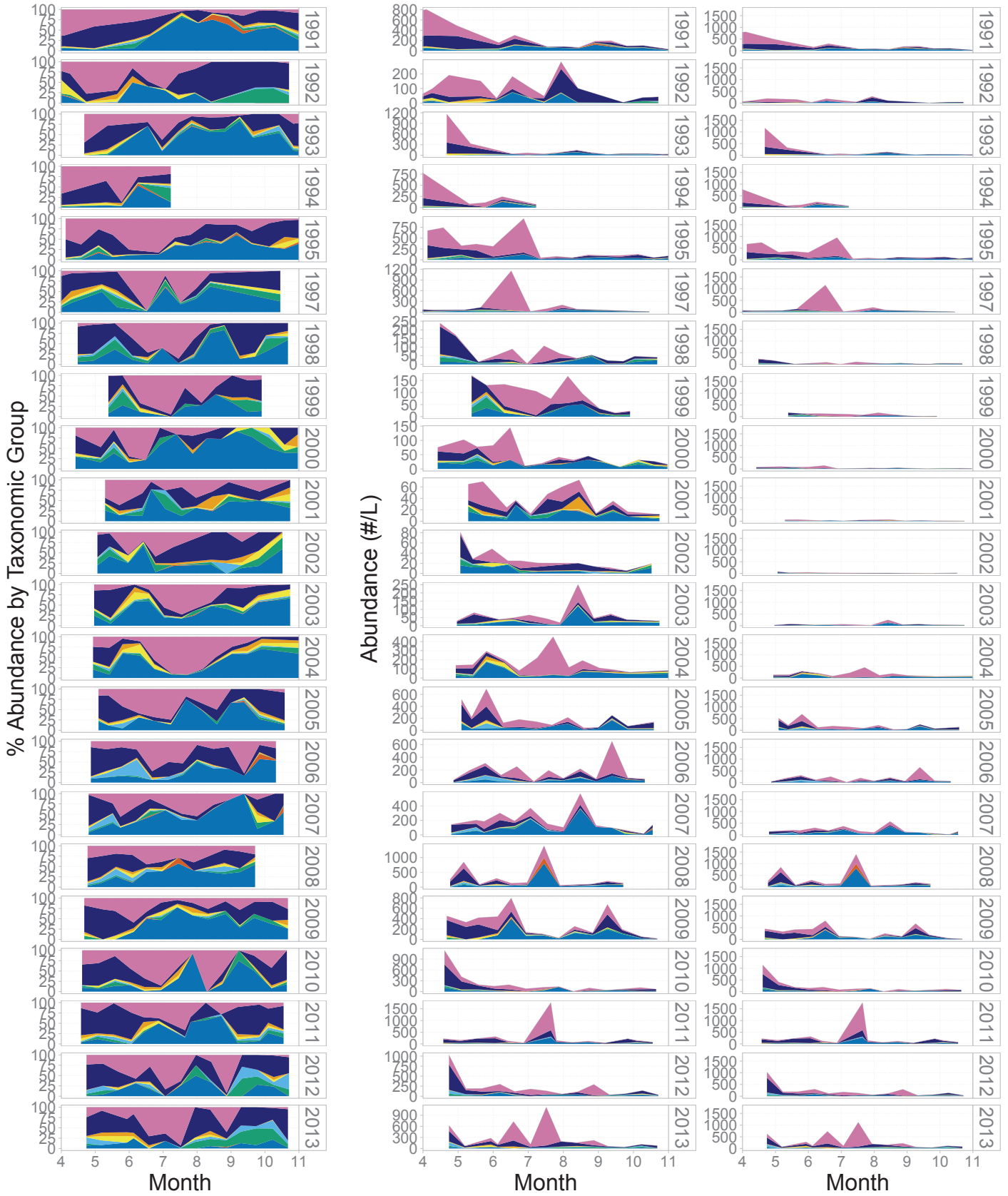
Phyto Taxonomic Groups and Chlorophyll-a: ML (UKL @ Mid-Lake), April-October



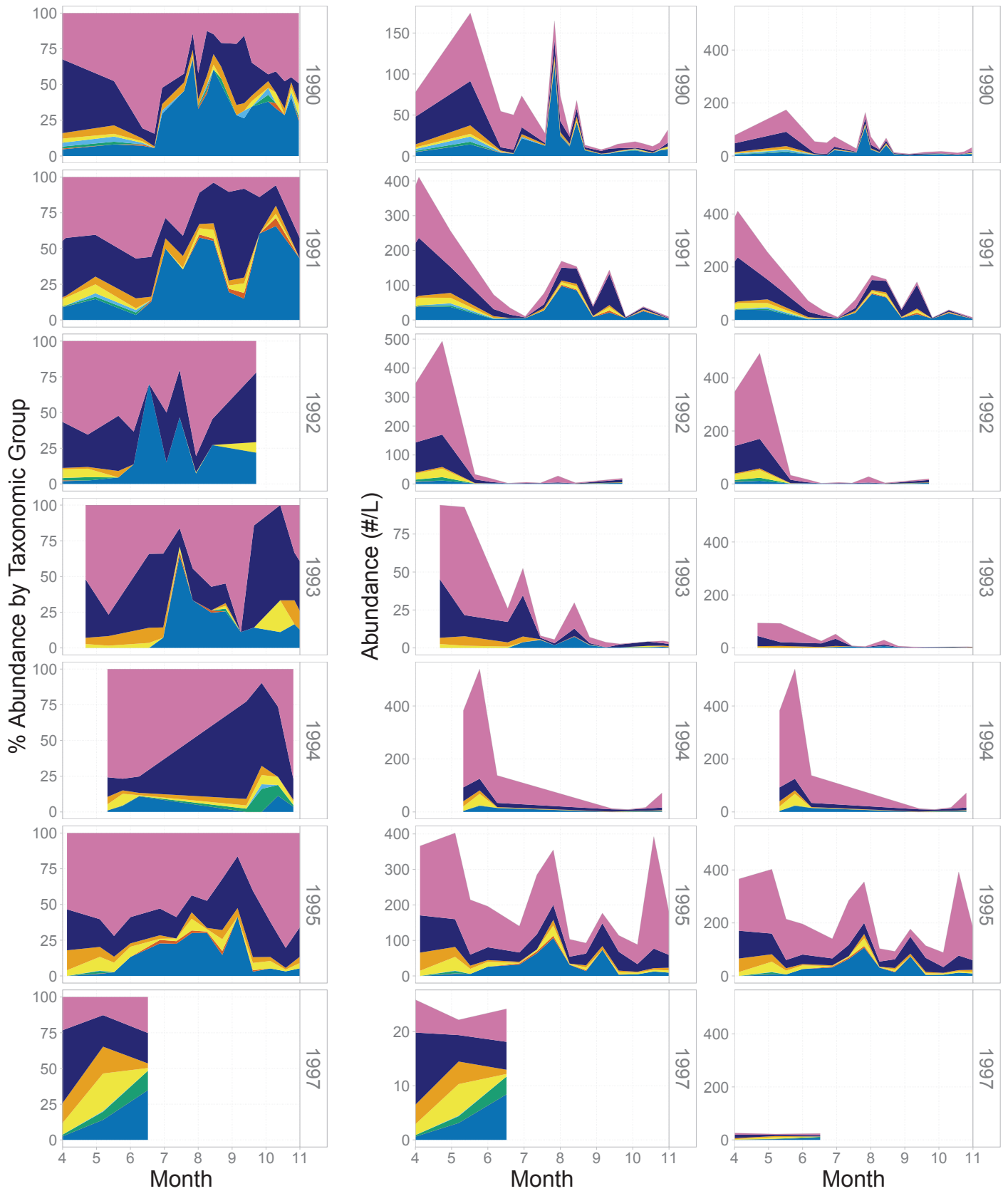
Phyto Taxonomic Groups and Chlorophyll-a: MN (UKL @ Mid-Lake North), April-October



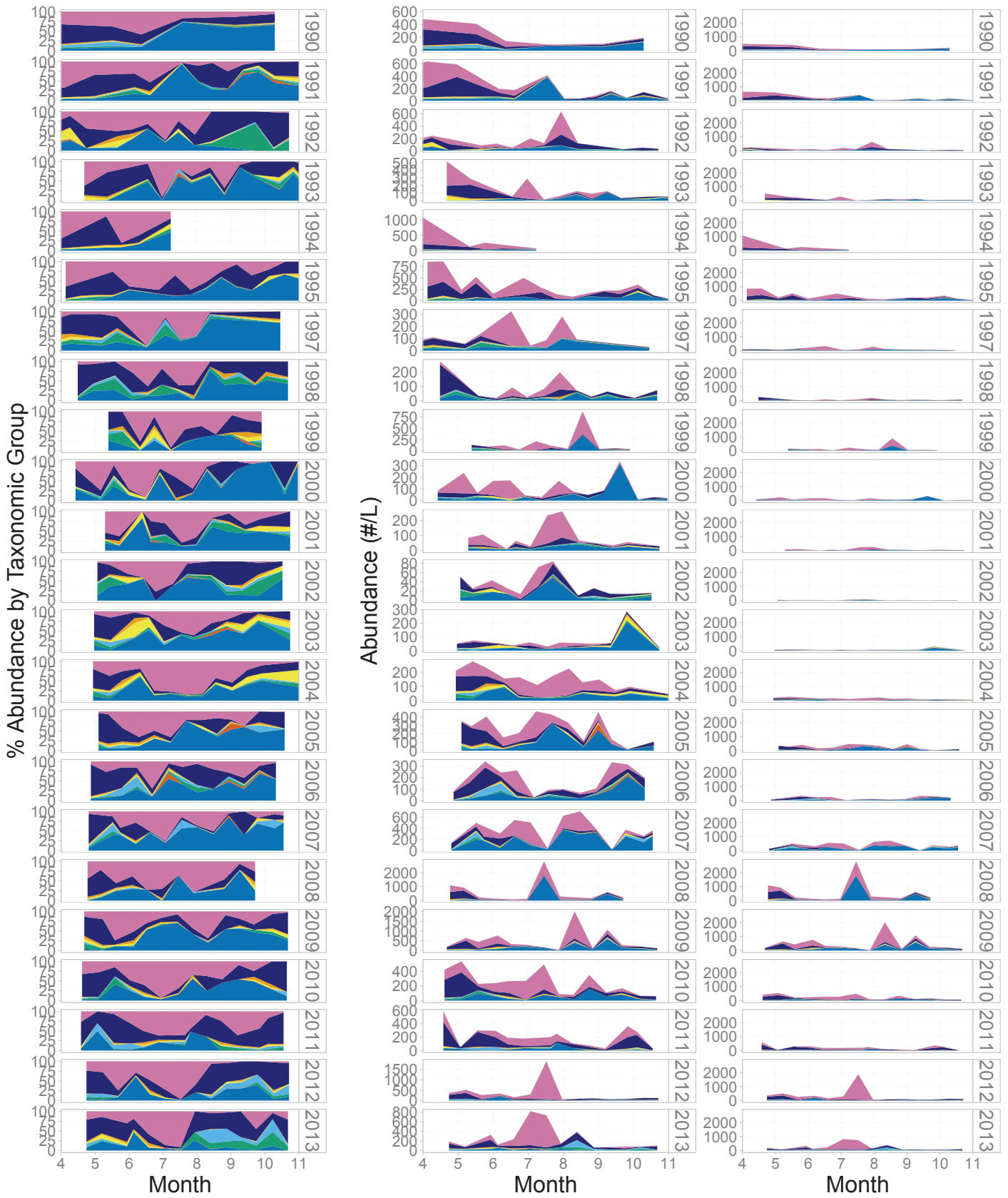
Phyto Taxonomic Groups and Chlorophyll-a: NB (UKL @ North Buck Island), April–October



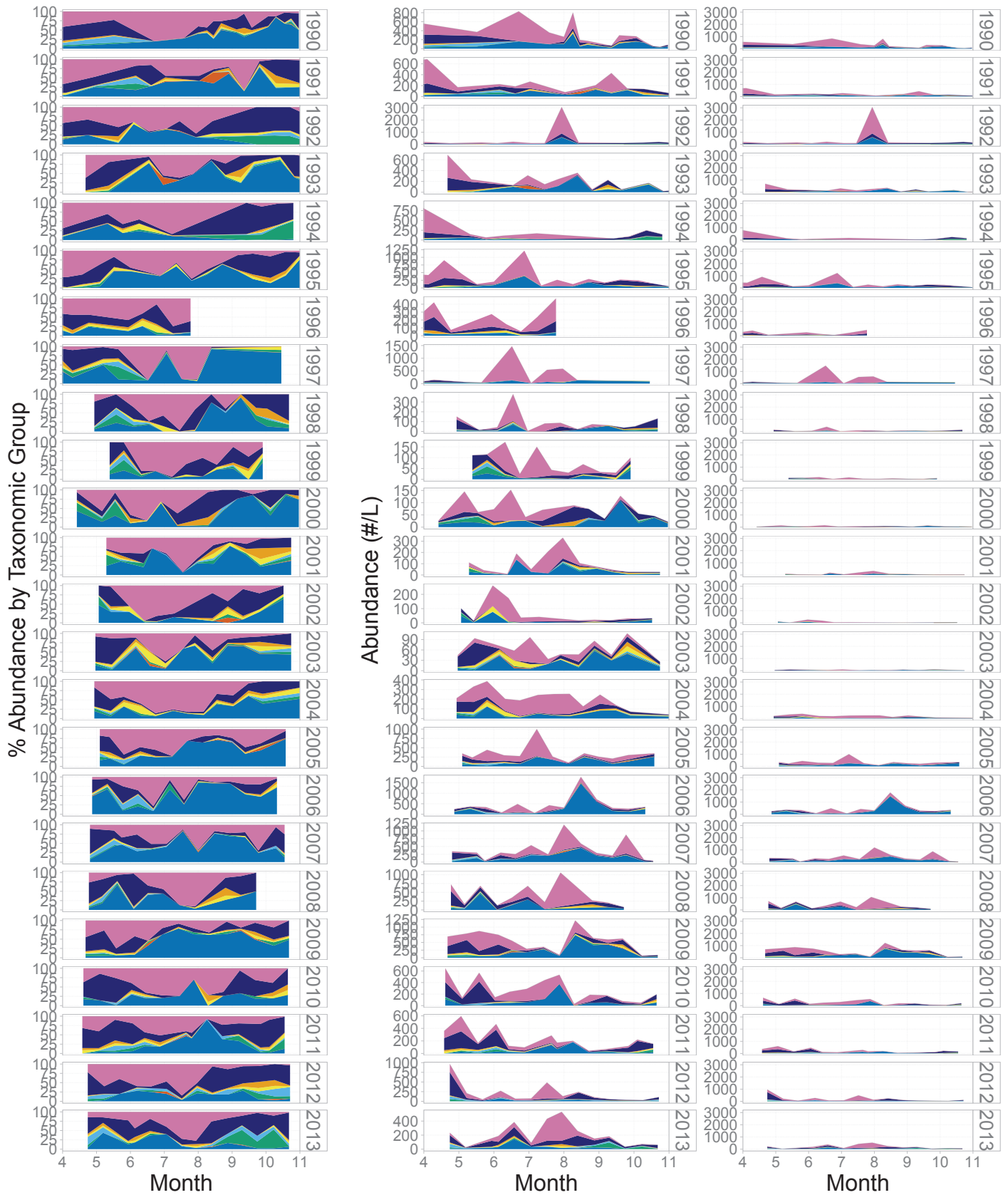
Phyto Taxonomic Groups and Chlorophyll-a: PB (UKL @ Pelican Bay), April–October



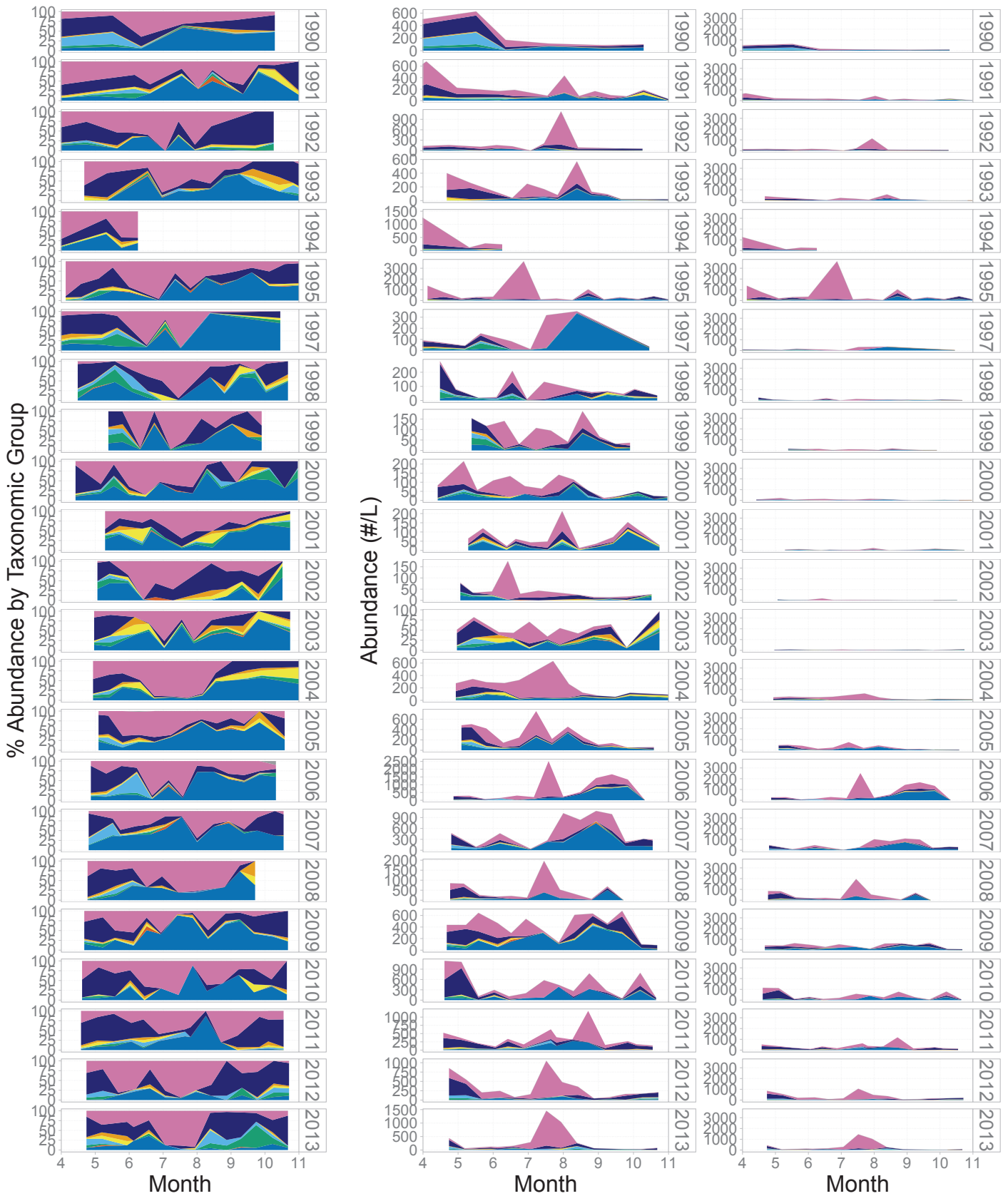
Phyto Taxonomic Groups and Chlorophyll-a: PM (UKL @ Pelican Marina), April-October



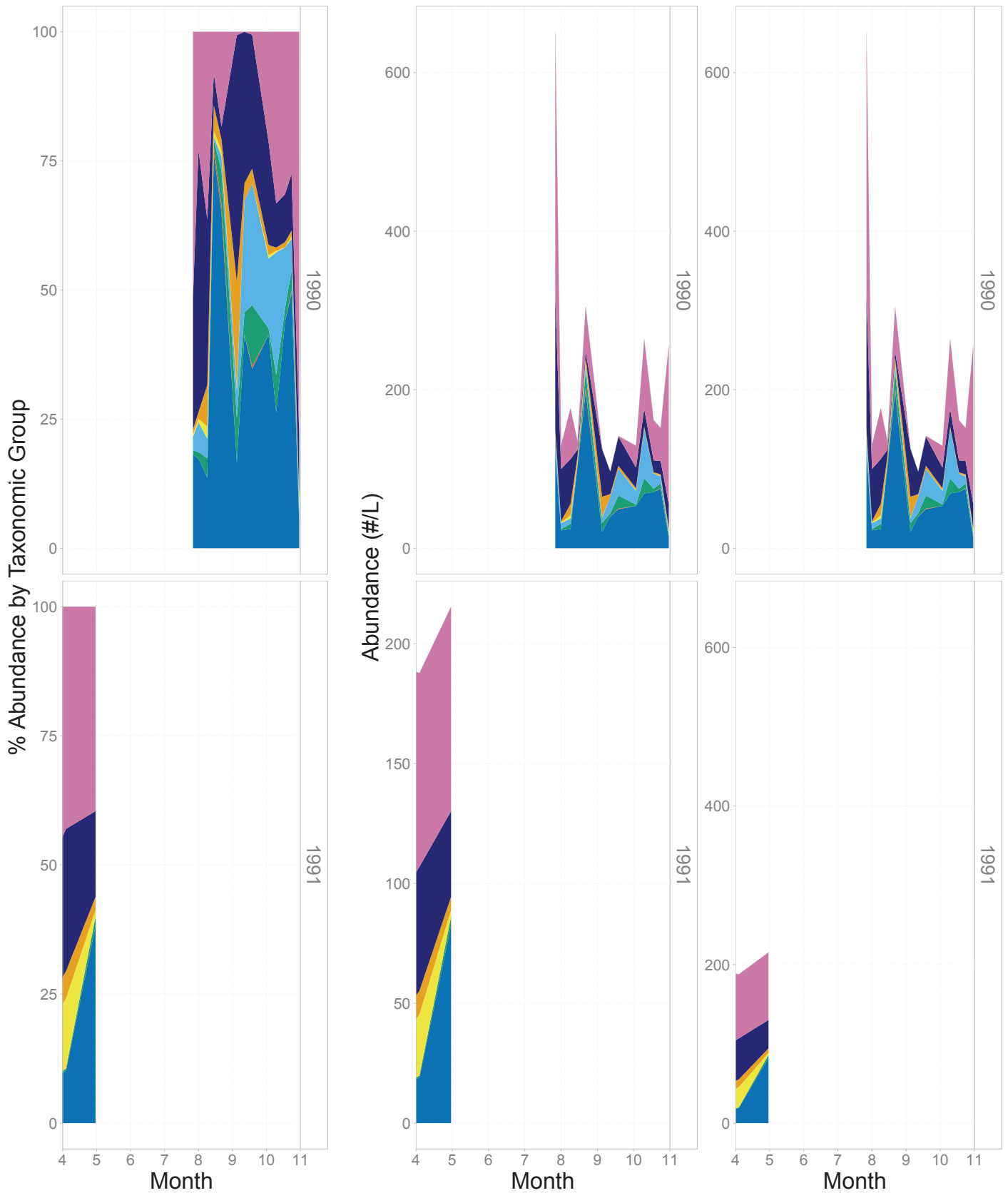
Phyto Taxonomic Groups and Chlorophyll-a: SB (UKL @ Shoal Water Bay), April–October



Phyto Taxonomic Groups and Chlorophyll-a: WB (UKL @ Wocus Bay), April-October

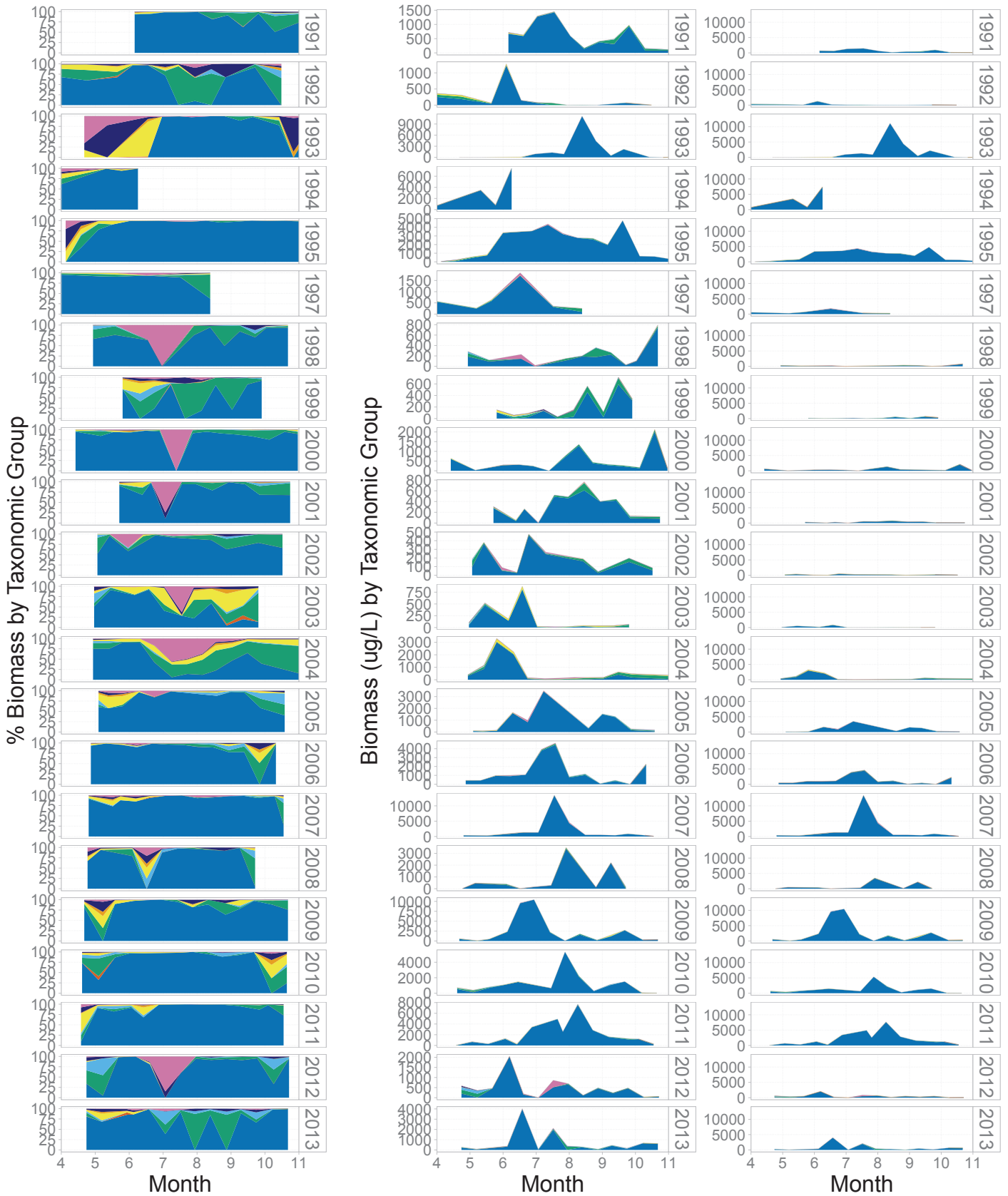


Phyto Taxonomic Groups & Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct.

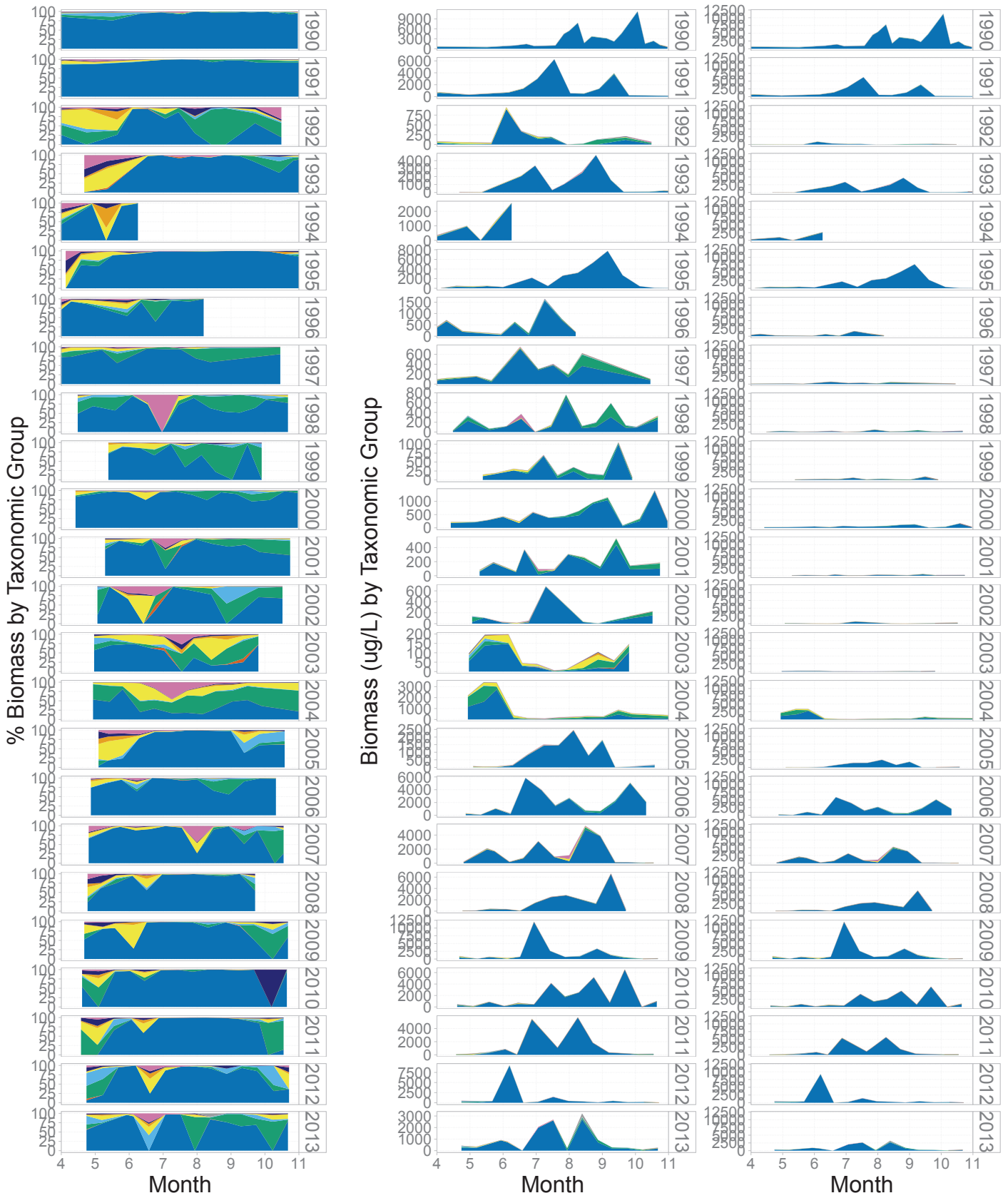


**APPENDIX H: DETAILED TIME SERIES CHARTS OF BIOMASS FOR ZOOPLANKTON
TAXONOMIC GROUPS FOR EACH SITE**

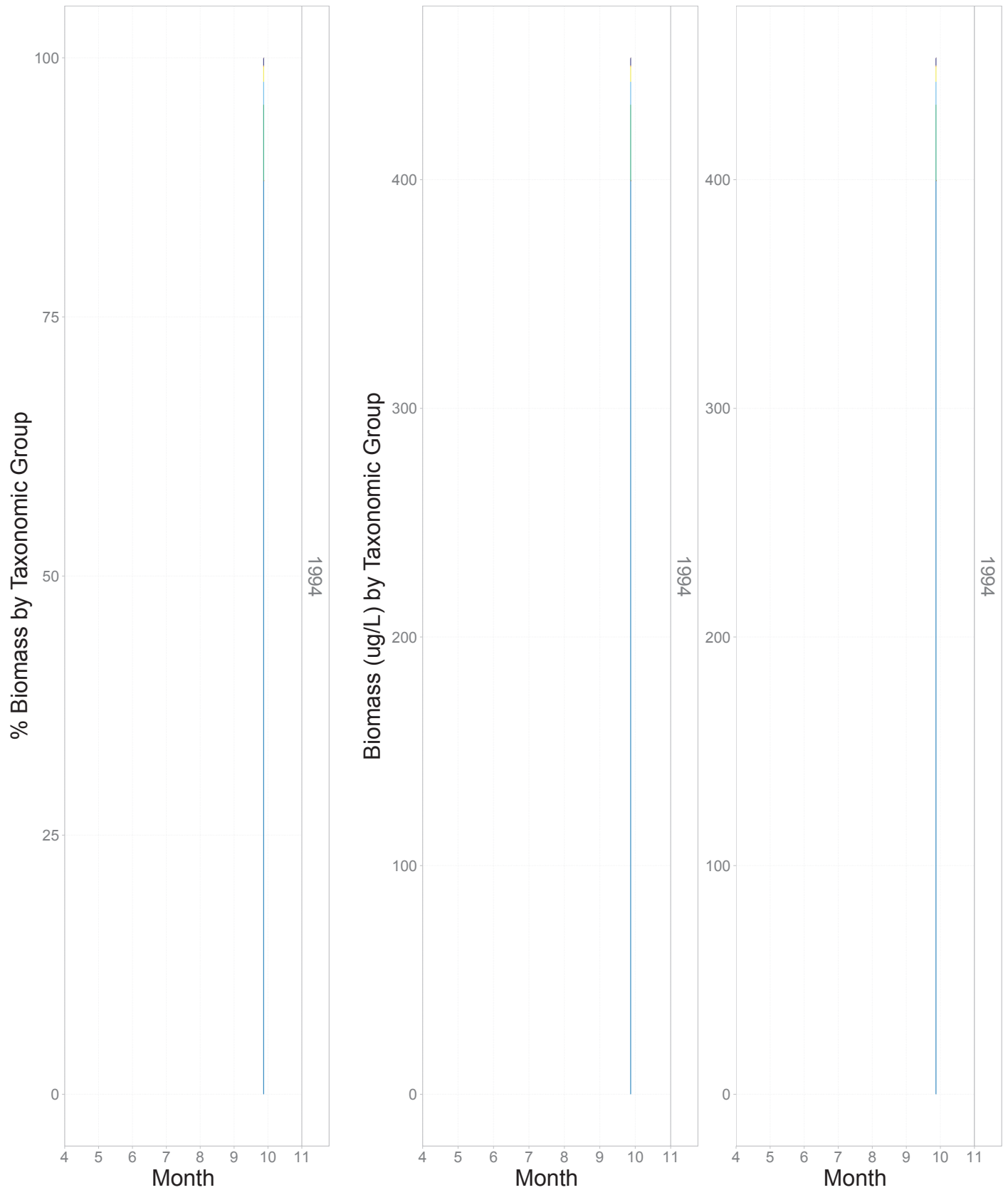
Phyto Taxonomic Groups and Chlorophyll-a: AN (UKL @ Agency Lake North), April-October



Phyto Taxonomic Groups and Chlorophyll-a: AS (UKL @ Agency Lake South), April-October



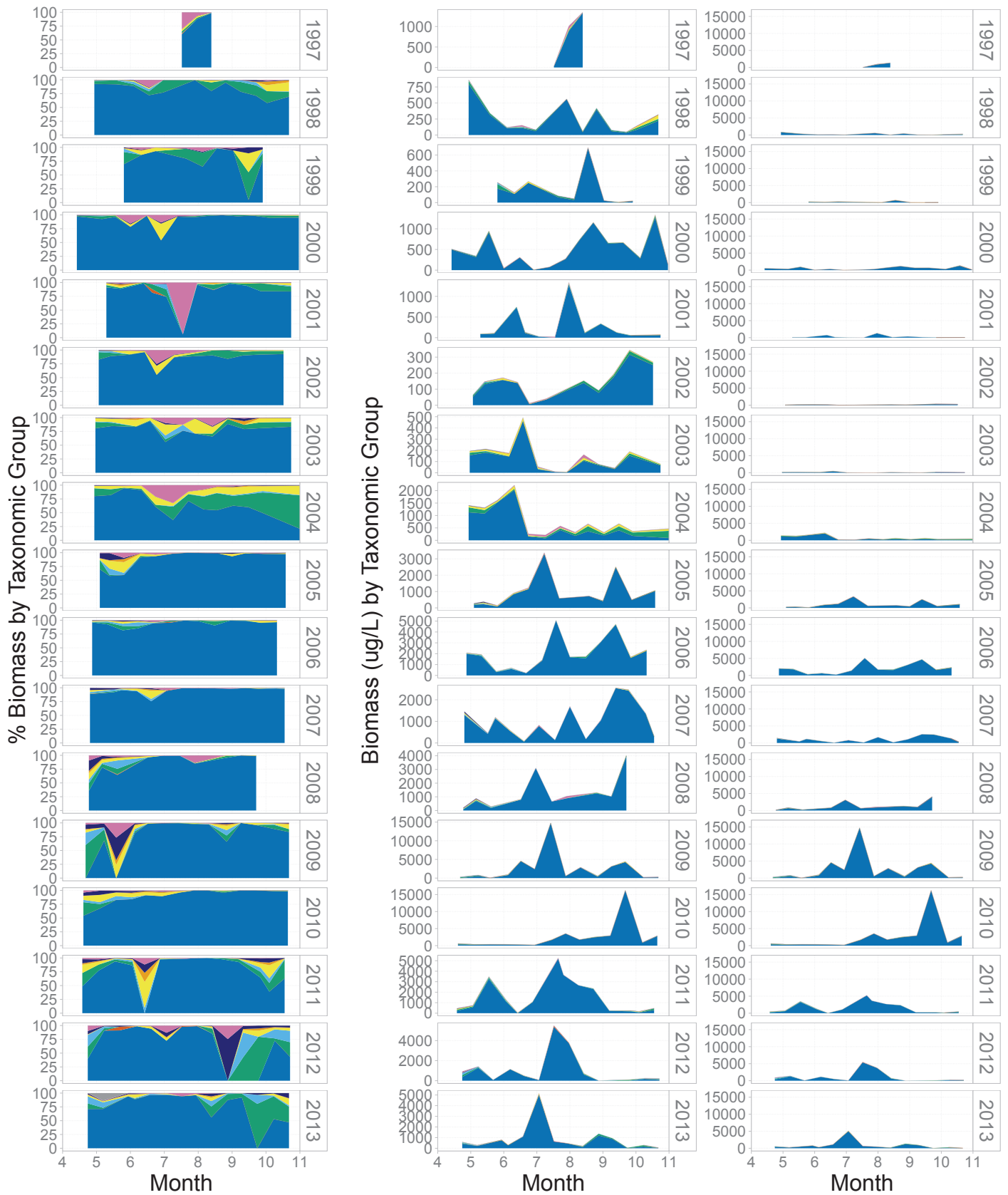
Phyto Taxonomic Groups & Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), April-Oct.



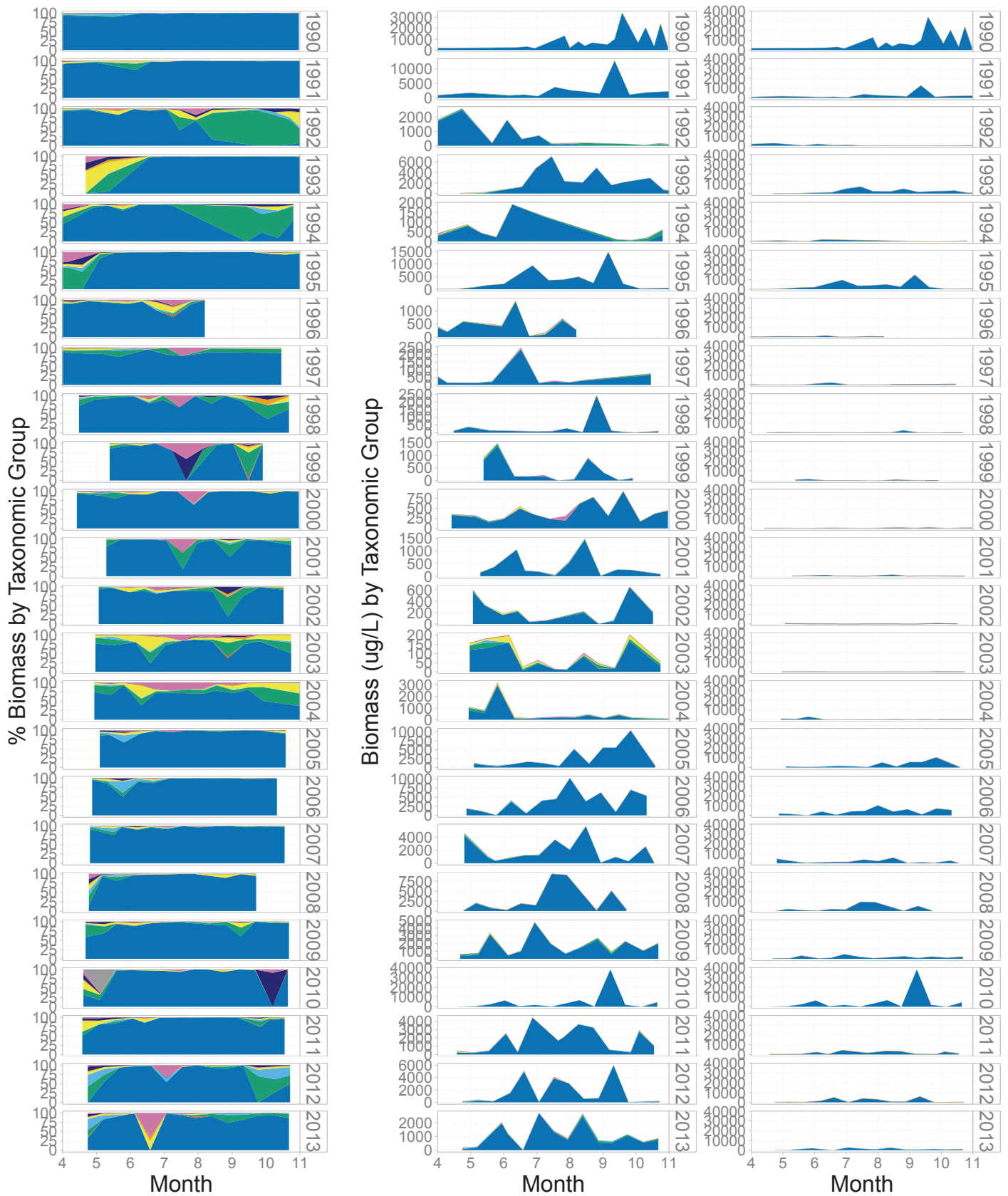
Taxonomic Group

- Ostracoda
- Copepoda Nauplii
- Cyclopoid Copepods Adult
- Calanoid Copepods Adult
- Cladocera Adult
- Rotifera
- Cyclopoid Copepods Copepodids
- Calanoid Copepods Copepodids
- Cladocera Immature

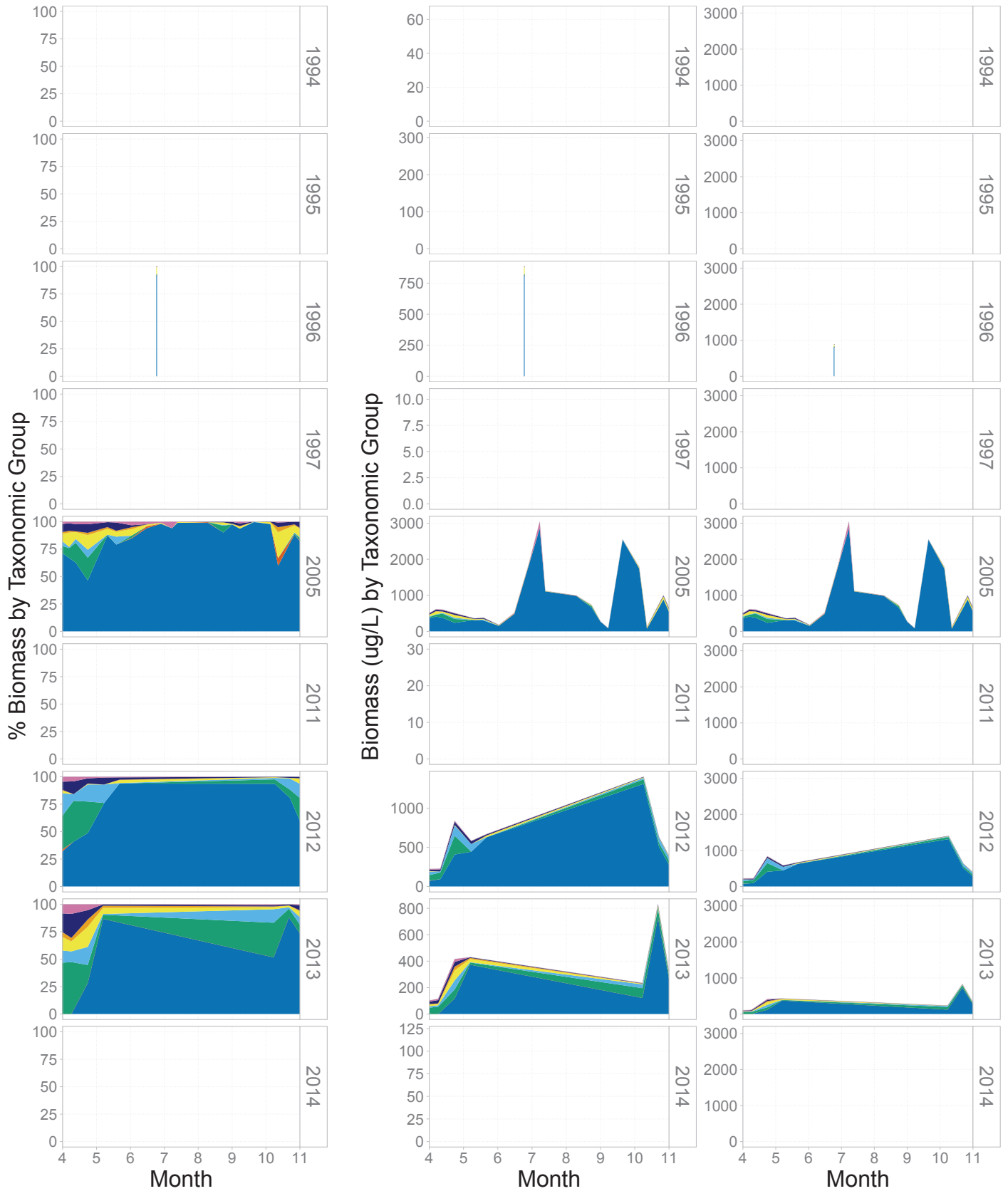
Phyto Taxonomic Groups and Chlorophyll-a: CP (UKL @ Coon Point), April-October



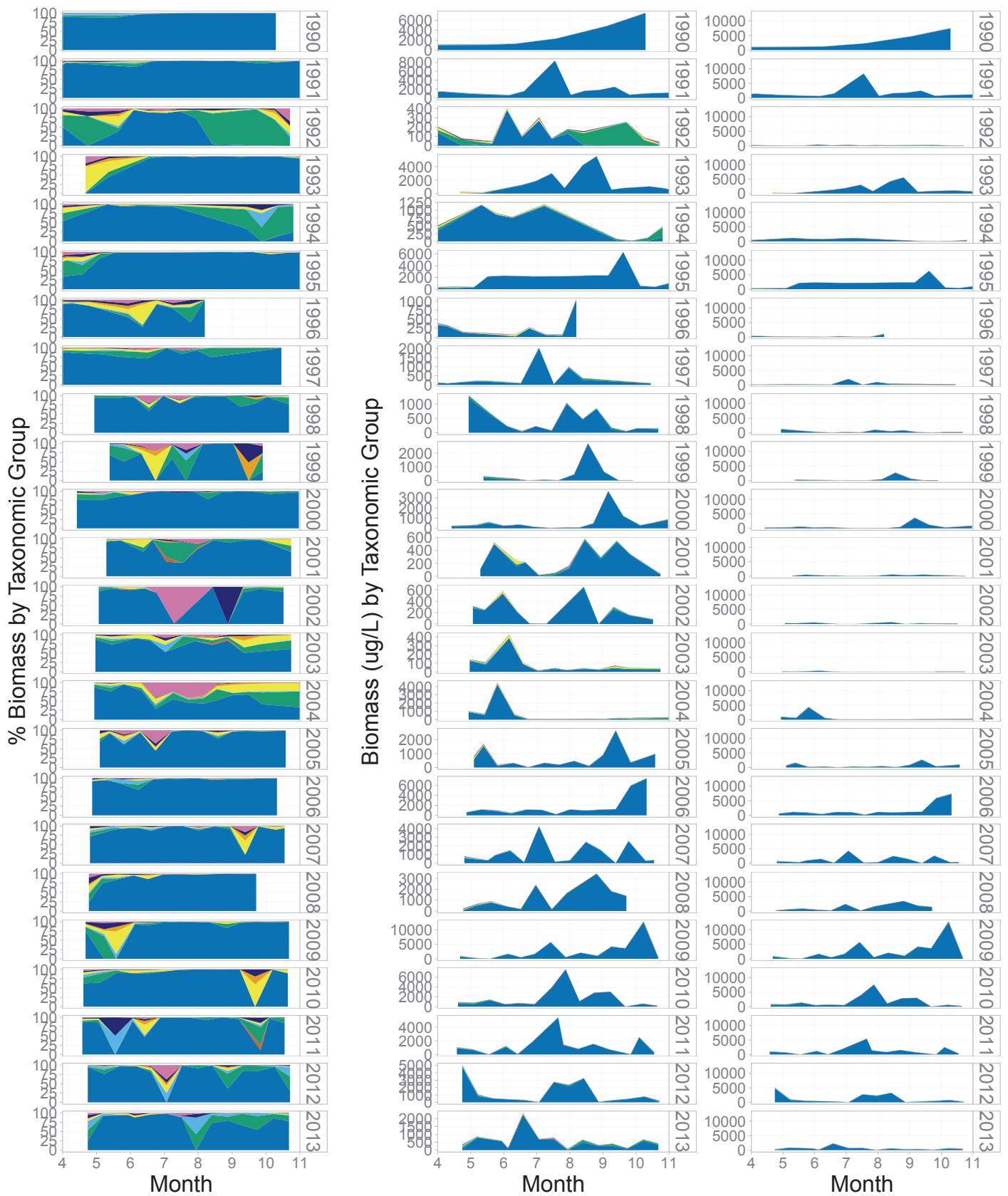
Phyto Taxonomic Groups and Chlorophyll-a: ER (UKL @ Eagle Ridge), April–October



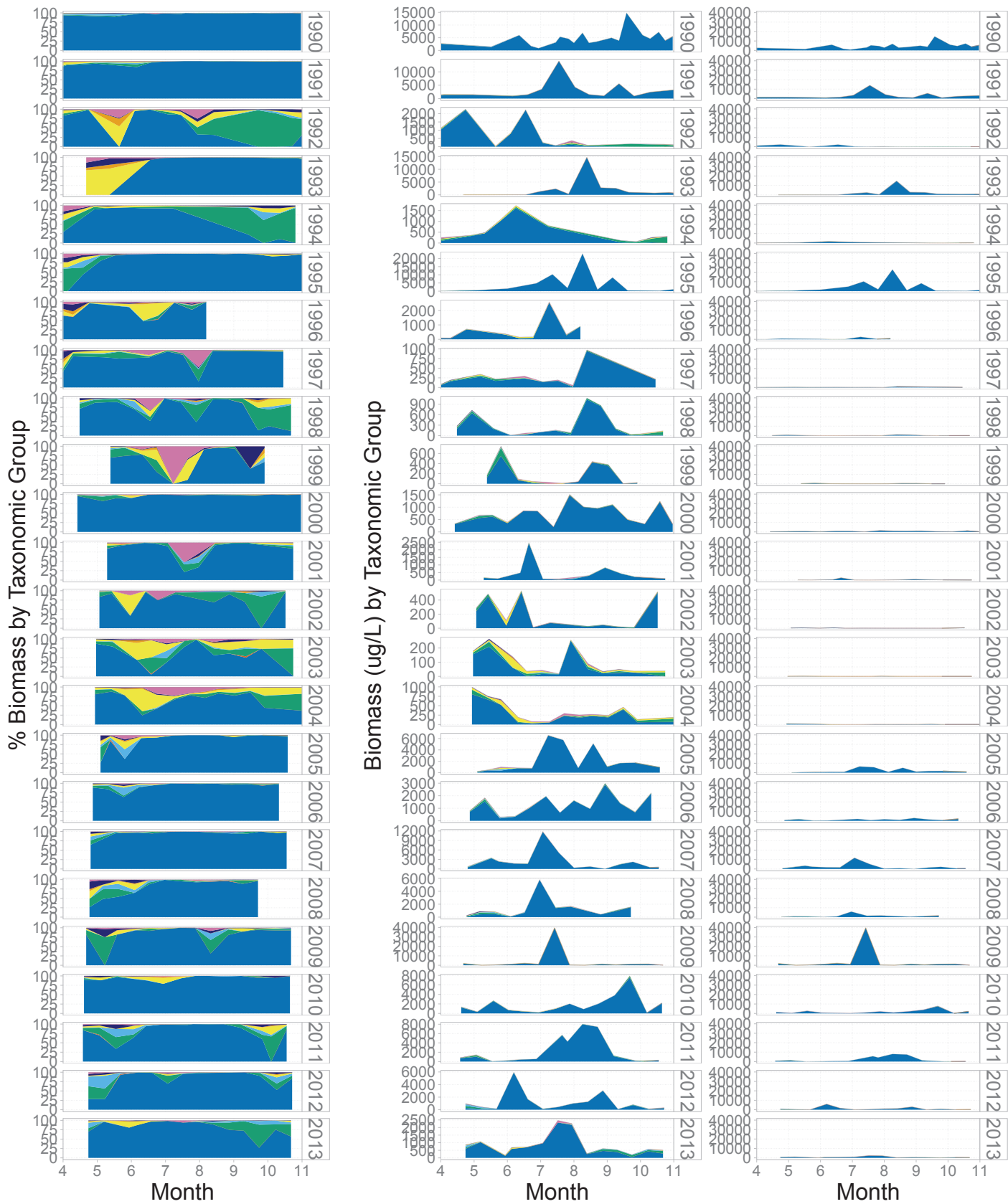
Phyto Taxonomic Groups and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), April-October



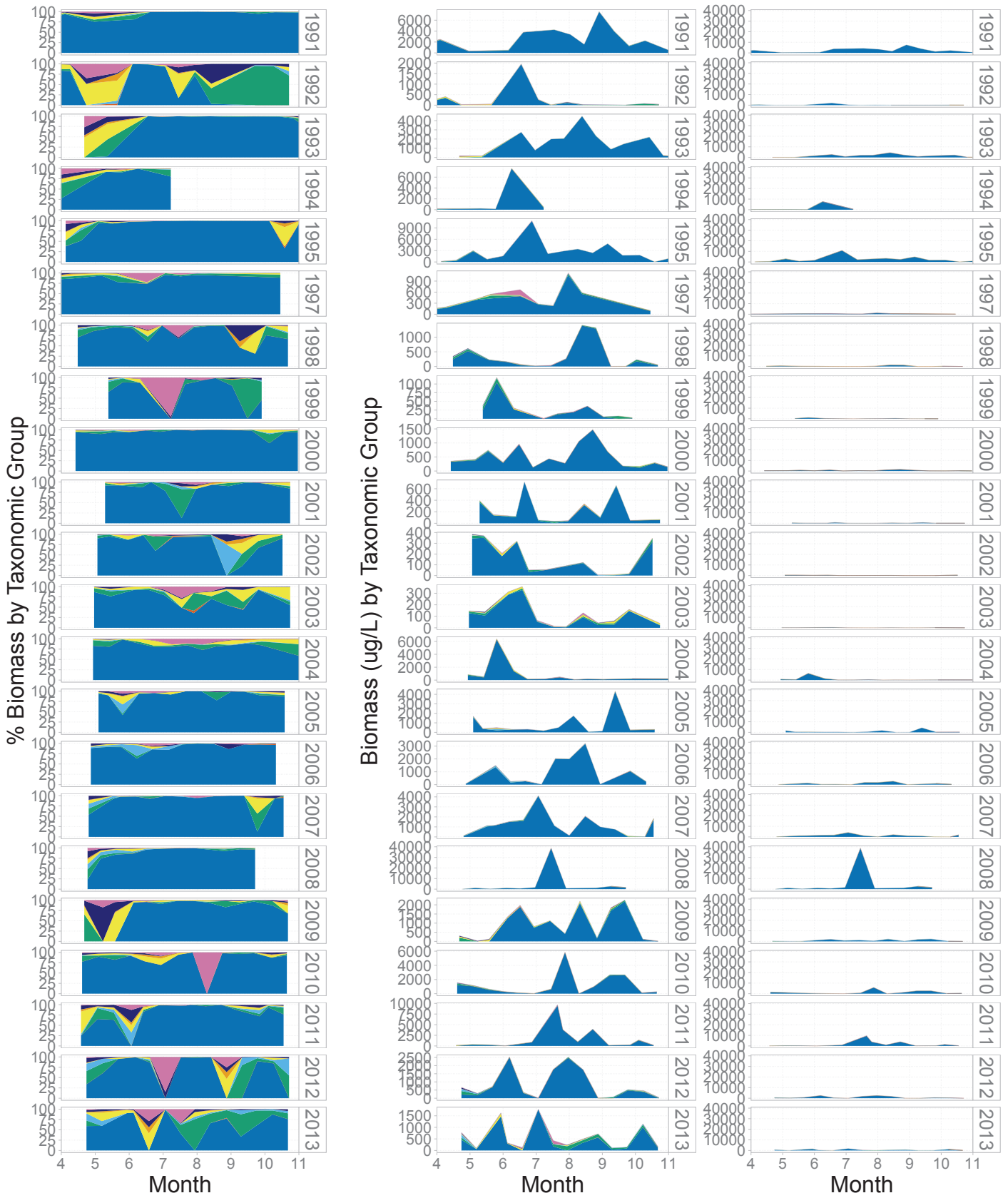
Phyto Taxonomic Groups and Chlorophyll-a: ML (UKL @ Mid-Lake), April–October



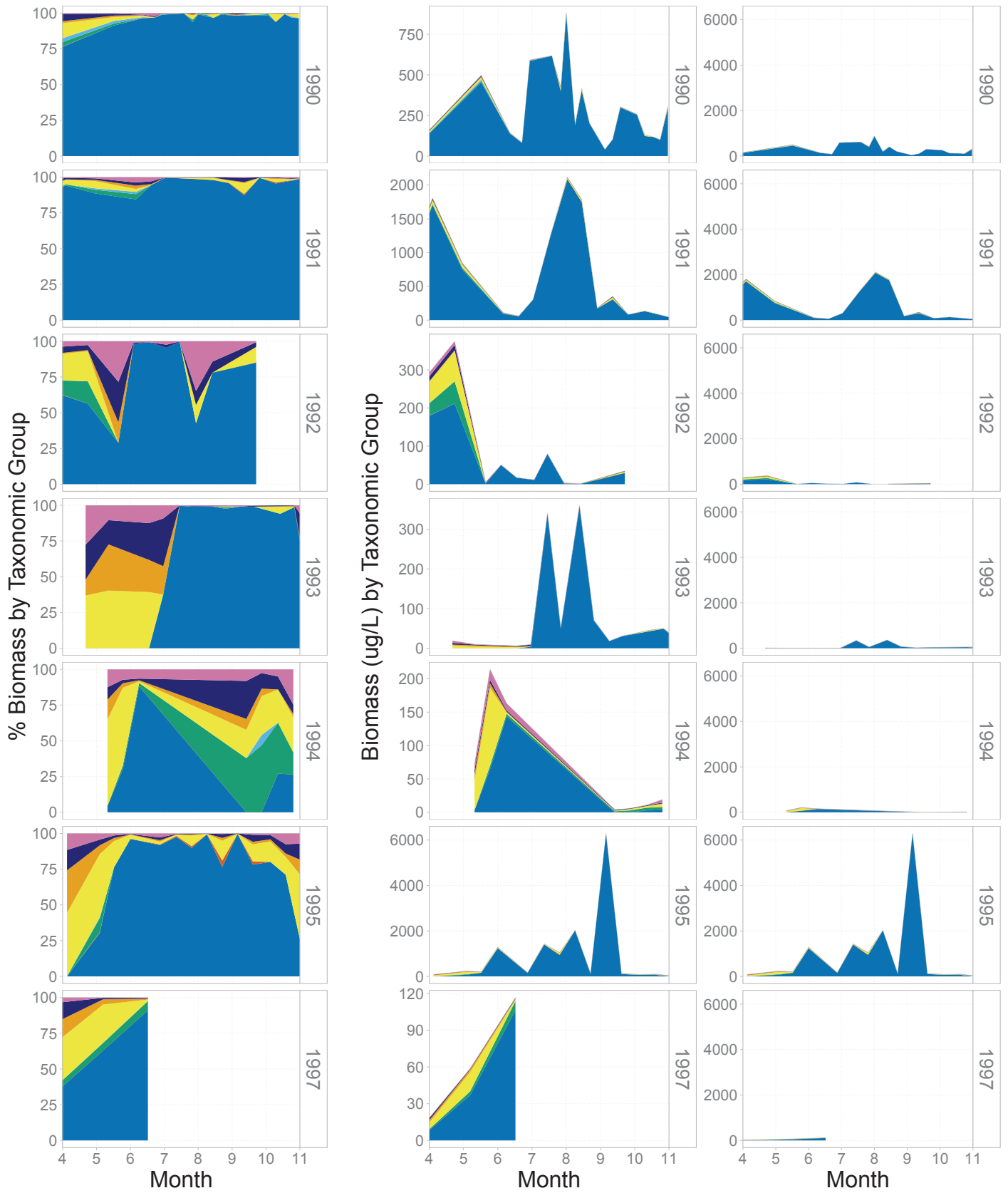
Phyto Taxonomic Groups and Chlorophyll-a: MN (UKL @ Mid-Lake North), April-October



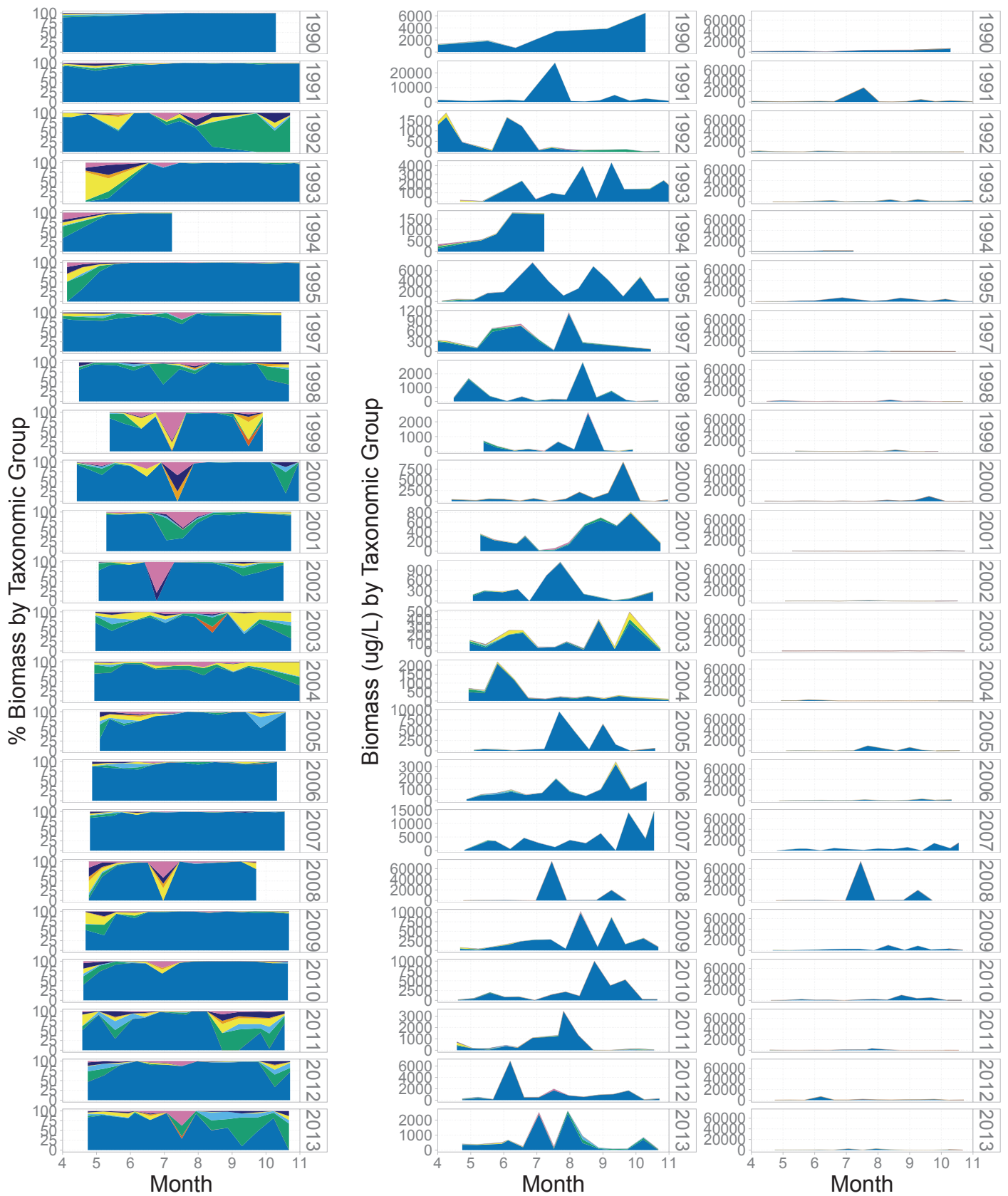
Phyto Taxonomic Groups and Chlorophyll-a: NB (UKL @ North Buck Island), April–October



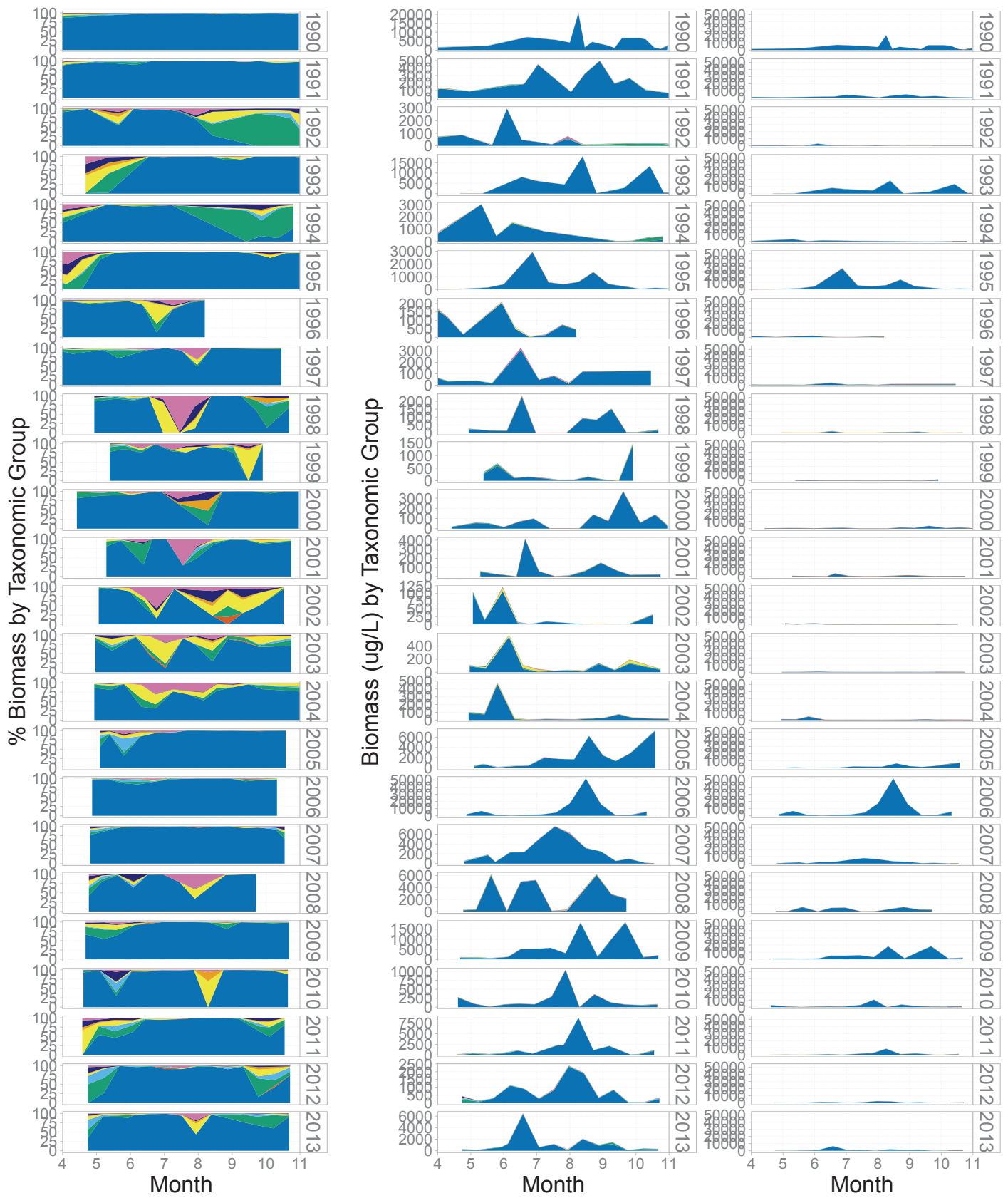
Phyto Taxonomic Groups and Chlorophyll-a: PB (UKL @ Pelican Bay), April–October



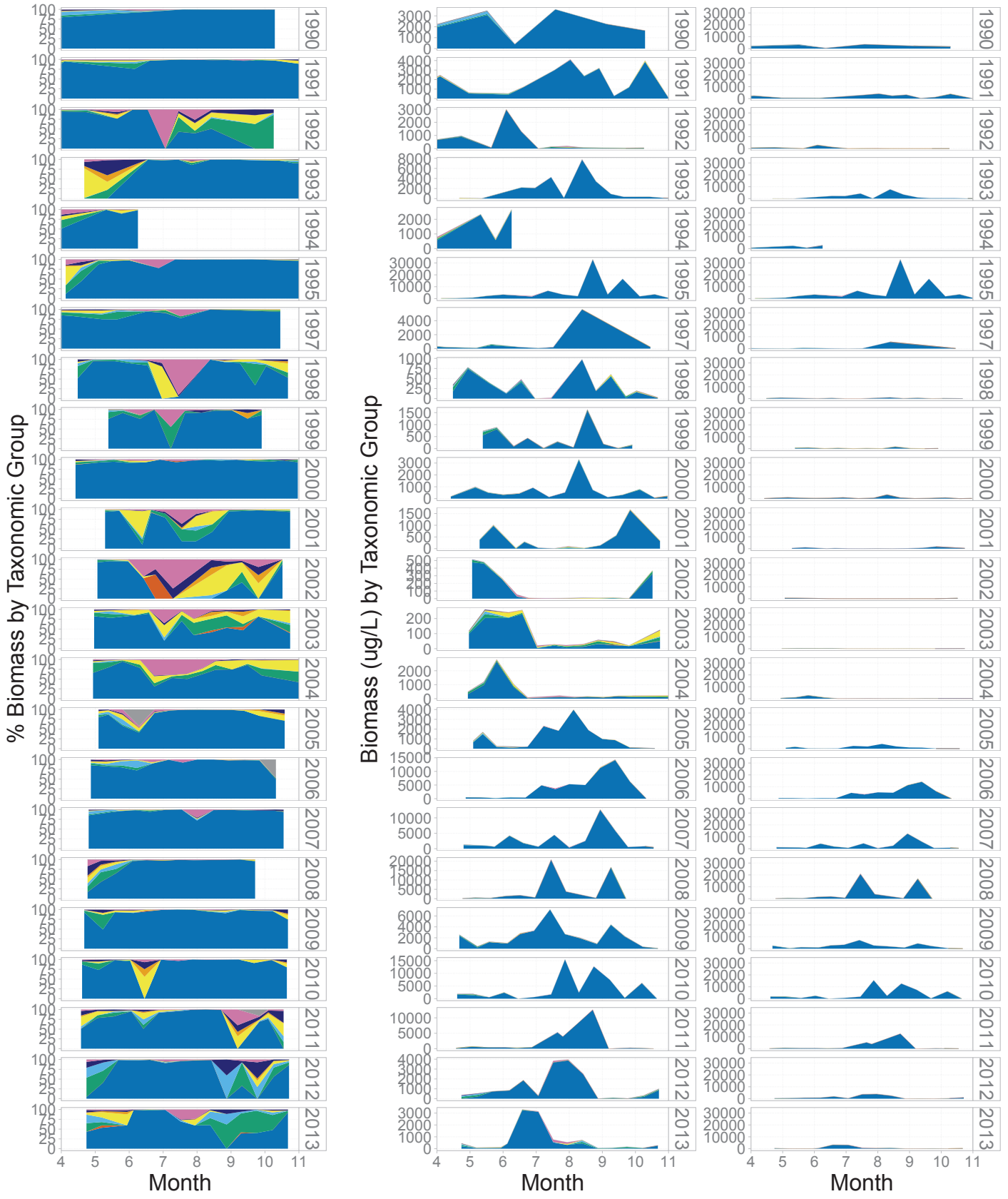
Phyto Taxonomic Groups and Chlorophyll-a: PM (UKL @ Pelican Marina), April-October



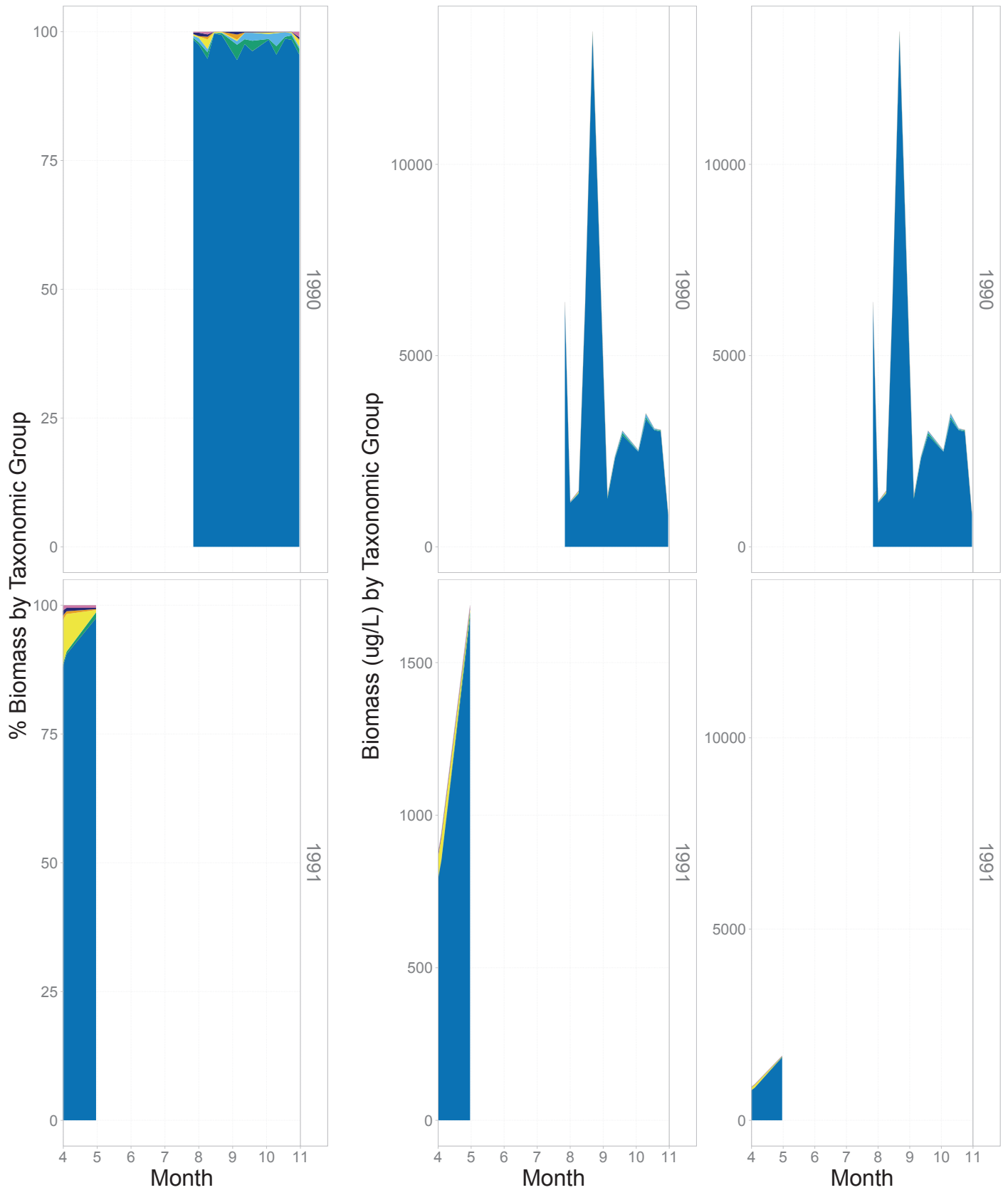
Phyto Taxonomic Groups and Chlorophyll-a: SB (UKL @ Shoal Water Bay), April–October



Phyto Taxonomic Groups and Chlorophyll-a: WB (UKL @ Wocus Bay), April–October

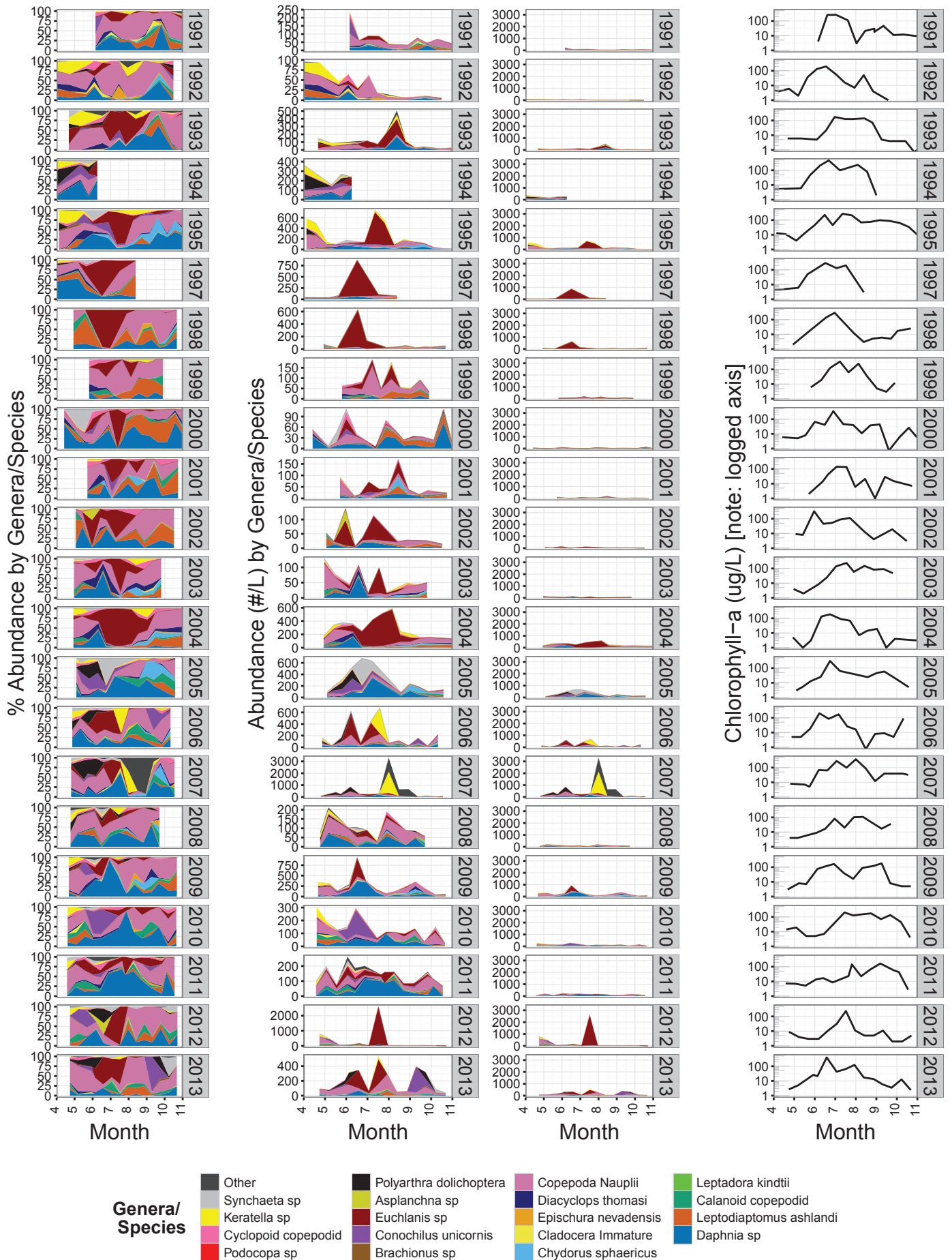


Phyto Taxonomic Groups & Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct

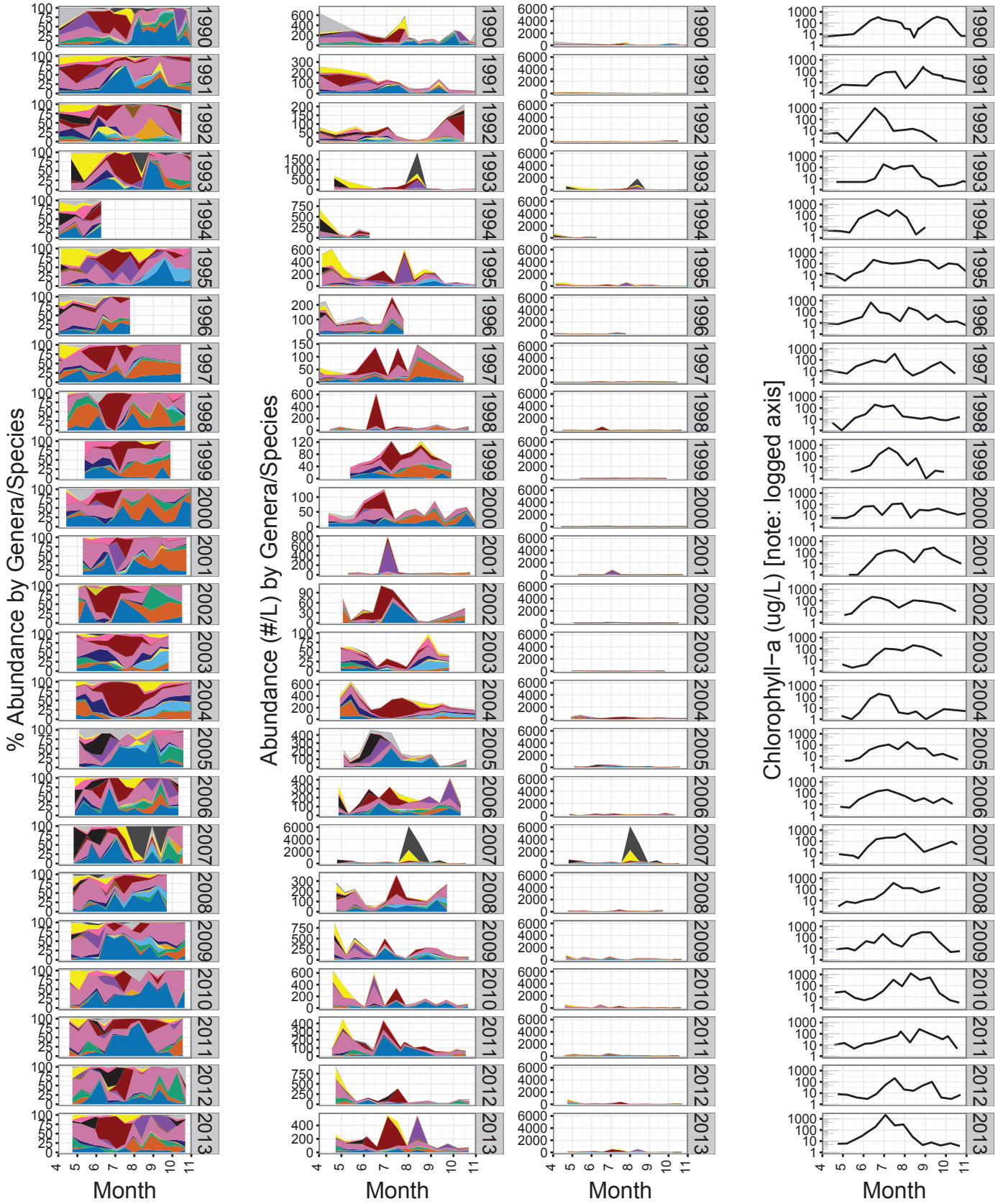


**APPENDIX I: DETAILED TIME SERIES CHARTS OF ABUNDANCE FOR ZOOPLANKTON
MAJOR GENERA/SPECIES FOR EACH SITE**

Zoop Genera/Species and Chlorophyll-a: AN (UKL @ Agency Lake North), Apr-Oct



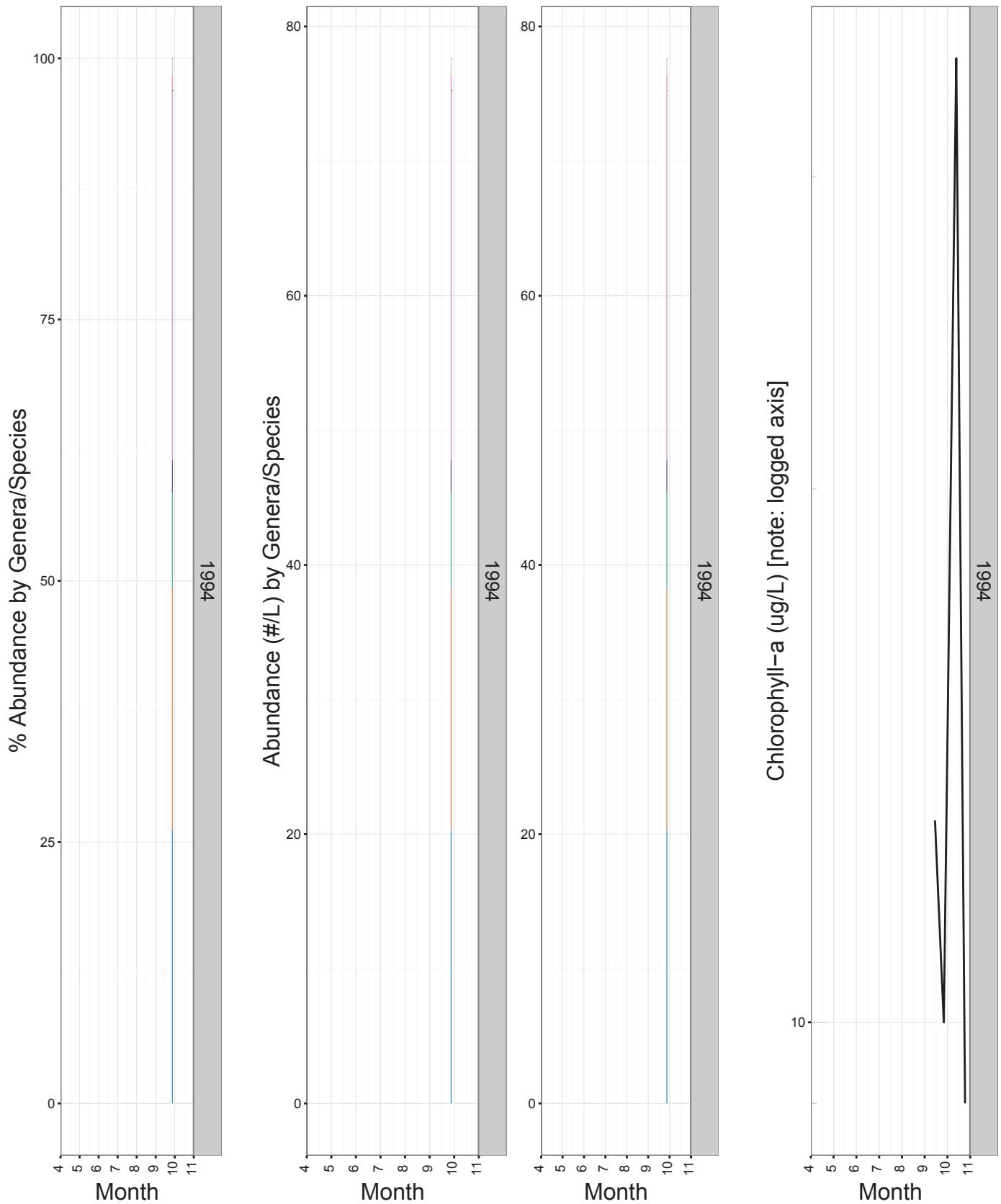
Zoop Genera/Species and Chlorophyll-a: AS (UKL @ Agency Lake South), Apr-Oct



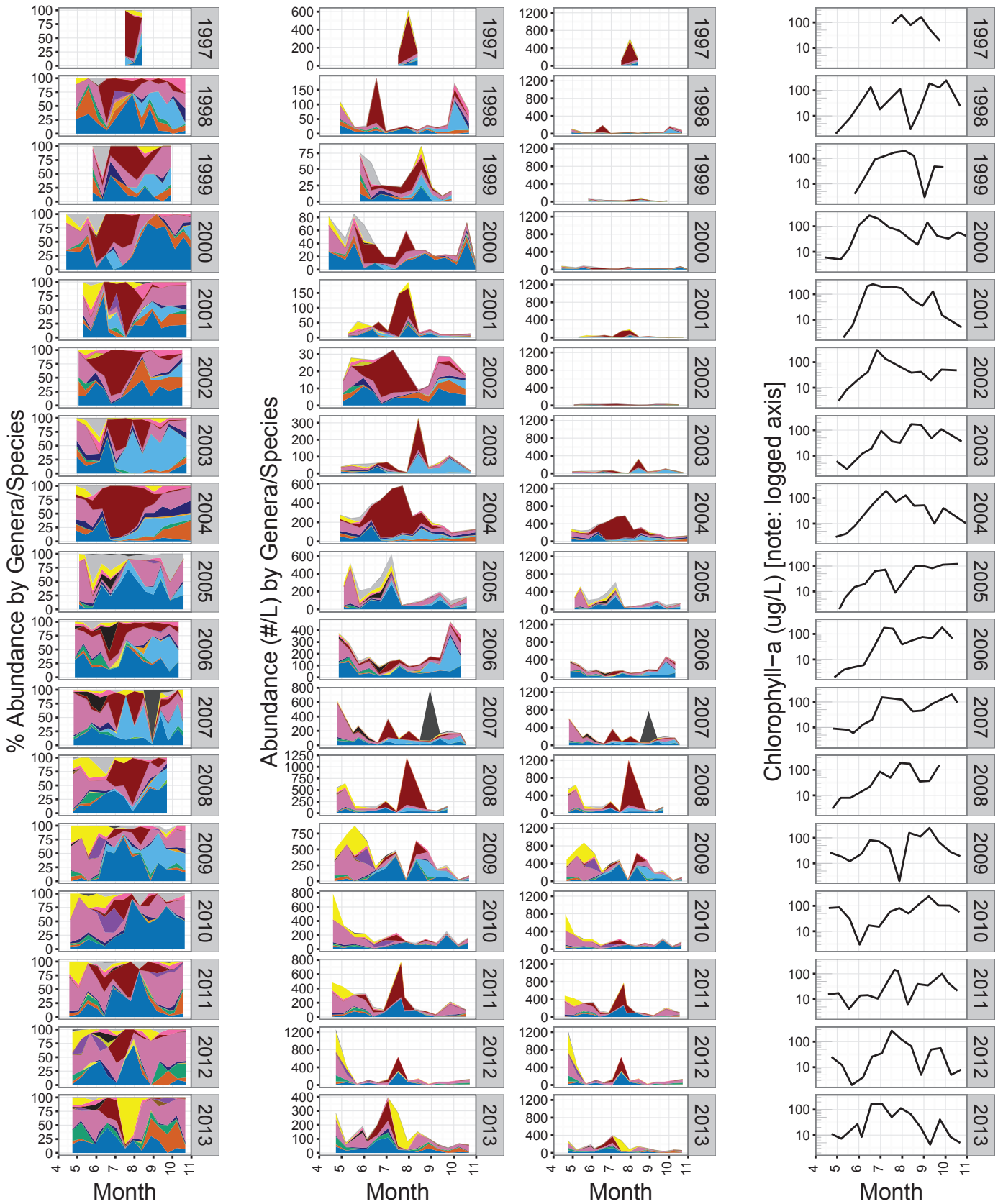
General/Species

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptodora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiatomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

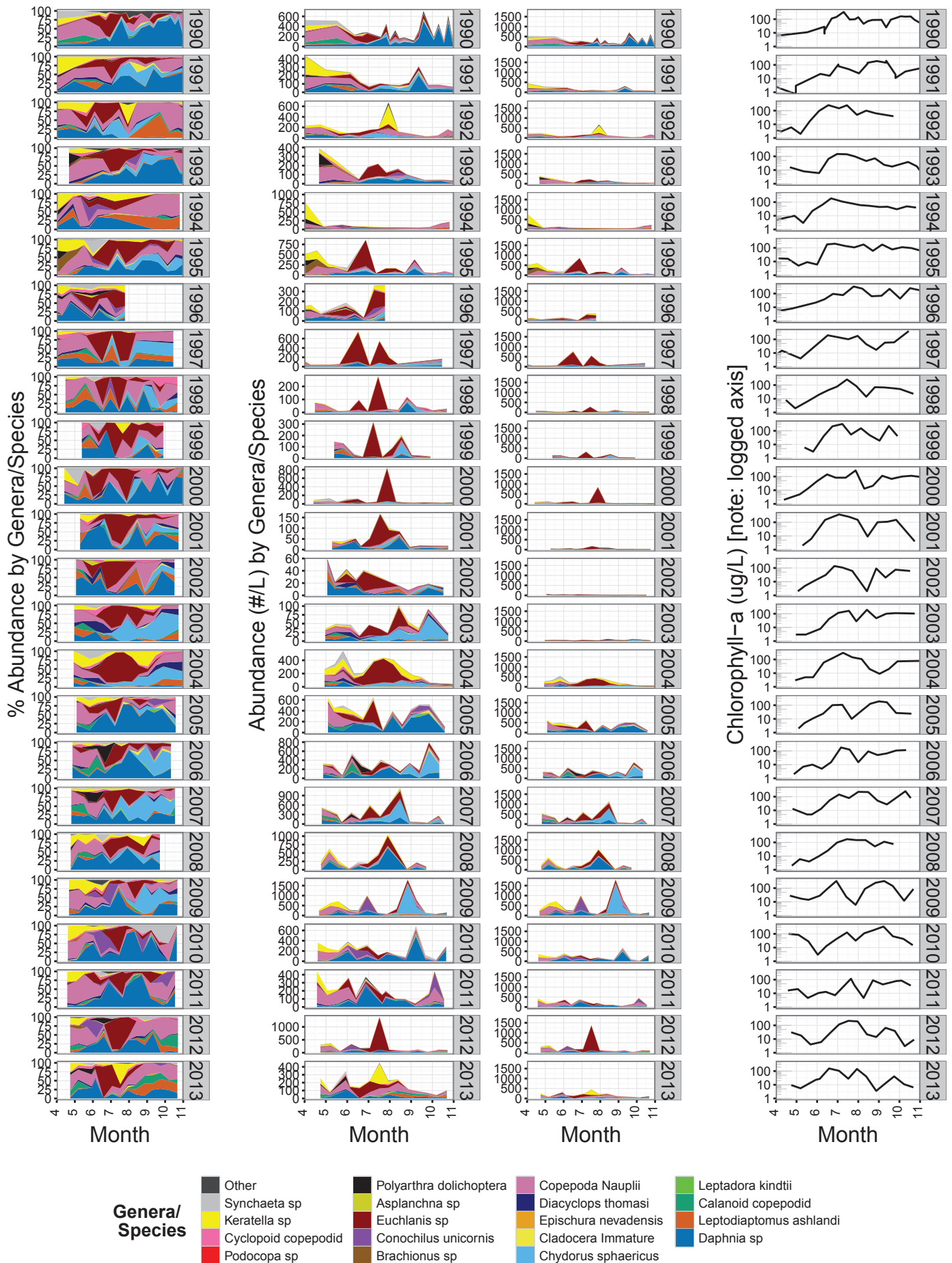
Zoop Genera/Species and Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), Apr-Oct



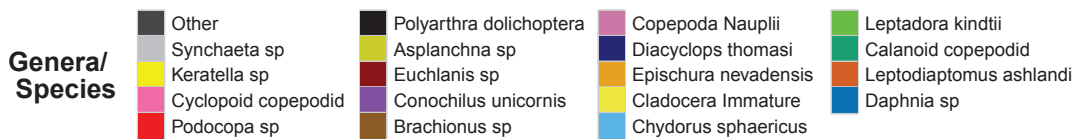
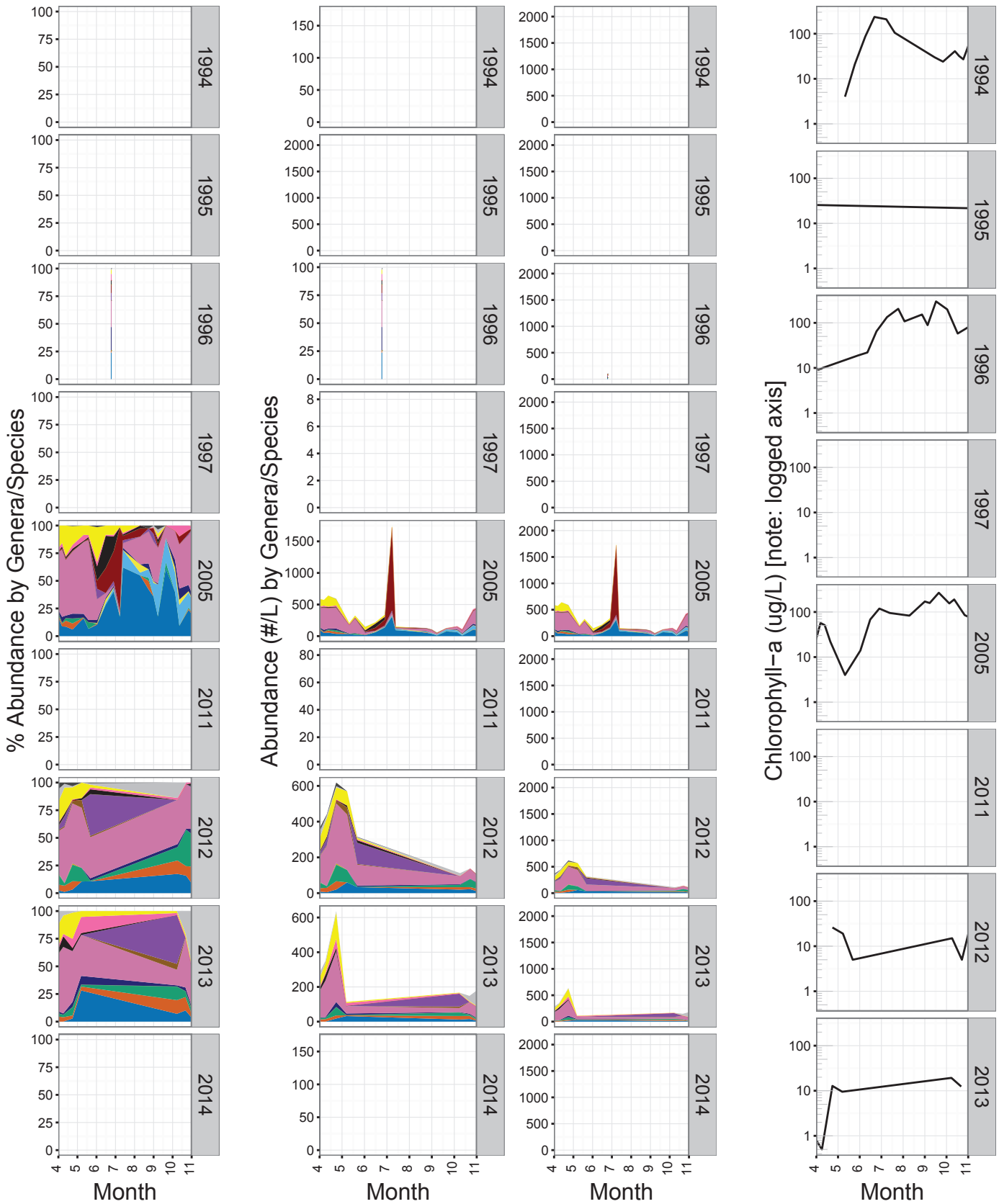
Zoop Genera/Species and Chlorophyll-a: CP (UKL @ Coon Point), Apr-Oct



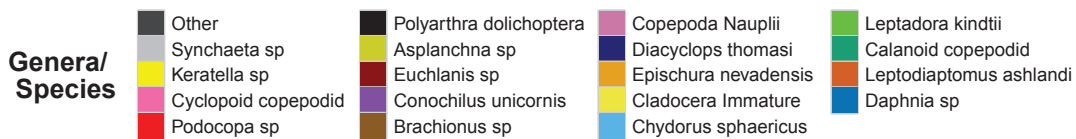
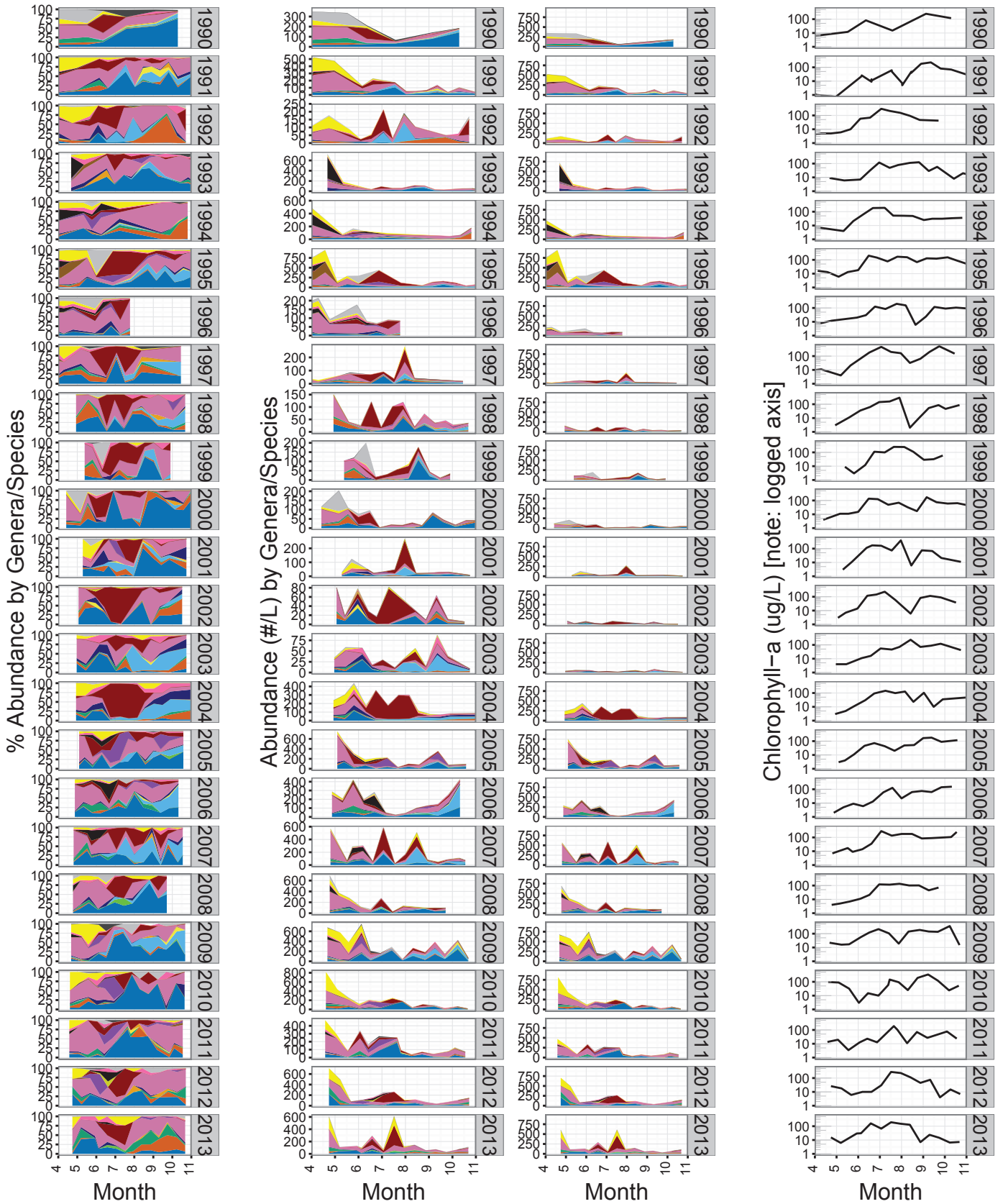
Zoop Genera/Species and Chlorophyll-a: ER (UKL @ Eagle Ridge), Apr-Oct



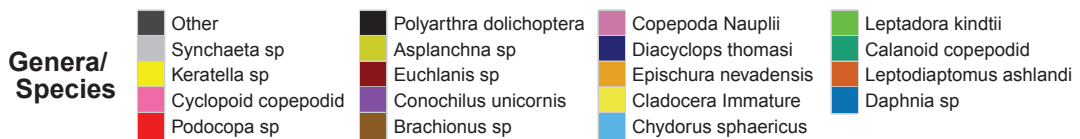
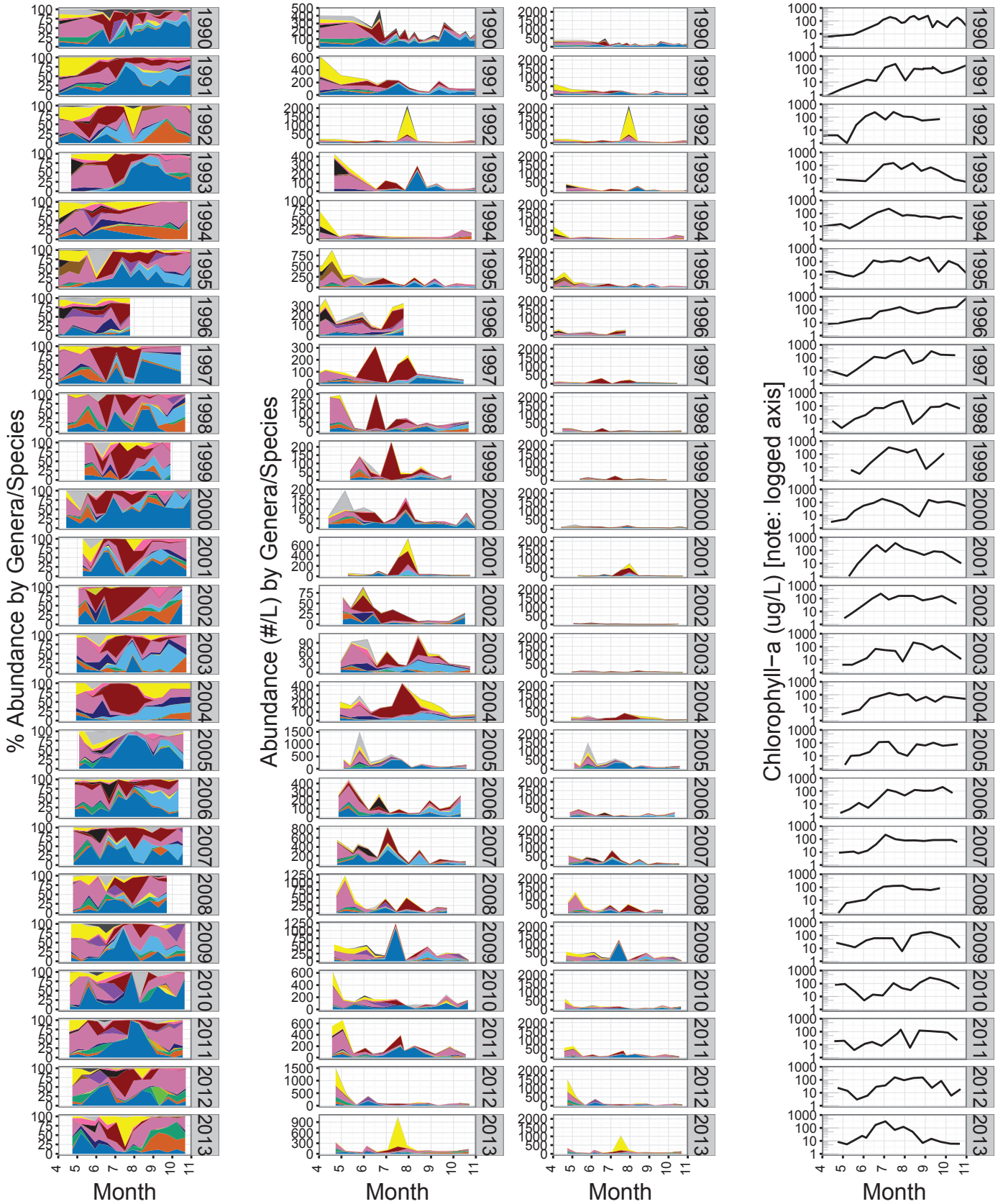
Zoop Genera/Species and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), Apr-Oct



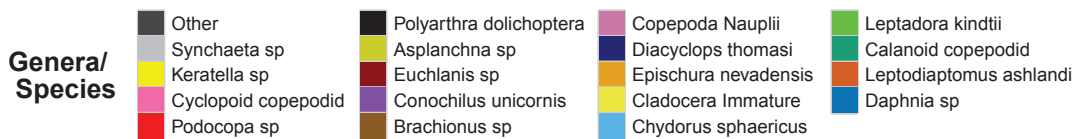
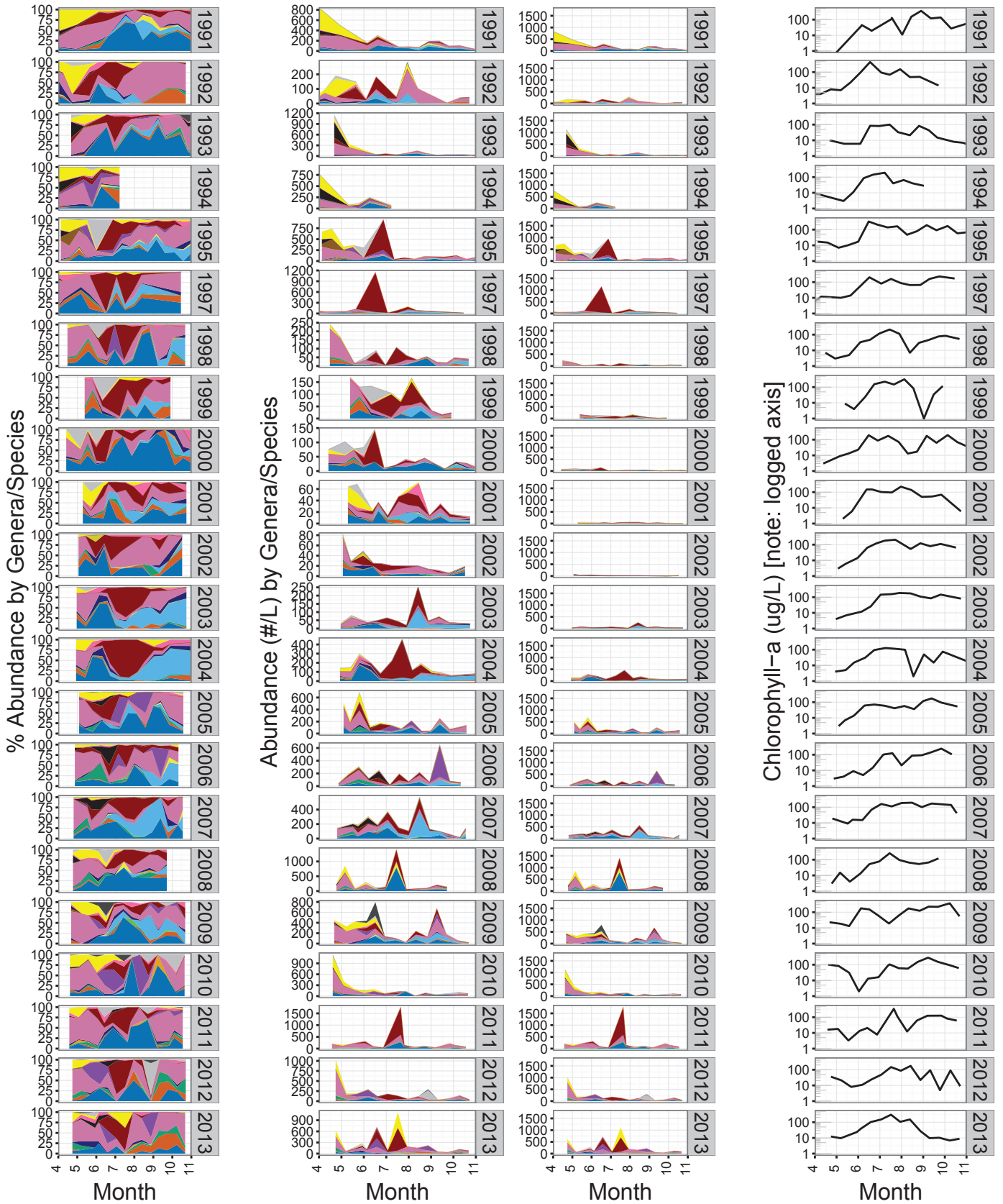
Zoop Genera/Species and Chlorophyll-a: ML (UKL @ Mid-Lake), Apr-Oct



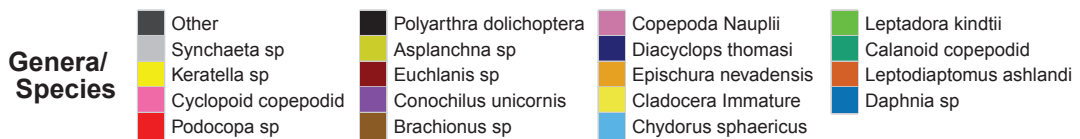
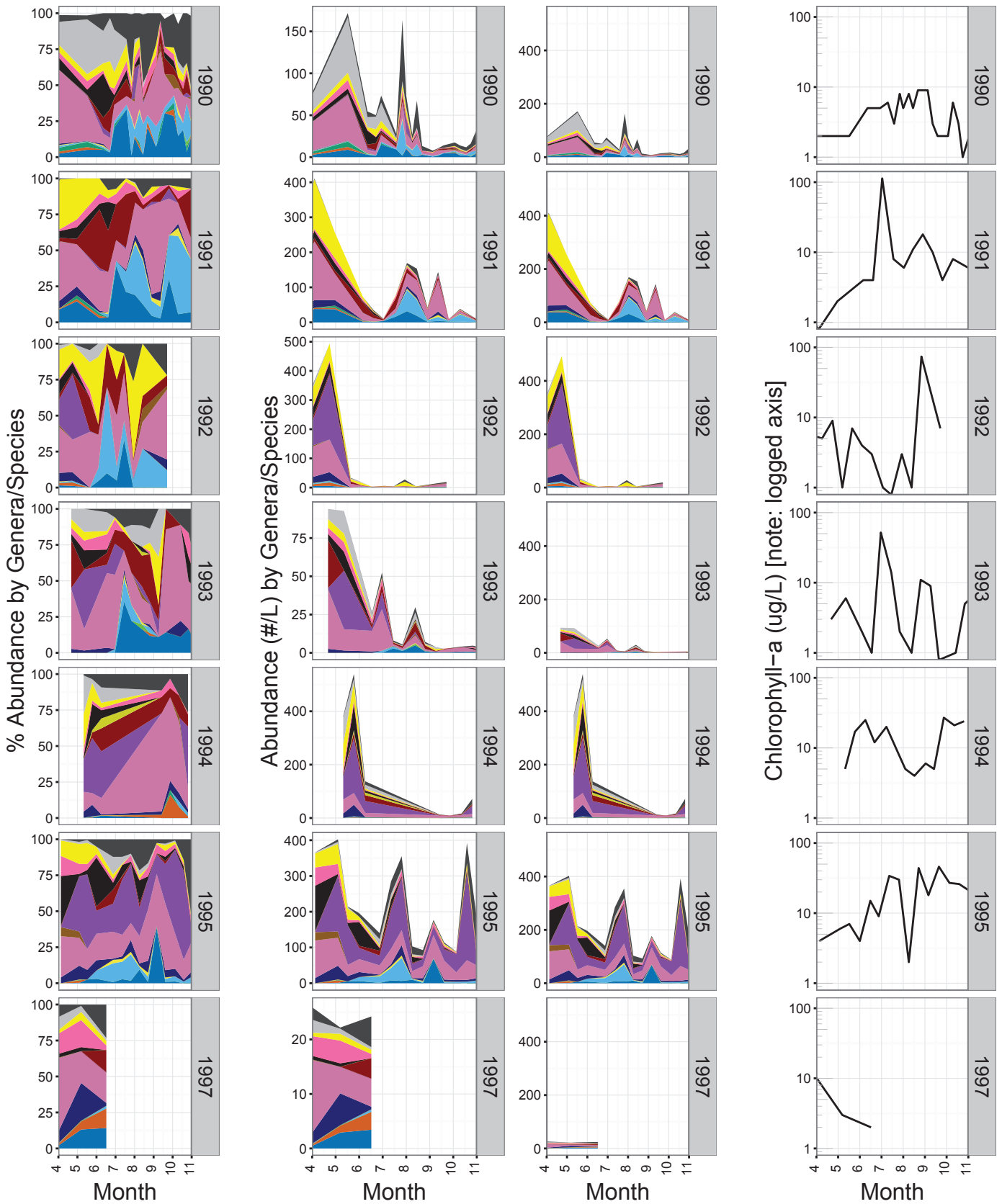
Zoop Genera/Species and Chlorophyll-a: MN (UKL @ Mid-Lake North), Apr-Oct



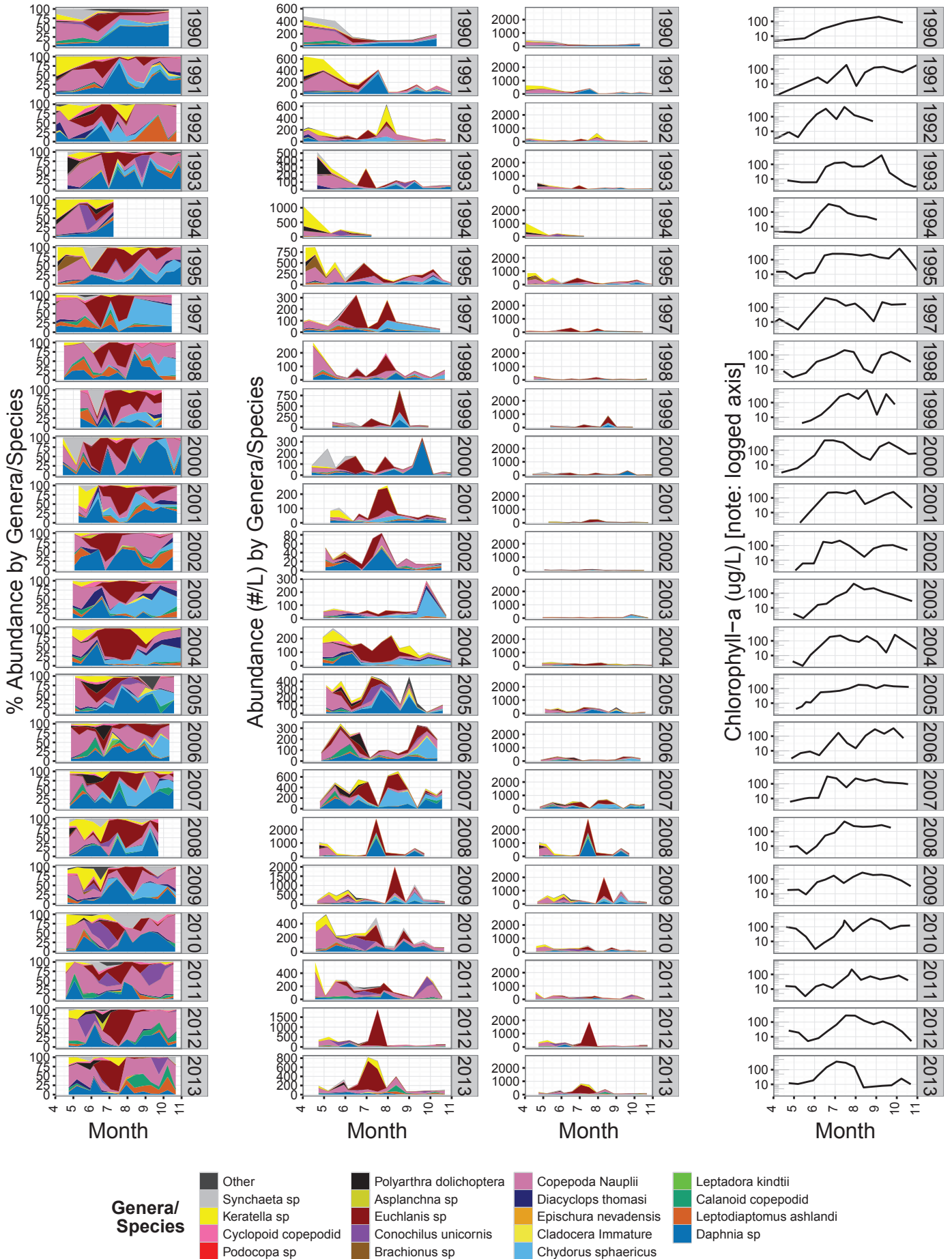
Zoop Genera/Species and Chlorophyll-a: NB (UKL @ North Buck Island), Apr-Oct



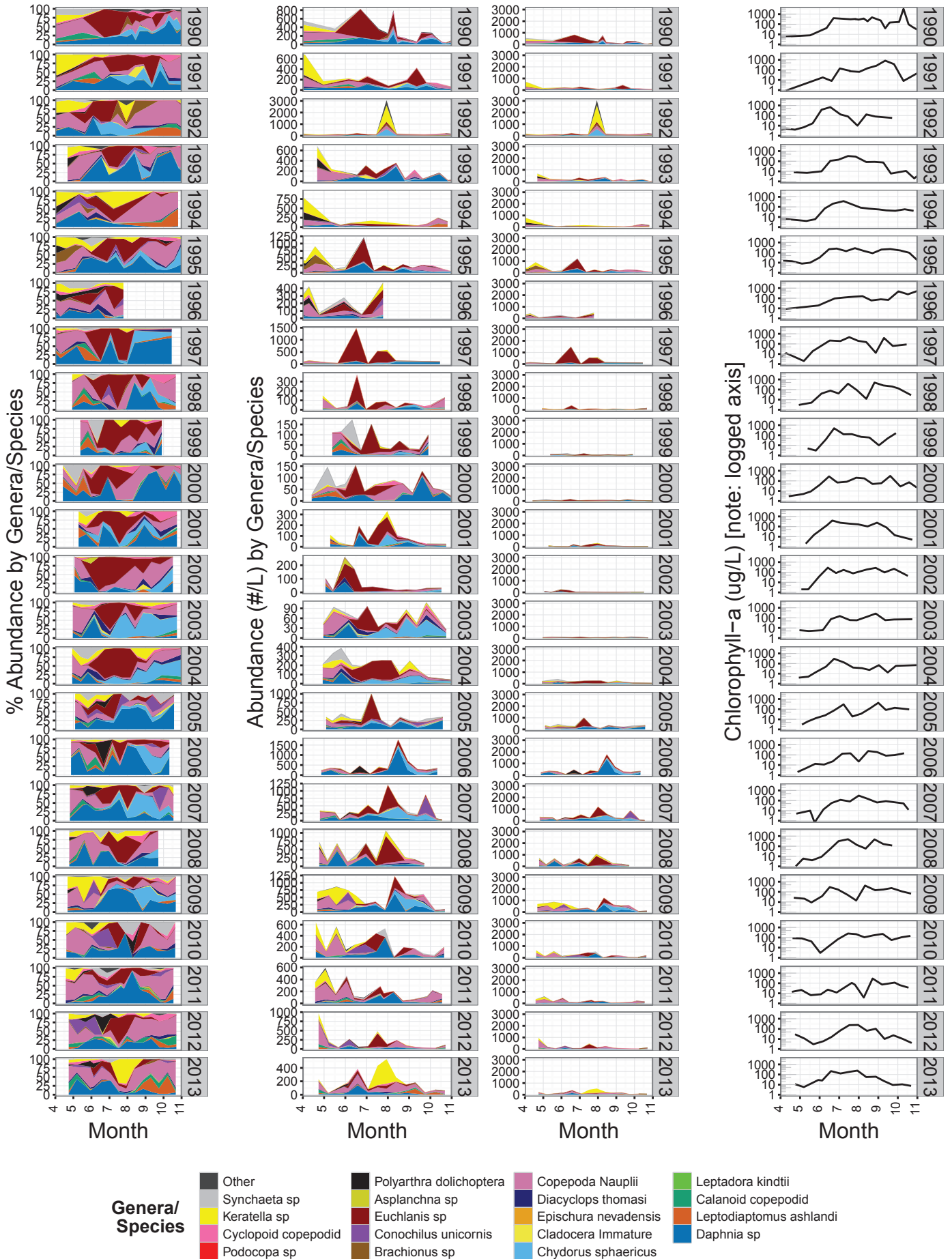
Zoop Genera/Species and Chlorophyll-a: PB (UKL @ Pelican Bay), Apr-Oct



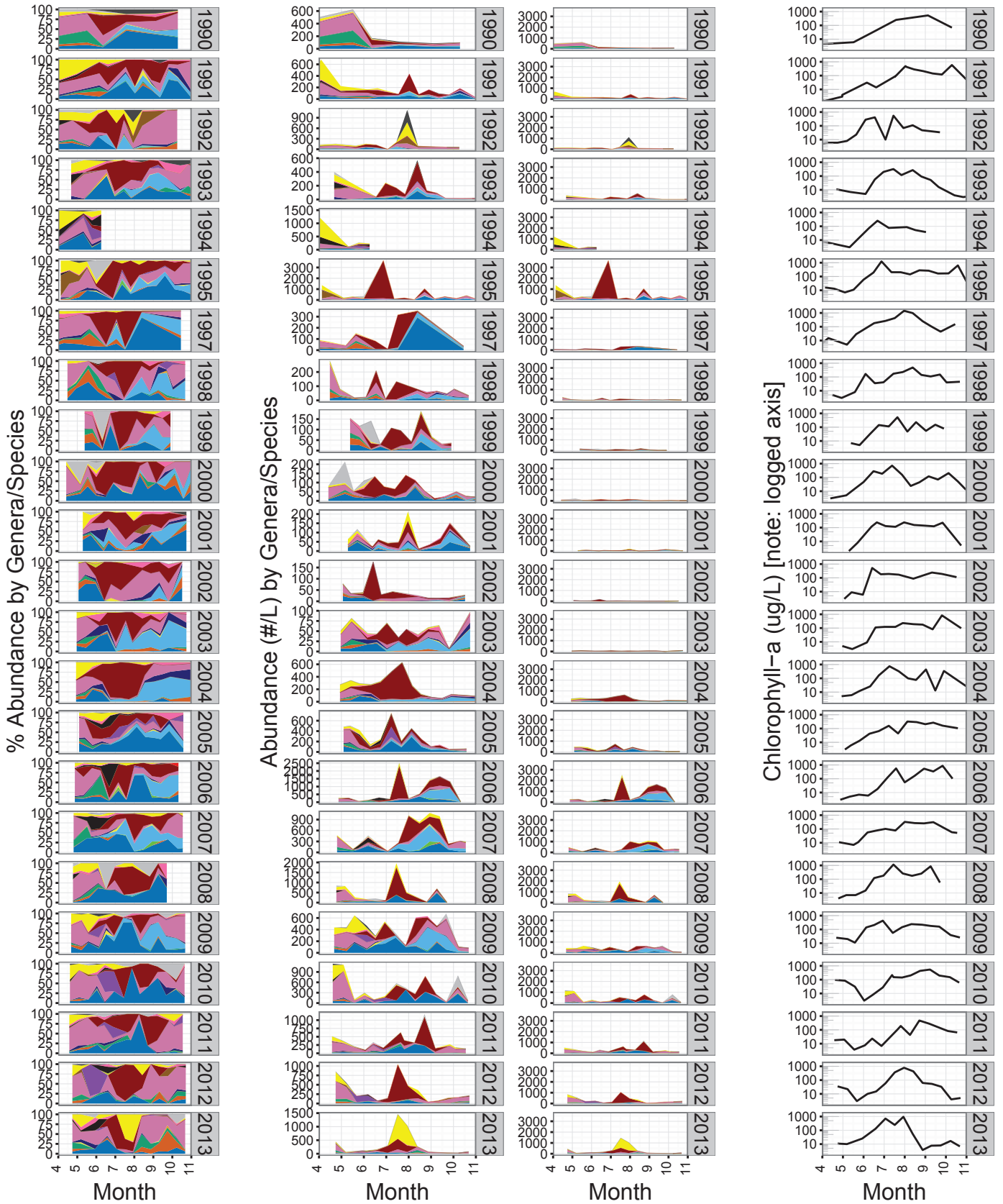
Zoop Genera/Species and Chlorophyll-a: PM (UKL @ Pelican Marina), Apr-Oct



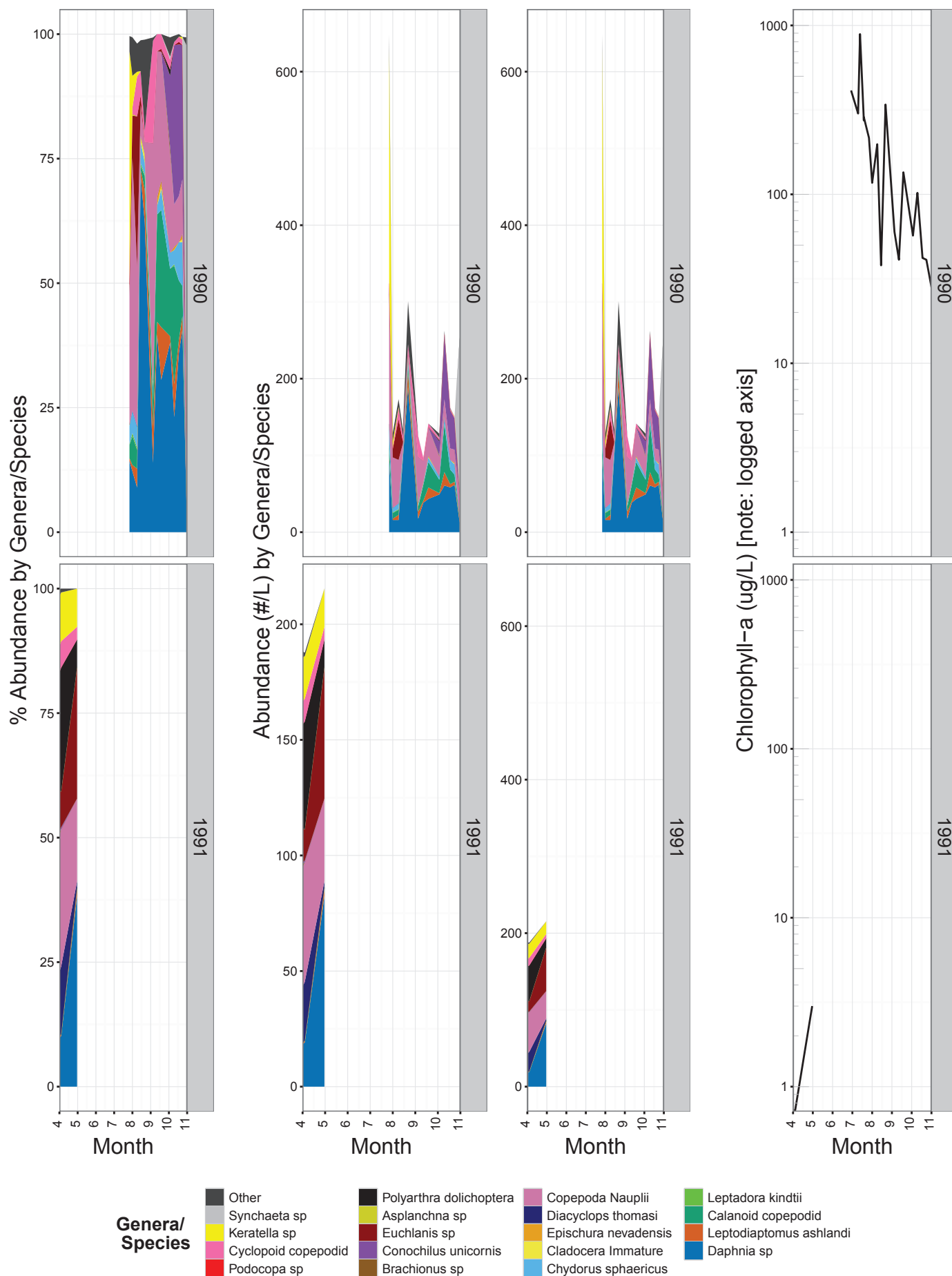
Zoop Genera/Species and Chlorophyll-a: SB (UKL @ Shoal Water Bay), Apr-Oct



Zoop Genera/Species and Chlorophyll-a: WB (UKL @ Wocus Bay), Apr-Oct

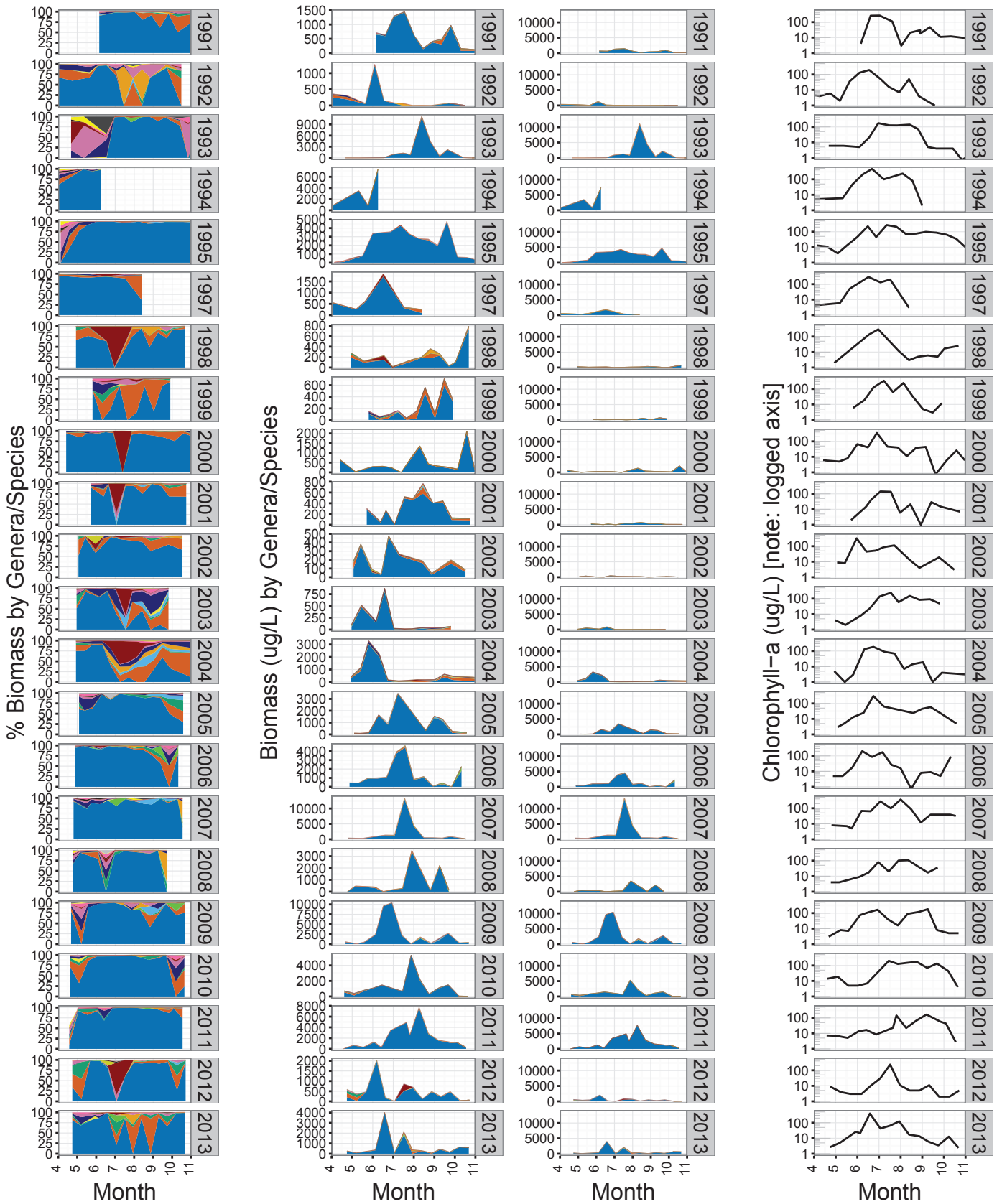


Zoop Genera/Species and Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct



**APPENDIX J: DETAILED TIME SERIES CHARTS OF BIOMASS FOR ZOOPLANKTON
MAJOR GENERA/SPECIES FOR EACH SITE**

Zoop Genera/Species and Chlorophyll-a: AN (UKL @ Agency Lake North), Apr-Oct



% Biomass by Genera/Species

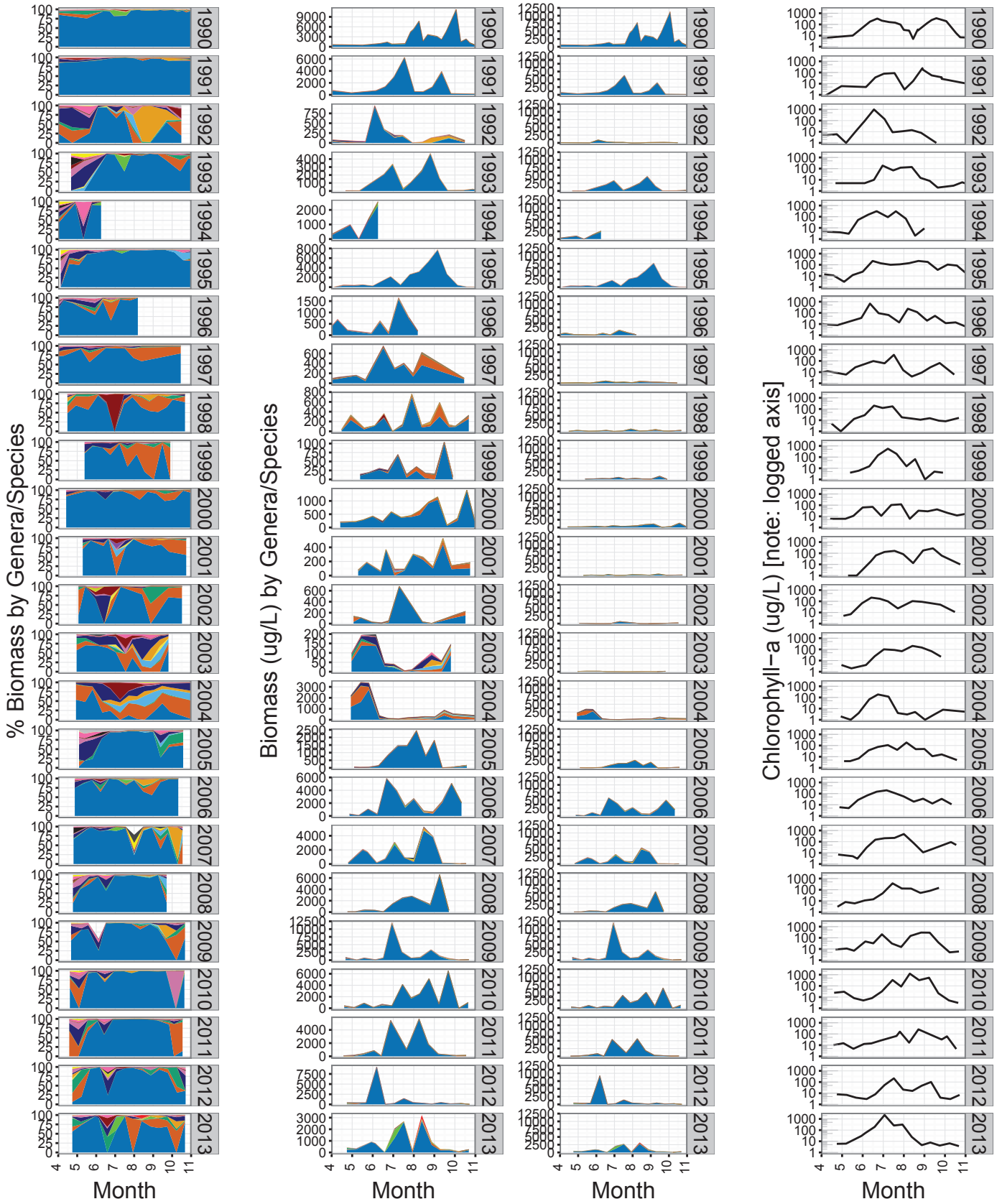
Biomass (ug) (by Genera/Species)

Chlorophyll-a (ug/L) [note : logged axis]

**Genera/
Species**

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiatomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

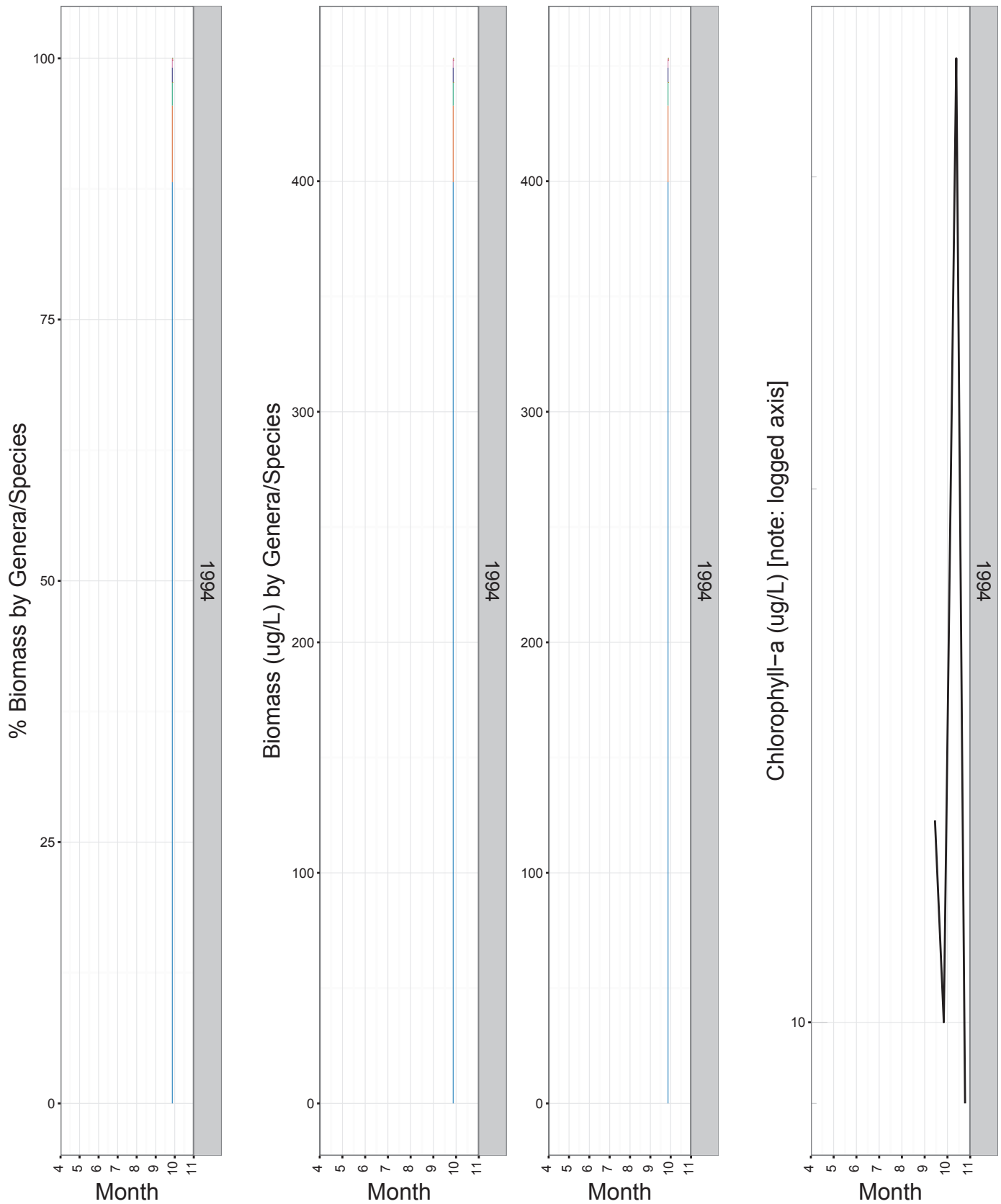
Zoop Genera/Species and Chlorophyll-a: AS (UKL @ Agency Lake South), Apr-Oct



**Genera/
Species**

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiatomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

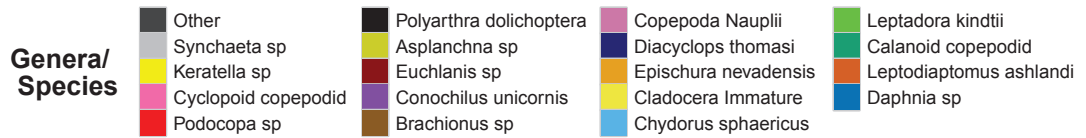
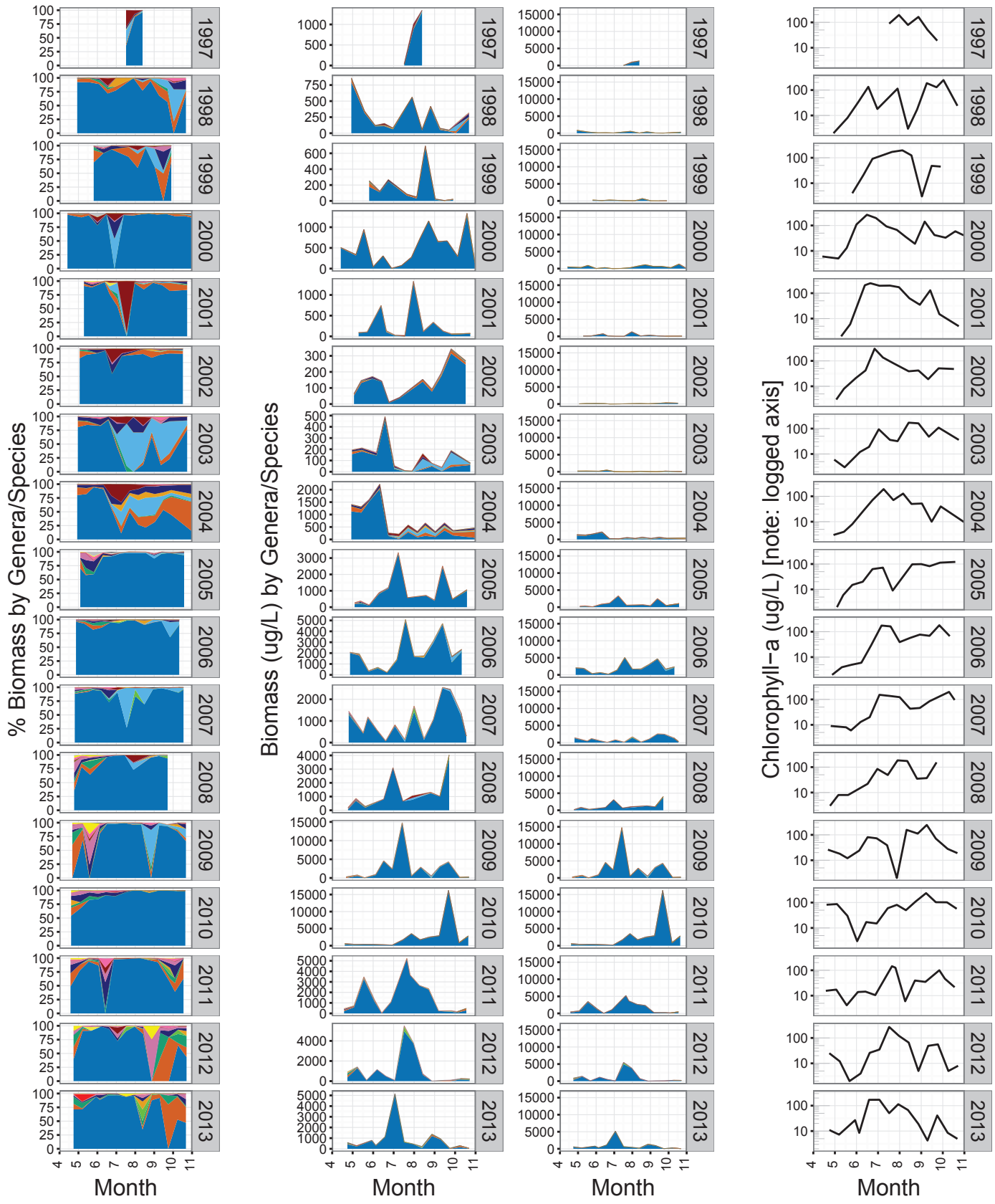
Zoop Genera/Species and Chlorophyll-a: ASJ (UKL @ Agency Jake's (very close to WS)), Apr-Oct



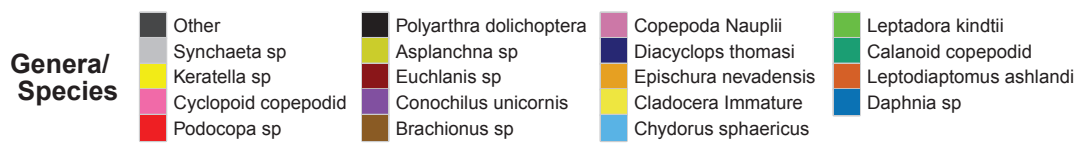
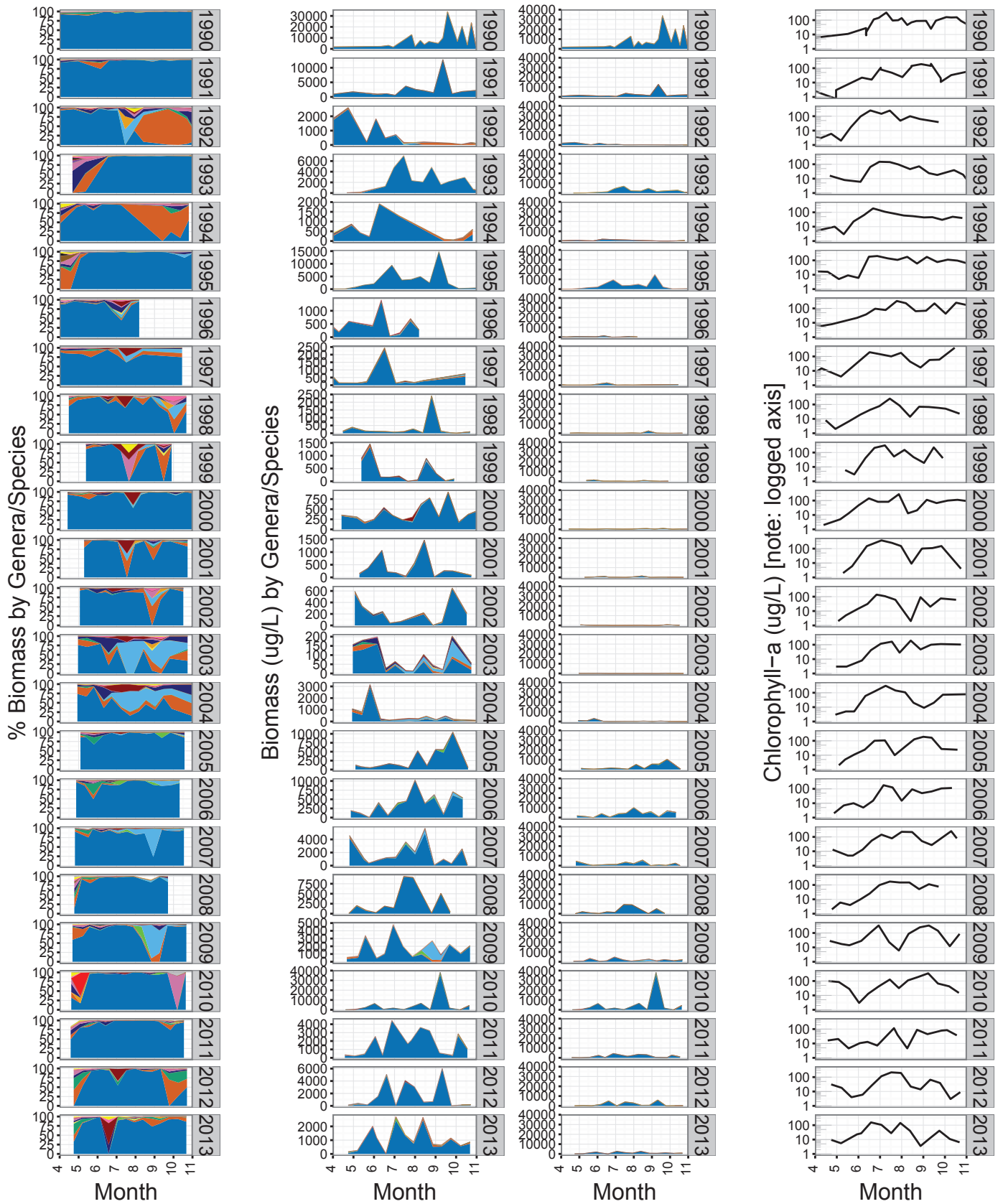
Genera/Species

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiptomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

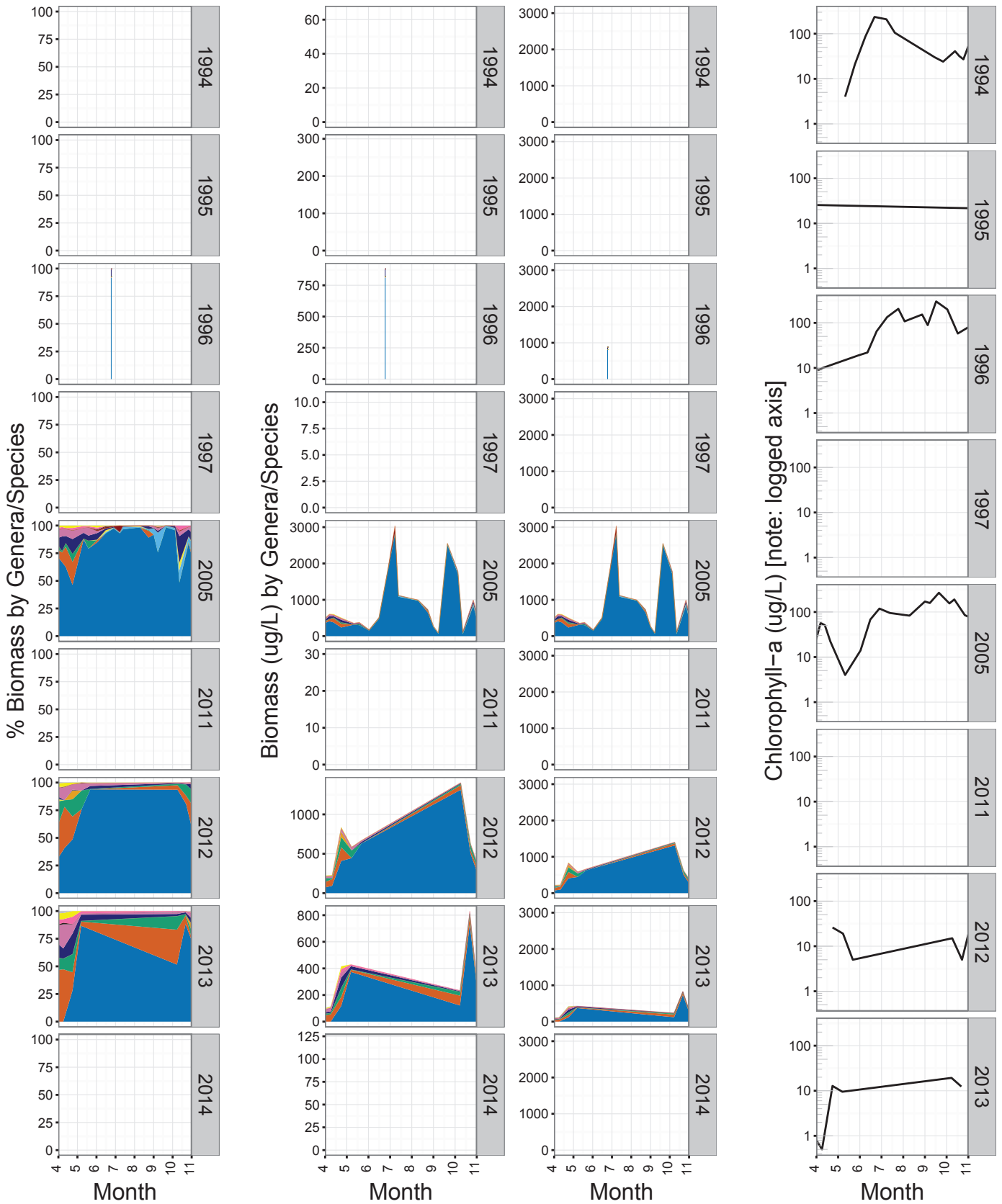
Zoop Genera/Species and Chlorophyll-a: CP (UKL @ Coon Point), Apr-Oct



Zoop Genera/Species and Chlorophyll-a: ER (UKL @ Eagle Ridge), Apr-Oct



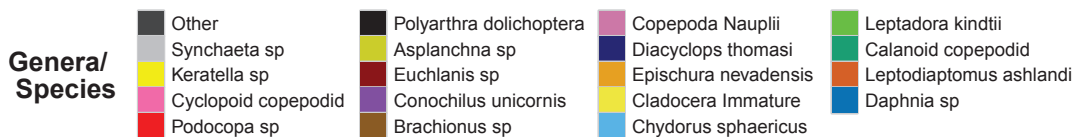
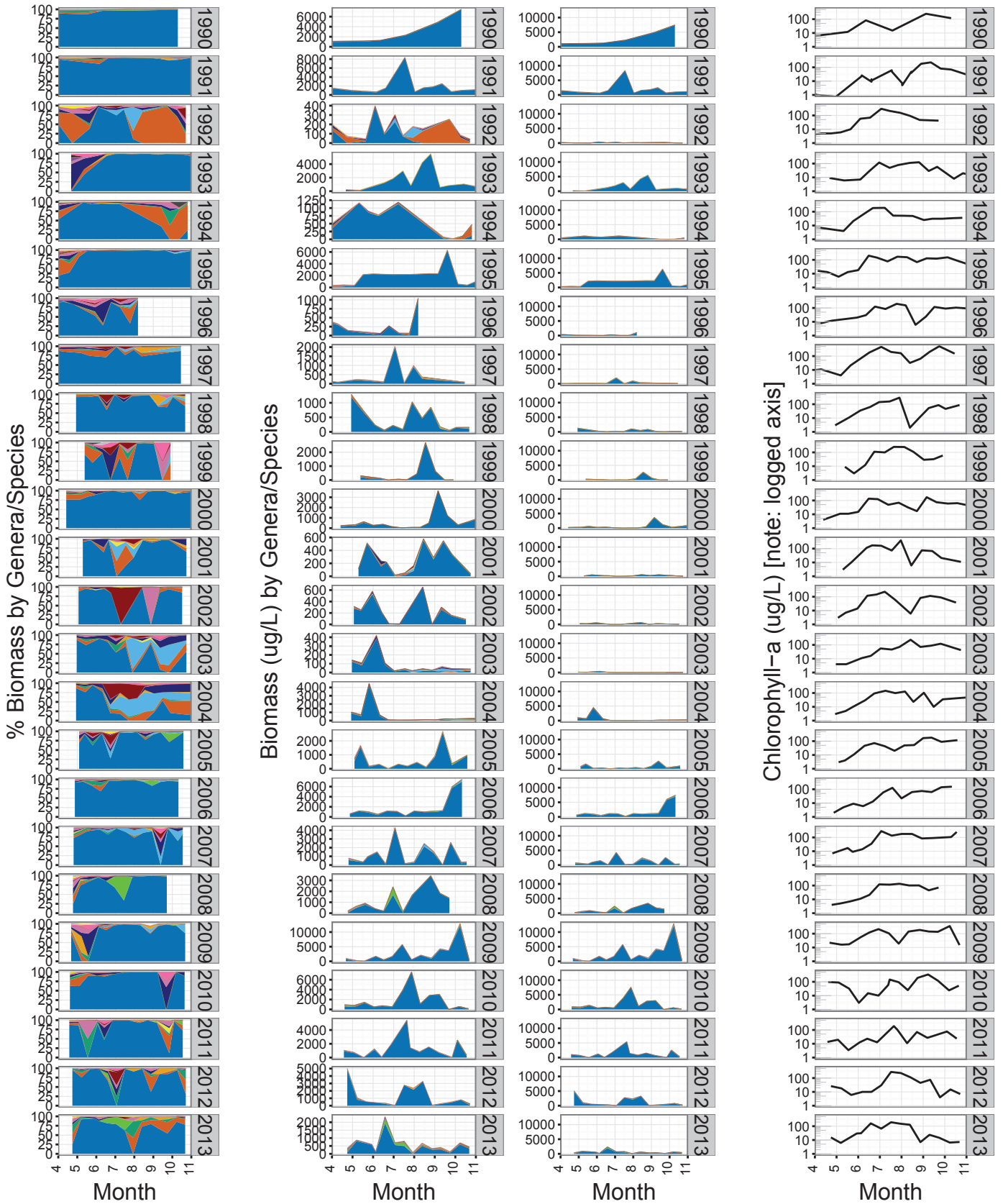
Zoop Genera/Species and Chlorophyll-a: FB (UKL @ Link/Freemont Bridge), Apr-Oct



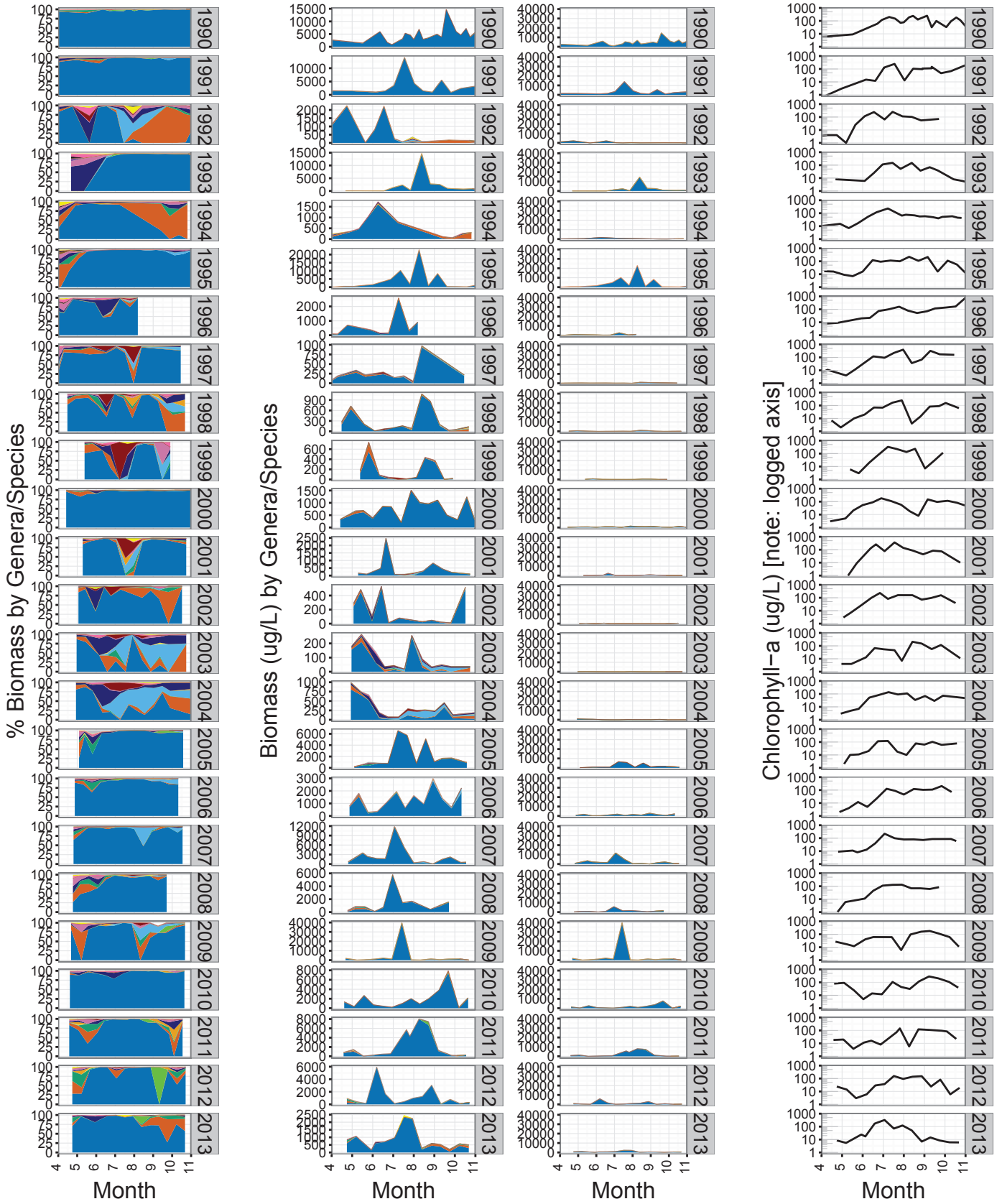
General/Species

- | | | | |
|---------------------|-------------------------|----------------------|-------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiaptomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

Zoop Genera/Species and Chlorophyll-a: ML (UKL @ Mid-Lake), Apr-Oct



Zoop Genera/Species and Chlorophyll-a: MN (UKL @ Mid-Lake North), Apr-Oct



% Biomass by Genera/Species

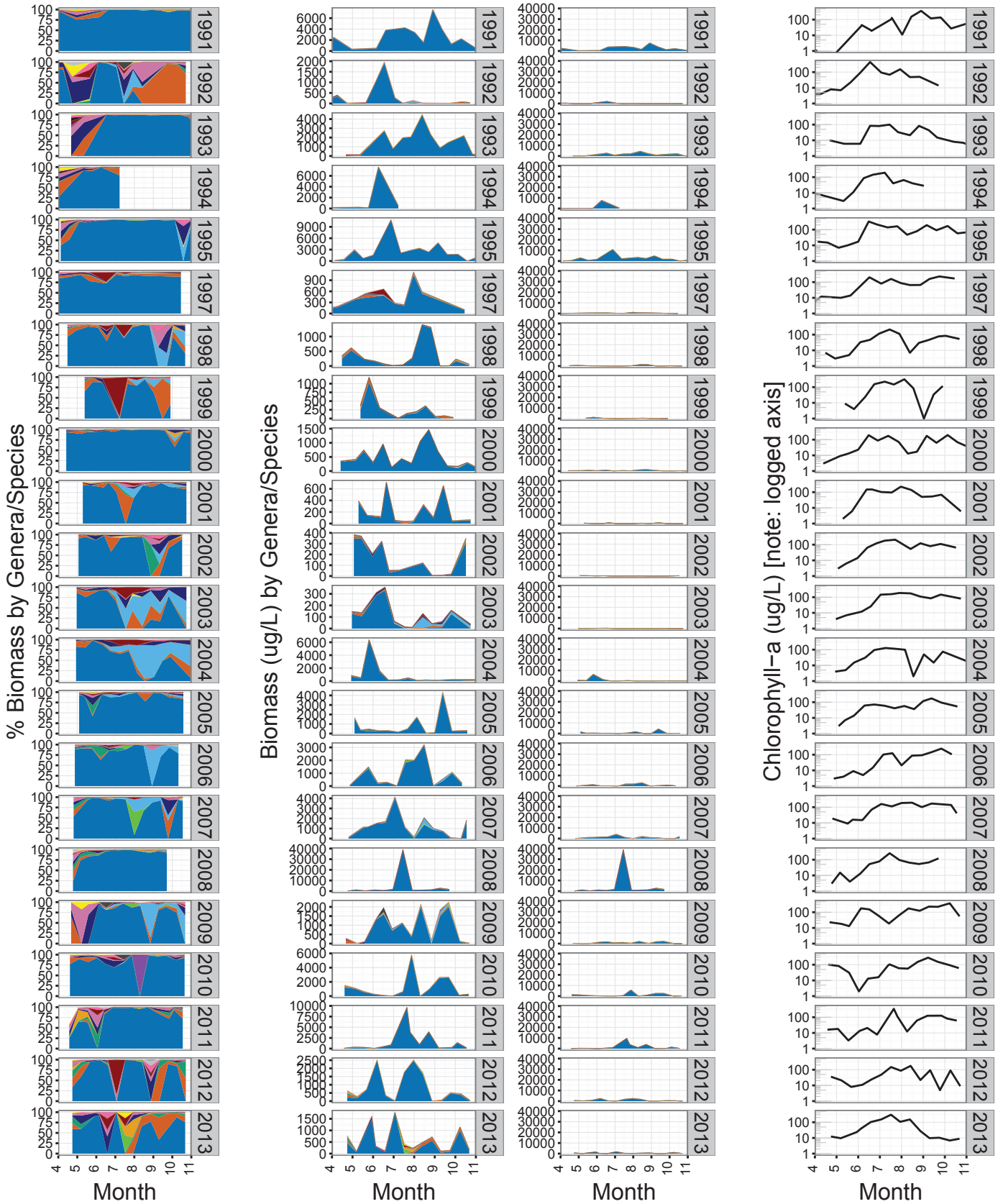
Biomass (ug/L) by Genera/Species

Chlorophyll-a (ug/L) [note :logged axis]

Genera/Species

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptodora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiptomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

Zoop Genera/Species and Chlorophyll-a: NB (UKL @ North Buck Island), Apr-Oct



Biomass by Genera/Species

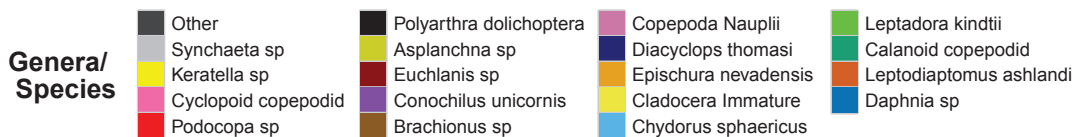
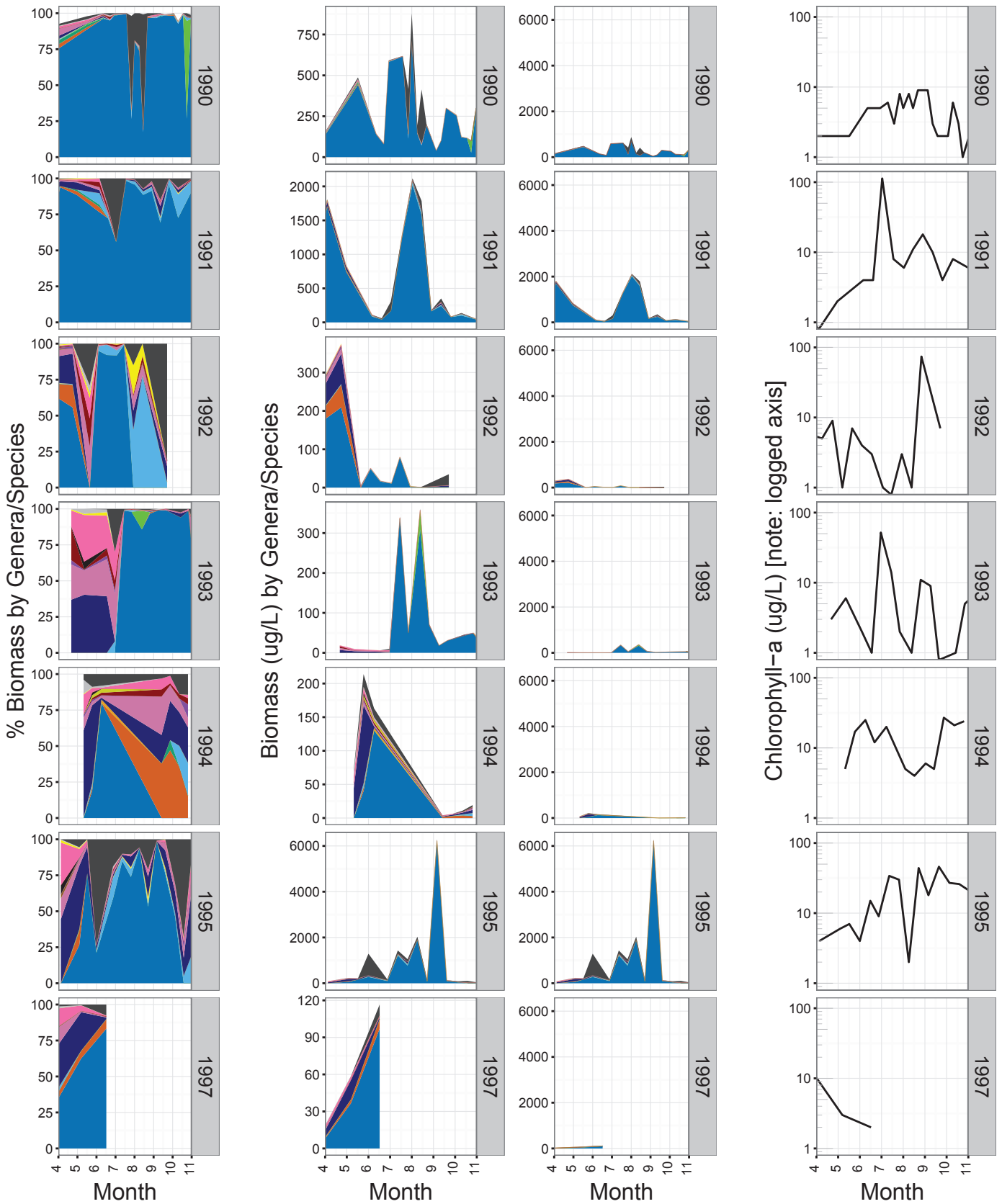
Biomass (ug) by Genera/Species

Chlorophyll-a [note :logged axis] (T/g/n)

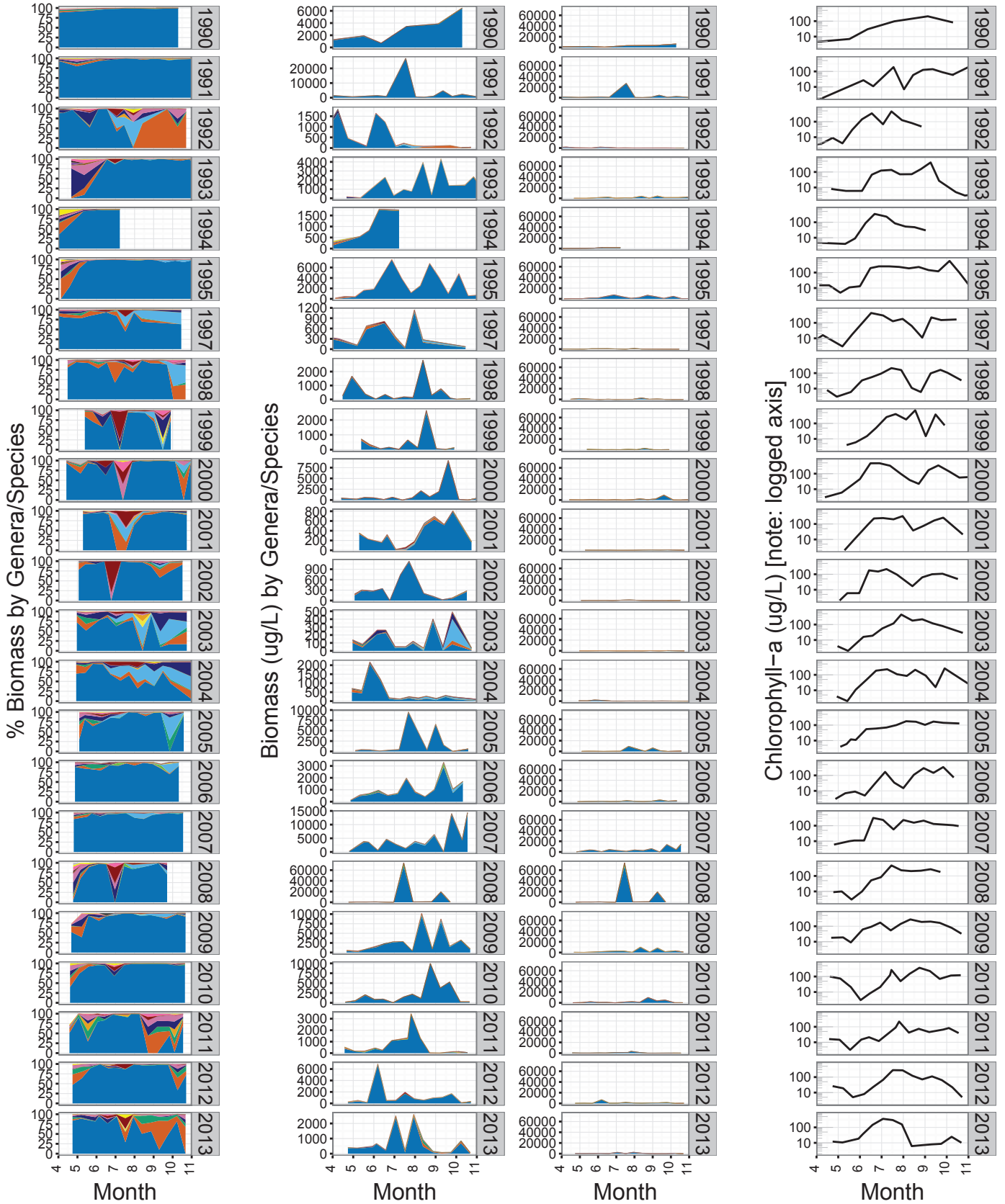
Genera/Species

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiatomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

Zoop Genera/Species and Chlorophyll-a: PB (UKL @ Pelican Bay), Apr-Oct



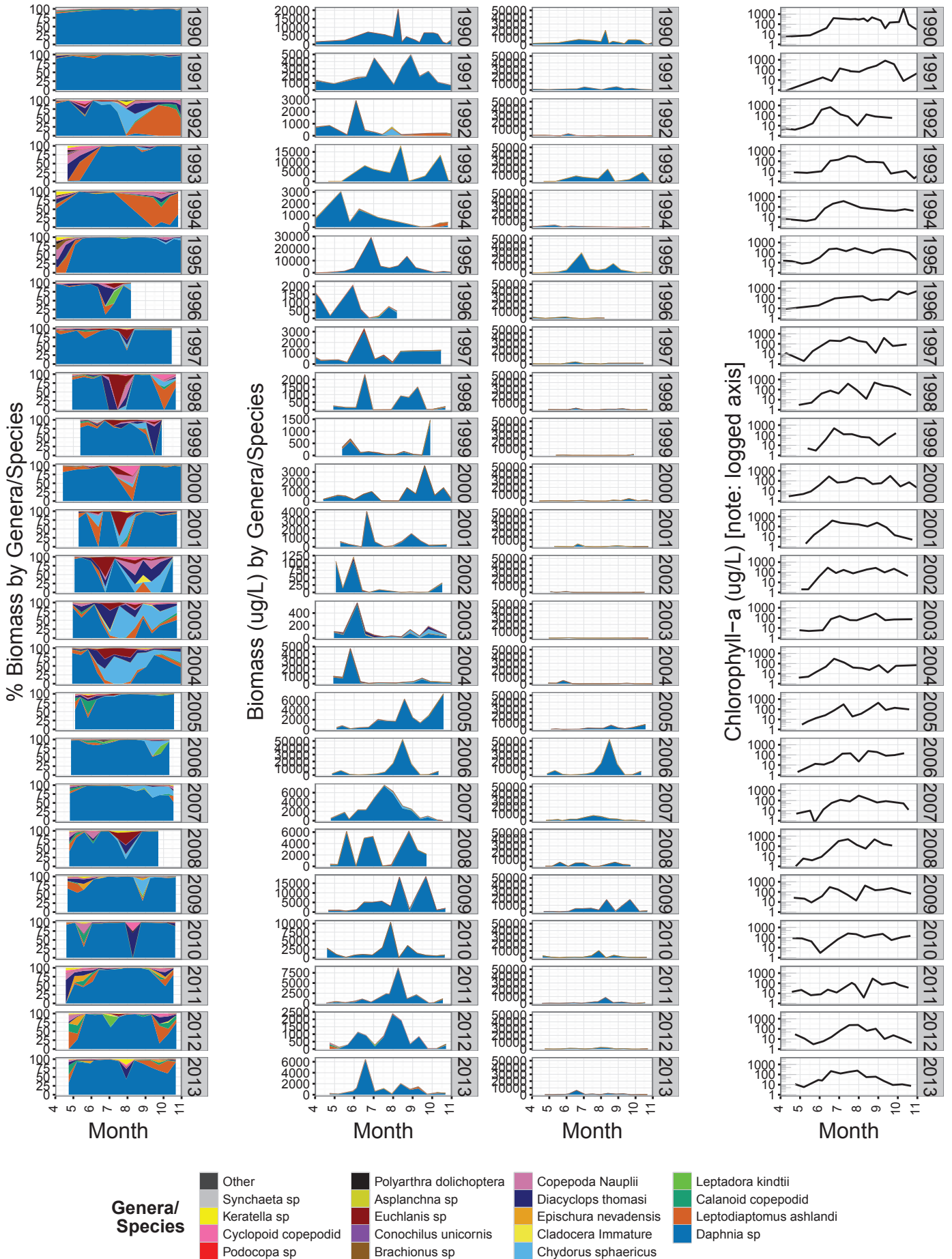
Zoop Genera/Species and Chlorophyll-a: PM (UKL @ Pelican Marina), Apr-Oct



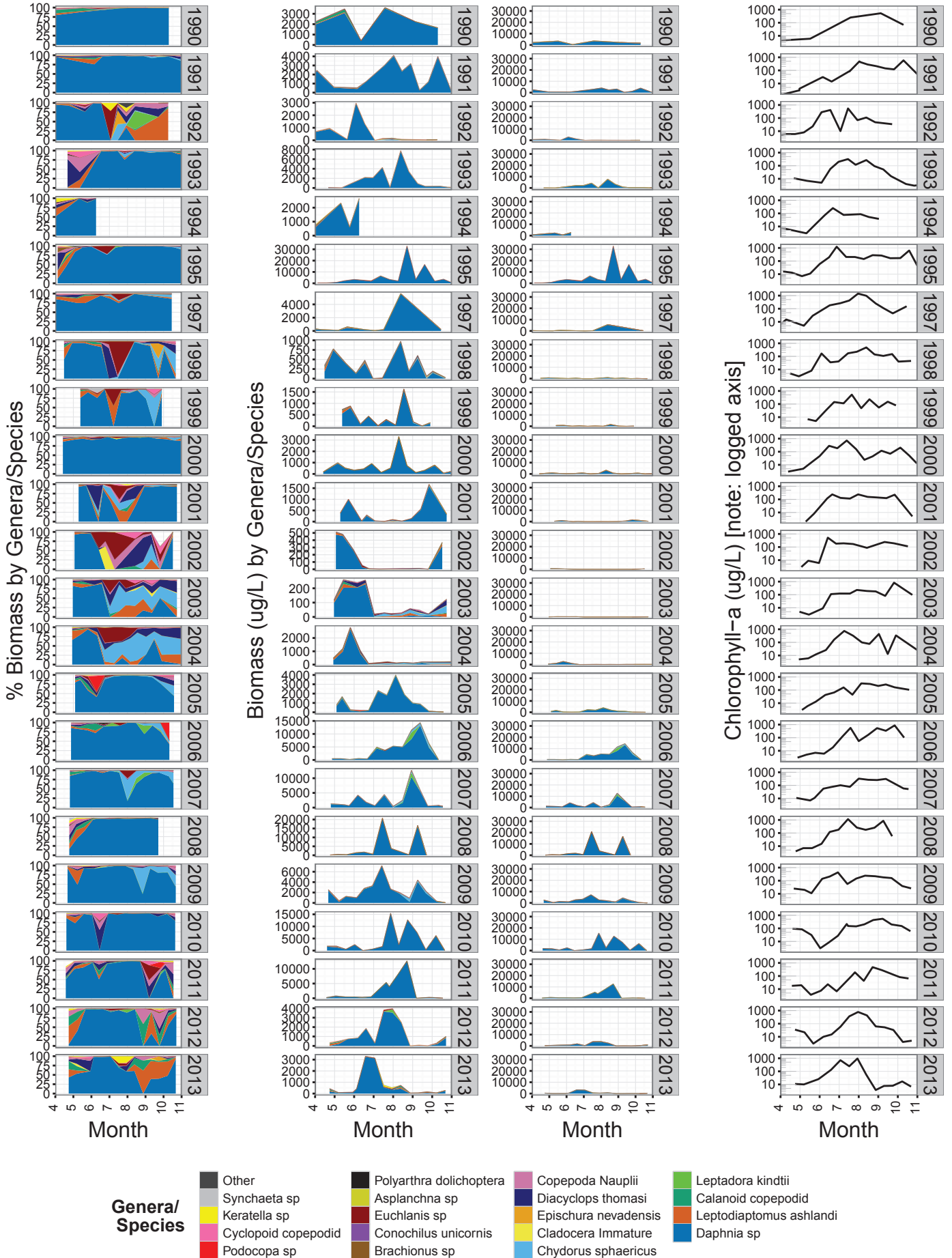
Genera/Species

- | | | | |
|---------------------|-------------------------|----------------------|------------------------|
| Other | Polyarthra dolichoptera | Copepoda Nauplii | Leptadora kindtii |
| Synchaeta sp | Asplanchna sp | Diacyclops thomasi | Calanoid copepodid |
| Keratella sp | Euchlanis sp | Epischura nevadensis | Leptodiatomus ashlandi |
| Cyclopoid copepodid | Conochilus unicornis | Cladocera Immature | Daphnia sp |
| Podocopa sp | Brachionus sp | Chydorus sphaericus | |

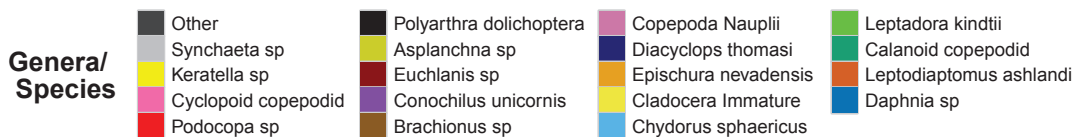
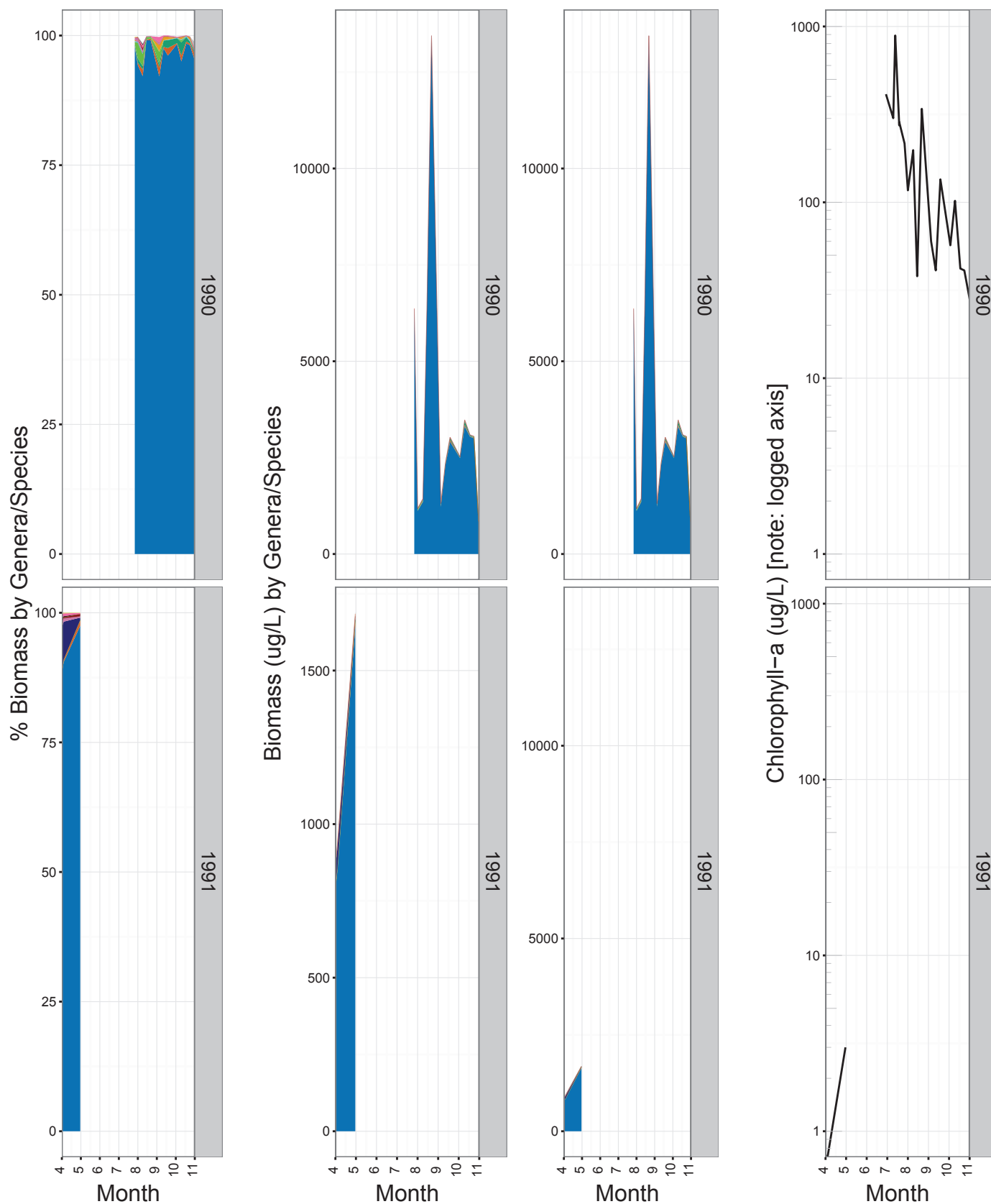
Zoop Genera/Species and Chlorophyll-a: SB (UKL @ Shoal Water Bay), Apr-Oct



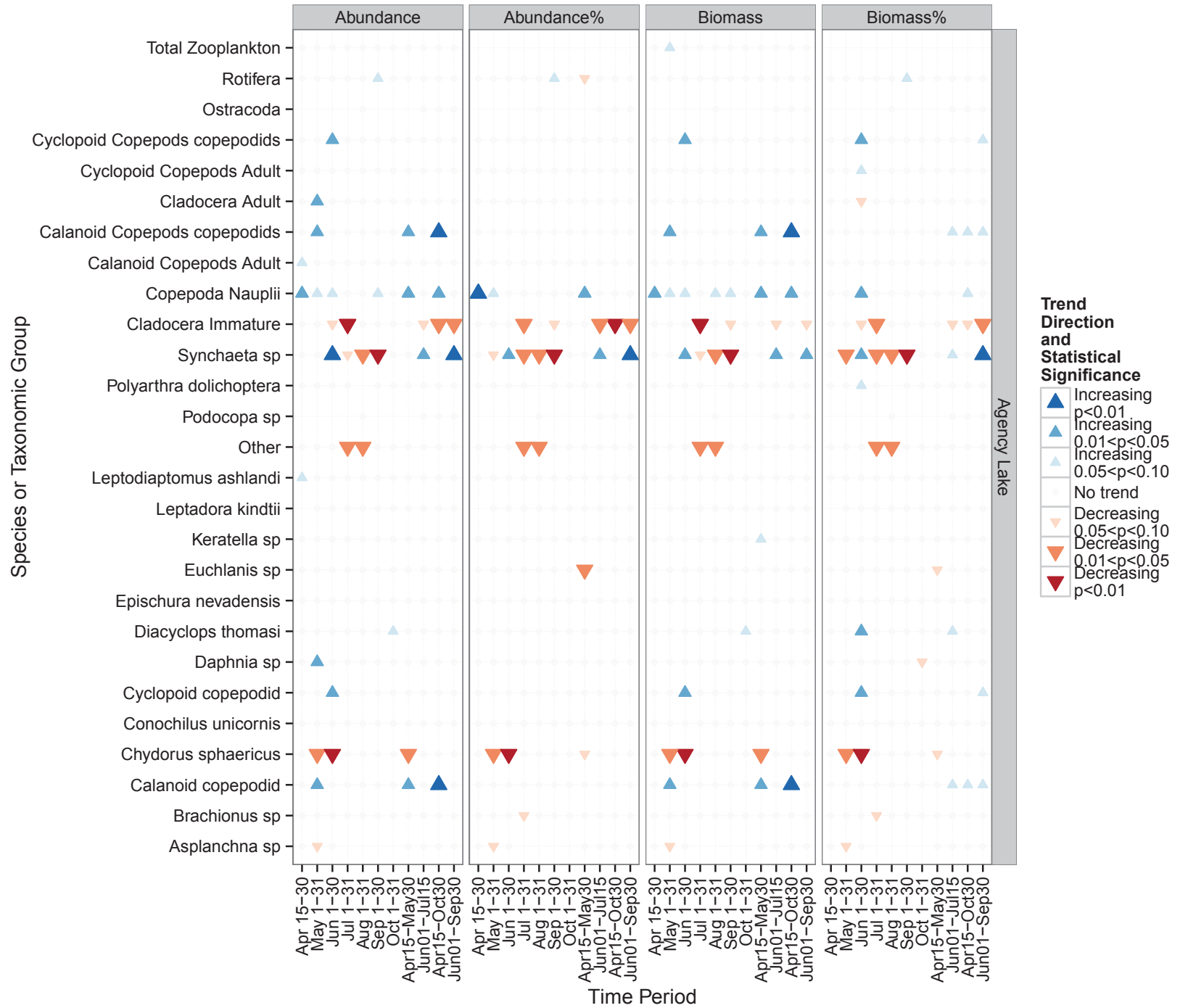
Zoop Genera/Species and Chlorophyll-a: WB (UKL @ Wocus Bay), Apr-Oct

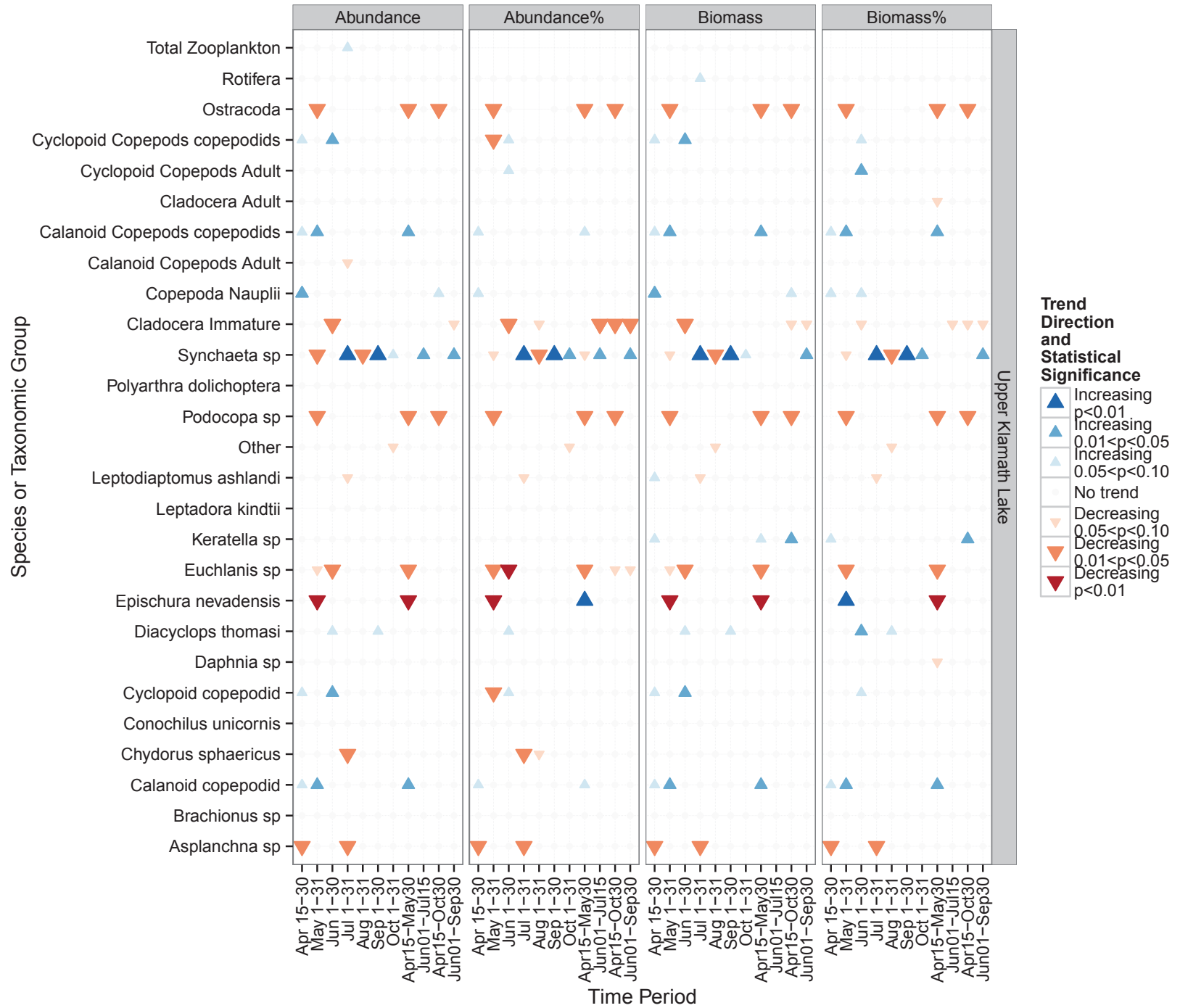


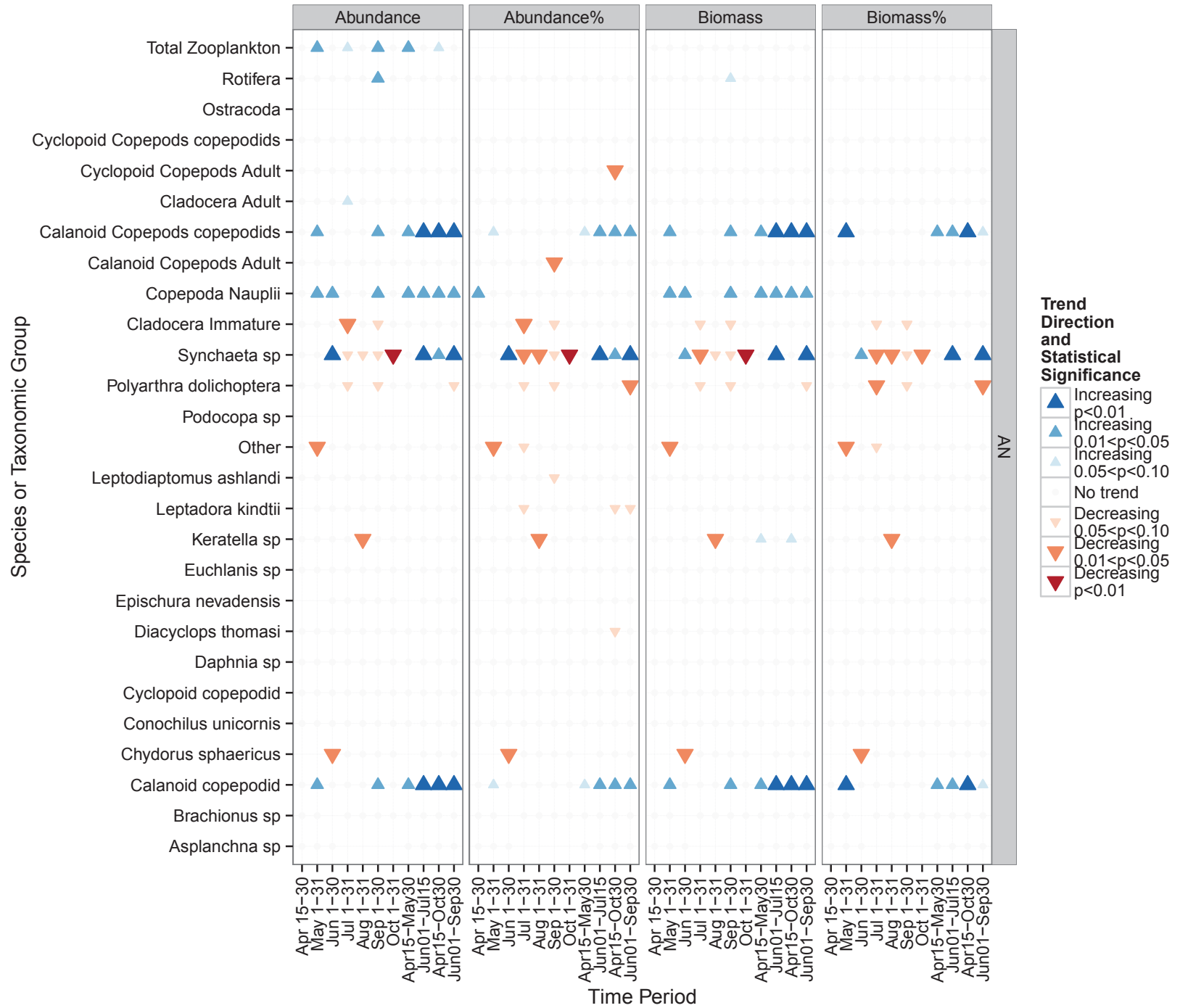
Zoop Genera/Species and Chlorophyll-a: WS (UKL @ Weather Station (very close to ASJ)), Apr-Oct

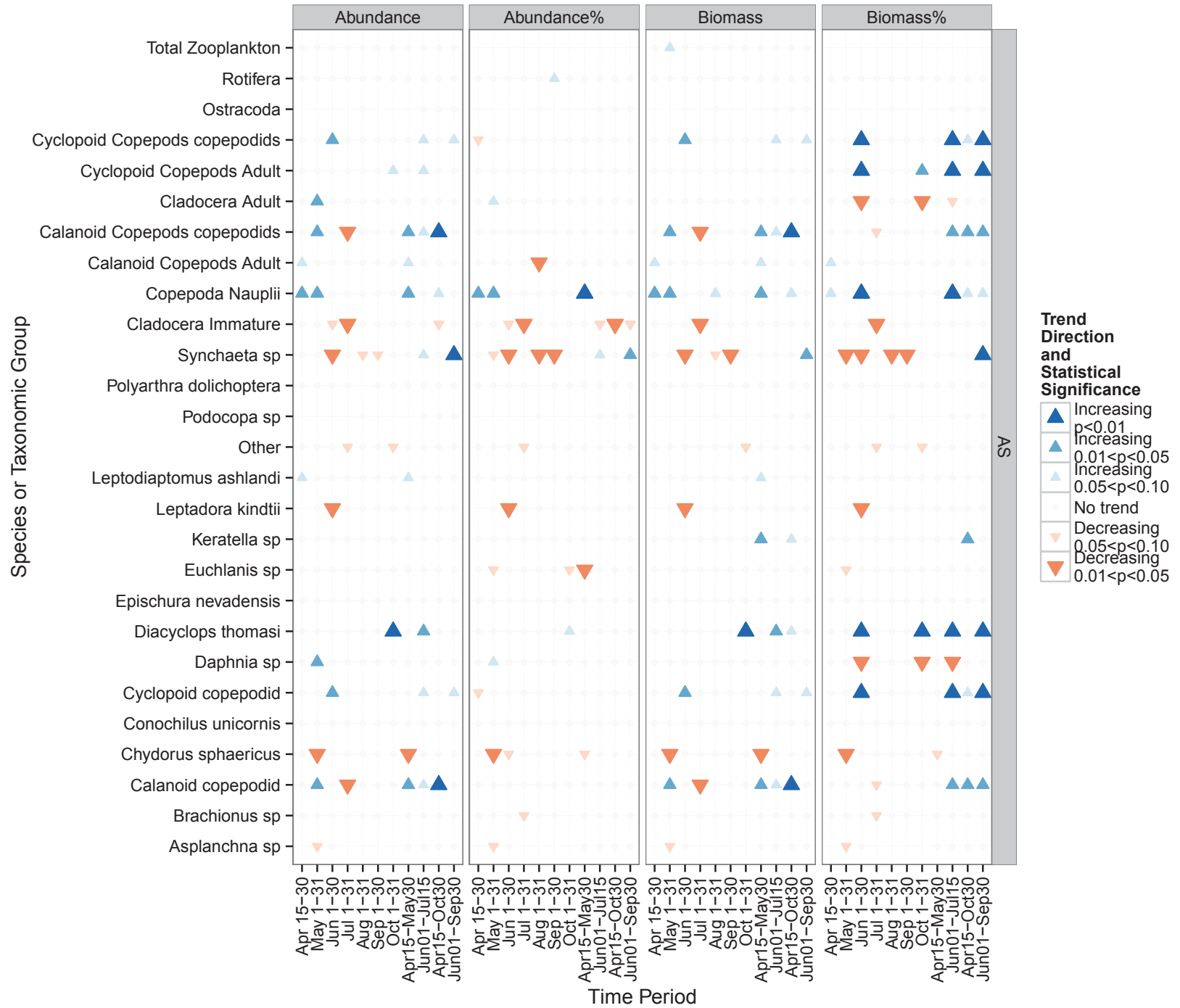


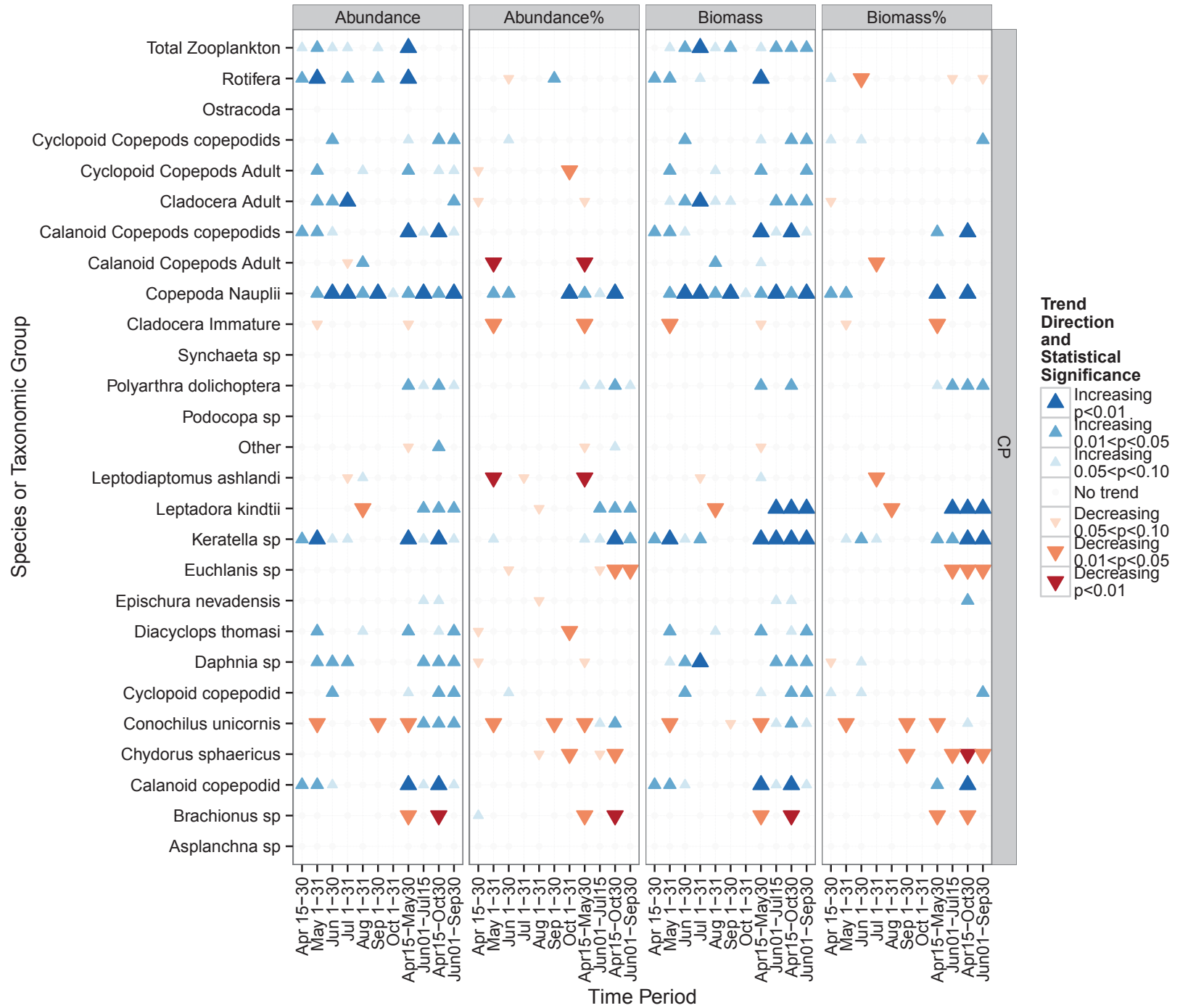
**APPENDIX K: LONG TERM TREND TESTS FOR ZOOPLANKTON TAXONOMIC GROUPS AND MAJOR
GENERA/SPECIES FOR EACH SITE**

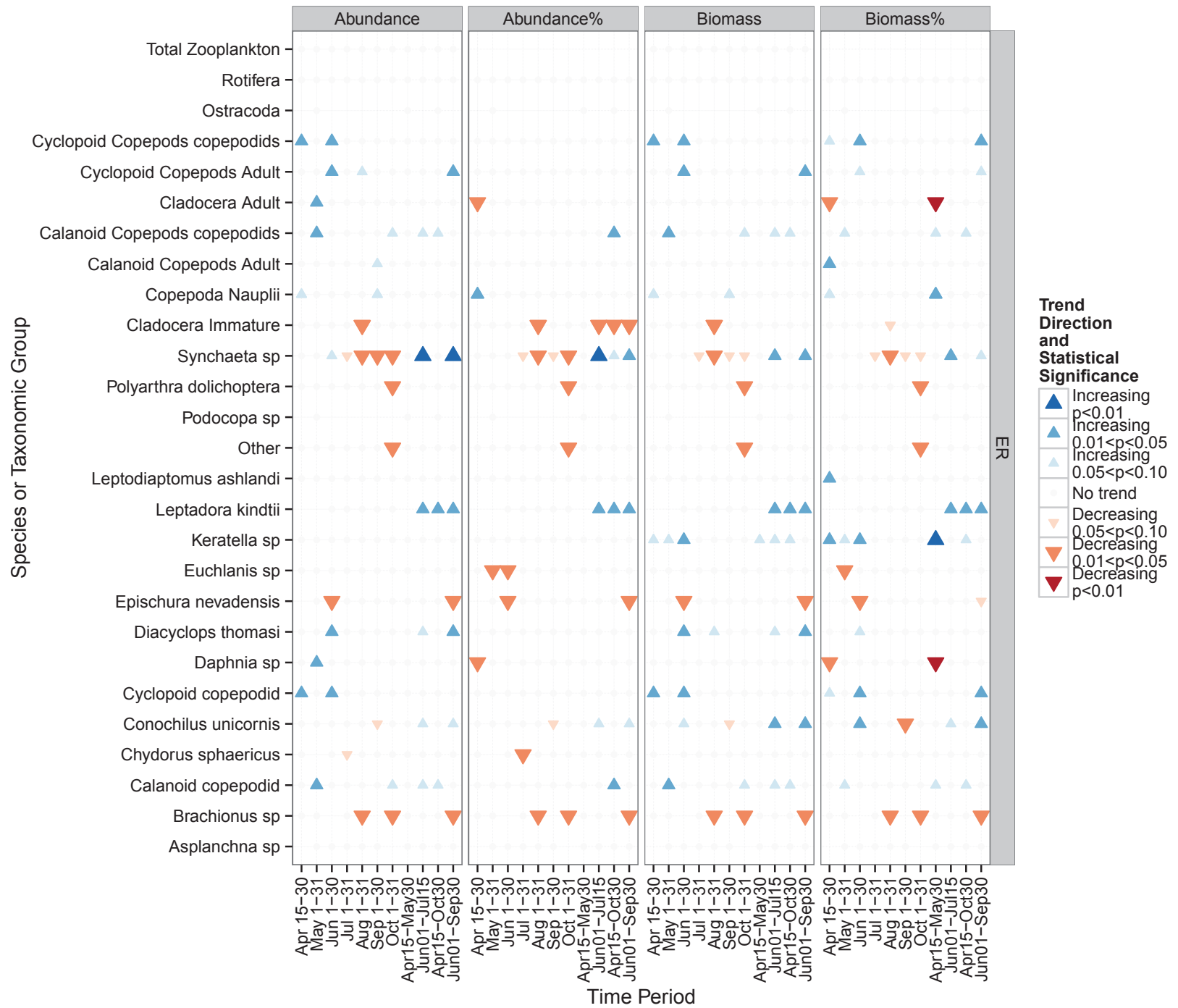


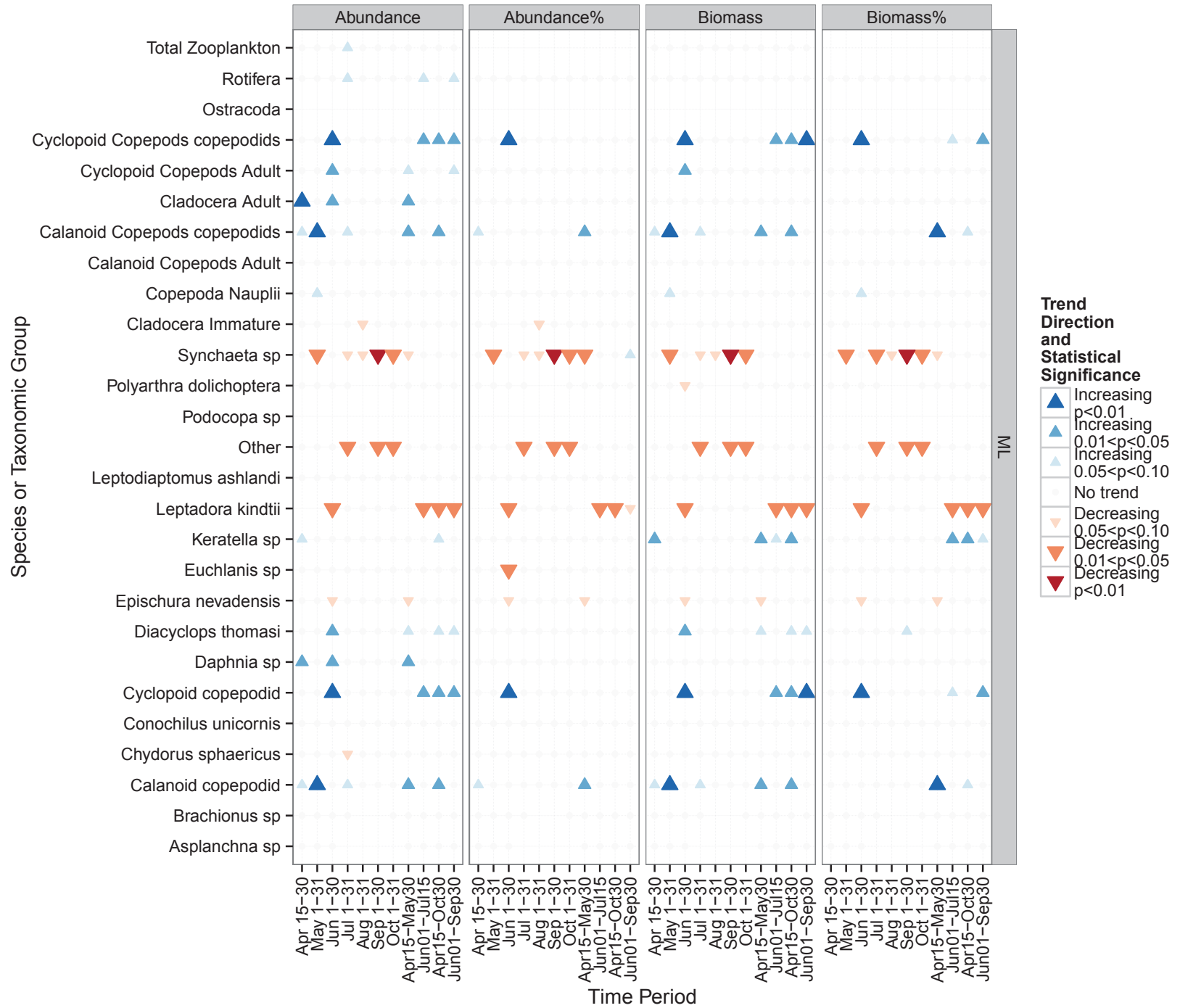


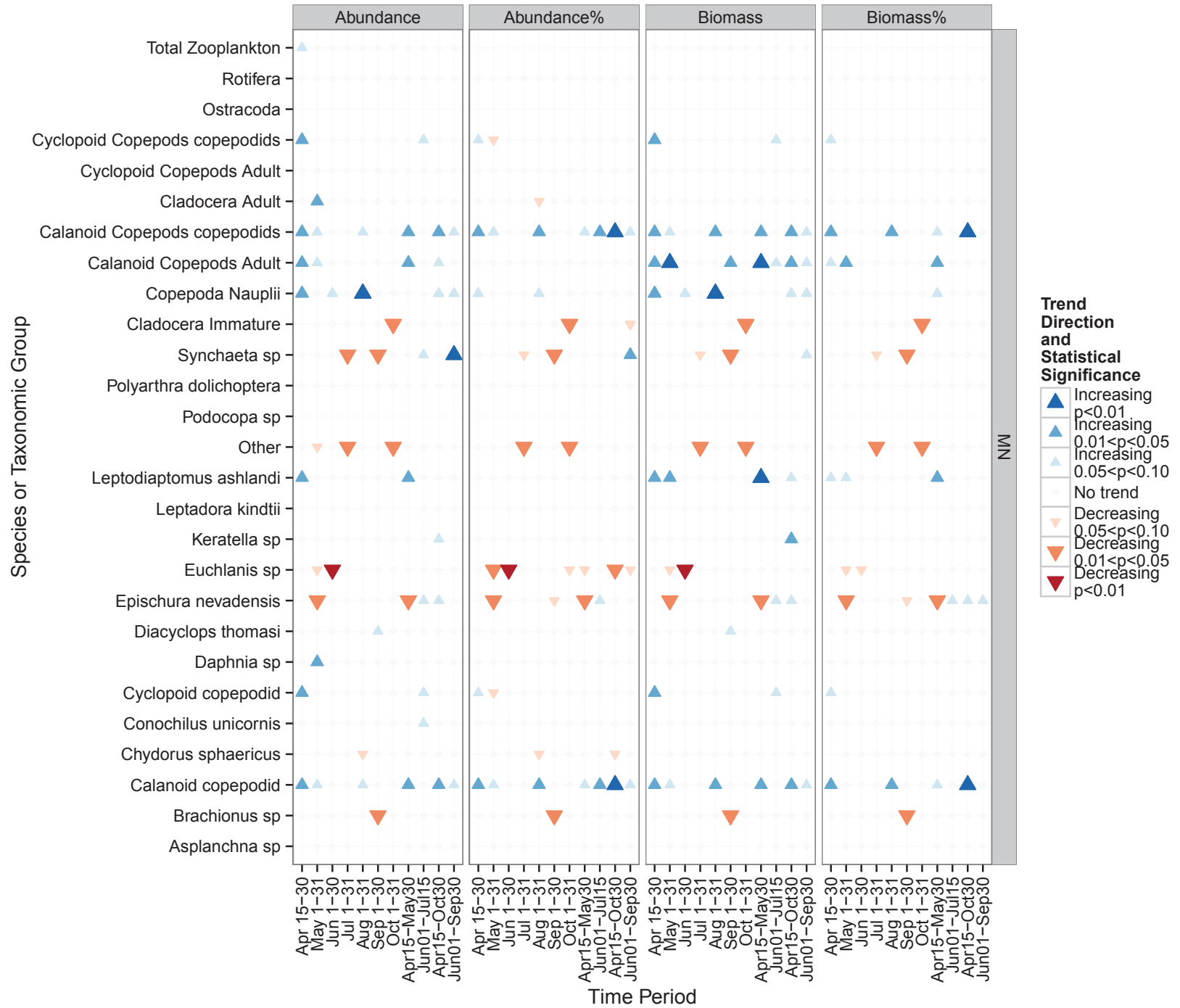


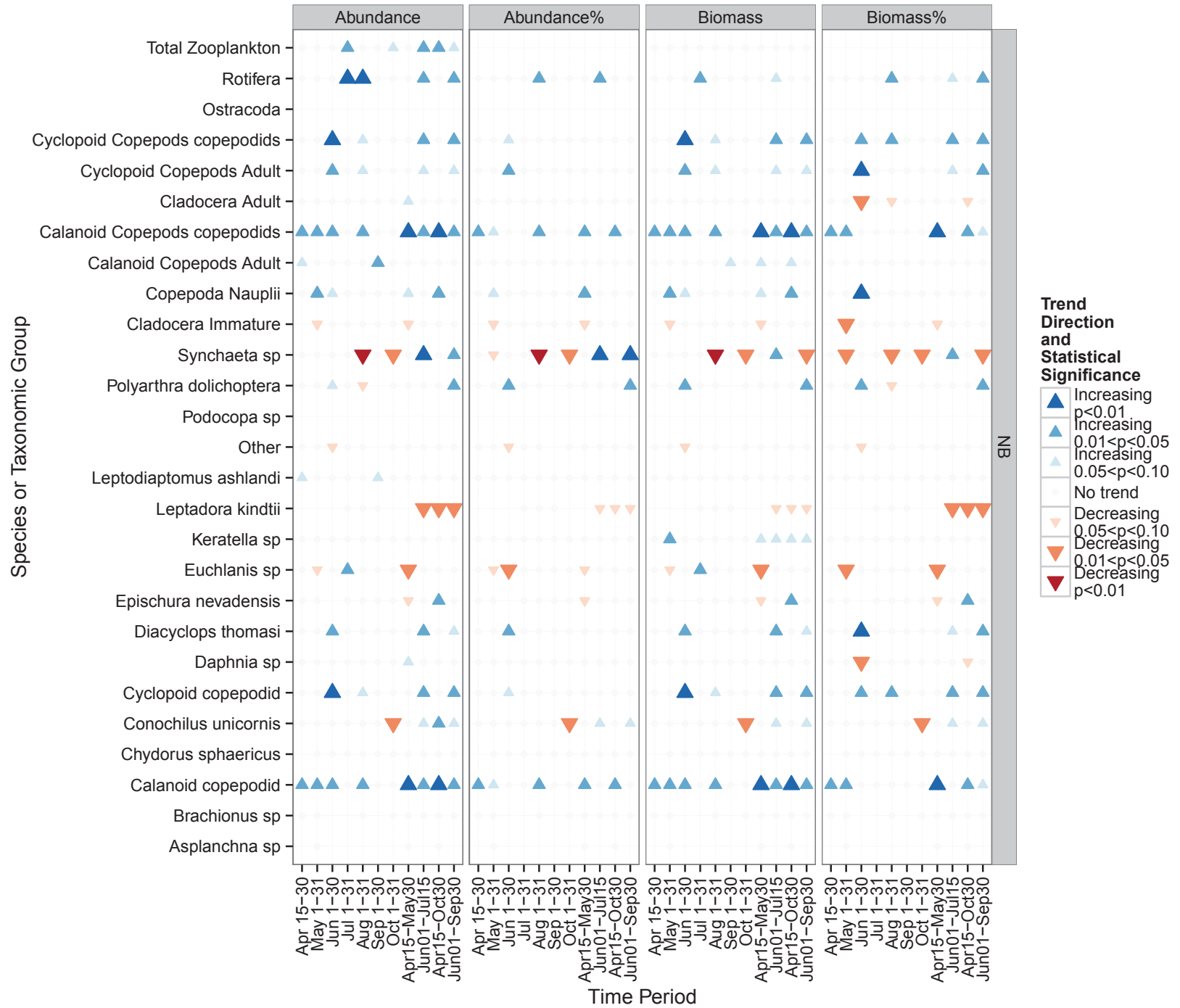


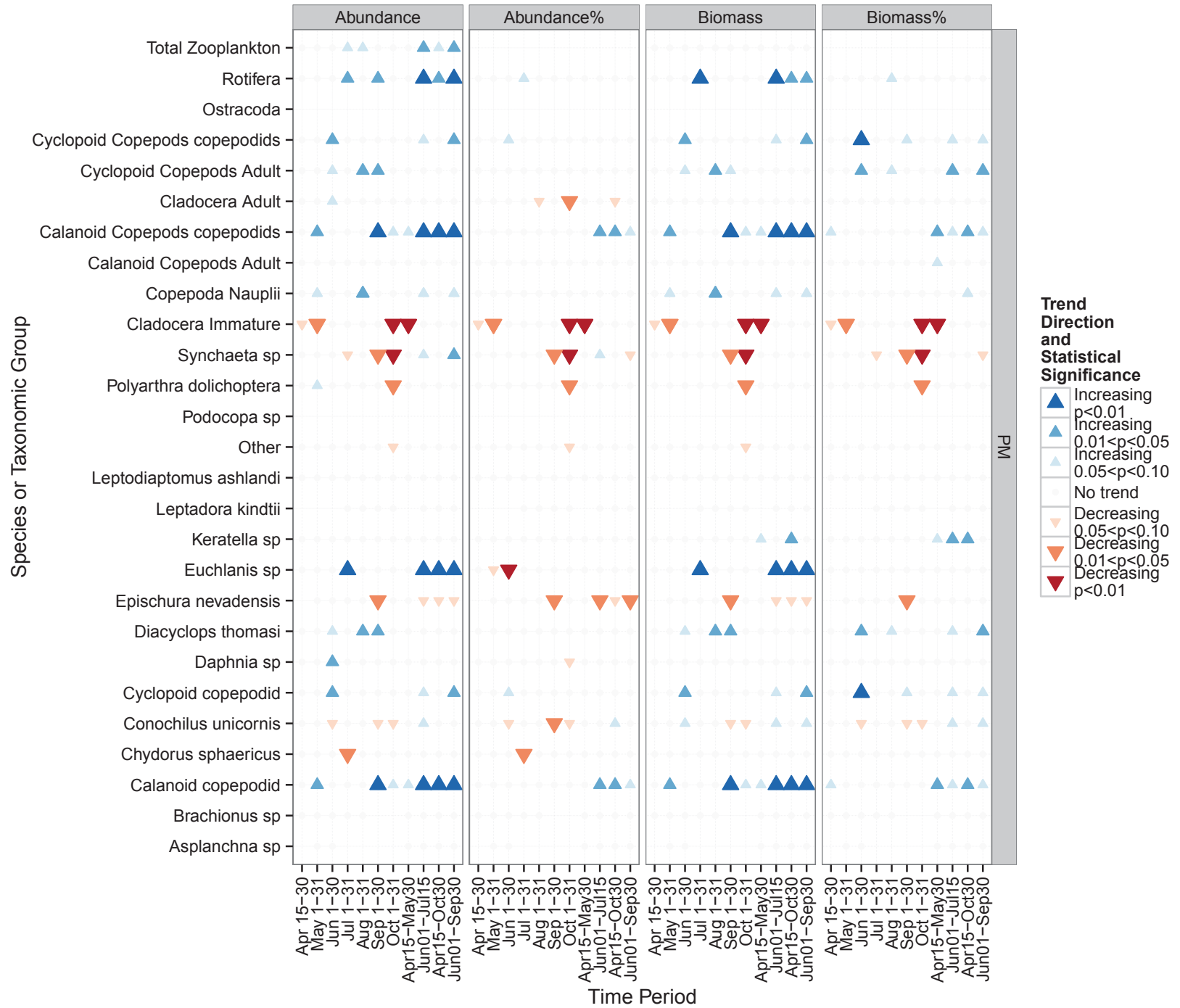


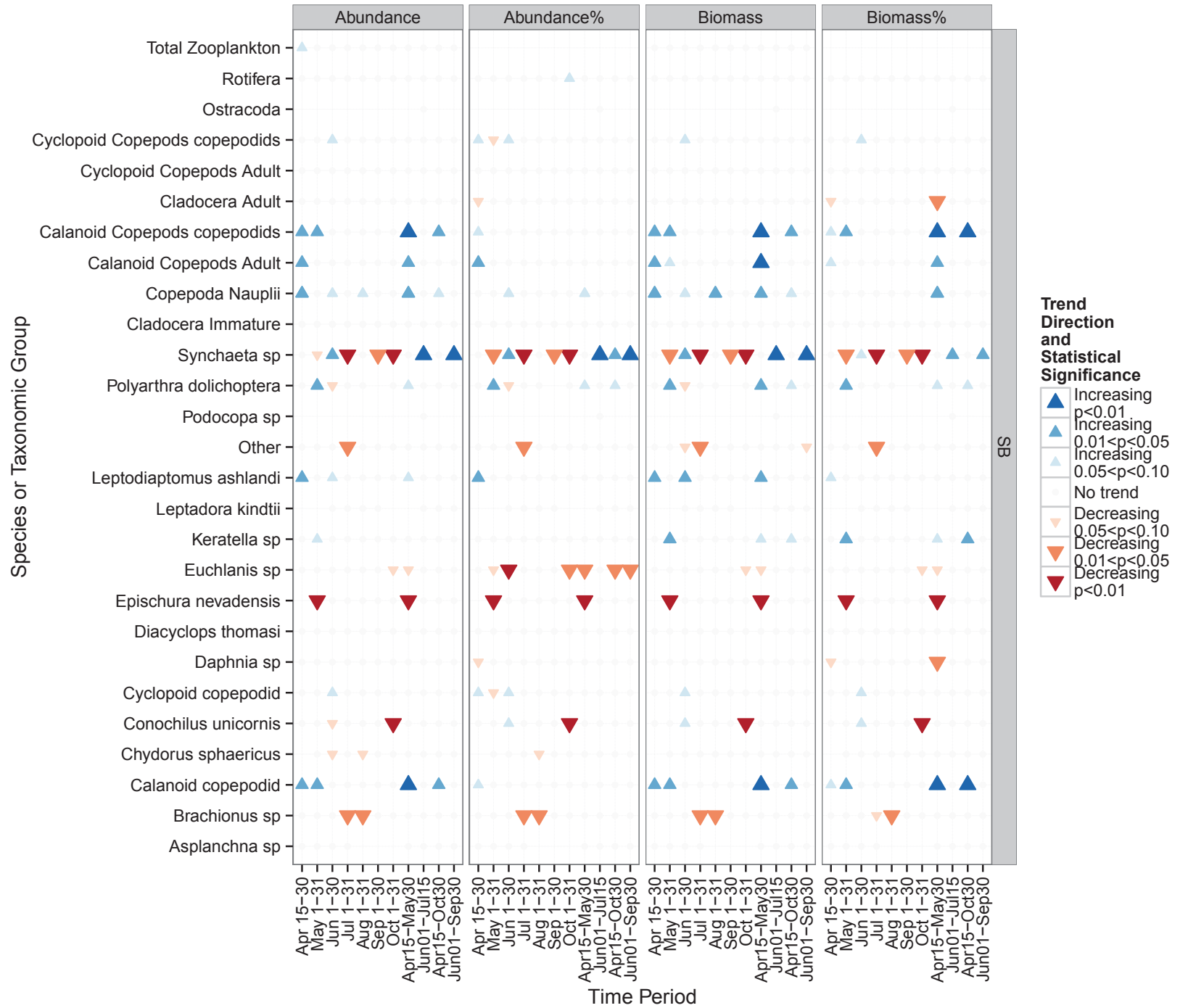


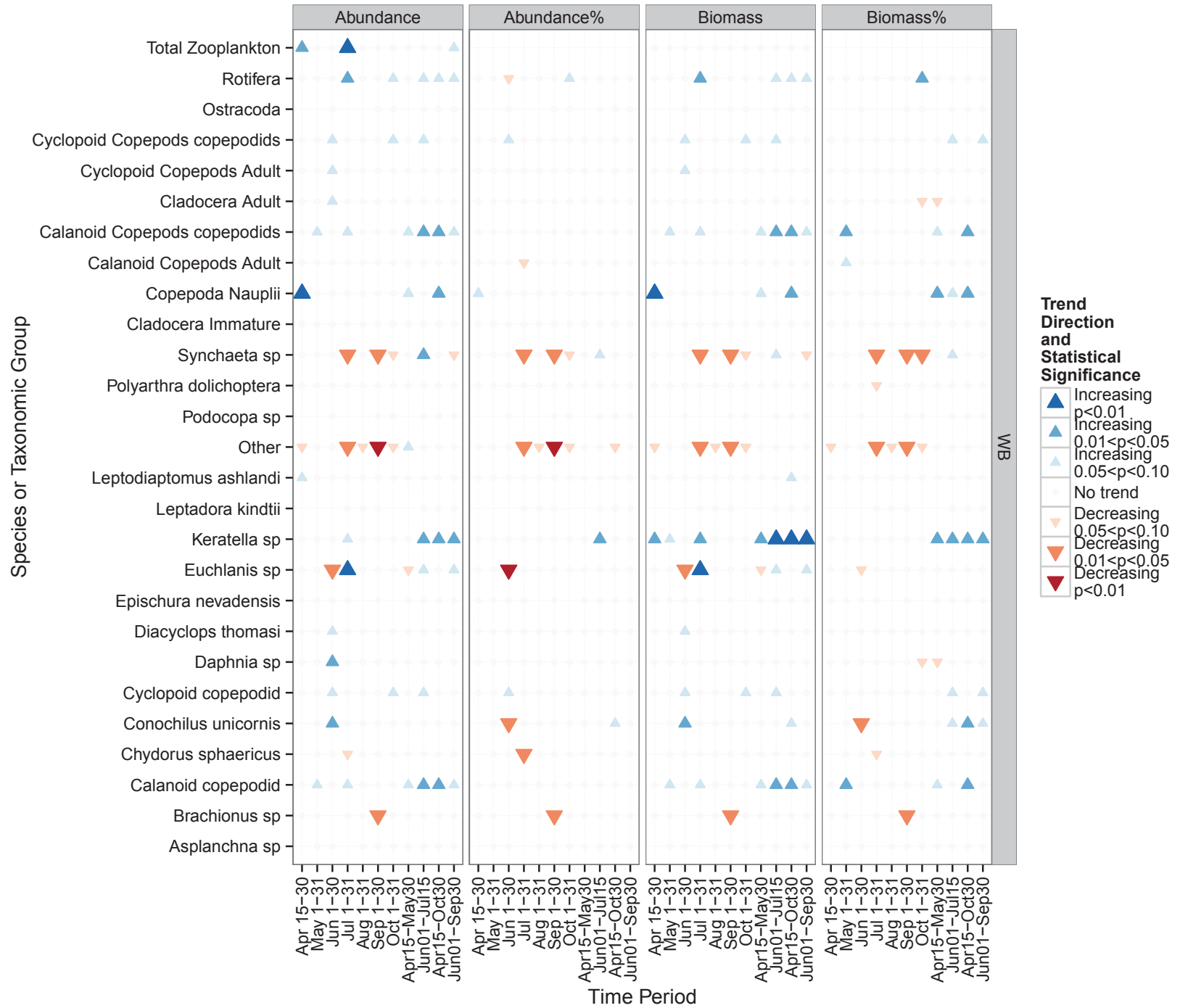






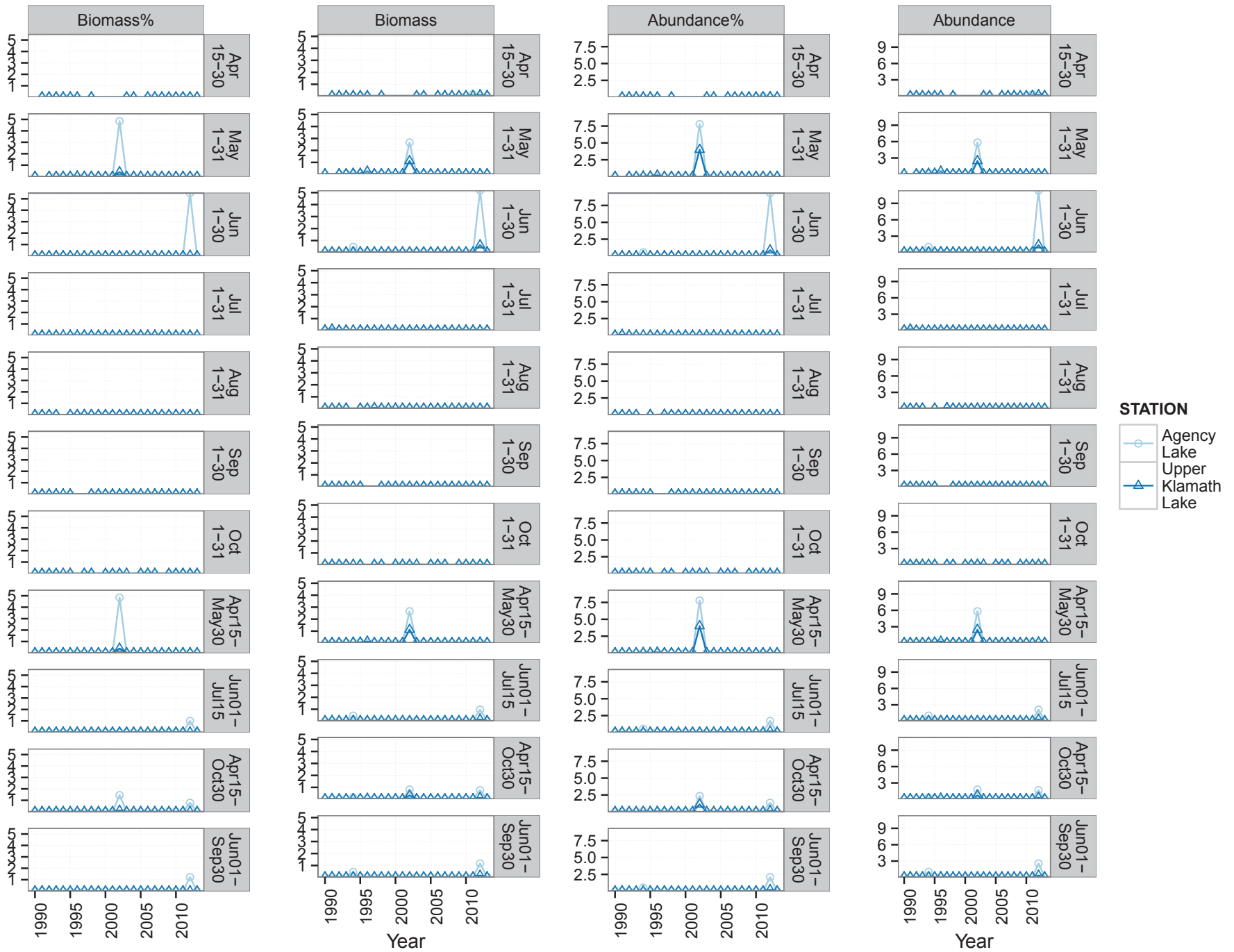




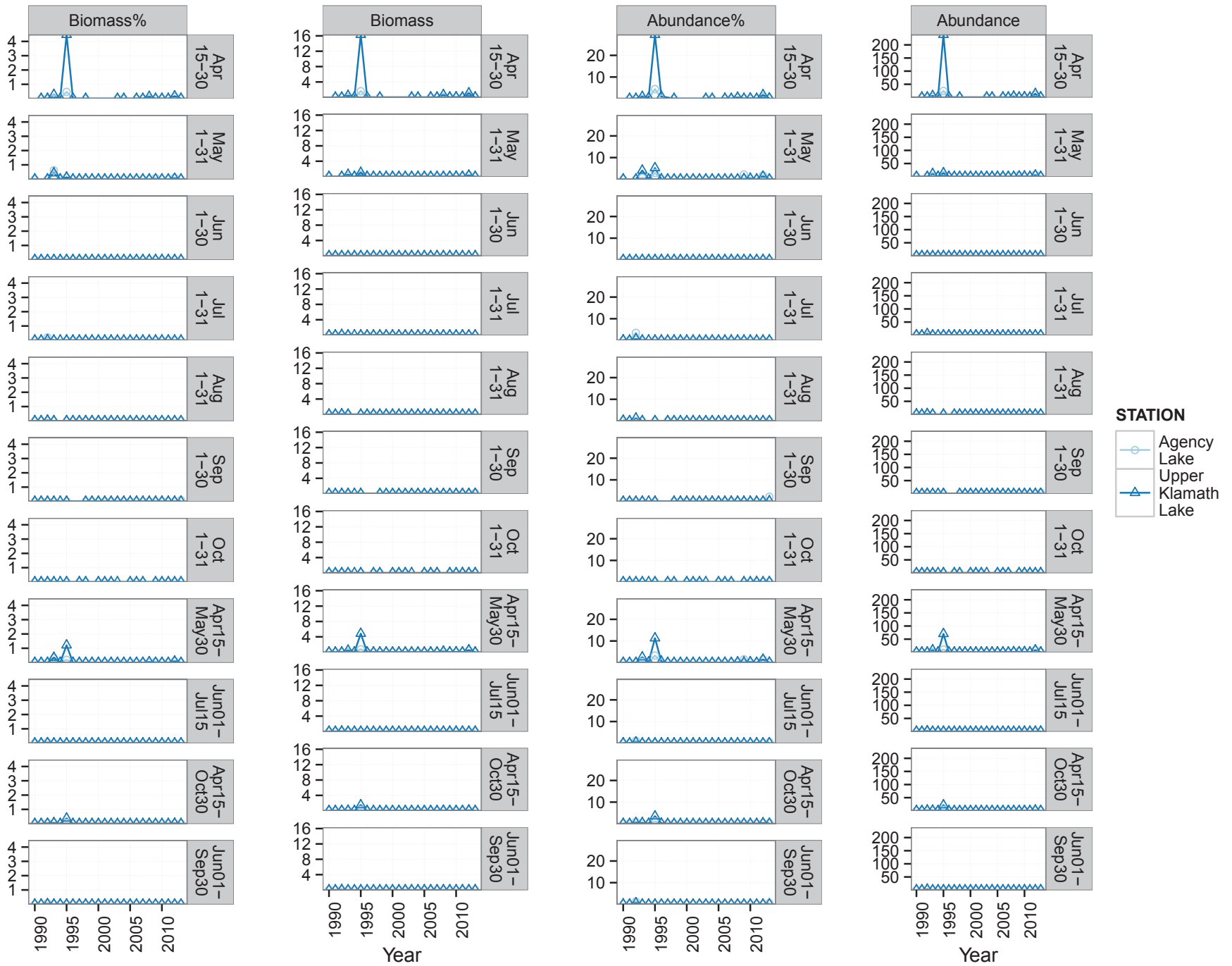


**APPENDIX L: ANNUAL TIME SERIES CHARTS OF LAKE-WIDE BIOVOLUME FOR ZOOPLANKTON MAJOR
GENERA/SPECIES**

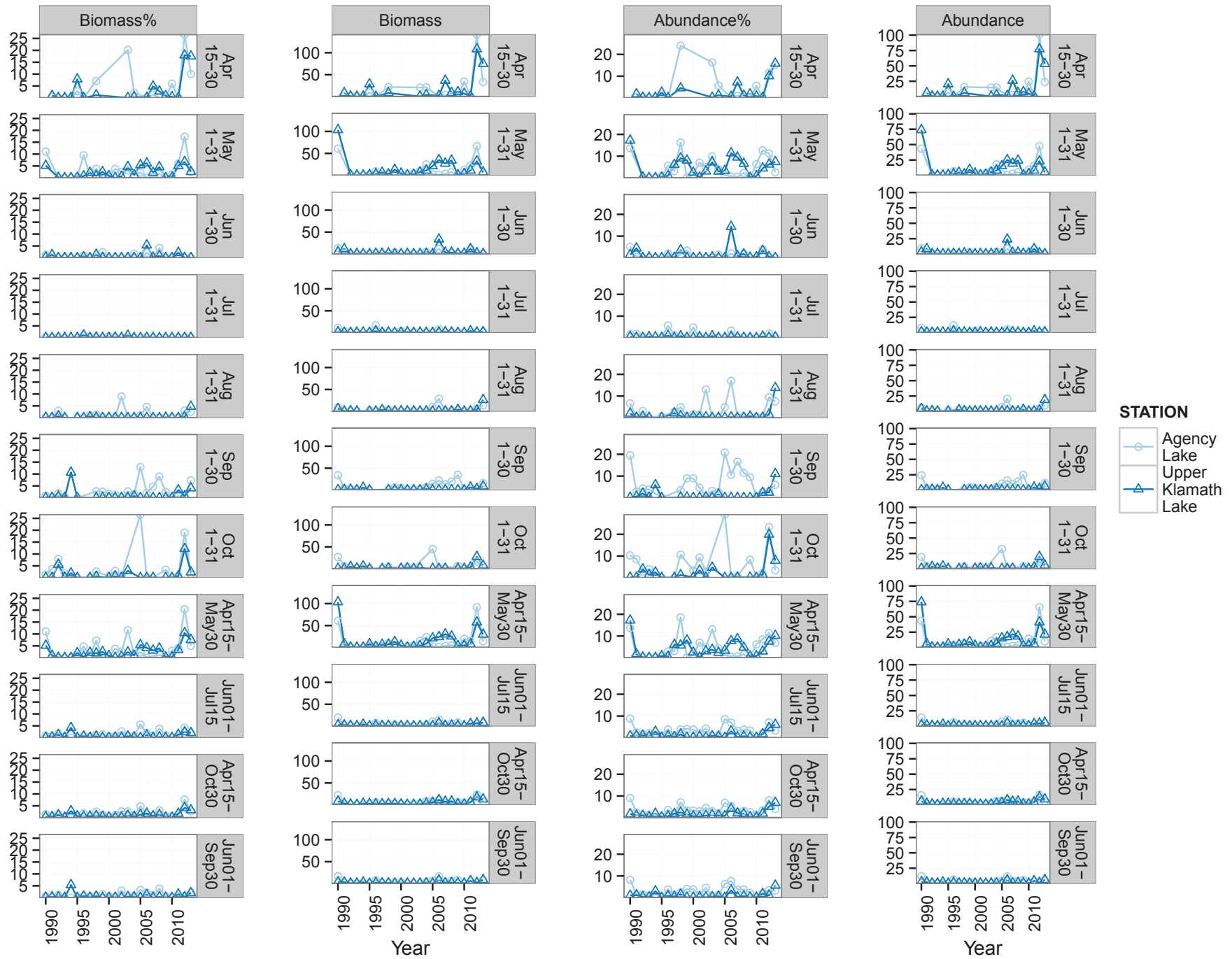
Average by Seasonal Periods and Year: *Asplanchna* sp



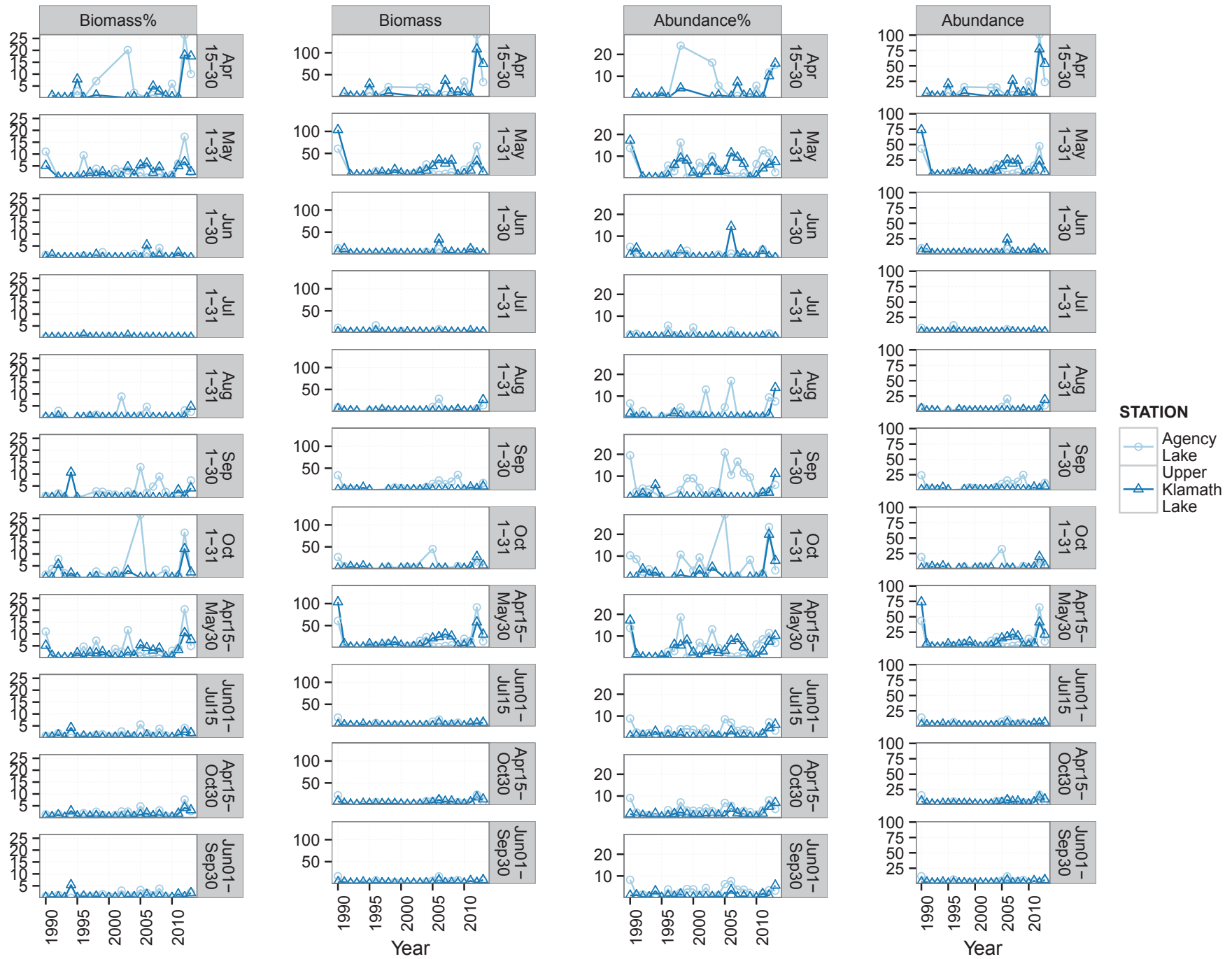
Average by Seasonal Periods and Year: *Brachionus* sp



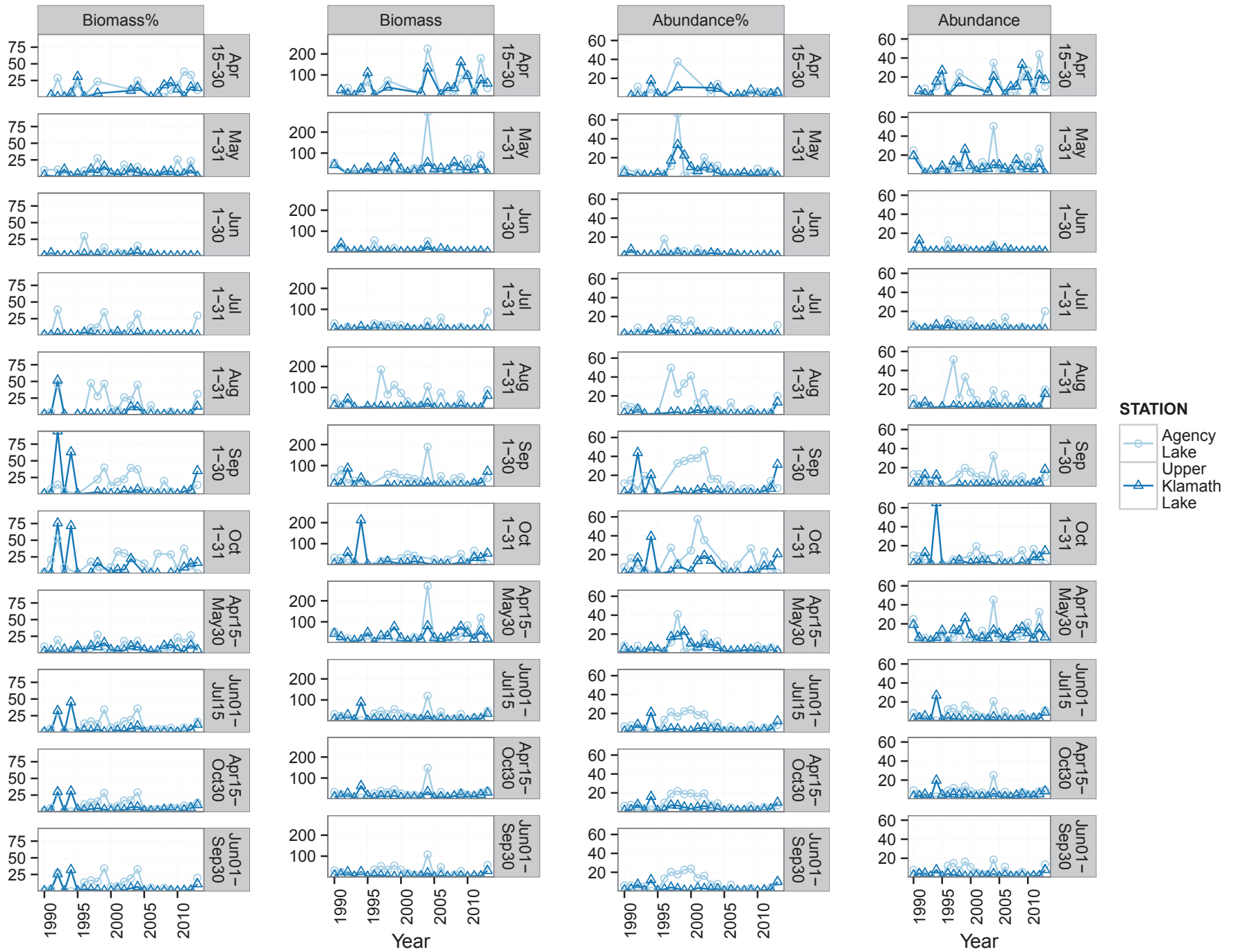
Average by Seasonal Periods and Year: Calanoid copepod



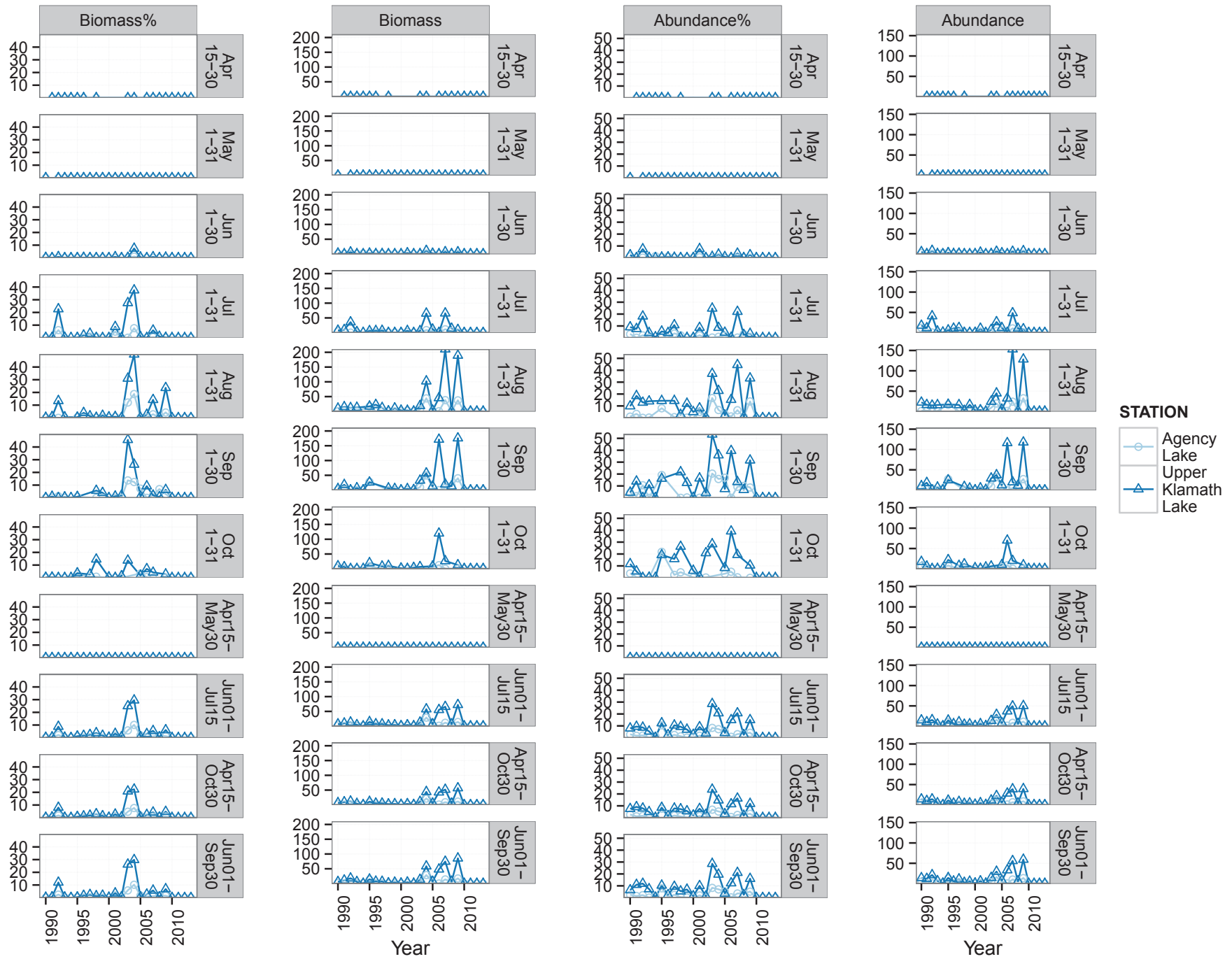
Average by Seasonal Periods and Year: Calanoid Copepods (copepodids) Immature



Average by Seasonal Periods and Year: Calanoid Copepods Adult

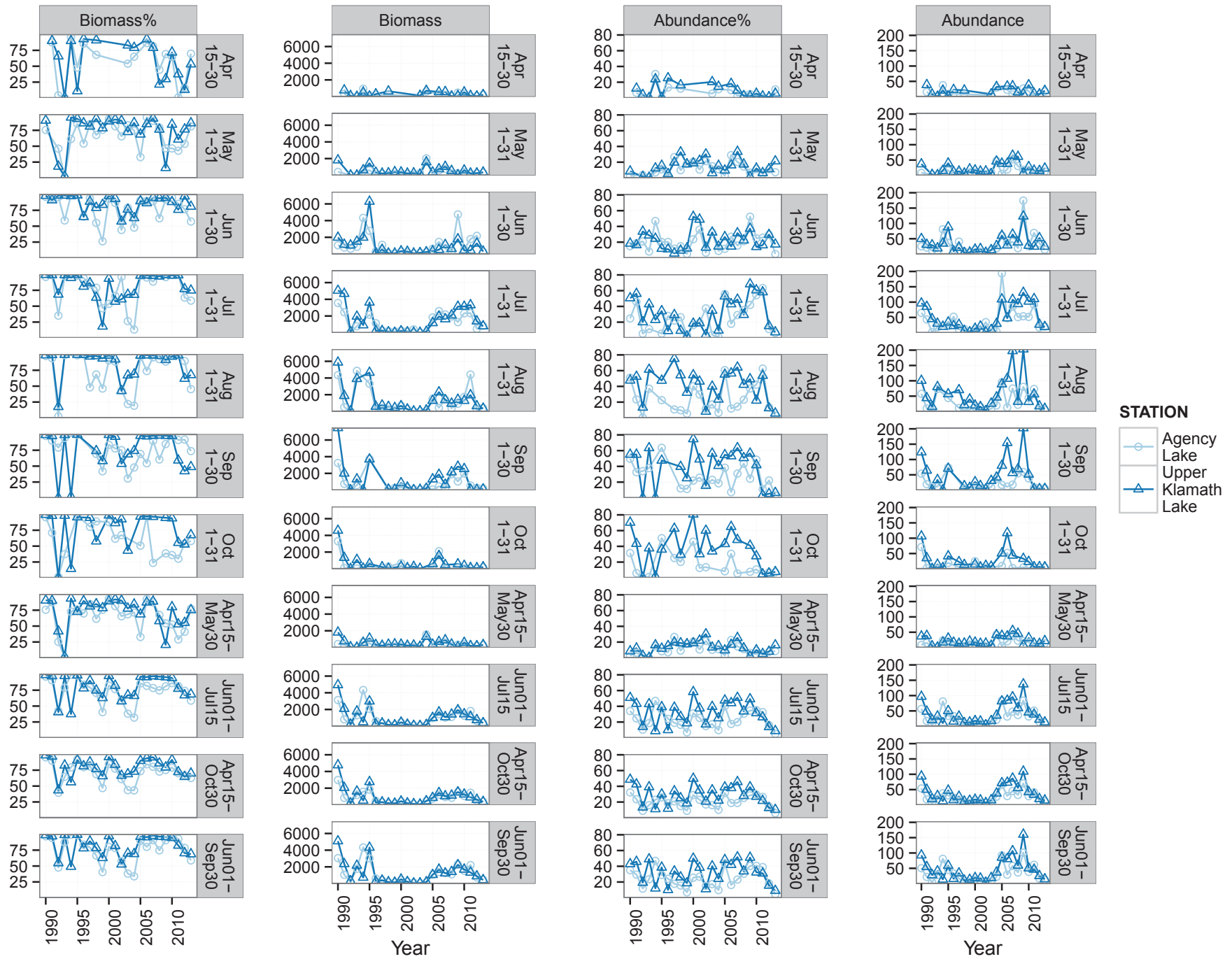


Average by Seasonal Periods and Year: Chydorus sphaericus

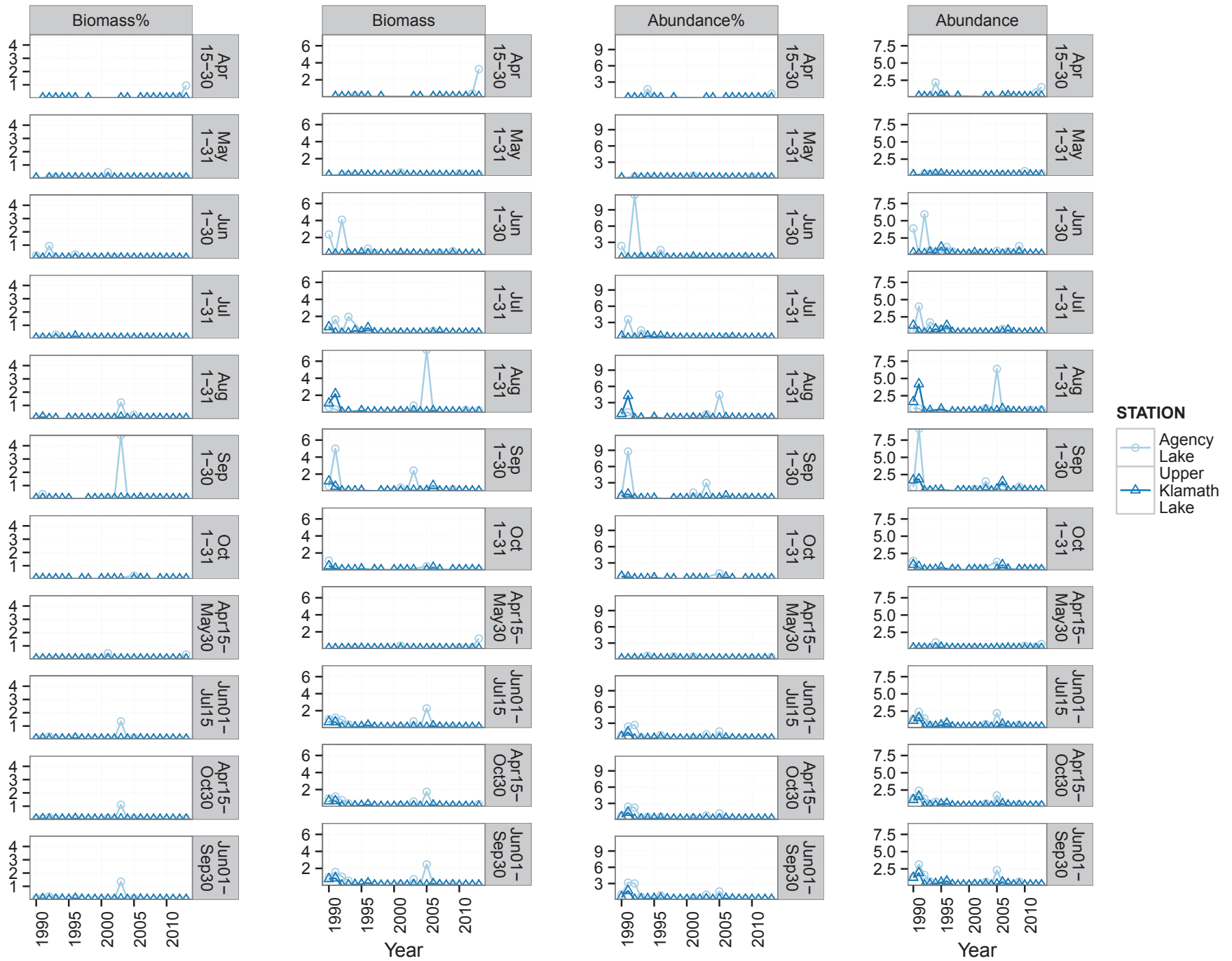


STATION
 ○ Agency Lake
 ▲ Upper Klamath Lake

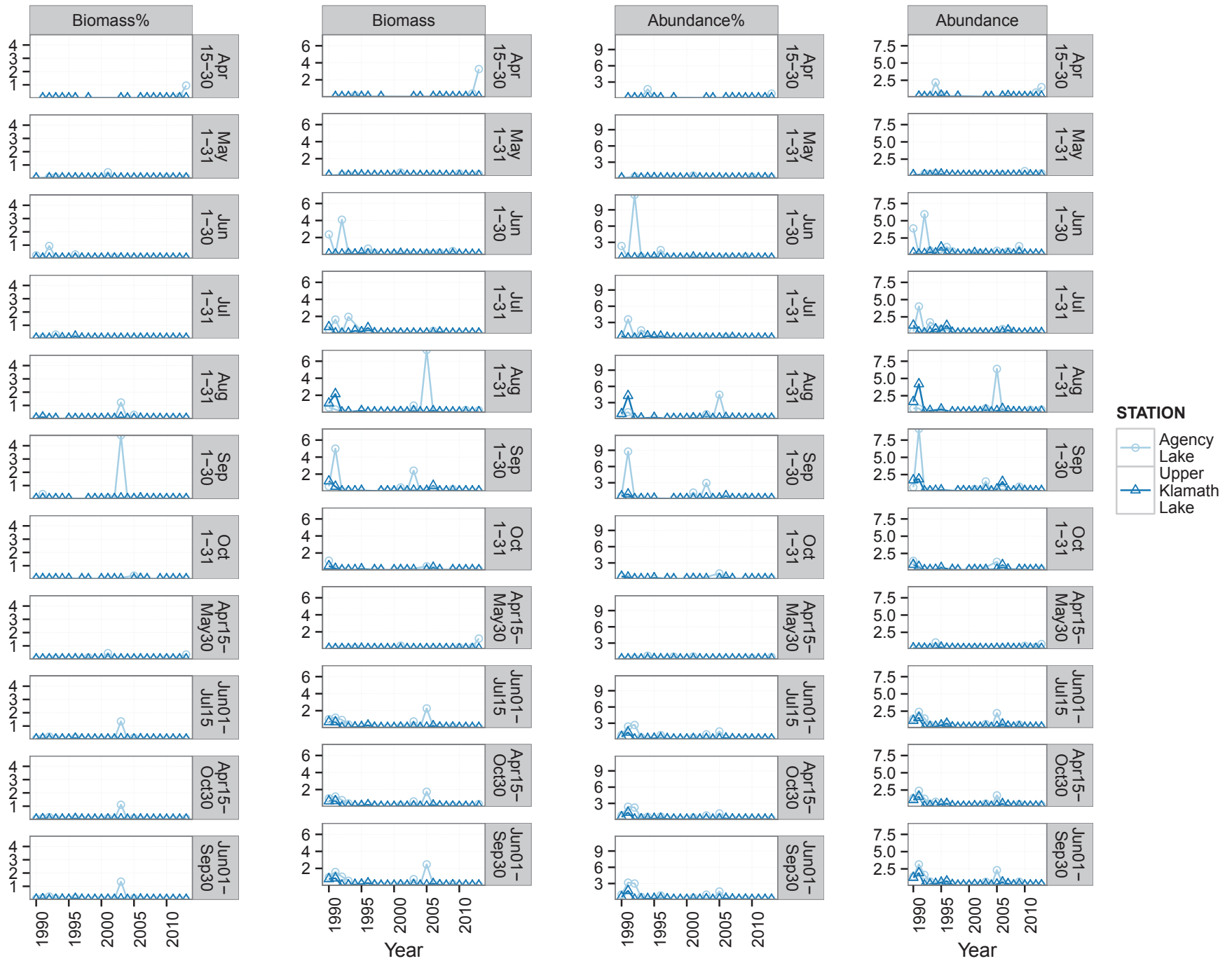
Average by Seasonal Periods and Year: Cladocera Adult



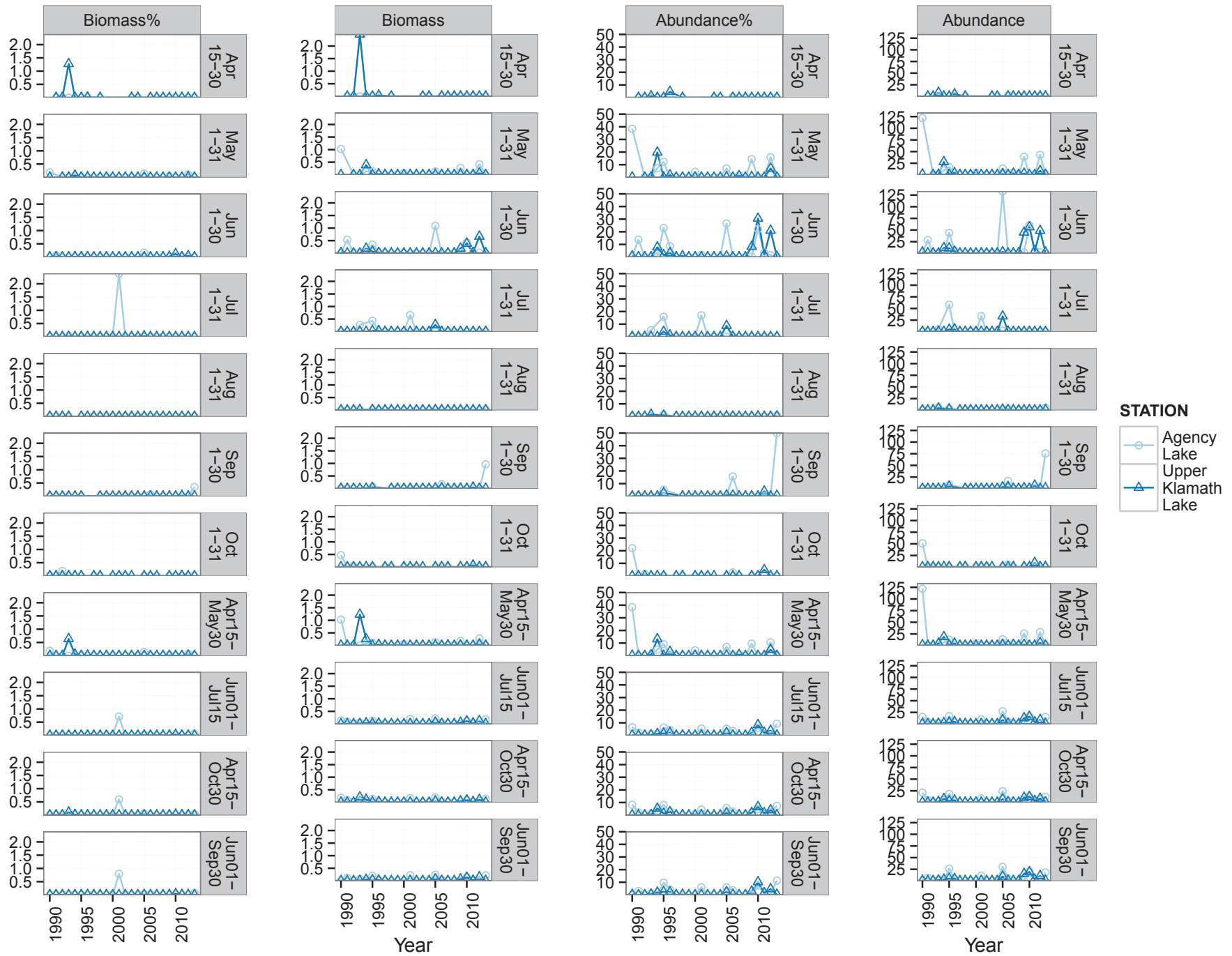
Average by Seasonal Periods and Year: Cladocera Immature



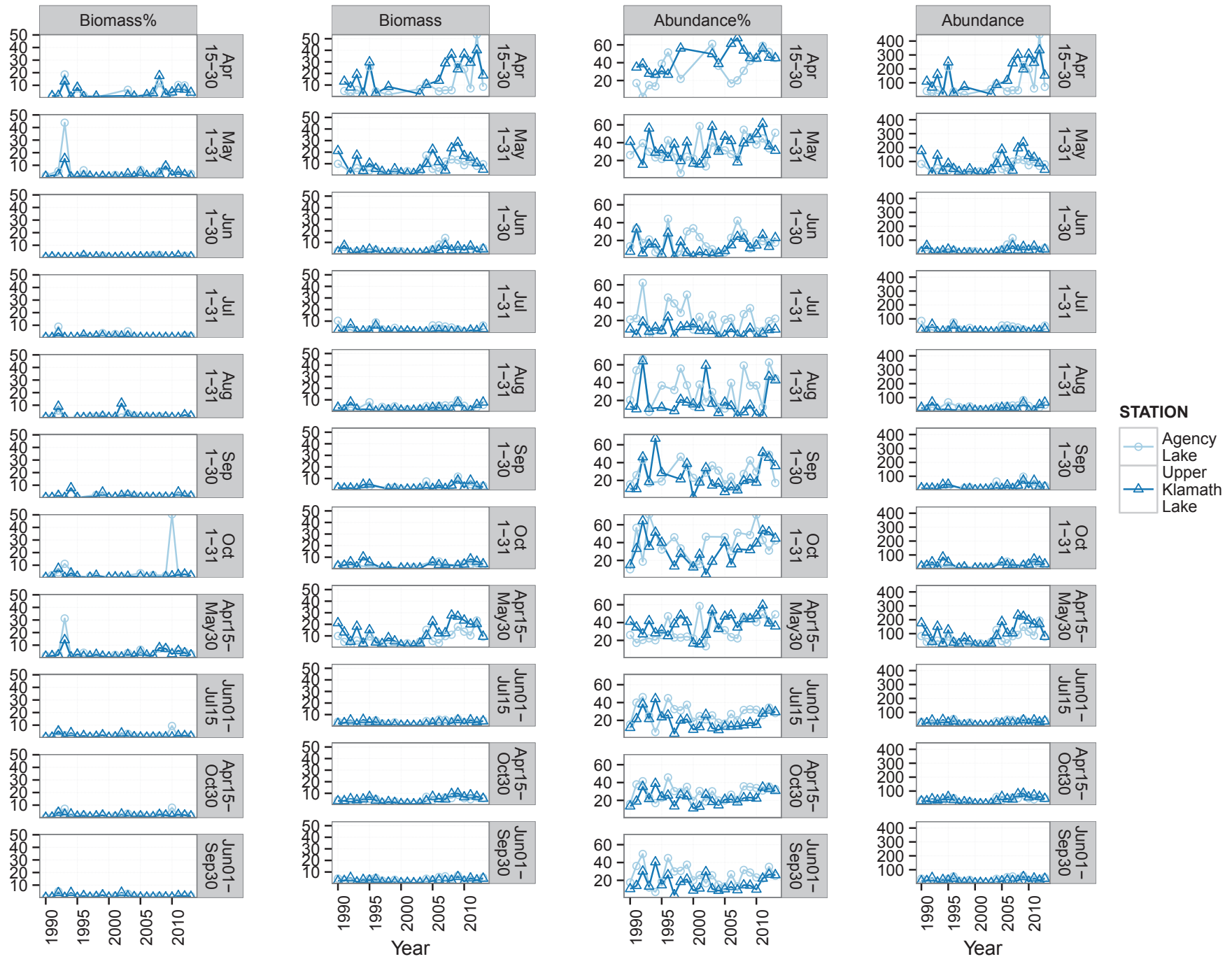
Average by Seasonal Periods and Year: Cladocera Immature



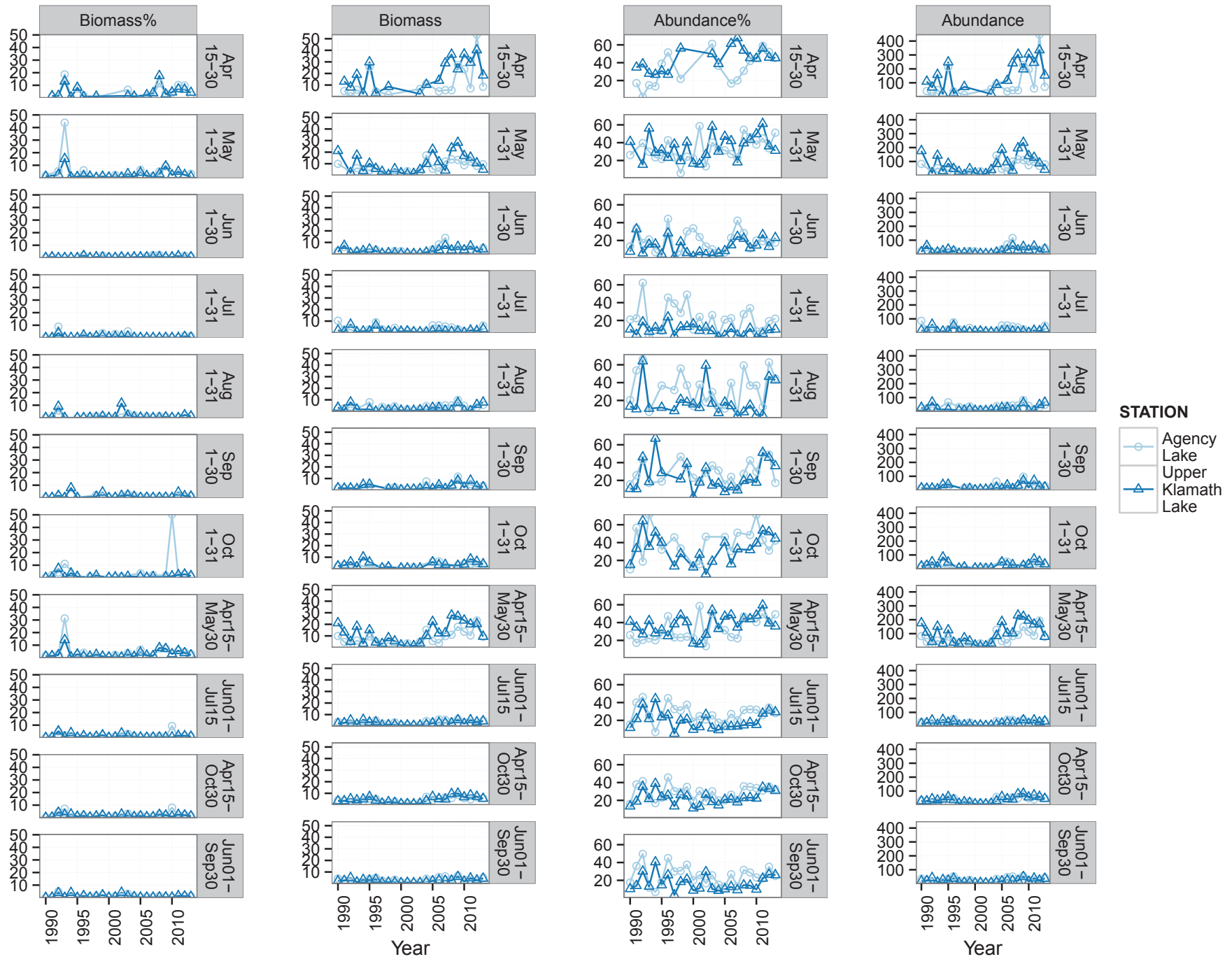
Average by Seasonal Periods and Year: *Conochilus unicornis*



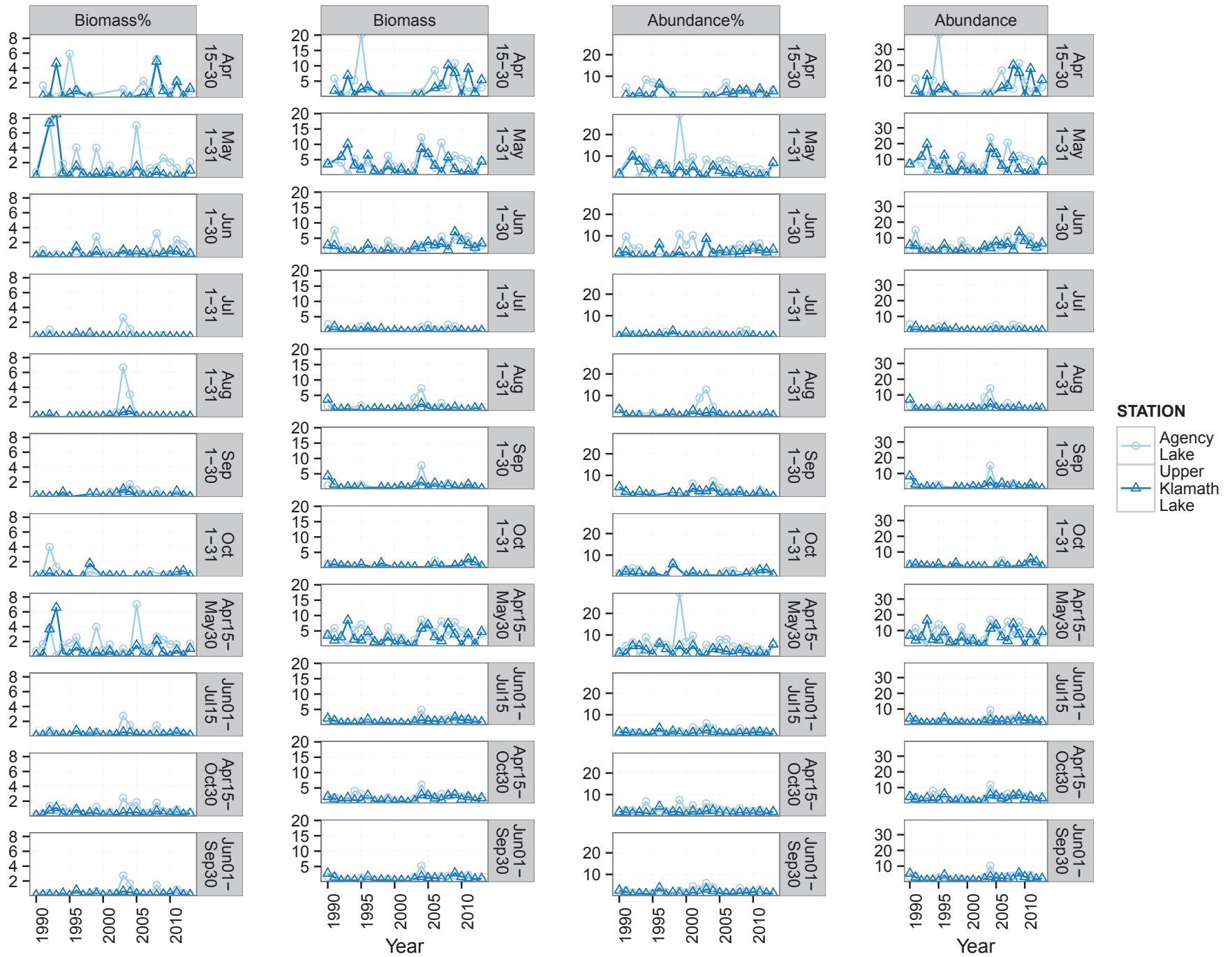
Average by Seasonal Periods and Year: Copepoda Nauplii



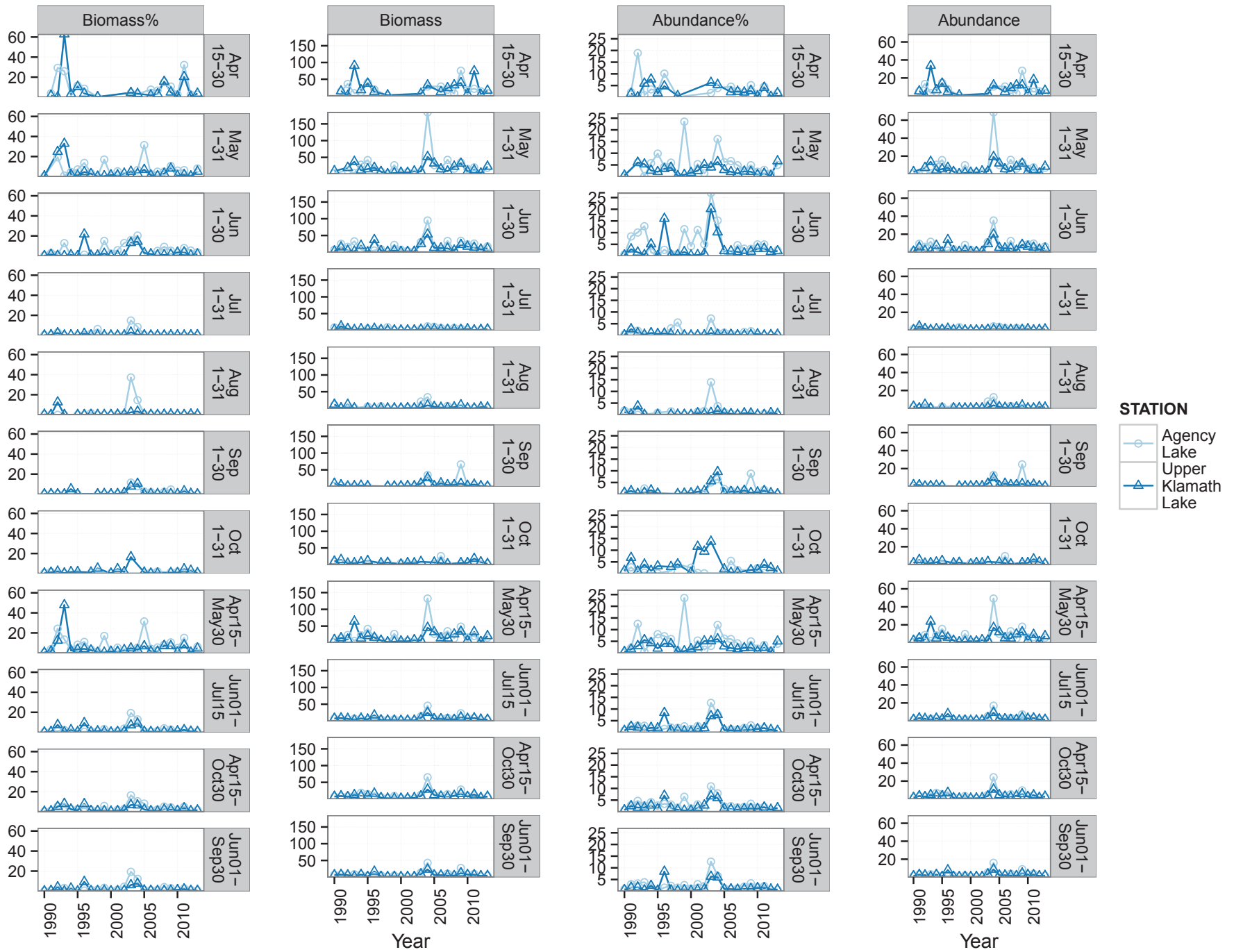
Average by Seasonal Periods and Year: Copepoda Nauplii



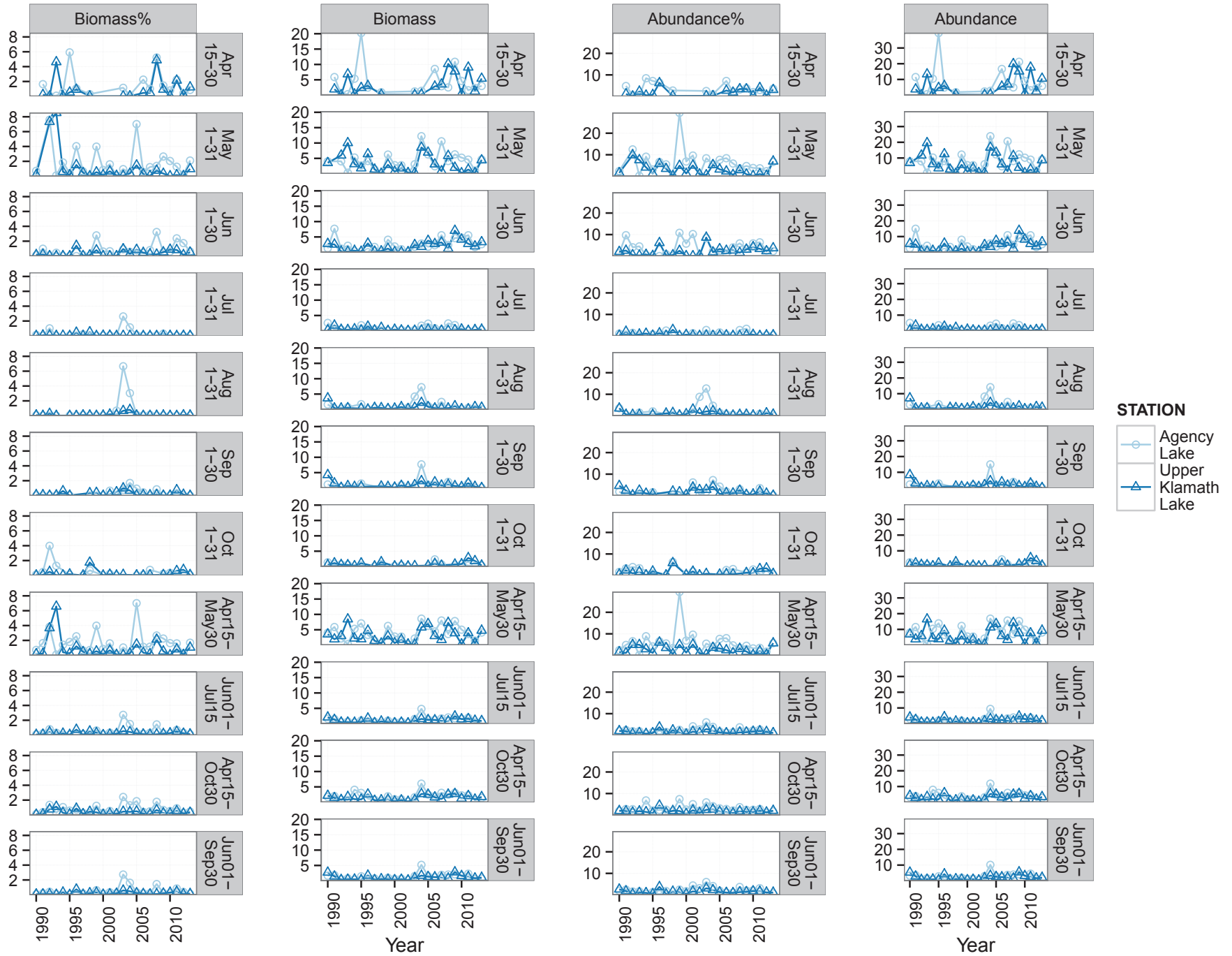
Average by Seasonal Periods and Year: Cyclopid Copepods (copepodids) Immature



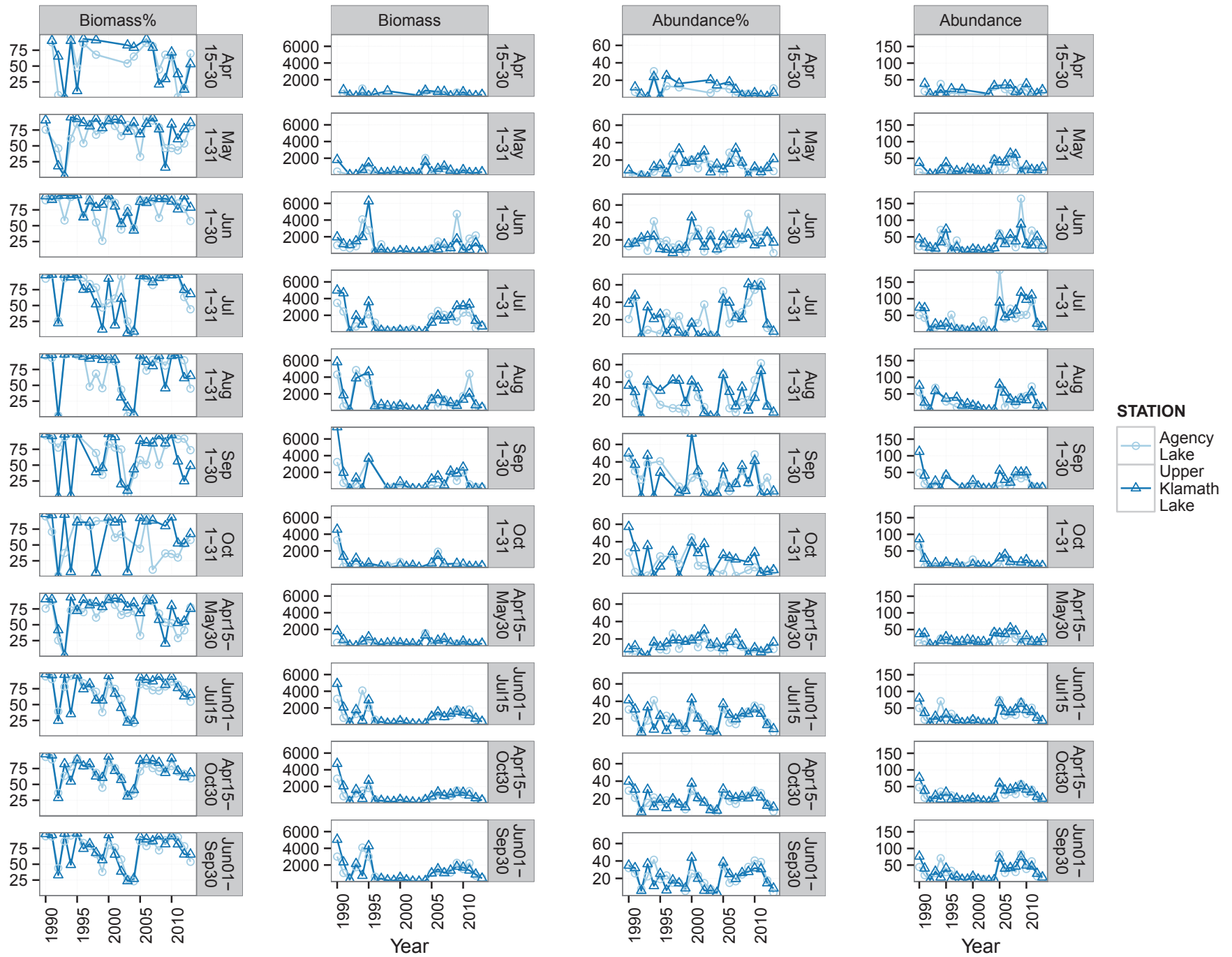
Average by Seasonal Periods and Year: Cyclopoid Copepods Adult



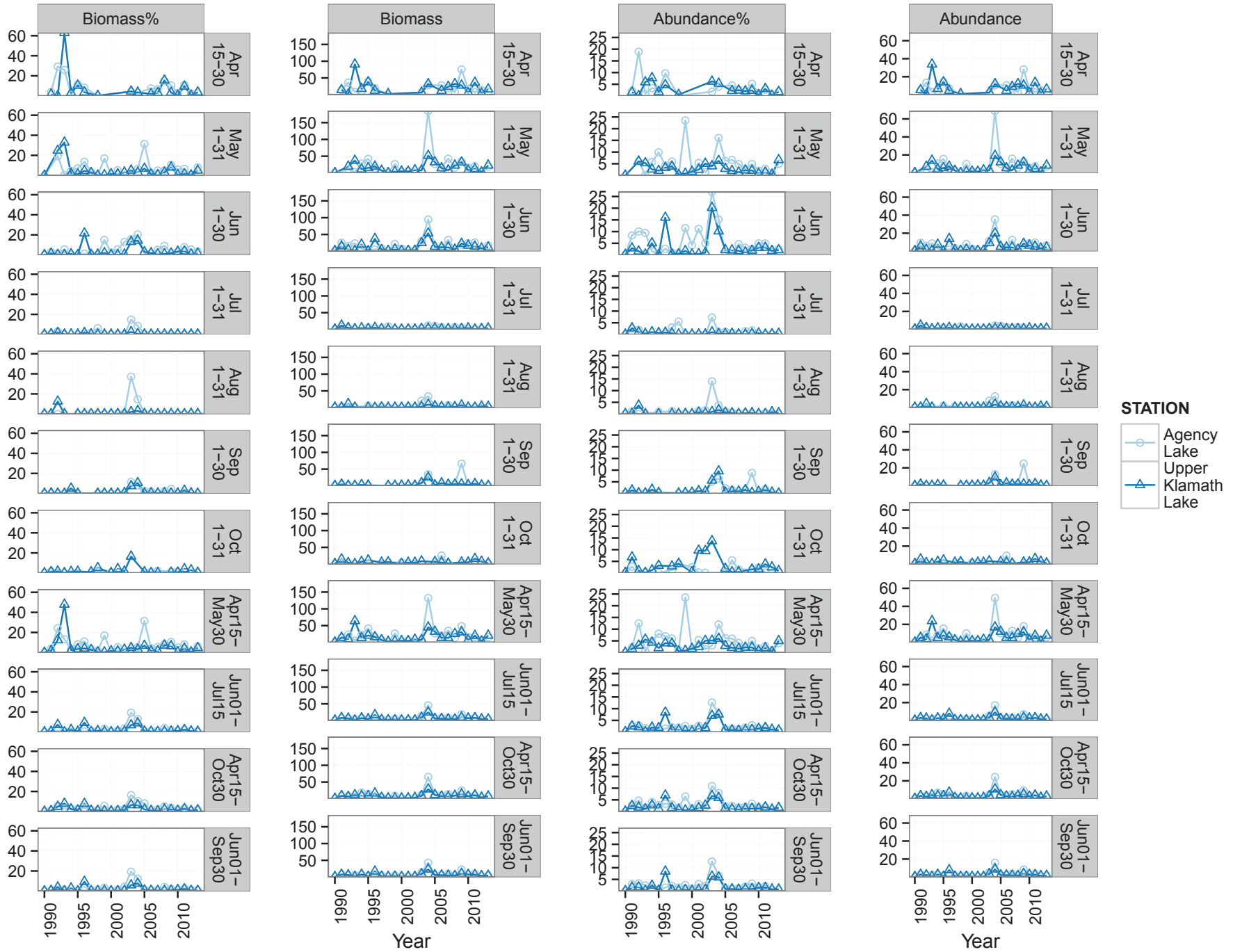
Average by Seasonal Periods and Year: Cyclopoid copepod



Average by Seasonal Periods and Year: Daphnia sp



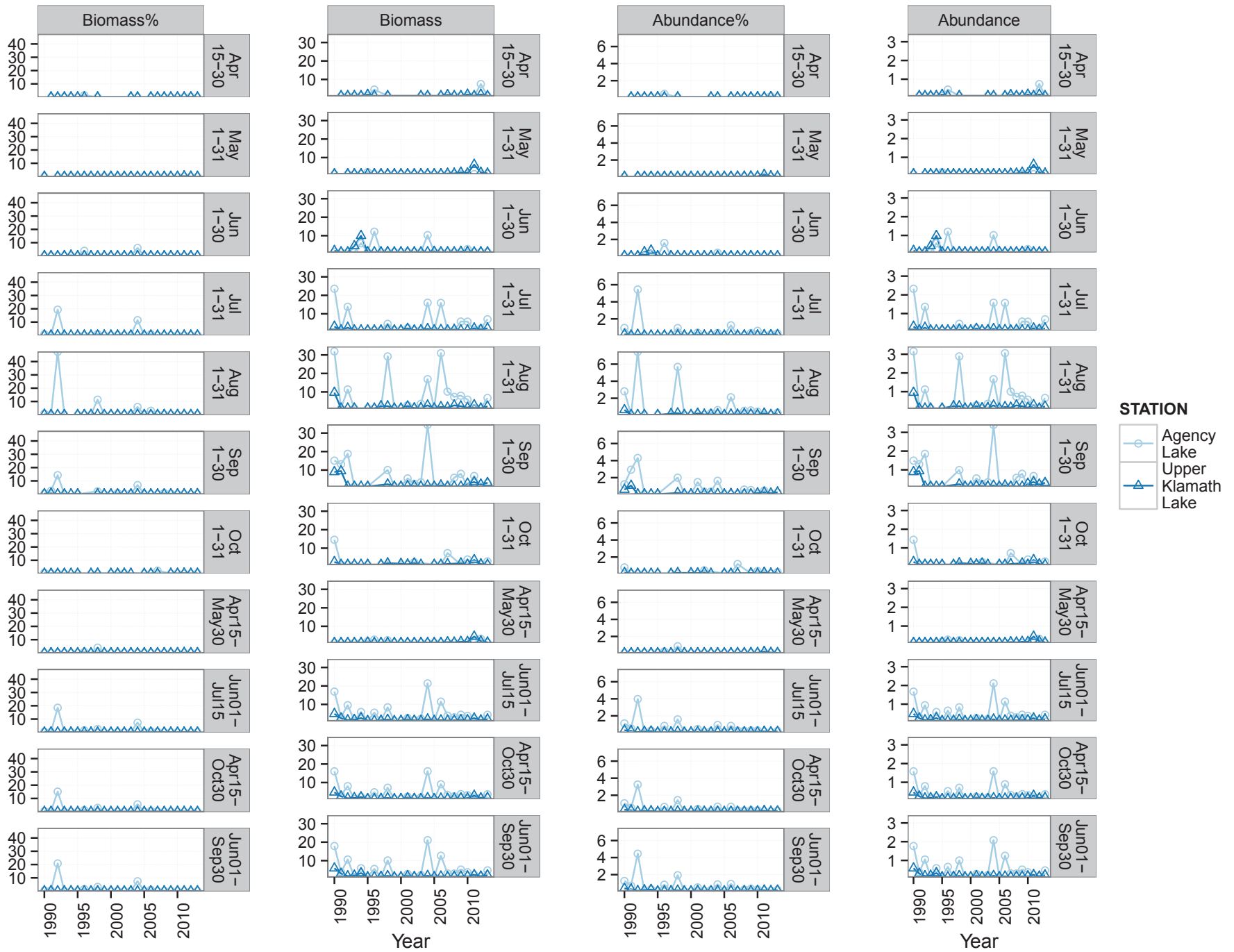
Average by Seasonal Periods and Year: *Diacyclops thomasi*



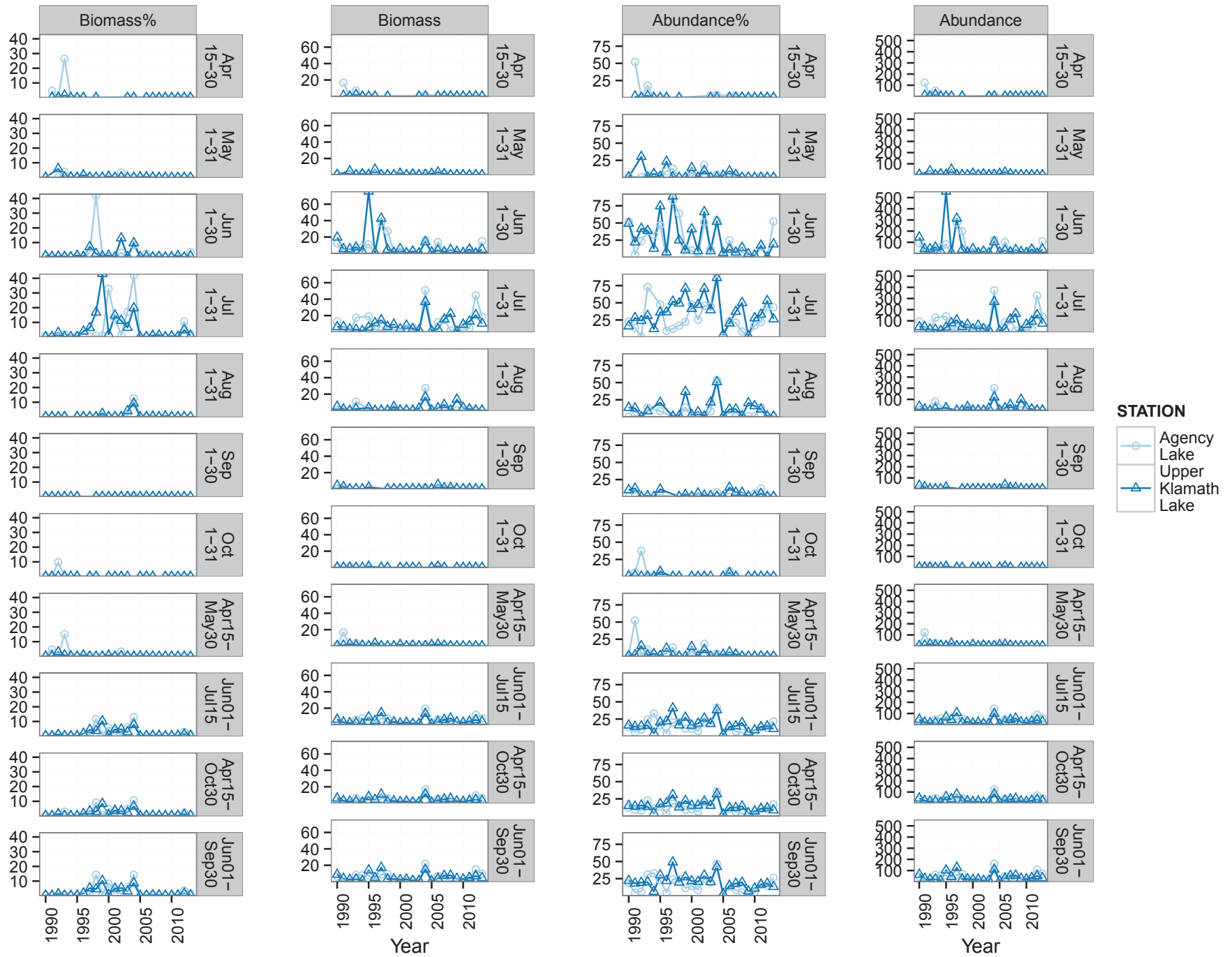
STATION

- Agency Lake
- △ Upper Klamath Lake

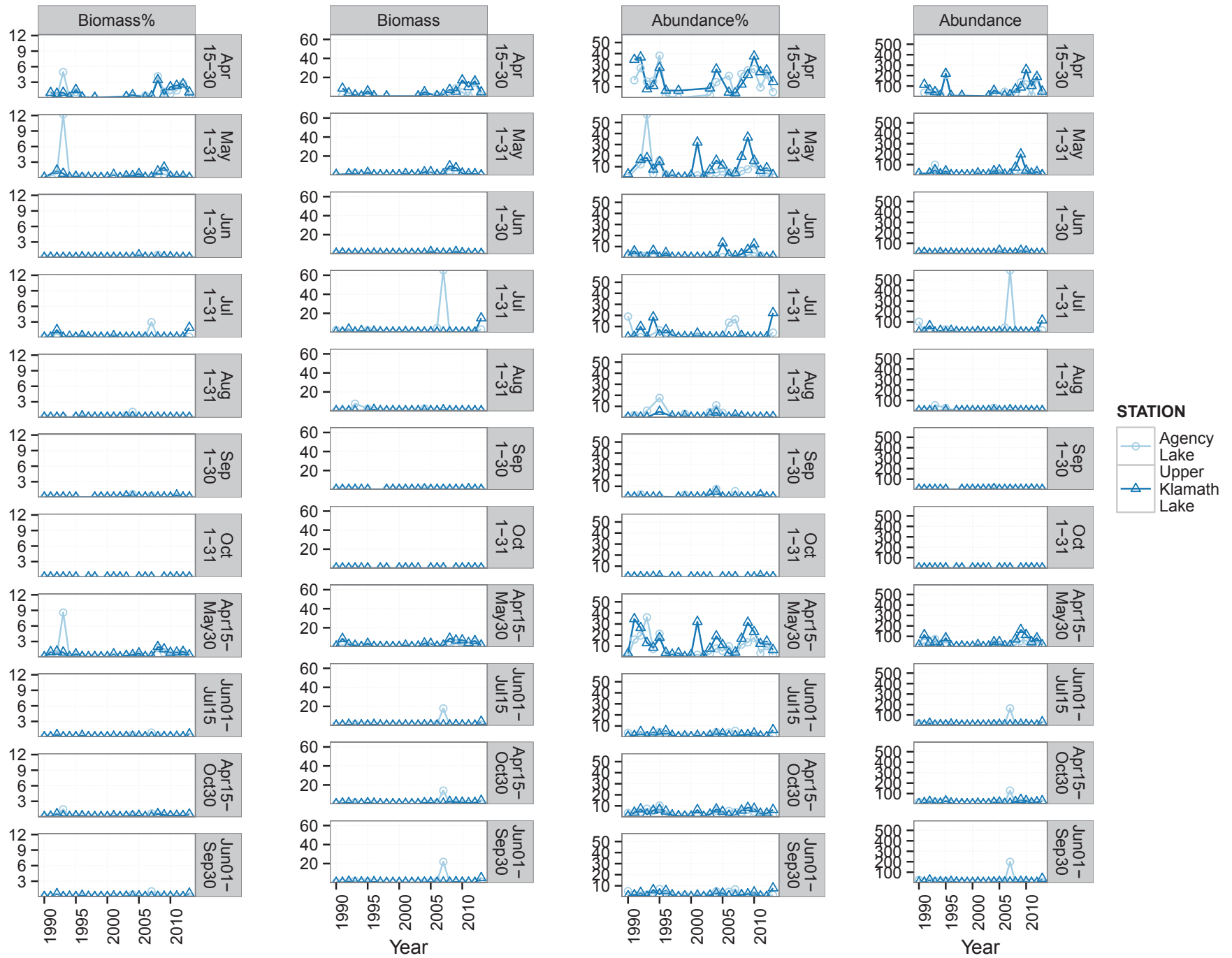
Average by Seasonal Periods and Year: *Epischura nevadensis*



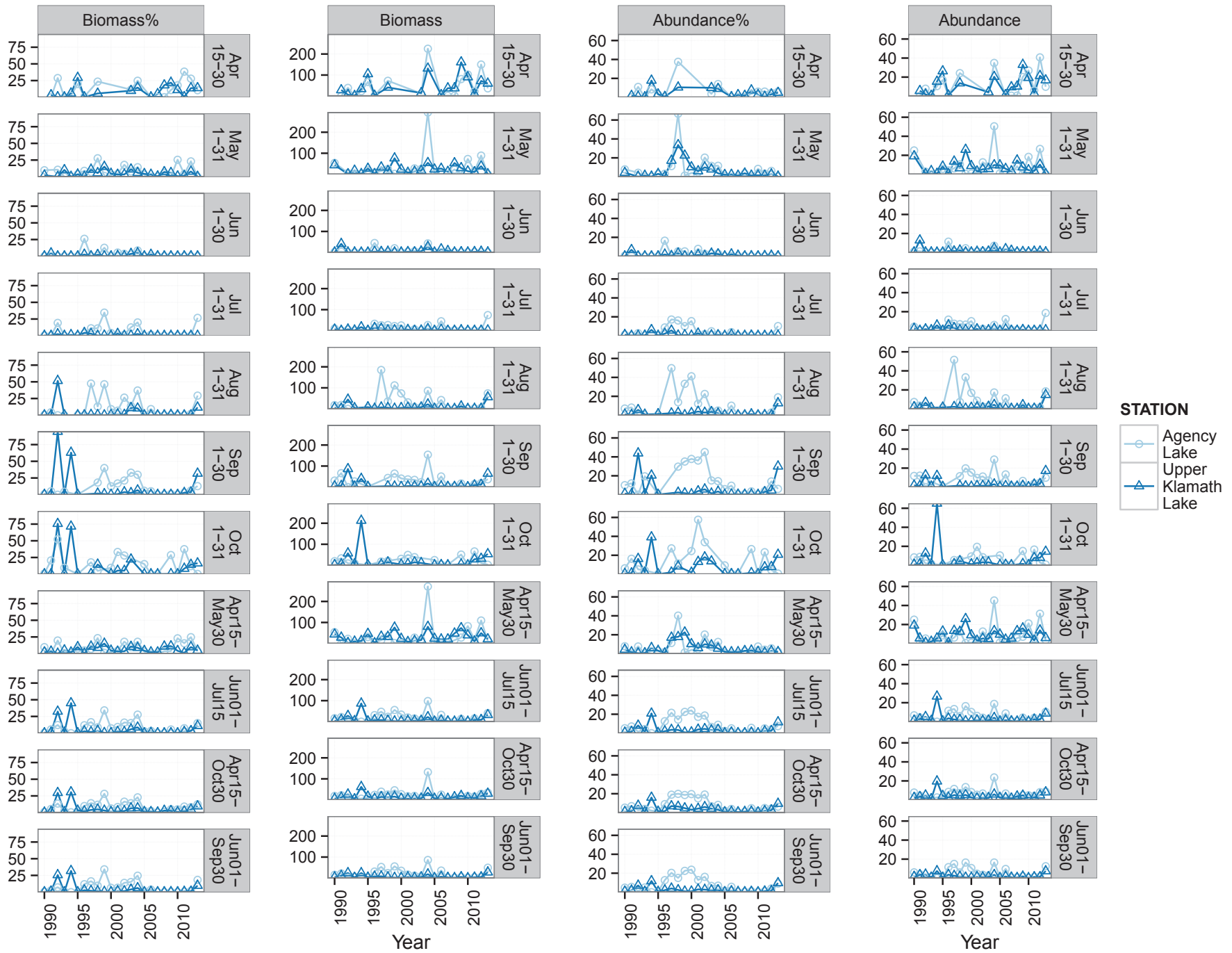
Average by Seasonal Periods and Year: *Euchlanis* sp



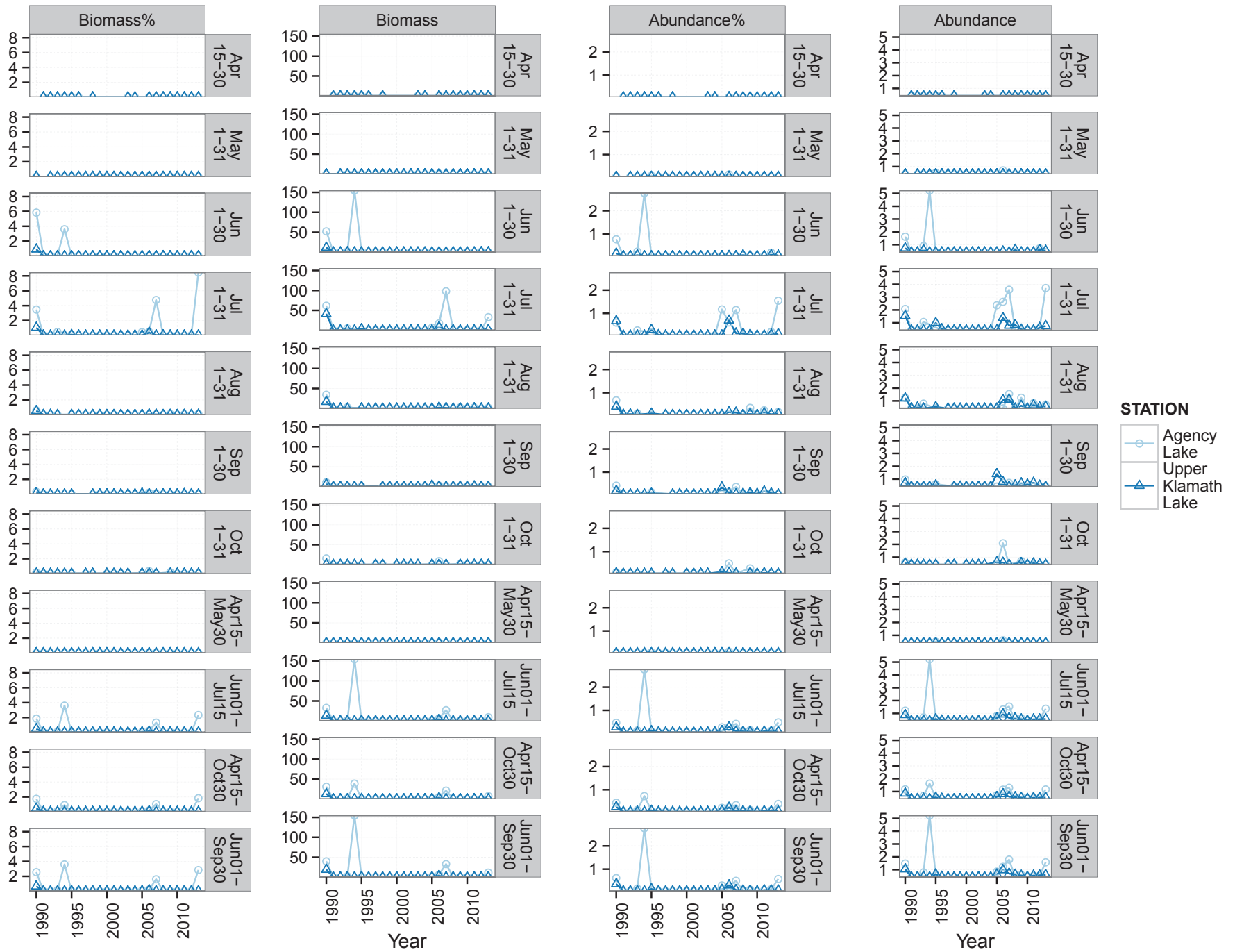
Average by Seasonal Periods and Year: Keratella sp



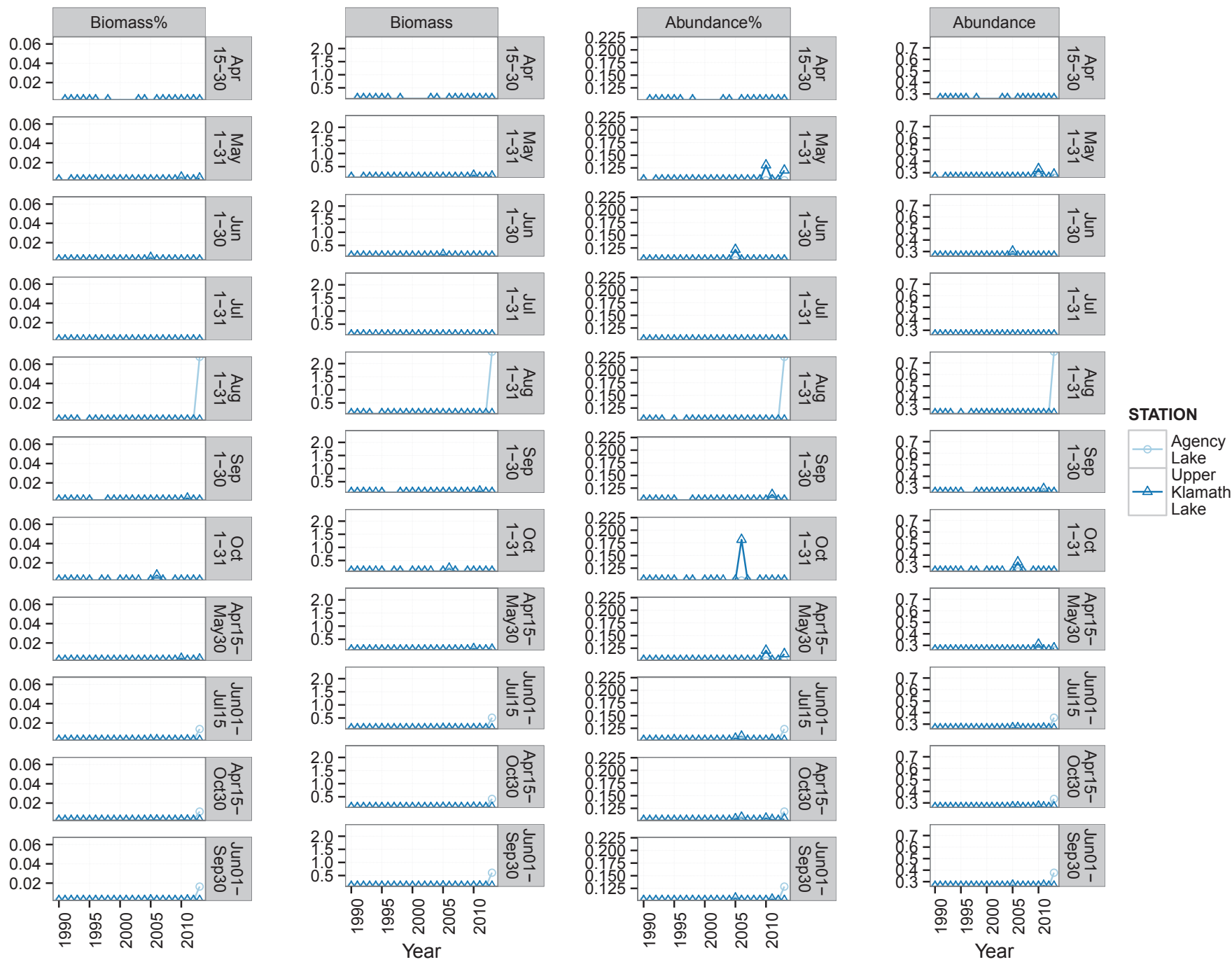
Average by Seasonal Periods and Year: *Leptodiatomus ashlandi*



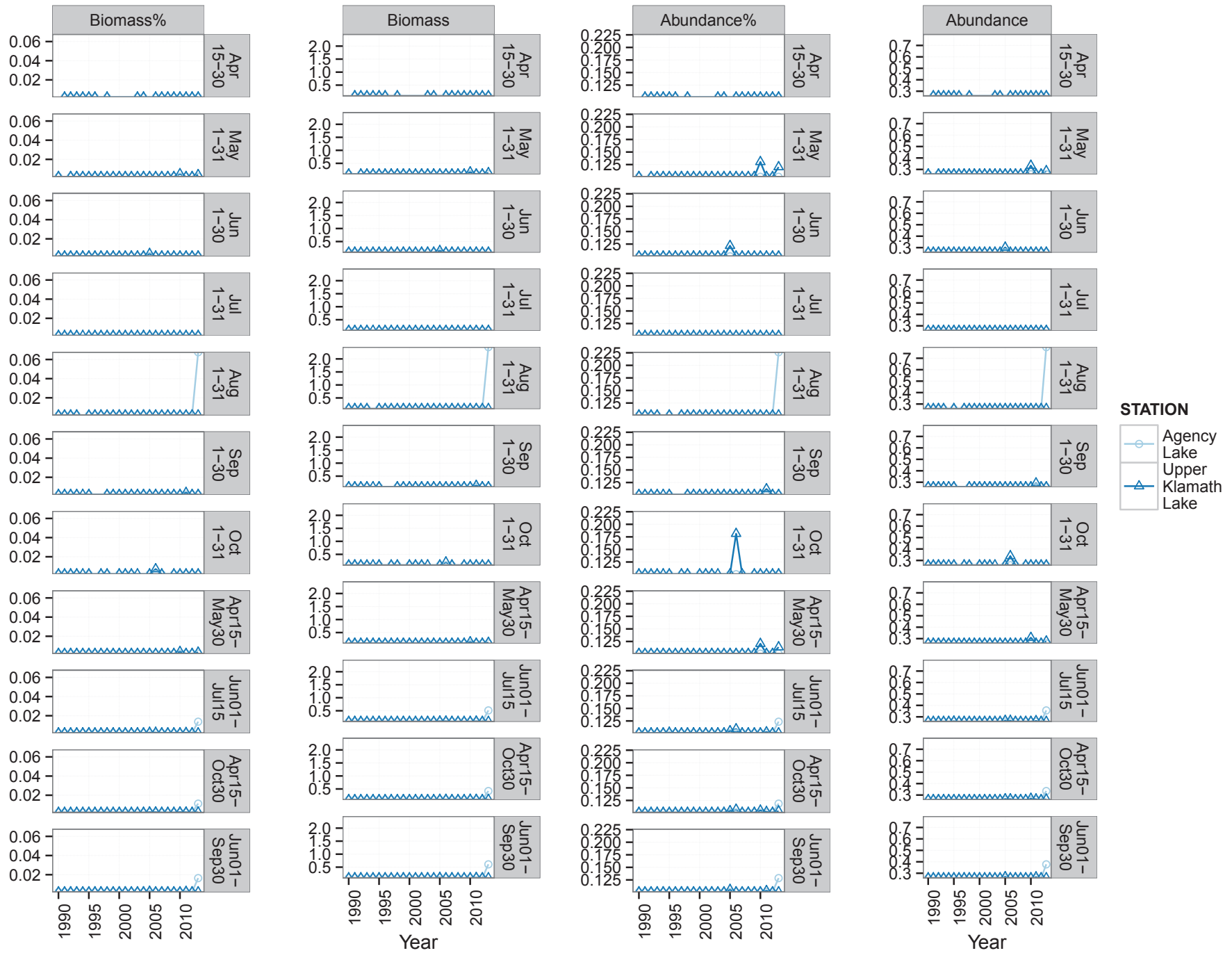
Average by Seasonal Periods and Year: *Leptadora kindtii*



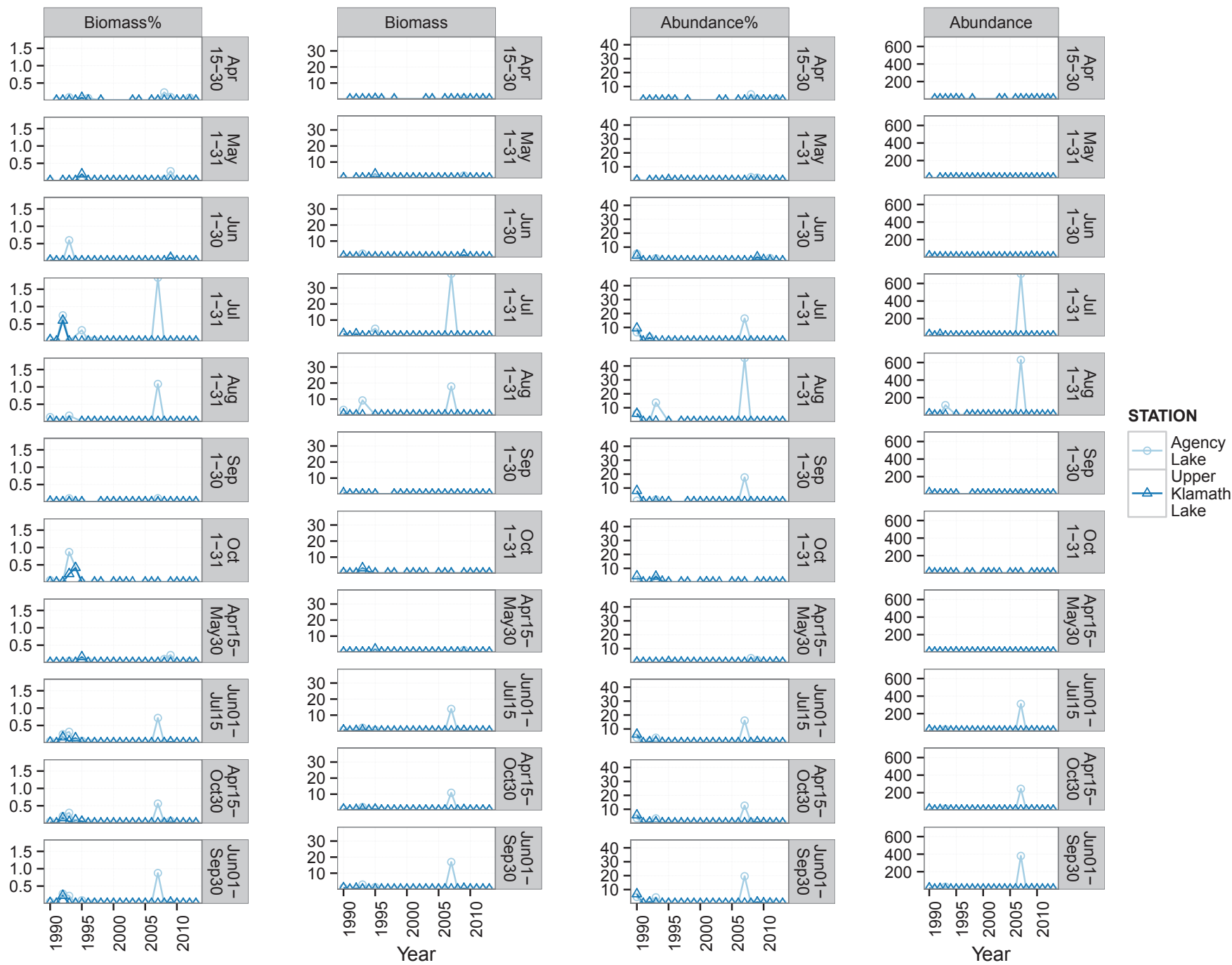
Average by Seasonal Periods and Year: Podocopa sp



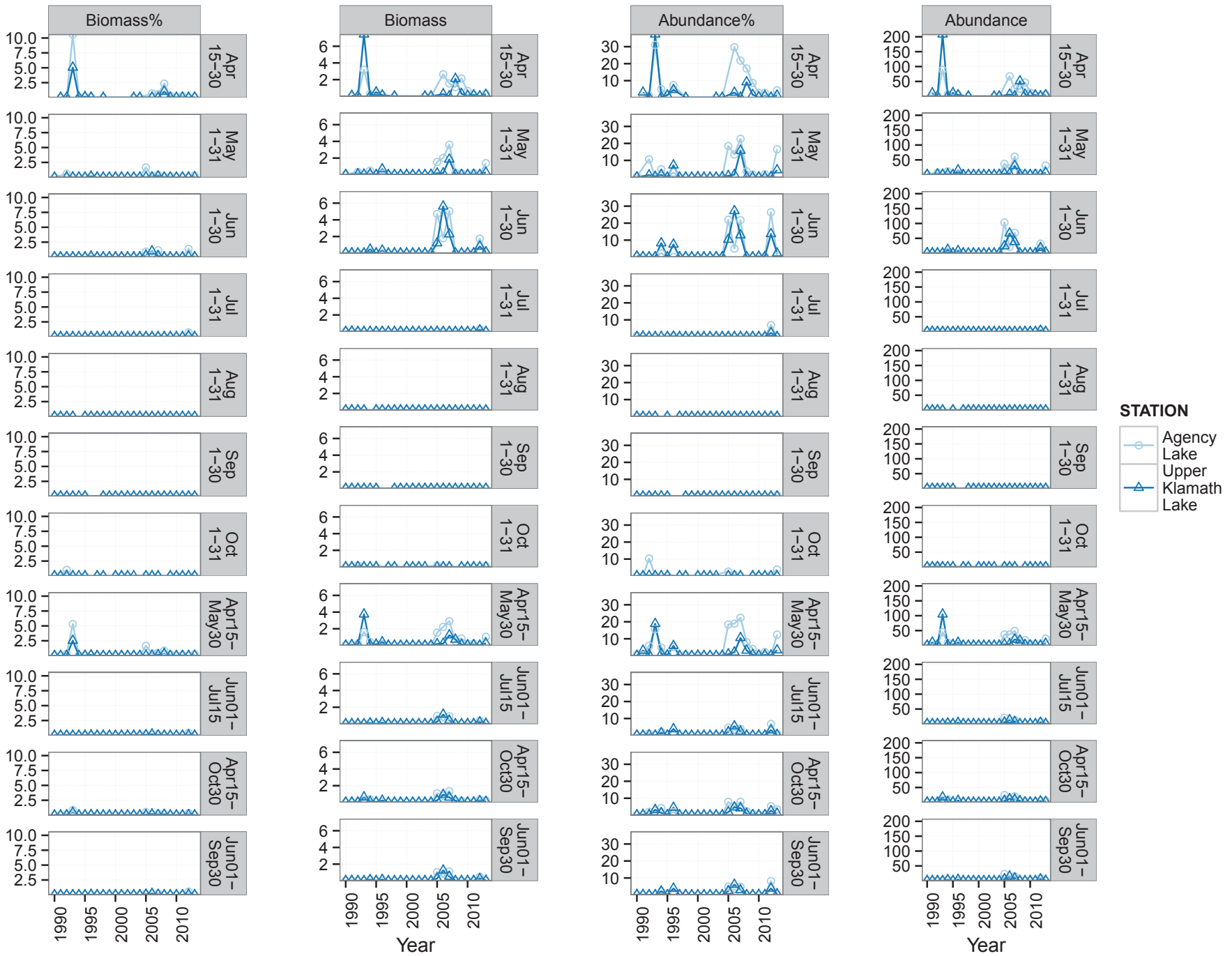
Average by Seasonal Periods and Year: Ostracoda



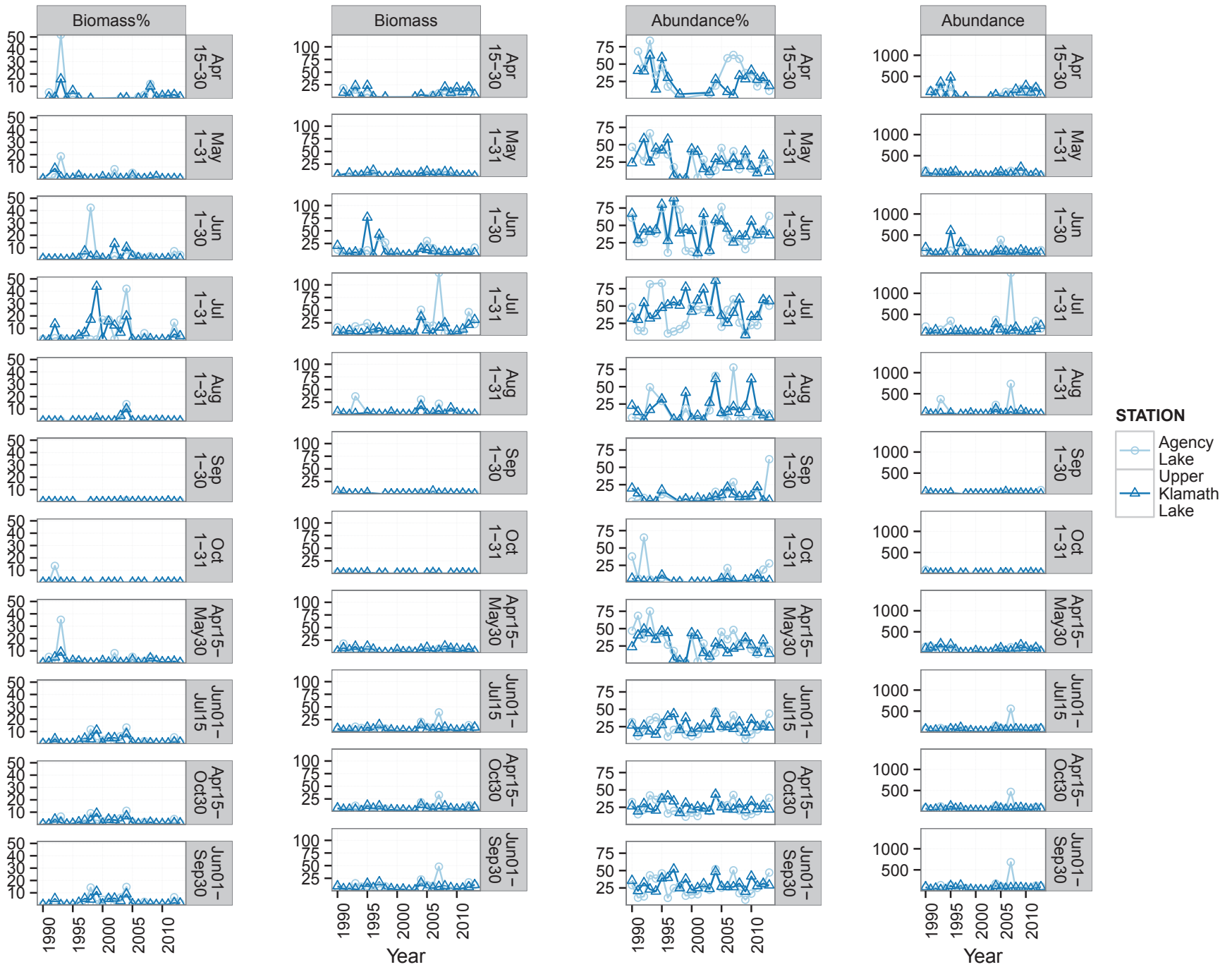
Average by Seasonal Periods and Year: Other



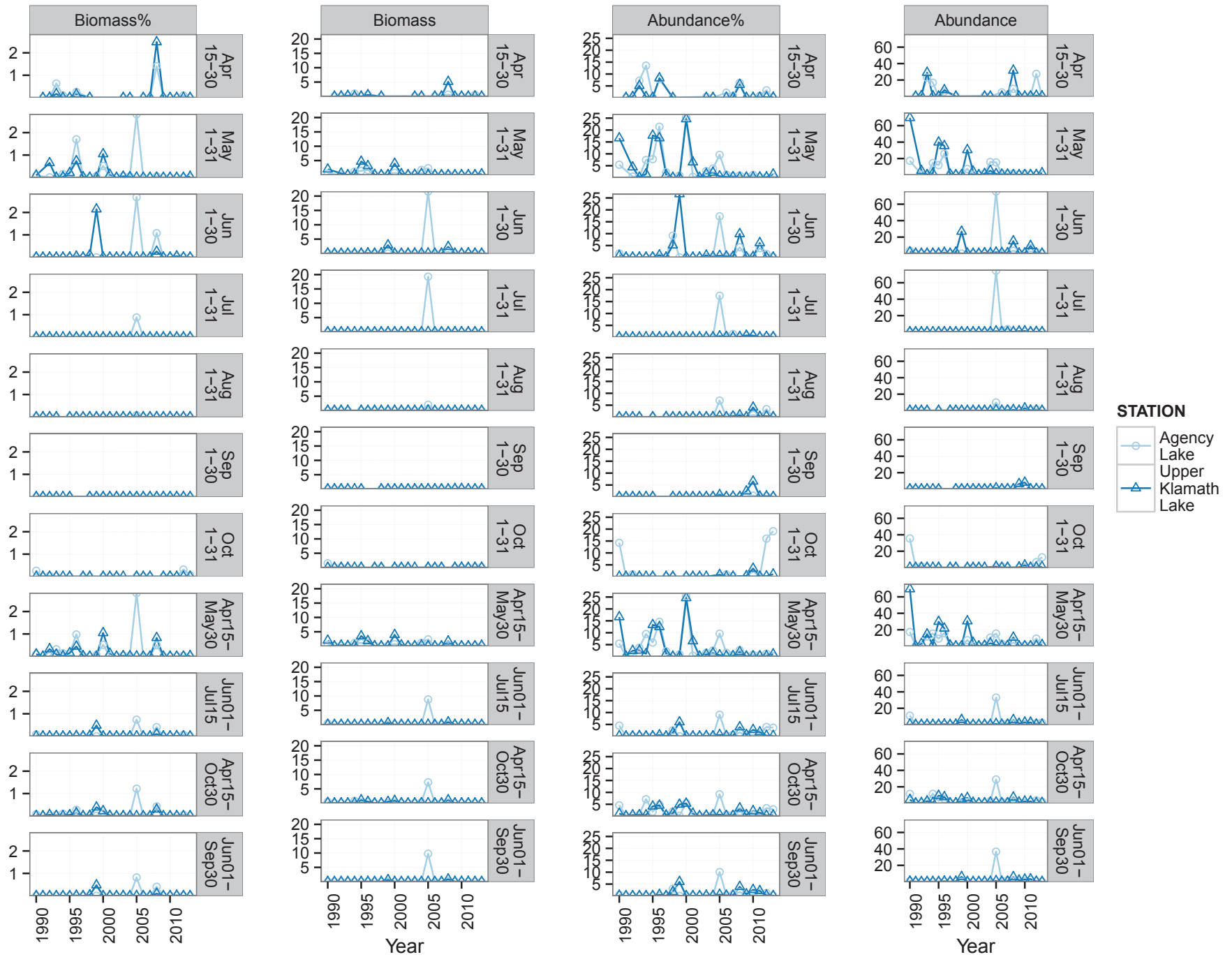
Average by Seasonal Periods and Year: *Polyarthra dolichoptera*



Average by Seasonal Periods and Year: Rotifera



Average by Seasonal Periods and Year: *Synchaeta* sp



Average by Seasonal Periods and Year: Total Zooplankton

