A Review of Aquatic Plant Monitoring and Assessment Methods

By John D. Madsen and Ryan M. Wersal
Geosystems Research Institute, Mississippi State University

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INTRODUCTION

Understanding the dynamics of aquatic plant populations in a given water body has become increasingly important due to the introduction and spread of numerous non-native species. These plants are generally introduced from other parts of the world, some for seemingly beneficial or horticultural uses; however, the majority have escaped cultivation and now cause widespread problems (Madsen 2004). Non-native plants affect aesthetics, drainage, fishing, water quality, fish and wildlife habitat, flood control, human and animal health, hydropower generation, irrigation, navigation, recreation, and ultimately land values (Pimentel et al. 2000, Rockwell 2003). For example, the estimated total cost of invasive aquatic plants, including management and losses, in the United States is approximately $110 million/yr (Pimentel et al. 2005). The cost of aquatic weed control in irrigation districts in 17 western states was estimated to be greater than $50 million/yr (Anderson 1993). Florida state agencies have spent nearly $250 million to manage hydrilla in Florida waters over the past 30 years; if one accounts for local government and local water management districts; this total approaches $750 million in management costs associated with hydrilla alone (Schardt pers. comm.).

The direct economic impacts, such as those listed above, are easy to quantify; however there are other impacts of aquatic plants that are much more difficult to ascertain. These impacts include the intrinsic benefits of aquatic habitats and the ecosystem services these habitats provide (Charles and Dukes 2007). Ecosystem services provide an important portion of the total contribution to human health and welfare on this planet (Costanza et al. 1997). Globally, it is estimated that marine systems provide $21 trillion in ecosystem services, followed by freshwater habitats at $4.9 trillion (Costanza et al. 1997). These estimates highlight the importance of conserving aquatic habitats and the services they provide to human welfare (Costanza et al. 1997). By any measure, the cost of invasion is significant, and the investment in management and research has not kept pace in order to minimize the costs associated with invasions (Sytsma 2008).

As the threat of non-native plant species increases, the development and refining of methods to detect, monitor, and ultimately assess management of these species is critical. However, the use of quantitative methods to monitor and assess aquatic plants has not become as standardized as other components in aquatic systems, such as the biotic or physical components (Lind 1979, Madsen 1999). Pursuant to this, millions of dollars are spent every year in managing aquatic vegetation in waters throughout North America; however, only a small fraction is allocated to acquiring reliable quantitative data regarding plant populations or in assessing management techniques (Madsen and Bloomfield 1993). In many cases, quantitative assessments are left out completely due to budget constraints, untrained personnel, or a lack of understanding with respect to what methods are available and how to implement them effectively.

There is a growing consensus among researchers and managers from all aspects of aquatic ecology and management that effective and quantitative methods need be utilized or standardized in order to maximize management efforts and monitor non-target impacts.

With respect to assessing management techniques; effective monitoring is needed to evaluate new biological control projects to determine which agents are effective and what factors limit or enhance their success (Blossey 2004). Often times monitoring programs are underfunded or inadequate in scope and do not identify where and why control is or is not successful (Blossey 2004). The development or improvement on methods for evaluating non-target impacts of herbicides are also critical, especially with respect to native species of concern or threatened and endangered species (Getsinger et al. 2008).

Environmental factors can also have an impact on plant growth and function to structure aquatic plant communities both spatially and temporally. For submersed and emergent plant communities, zonation along a depth gradient is often observed as a function of light availability (Middelboe and Markager 1997). Sediment composition also influences submersed plant colonization and distribution (Case and Madsen 2004, Doyle 1999, Madsen et al. 2001, 2006). Floating aquatic plant growth is often limited by available nutrients in the water column with nuisance growth following temporal changes in nutrient loading. For example, water hyacinth responds to flooding events in large riverine systems where during flood cycles, water moves out into adjacent lands and upon receding brings with it an increase in nutrients to support water hyacinth growth (Kobayashi et al. 2008). In general, there are a number of factors that impact plant growth across spatial and temporal scales; and effective management requires an understanding of aquatic plant biology and the response of plants (both target and non-target) to management actions (Sytsma 2008). The only way to effectively achieve this is to utilize methods that can document the distribution, growth, and abundance of aquatic plants over time (Sytsma 2008).

Assessment and monitoring of aquatic plants has become more important over the last year as the National Pollutant Discharge Elimination System (NPDES) permit program has been implemented to regulate aquatic plant management activities, most notably the use of herbicides. One of the requirements included in the federal NPDES pesticide general permit is for the quantitative assessment of nuisance plant coverage in order to document that the target species exceed a nuisance threshold. Quantitative methods are also required to assess the impacts of management activities on target and non-target plant species. Therefore, the objectives of this paper are to 1) offer a broad overview of available methods that can be utilized for aquatic plant monitoring and assessment, and 2) provide guidelines regarding using these methods for assessing aquatic plants, as well as pointing out methods that are not effective for this purpose. These guidelines will cover submersed, floating, and emergent plant species for lakes and flowing waters, as well as nuisance planktonic and periphytic algae. The goal is to equip natural resource managers and permit holders with the tools and justifications to address NPDES permit requirements.

OVERVIEW OF AQUATIC PLANT MONITORING AND ASSESSMENT METHODS

Before undertaking any sort of monitoring or assessment program, one must correctly identify the species of interest. Often, when incorrect identifications occur, the process used to document species identifications is poor, including the lack of herbarium specimens (Hellquist 1993) or digital photography adequate to correct these misidentifications. Correct identification of both target and non-target plants are crucial in identifying rare or threatened species, as well as aiding in delineating areas with species of special concern (Hellquist 1993). Devoting time and resources to construct a proper species list for a given water body can be invaluable in developing a management plan; furthermore, species lists are often required in the preparation of environmental impact statements and permitting requirements (Hellquist 1993).

A number of methods exist for sampling aquatic plants in order to develop a species list, determine distributions, and to estimate abundance in a given water body. These methods range from low cost visual estimations of plant occurrence and cover to high cost remote sensing that can sample a water body or an entire landscape. An important factor to remember when selecting a method is to choose the method that will meet the desired objectives for the project; but more importantly, to choose a method that is quantifiable and can be subjected to statistical analyses (Madsen and Bloomfield 1993, Spencer and Whitehand 1993). Madsen and Bloomfield (1993) summarized the importance of collecting quantitative as:

- ♦ *Quantitative data are objective measurements, and relying on subjective measurements leads to opinion which is not a sound basis for management decisions.*
- ♦ *Quantitative data can be subjected to rigorous statistical analyses that can lead to the development of scientifically based management guidelines.*
- ♦ *Quantitative data can identify management techniques that were ineffective and reduce the cost of a management program.*
- ♦ *Quantitative data can be utilized by different users other than the observer.*

In order to ensure that monitoring and assessment data are collected in a manner that is suitable for quantifiable analyses it is important to collect data using an appropriate sampling design. The four most common sampling designs are the completely random, stratified random, random- systematic, and systematic designs (Figure 1). In general, the completely random design removes biases associated with the selection of sampling locations; however, Barbour et al. (1999) points out several limitations to this design in larger areas. A random selection of points may place points in difficult to access or inaccessible areas, and the little information these points would provide does not compensate for the added time it would take to sample them. The field time required to sample random points is large and would likely be an inappropriate choice for large surveys. A random selection of points may result in the location of some points being clumped, leaving large areas under-sampled. A completely random design would under-sample rare yet important species that would be sampled using other designs.

A stratified random design is typically utilized if a gradient exists in the survey location, for aquatic surveys this could include a river or stream channel running through a reservoir. The area can be divided into homogenous sections with sampling points randomly distributed within each section. The systematic sampling design places sample locations within an area based on grid with a pre-determined spacing. The systematic design works well for an initial survey as it will cover the entire water body and the observer is more apt to find most species. Also, if data such as water depth or Secchi depth is collected at sampling locations, the maximum depth of plant colonization can be determined and the littoral zone delineated for future surveys. A random-systematic design selects areas either by random or using a stratified approach, the survey is then initiated by selecting the starting point either a randomly or in a stratified fashion then conducted using a systematic sampling approach (Barbour et al. 1999). The random-systematic design works well if a gradient is present, or if the littoral zone is well defined thereby allowing sampling locations to be stratified within the littoral zone.

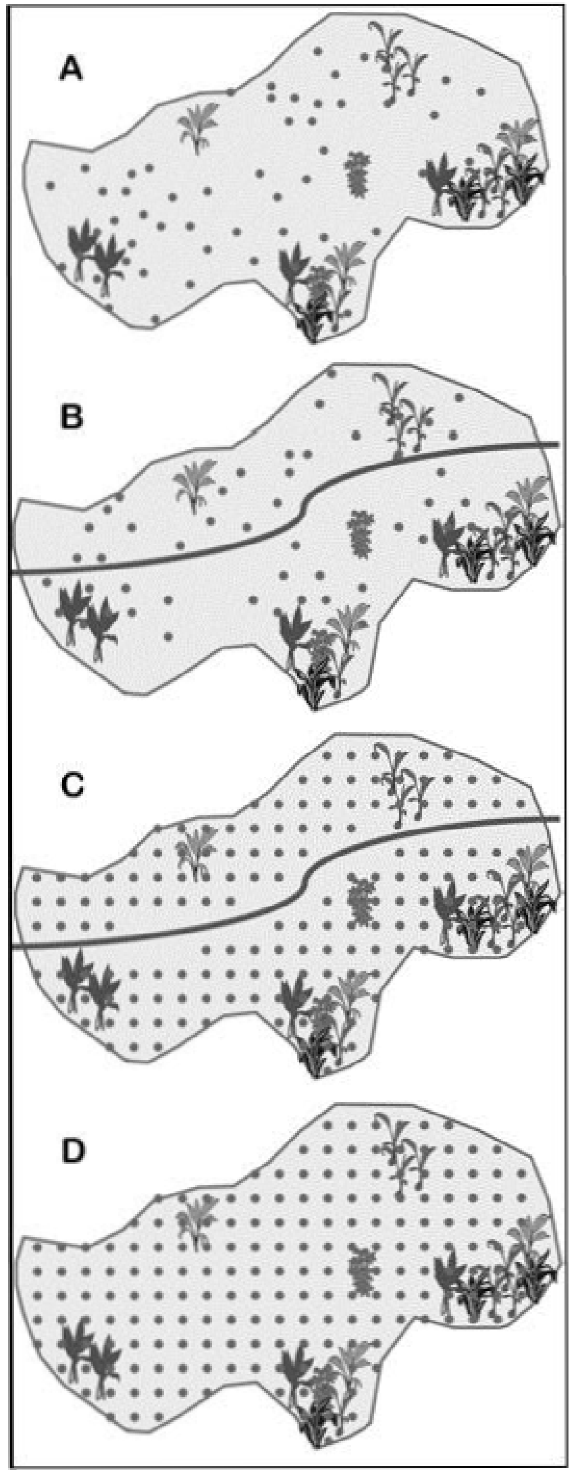

Figure 1. A conceptual representation of plant community sampling designs (A) completely random, (B) stratified random, (C) random-systematic, and (D) systematic.

A summary of the more common aquatic plant sampling methods (including non-quantifiable) are listed in Table 1 with specific guidelines discussed in later sections. The simplest estimates of plant cover and abundance can be achieved using visual observations while on a water body. Generally, total acreage is estimated for each species based on the total area of the water body. Visual estimations are highly subjective, are not repeatable, and highly variable among observers, making them not amendable to statistical treatment. Also, it is very difficult to estimate abundance of submersed aquatic plants, and as such species are missed or underestimated.

Table 1. A summary of vascular aquatic plant monitoring and assessment methods (adapted from Madsen and Bloomfield 1993).

Method	Techniques	Effort	Variability	Recommendation*	Applications
Point Intercept	Presence/Absence	Low	Low, can be spatially variable	S,E,F	Small plot assessments, baseline surveys, whole lake monitoring, and long- term assessments
Line Transect	Points, Quadrats	Moderate	Moderate, can be spatially variable	S,E,F	Small plot assessments, monitoring species distribution
Subjective Estimates	Visual	Low	Low-High, depends on how many people are making estimates	S,E,F	Initial survey though this method is highly subjective and not quantifiable
Semi-quantitative	Visual	Low	Low, can be spatially variable	S,E,F	Initial surveys
	Rake Fullness or Spinning Rake Methods	Moderate	High	S	Small plot assessments, will over or under estimate species depending on composition
Biomass	Coring, Quadrats, Box Sampler, Ponar Dredge	High	High, can be spatially and temporally variable	S,F	Small plot assessments
Non-Destructive	Hydroacoustics	Moderate	Moderate, can be temporally and spatially variable	S	Small plot assessments, Long-term monitoring
	Plant Morphological Measurements	Moderate-High	Moderate, can be temporally variable	E,F	Small plot assessments
	GIS, Remote Sensing	Moderate	Low-High, will depend on the resolution of images	E,F	Visualization of data, whole lake, long-term monitoring, not species specific
	Mathematical Models	Low-High	Low-High, will depend on data underlying the models	S,E,F	Potential predictability, estimations of future invasions and plant growth, evaluate effects of alternative approaches

*S=Submersed, E=Emergent, F=Floating

A compromise between subjective estimates and quantitative methods would be a semi-quantitative survey in which preselected areas are surveyed using a presence/absence approach to establish the frequency of occurrence for species (Madsen and Bloomfield 1993). Divers or a plant rake can be utilized to sample submersed species. This method would be useful to establish basic plant community composition if a number of sites were surveyed, and would capture more species than subjective estimates. Though again, similar to subjective estimates, these data cannot be readily analyzed and may not be adequate in establishing thresholds to meet permitting requirements.

Quantitative methods that can be utilized to rapidly collect information regarding plant occurrence, species richness, and distribution include the point intercept and line transect and methods. These methods can be used in both small plots and in multiple locations within a water body to establish plant community characteristics or assess management efficacy. Point intercept surveys are typically conducted using a pre-selected grid of points at a user specified interval (Madsen 1999). By pre-selecting points, it removes the subjectivity with respect to sample locations. Once on the lake a Global Positioning System (GPS) is then used to navigate to each point where a plant rake is deployed to sample submersed vegetation. Emergent and floating vegetation can also be recorded at each point as well. The point intercept method is very adaptable to meet the desired objectives of a management program. More importantly, surveys are developed based on a given sampling design (random, stratified random, random-systematic, and systematic) which allow data to be statistically analyzed to compare changes in species occurrence over time and to assess the effectiveness of management techniques (Wersal et al. 2010). With advances in GPS and Geographic Information Systems (GIS) technologies, point intercept survey protocols can be developed, implemented, and results analyzed while still on the water. Point intercept is a robust sampling method that is less sensitive to differences in abundance or season, but also may not register those very difference in abundance that are the result of management activity.

Line transect methods are similar to the point intercept method, however, with transects one can collect presence/absence data, cover data, or use quadrats along transects to collect density and abundance measurements (Grieg-Smith 1983, Madsen et al. 1996, Titus 1993, Getsinger et al. 1997). In general, the line transect method requires less technology then point intercept surveys, as transects can be established and samples without the use of a computer or GPS technology (Madsen 1999); though these technologies are more readily available and more cost effective than in previous years and are routinely used for transect establishment. Transects can be arranged in any number of sampling designs to capture variability within the water body as long as an appropriate number of transects are sampled (Titus 1993). Transect lengths can be any length from large field based projects (Titus 1993), to small scale (3 cm) intervals to estimate foliage coverage of submersed plants (Sidorkewecj and Fernández 2000). The line transect method is particularly useful in determining aquatic plant community characteristics in small study sites over time and to assess management efficacy in small plots.

In addition to constructing a species list through presence/absence information, often times it is of interest to collect plant abundance data. Plant abundance is best characterized using a biomass harvesting technique such as a coring device, quadrats with and without divers, ponar dredge, or the semi-quantitative rake fullness method. Biomass harvesting is labor intensive and can be subject to spatial and temporal variability depending upon plant densities, plant community composition, and life history traits. However, biomass techniques provide the best information on species abundance as long as an adequate number of samples are collected to overcome issues with variability (Madsen and Bloomfield 1993, Madsen 1993). Pursuant to this, biomass techniques such as coring devices, box corers, and dredges are the only techniques that can adequately sample below ground plant biomass such as root crowns, rhizomes, tubers, and turions (Madsen et al. 2007, Owens et al. 2010). Though, emergent vegetation is often difficult to harvest with corers and dredges.

Before undertaking a biomass sampling program, it is necessary to understand the trade-offs between the labor involved in using the sampling device, the area of the sampling device, and the number of samples needed to adequately assess the target plant population (Madsen 1993). For example, box corers generally have an area of 0.1 m^2 and PVC coring devices and area of 0.018 m^2; therefore, fewer samples are needed with the larger sampling device to overcome issues with variability and collect a statistically-relevant number of samples (Downing and Anderson 1985). However, larger samplers require more processing time, and therefore it may be beneficial to use a smaller sampling device and collect more samples (Downing and Anderson 1985). For instance, a corer of 0.018 m^2 may require 30 samples in a given community to get a statistically-significant sample, but may actually require less time to collect and sort than the 10 samples needed for a statistically-adequate sample with a 0.1 m^2 quadrat. The spinning rake method is conducted by lowering a plant rake on a fixed pole to the bottom of the water body (Skogerboe et al. 2004, Skogerboe and Getsinger 2006, Owens et al. 2010). The plant rake is then turned once 360° to harvest aboveground plant material. The rake head has a known length, and when turned, serves as a circular quadrat in which an area can be calculated. Although this method is easy and low intensity, it is less precise than other biomass methods especially in dense vegetation (Johnson and Newman 2011) where it tends to overestimate abundance and will not sample below ground plant structures. As with any quantitative method, biomass techniques should be used following a sampling design, and in doing so, will allow for statistical analysis of collected data. To determine if a statistically-adequate number of samples has been collected, a power analysis should be performed on an initial set of data from the site (Madsen 1993, Spencer and Whitehead 1993, Downing and Anderson 1985).

To overcome the labor intensity associated with biomass techniques, some researchers have developed plant rake methods such as the rake fullness method (Indiana Department of Natural Resources 2007, Hauxwell et al. 2010). The rake fullness method is divides the rake (and sometimes tines) into discrete increments and when plants are harvested an abundance ranking is given for each species. This method while easy and low intensity, relies on subjective ratings by an observer. Visual ratings tend not to be consistent between observers and should not be relied upon as a stand-alone measurement. Pursuant to this, Yin and Kreiling (2011) also reported potential issues with using rake methods to estimate density, and concluded that cross-species comparisons is not encouraged unless the efficiency of the rake method has been determined for each species being compared. This would increase survey time and the overall cost of a management program.

In some instances it may not be desirable to harvest biomass or use a method that may damage existing aquatic plants, especially in the presence of rare or threatened species are in the area. In these cases, non-destructive methods could be used to estimate plant abundance, though some methods like hydroacoustics and remote sensing cannot differentiate plant species. Hydroacoustic sampling targets submersed aquatic plants by using and echosounder or fathometers (depth-finders) that can record information from the transducer onto flash memory devices (Sabol et al. 2002, Hohausová et al. 2008, Sabol et al. 2009). The equipment needed to perform hydroacoustic surveys can be cost prohibitive for most programs, but large natural resource agencies that would use the system regularly could map submersed vegetation for approximately $2.06/ac (Sabol et al. 2009). Hohausová et al. (2008) reported a positive relationship between the hydroacoustic signal and dry biomass, though the relationship could not differentiate species and results would likely be influenced by the dominant species present.

With respect to monitoring and assessment, hydroacoustic surveys allow for the estimation of total biovolume of plants in a given area, which could be used to quantify seasonal changes in the whole plant community over time. Species specific information cannot be determined unless another sampling method like point intercept surveys are utilized to construct a species list.

Unlike hydroacoustic surveys, remote sensing is most effective in targeting riparian, emergent and floating vegetation (Everitt et al. 2007, Liira et al. 2010, Midwood and Chow-Fraser 2010, Robles et al. 2010). Remote sensing is often expensive as satellite images of the target area have to be purchased, specialized software is needed to analyze images, and trained personnel are needed to complete the analyses. However, remote sensing is useful in long-term quantification of vegetation in a given area without having to actually use survey crews year after year. It also allows for the monitoring of larger areas than what are feasible using survey crews alone; though it is recommended to implement some sort of ground-truthing survey to verify plant species composition and the spatial accuracy of remotely sensed data. Other non-destructive sampling can also be done at smaller scales to estimate abundance based on plant morphology measurements (Daoust et al. 1998, Thursby et al. 2002); however, this is typically only used on emergent or floating vegetation as these species are readily accessible and measurements can be taken easily.

GUIDELINES FOR SAMPLING AQUATIC PLANTS

When considering which method or methods to choose for a monitoring or assessment program it is essential to consider the target species, co-occurring nontarget species, the growth form of the target species, and the species life history traits. Ultimately, a method should be chosen to meet the objectives of the management plan. We have offered a decision matrix to assist in choosing a monitoring or assessment method (Table 2), and have developed guidelines for the three growth forms of aquatic vascular plants along with planktonic and filamentous algae. These guidelines are not meant be exhaustive or definitive, but are effective methods that have been verified by scientific evaluations or are recommended in the Standards Methods for the Examination of Water and Wastewater (Rice et al. 2012) to estimate plant coverage or abundance.

Table 2. A decision matrix to guide selection for aquatic plant monitoring and assessment methods.

	Desired Application						
	Initial Survey	Small Plot Assessment	Whole Lake Assessment	Long Term Monitoring	Quantifiable	Cost	Satisfies NPDES Requirements
Point Intercept	X	X	X	X	X	Low	Yes
Line Transect	X	X		X	X	Low	Yes
Subjective Estimate	X	X				Low	No
Semi- quantitative (Visual)	X	X				Low	No
Semi- quantitative (Rake Fullness or Spinning Rake)	X	X		X	Marginal	Moderate	Yes
Biomass		X		X	X	High	Yes
Plant Measurements		X		X	X	Moderate	Yes
GIS				X	X	Moderate	No
Remote Sensing			X	X	X	High	Yes
Mathematical Modeling				X	X	Low	No

Submersed Species

<u>Estimating Cover and Distribution in Lakes.</u> The simplest quantitative approach to estimating submersed aquatic plant cover and distribution in a monitoring program is to perform a point intercept survey. The point intercept survey works well to characterize the aquatic plant community (Mikulyuk et al. 2010), and monitor trends in community composition through time within a water body or system (Wersal et al. 2006, Madsen et al. 2006, Madsen et al. 2008). The point intercept method (or variations of rake methods) has become standard sampling protocol in the states of Washington (Parsons 2001), Idaho, Montana, Minnesota, and Wisconsin to collect initial plant community information and to establish management areas.

The point intercept survey works well in assessing field scale studies and operational management programs. Points can be generated in any treatment area and rapidly sampled to assess a number of small plots or effects throughout a water body in the case of a whole lake treatment (Parsons et al. 2001, Parsons et al. 2004, Parsons et al. 2007, Parsons et al. 2009, Wersal et al. 2010, Robles et al. 2011). This method offers a more strict assessment compared to abundance method as plants are either present or absent and will be influenced by spatial variability in plant beds. It is also important to note that survey resolution will affect detection rates and it is advisable to set one grid interval and maintain that interval in successive years to make comparisons easier and more meaningful. Also, a common misconception with this method is that data can be interpreted as abundance; however sample points are a dimensionless unit so abundance estimates are not possible.

Estimating Cover and Distribution in Rivers. Riverine habitats are much harder to quantify submersed plant species characteristics due to flowing water and inaccessibility in many areas. Submersed aquatic plants often grow in bands along the shoreline of rivers with depth distribution limited by high flows and unsuitable substrate. However, in larger rivers transects have been effective in quantifying plant species cover and assessing management operations (Getsinger et al. 1997). In smaller rivers, line transects could be established perpendicular to the shoreline to run through the vegetation band towards the middle of the river channel. Or, line transects could be established parallel to the shoreline to follow the contour of the vegetation bands, with transects evenly spaced or in a stratified random design (Figure 2). In very small rivers or creeks, a line transect could be established across the entire width of the channel, if flows permit, and space transects in an appropriate sampling design.

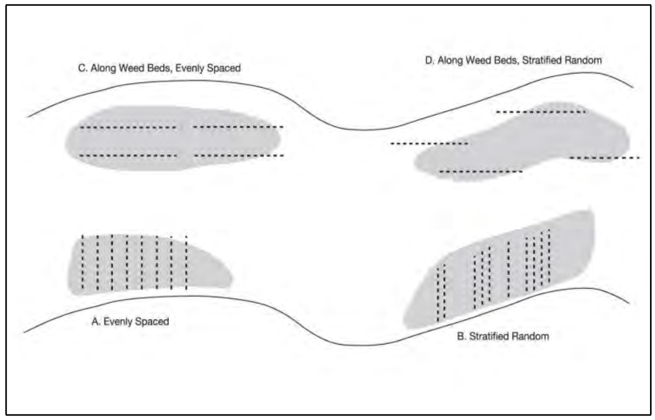

Figure 2. Line transect sampling designs for aquatic plant monitoring and assessment in riverine habitats.

Estimating Abundance in Lakes. When plant abundance is important, biomass collection techniques offer the best data that is also species specific. There are a number of biomass collection techniques and devices, and the appropriate technique should be chosen to meet the objectives of the project, but also to adequately sample the target species. The PVC coring device as developed by Madsen et al. (2007) works very well in sampling submersed aquatic plants, especially below ground reproductive structures. The PVC corer can be utilized in monitoring the abundance of native aquatic plants over time (Case and Madsen 2004, Wersal et al. 2006, Madsen et al. 2006), or non-native plant abundance in small plots (Wersal et al. 2011). When using the PVC corer it is important to collect an adequate number of samples; we typically recommend 20-30 core samples per site. The PVC corer does not sample emergent above ground biomass very well, especially tall plant species. Also, in dense beds of Eurasian watermilfoil and curlyleaf pondweed, care must be taken to ensure the coring device has cut through the vegetation and root crowns and has been pushed deep enough into bottom sediments. Failure to do this will result in a lost sample and extra expenditures in labor. Owens et al. (2010) suggested that a box-corer (similar to an Eckman or Ponar dredge) may sample some species of submersed aquatic plants more effectively than the PVC coring device. However, the box-corer is large and cumbersome to operate and any benefit from using it can generally be overcome by collecting more samples using a smaller area sampler such as the PVC corer.

Another abundance technique is for divers to set quadrats on the bottom of the lake. Sampling in this manner will allow for the collection of species specific presence/absence, species density, and biomass data. Research suggests that the diver quadrat method results in greater accuracy and precision with respect to abundance estimates than boat based methods (Capers 2000, Johnson and Newman 2011). In particular, small species and less frequent species are often underestimated using boat methods (Capers 2000). However, in water methods (diver quadrat) incur more risk to perform, require special training (i.e. SCUBA), and are more time consuming than other methods.

The and spinning rake method (Skogerboe et al. 2004, Skogerboe and Getsinger 2006, Owens et al. 2010) has been used to measure aboveground plant abundance. The spinning rake method was found to be a suitable alternative to the diver quadrat method especially in large scale studies requiring a high sampling intensity (Johnson and Newman 2011). It was concluded that the increased sampling efficiency with which the spinning rake method offered offset its inherent lower precision (Johnson and Newman 2011). The spinning rake method will also be influenced by dense vegetation and overestimate biomass of the dominant species present (Johnson and Newman 2011). Furthermore, rake methods are not as effective in sampling species with basal growth forms such as wild celery; or in sampling below ground structures (Owens et al. 2010). In order to adequately sample below ground structures, one should use the PVC coring device (Madsen et al. 2007).

Recently, there has been a great deal of attention to adapting plant rake methods to collect plant biomass instead of using coring devices and divers. The aforementioned rake fullness method (Indiana Department of Natural Resources, Hauxwell et al. 2010) has been utilized to rapidly assess plant communities. In Florida, it was determined that a rake based method was a suitable alternative to a ponar dredge and diver harvested quadrats in estimating submersed plant abundance (Rodusky et al. 2005).

If species specific abundance data are not required for a given project than remote sensing (including hydroacoustic sampling) can be used to estimate abundance (biovolume) of aquatic plant species (Rice et al. 2012). In general the larger the area, the greater the advantage of using remotely sensed data especially if sampling is required over long time scales (Rice et al. 2012). Some studies have reported that remote sensing could be used to monitor canopy forming submersed aquatic plants (Everitt et al. 2003, Fitzgerald et al. 2006, Nelson et al. 2006). Remote sensing of hydrilla (*Hydrilla verticillata*) infestations using satellite imagery and aerial photography has worked well as long as plants were at or near the water surface.

Large-scale management programs in Texas have utilized aerial photography to successfully assess the efficacy of grass carp (*Ctenopharyngodon idella*) herbivory on hydrilla in Lake Conroe (Martyn et al. 1986). Similarly, hyperspectral imagery was used to evaluate the efficacy of herbicide applications in the Sacramento-San Joaquin River Delta in California (Santos et al. 2009). In regards to submersed plants, an underestimation is likely to occur depending upon the reflectance bands used in the analysis, water clarity, and the depth to which submersed plants are growing. It may be more cost effective to utilize hydroacoustic surveys for submersed aquatic plants, especially since many depth-finders now days are less expensive and record transect data to portable memory (Maceina et al. 1984, Sabol et al. 2009). Hydroacoustic surveys can give a very precise estimate of total plant volume in a given water body and is relatively rapid to perform (Sabol et al. 2009).

Estimating Abundance in Rivers. Line transects and diver harvested quadrats were used to assess herbicide efficacy and non-target impact in the Pend Oreille River, WA (Getsinger et al. 1997). Core samplers could also be utilized to randomly collect biomass samples within plots, or to collect samples along a line transect or grid instead of using divers. In fact, the PVC coring device was used in Lake Pend Oreille, ID (in both the lake and riverine portion) to assess plant abundance before and after herbicide treatments and diver operated suction dredging (Madsen and Wersal 2008). In larger deeper rivers it may be possible to use hydroacoustic surveys to delineate plant beds and estimate cover. Satellite and aerial imagery can also be used to monitor and assess submersed species such as hydrilla and egeria (*Egeria densa*) in large rivers as long as they are at or near the water surface (Everitt et al. 1999, Everitt et al. 2003, Santos et al. 2009). Submersed aquatic plant biomass can be harvested in small rivers and shallow creeks using quadrats following an appropriate sampling design (Madsen and Adams 1988, Madsen and Adams 1989).

Emergent and Floating Species

Estimating Cover and Distribution in Lakes. For whole lake monitoring, a point intercept survey could be used to collect basic information regarding emergent and floating species composition, cover, and distribution (Robles et al. 2011). However, the line transect method may be a better choice to effectively monitor and assess emergent and floating aquatic plant communities in small plots within lakes as their distributions are typically more concentrated in smaller areas than with submersed species. The line transect method is likely a better choice than the point intercept method as transects typically start along the shoreline and move out into deeper water. The point intercept method may underestimate emergent and floating species in small plots because the dispersion of points may limit detection. Titus (1993) offers a detailed description regarding the use of the line transect method, sampling designs, sample number, and data that can be collected. To properly implement a line transect protocol we recommend using a sampling design that will meet the desired objectives for the project. Effective transect sampling designs are depicted in Figure 3 and are adapted from Titus (1993). Line transects have been used to characterize the plant communities in wetlands of South Carolina and also allowed for the development of a landscape model to predict changes in the vegetation type based on hydrologic and environmental factors (De Steven and Toner 2004).

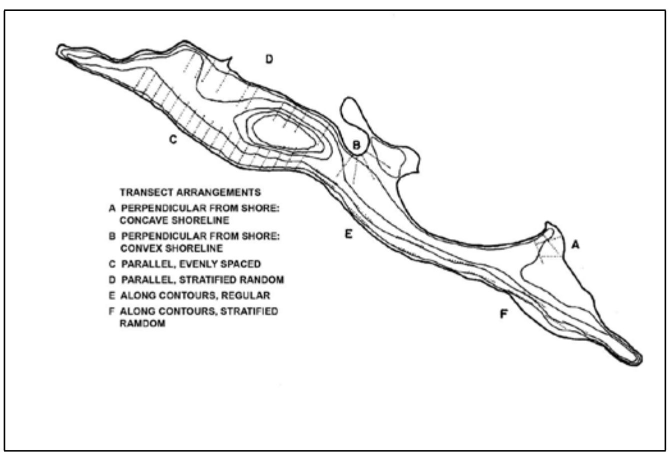

Figure 3.Line transect sampling designs for aquatic plant monitoring and assessment in lakes, adapted from Titus (1993).

Estimating Cover and Distribution in Rivers. When sampling rivers for emergent and floating plant species, the same factors that limit sampling of submersed vegetation still apply. Therefore, it is recommended to follow a similar sampling protocol as outlined in the aforementioned section on estimating cover and distribution of submersed aquatic plants in rivers.

Estimating Abundance in Lakes. If the objective is to monitor or assess small plots as part of a management program, establishing permanent quadrats in these plots would allow for repeated sampling over longer periods of time to assess impacts on both target and non-target species. Welling et al. (1988) utilized permanent quadrats to assess the recruitment and zonation of emergent vegetation in response to drawdown events in prairie wetlands. Overall, quadrats are better for sampling taller emergent species and floating species as these growth forms do not lend themselves well to sampling with box-corers or the PVC corer.

In addition to biomass sampling, remote sensing can be used to delineate emergent and floating plant beds, assess large-scale changes in area in response to management techniques, and unlike with submersed aquatic plants, emergent and floating plants can often be classified using spectral signatures (Marshall and Lee 1994, Hanlon and Brady 2005, Midwood and Chow-Fraser 2010). Pursuant to this, remote sensing has the potential to predict herbicide injury to aquatic plants before the human eye can detect any effect (Robles et al. 2010). If a remote sensing approach is implemented, it may be necessary to periodically ground-truth data to ensure the accuracy of the imagery and algorithms used to monitor and assess plant communities.

Non-destructive measurements of emergent plants such as plant height, stem densities, leaf length, stem diameter, number of leaves, leaf thickness number of axillary stems, and number of nodes can be used to construct mathematical models to estimate aboveground biomass of plant species (Daoust et al. 1998, Thursby et al. 2002, Spencer et al. 2006, Gourard et al. 2008). The development of mathematical models based on non-destructive measurements to estimate plant biomass may be beneficial in cases where sampling of rare or threatened species is necessary.

However, it may be necessary to harvest a sub-sample of individuals to assess which types of measurements could be useful in developing a predictive model. For example, Van et al. (2000) harvested 138 melaleuca trees in South Florida to determine relationships between dry weight biomass and stem diameter measurements. Their resulting model based on inside-bark diameter measurements explained 97% of the total variation in dry weight biomass. It was concluded that this model would be useful in assessing the impacts of biological control agents, by allowing estimation of biomass from measurements made in melaleuca stands where destructive sampling was not possible (Van et al. 2000).

Estimating Abundance in Rivers. Many of the same methods used to estimate abundance of submersed vegetation could be used for emergent and floating vegetation including line transects and quadrats. However, remote sensing may be a good choice especially if large areas of a river basin or drainage are being monitored or assessed. Remote sensing has been utilized in the Rio Grande system to monitor changes in wild taro (*Colacasia esculenta*), giant reed (*Arundo donax*), and water hyacinth (*Eichhornia crassipes*) populations (Everitt et al. 2003, Everitt et al. 2007, Everitt et al. 2008). Herbicide effects on the aquatic plant community in the Sacramento- San Joaquin River Delta was assessed from 2003 to 2007 using hyperspectral remote sensing in the (Santos et al. 2009).

Algae

Planktonic algae. As with aquatic macrophytes, the sampling approach and site selection for phytoplankton will depend upon the project's objectives, sampling frequency, site location, time of sampling, and how the samples need to be collected (Rice et al. 2012). The following is an abbreviated handling of recommendations for sampling planktonic algae in lakes and rivers from The Standard Methods for the Examination of Water and Wastewater (Rice et al. 2012), for additional details please see section 10-1 to 10-51. Establish enough sampling stations in as many locations as needed to adequately define the types and quantities of phytoplankton, keeping in mind that the water's physical nature will influence site choice. If possible, use sites that have been previously used by other observers to ensure that historical data are present.

In lakes and reservoirs use a grid pattern (systematic design), or transects in combination with random procedures (random-systematic design). Sample circular lakes using at least two perpendicular transects stretching from shoreline to shoreline and include the deepest point in the basin. Sample long narrow lakes at several points along at least three regularly spaced parallel transects that are perpendicular to the long axis of the basin, with the first near the inlet and the last near the outlet. Collect an adequate number of samples with respect to water depth within the euphotic zone.
In rivers, sample in both upstream and downstream locations, as well as on both sides of the river channel. Rivers are typically vertically mixed, but may not mix laterally for long distances downstream. Samples collected in the main channel of a river are representative of the general composition of the survey area; while samples collected in backwater areas and sloughs are more representative of local habitat conditions. In rivers, if planktonic distribution is uniform use a random sampling design. However, if plankton distribution is patchy, it may be necessary to increase the number of samples collected, the number sample locations, or collect composite samples.

It is recommended to collect whole, unfiltered and unstrained water samples. Water sample volumes should be >1.0 L in oligotrophic lakes and 0.1 to 1.0 L in more eutrophic systems. In general, nets are not suitable for collecting phytoplankton samples as mesh size will bias species composition in collected samples (Rice et al. 2012). Sampling devices that are typically used for the collection of water samples include the Alpha, Kemmerer, Niskin/Nansen, and Van Dorn; though the Van Dorn is the preferred sampler for standing crop, productivity, and other quantitative determinations (Rice et al. 2012).

Once water samples have been collected and preserved (if necessary) a simple quantification method for algae is counting cells or colonies to determine concentrations and densities. Rice et al. (2012) recommends reporting both cell counts and natural unit counts for algae. A natural unit is the unit that appears in the environment and that aquatic organisms encounter (Rice et al. 2012). Phytoplankton can be counted using low magnification (up to 200x), intermediate magnification (low to 500x), and high magnification (> 500x). A popular low cost counting technique for low magnification is using a Sedgewick-Rafter Chamber with a microscope having a Whipple grid in the eye piece. The Sedgewick-Rafter Chamber has a known area (1000mm^2) and volume (1.0mL) and therefore algae densities can be estimated fairly quickly, and would likely be the easiest technique for monitoring and assessment programs. The Sedgewick-Rafter Chamber cannot be used with higher magnification.

Smaller phytoplankton species can be counted using intermediate magnification and a Palmer- Maloney nanoplankton cell, which is a circular chamber that has a diameter of 17.9mm and a volume of 0.1mL (Palmer and Maloney 1954). Samples requiring higher magnification will need to use an inverted microscope and associated counting procedures (Sandgren and Robinson 1984). However, inverted microscopes are expensive and may limit the applicability of this technique for management assessments.

If species specific information is not required for a particular project it may be possible to estimate total algal concentrations and biomass by chlorophyll a measurements (Creitz and Richards 1955). Chlorophyll a can be determined using spectrophotometry (Jeffrey and Humphrey 1975), fluorometrics (Loftus and Carpenter 1971), and high performance liquid chromatography (HPLC) (Bidigare et al. 2005). Fluorometric determinations of chlorophyll a are more sensitive than spectrophotometry methods, so smaller samples can be collected (Rice et al. 2012). All three methods can be done in a laboratory setting by extracting chlorophyll a, with the HPLC method likely to give more precise and accurate results. However, the HPLC method will require more specialized training and equipment to perform analyses. Recently, handheld fluorometers have become more common and are fairly inexpensive; more importantly they can be used directly in the field for in-vivo chlorophyll a determinations (Simmons 2012). In most cases for management programs, handheld fluorometers would be sufficient to assess efficacy and changes in algal biomass within treatment areas.

Benthic and Periphyton algae (e.g. *Didymosphenia geminata* and *Cladophora spp.*)

Benthic algae serve as the primary source of energy in many stream food webs (Stevenson 1996), and are represented by a number of growth forms and life history strategies (Sheath and Wehr 2003). A species of benthic algae that is of increasing concern is Didymo (*Didymosphenia geminata*). Didymo is a freshwater diatom that is likely from Scotland, Sweden, and Finland. Didymo has acquired the ability to expand its range and it is estimated that it could invade aquatic habitats on every continent except Antarctica (Spaulding and Elwell 2007). It is considered one of the worst freshwater introduced algal species (Bothwell et al. 2009, Smith 2011). Didymo is capable of producing large amounts of “stalk” (extracellular mucopolysaccarides) that can cover stream beds resulting in changes phytoplankton, zooplankton, invertebrate, and fish assemblages (Kilroy et al. 2006, Larned et al. 2006, Larson and Carreiro 2008). A major problem in rivers and streams is how to quantify cover and abundance of benthic algae species.

A semi-quantitative protocol has been adopted by the U.S. Environmental Protection Agency (EPA) in an attempt to standardize rapid assessment of benthic algae species (Stevenson and Bahls 1999). The method utilizes a viewing bucket (≥0.5 m diameter) marked with a 50 dot (7 x 7 x 1) grid and a biomass scoring system. The protocol allows for the rapid assessment of algal biomass over large spatial scales, coarse-level taxonomic characterizations, and biomass estimations (Stevenson and Bahls 1999). The protocol is a field based method and therefore no laboratory procedures are required unless verification samples are needed for algae taxa (Stevenson and Bahls 1999).

Protocol implementation requires the establishment of at least three transects across the water body in areas were algae accumulation occurs. Using a stratified random approach, select three areas along each transect for sampling (e.g. right bank, middle of channel, and left bank). At each sampling location, immerse the viewing bucket and characterize the macroalgae by counting the number of dots that occur over each algae species present. Record the number of dots for each species separately. Mat thickness can be assessed using a ruler and by using the mat thickness rating scale (Stevenson and Bahls 1999). Cover and abundance can be estimated using the following metrics:

♦ Average percent cover for each species of macroalgae is estimated by (Dm/Dt) x 100; where Dm is the number of dots over a given macroalgae species, and Dt is the total number of dots evaluated at the site.
♦ Mean density for each species of macroalgae is estimated by ∑diri/dt; where di is the number of dots over algae of different thickness ranks for each type of algae, ri is thickness ranks, and dt is the total number of dots over suitable substrate for algae at the site.

For a more detailed description of the protocol see the Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish (Stevenson and Bahls 1999).

Other methods are available and could be considered depending upon the objectives of the project, available resources, the number of water bodies to be sampled, and the physical environment within each water body sampled (Stevenson and Bahls 1999). For example, Stancheva et al. (2012) present a new method for quantifying non-diatom benthic algae with respect to taxonomy and biovolume within samples. However, this method is lab intensive and may not be suitable for large assessment projects where a large number of samples will be collected. It may also be possible to use line transects to estimate cover of macroalgae and use small quadrats to assess density and biomass; though it will be necessary to collect subsamples at each location to identify algae species.

CONCLUSIONS

We have offered a number of aquatic plant community sampling methods that can be used for large-scale long-term monitoring, and for small scale assessments of management techniques. It is important to choose an appropriate method to meet the goals and objectives of a given program, and to be willing change methods as the needs and objectives of the program change. It is unlikely that the same monitoring and assessment method will be used throughout a program, especially a long-term program. We recommend choosing methods that are 1) quantifiable, that is, data can be statistically analyzed, 2) follow an appropriate sampling design, 3) are repeatable and flexible enough to change based on needs and personnel. Ideally, monitoring and assessment methods need to incorporate both target and non-target impacts, collect data that is objective and can be quantified, and is labor and cost effective.

Monitoring and assessment is critical in documenting the success or failures of a particular management technique, and will allow for the evaluation of different techniques if needed; thereby preventing costly mistakes. A long term management plan should be developed and incorporate not only year-of-treatment management evaluations, but also long term monitoring of the aquatic plant community. Intensive monitoring has been cited as the only effective way to determine a program's success and when to terminate a management program (Simberloff 2003). However, all too often, monitoring and assessment protocols are the first items to be removed from management programs when funding is limited.

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AERF

Aquatic Ecosystem Restoration Foundation

The AERF Mission:
TO SUPPORT research and development that provides strategies and techniques for the environmentally sound management, conservation, and restoration of aquatic ecosystems. To accomplish this mission, the Aquatic Ecosystem Restoration Foundation (AERF) supports research on the biology and ecology of nuisance aquatic and wetland plants, particularly exotic species.

In addition, the AERF:

♦ PROVIDES Public information concerning the benefits and value of conserving aquatic ecosystems.

♦ PROMOTES Cooperation among federal, state, and local natural resource and regulatory agencies, as well as between the public and private sectors.

♦ FUNDS Graduate stipends in applied aquatic plant management research at major universities

For more information:
Carlton R. Layne, AERF Executive Director
3272 Sherman Ridge Drive, Marietta, GA 30064
Phone: 678-773-1364; Fax 770-499-0158; email clayne@aquatics.org
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