Rainbow River Environmental Study

Dunnellon, Florida

Final Report

September 2012
(Revised)

Charles E. Cichra, PhD
Program in Fisheries and Aquatic Sciences
School of Forest Resources and Conservation
Institute of Food and Agricultural Sciences
University of Florida

and

Stephen M. Holland, PhD
Department of Tourism, Recreation and Sports Management
Eric Friedheim Tourism Institute
University of Florida

This project was funded by the Florida Department of Environmental Protection, Division of Recreation and Parks as Contract RP728

Acknowledgements

This project could not have been completed without the assistance of many people.

The user counting aspects of this study was an example of excellent teamwork. In Dunnellon, local residents Burt Eno, Bill Vibbert, and Paul Marraffino were helpful in identifying potential and actual camera sites, installing and uninstalling the recording stations, and assisting Steve Holland in changing tapes throughout the year. They also monitored the equipment periodically and maintained contact with the residents who allowed the use of their river docks to be the base for each camera station. Those residents will remain anonymous, but it is not an exaggeration to say that this study could not have been done without their generous willingness to tolerate our random arrivals to check equipment and change tapes and in their willingness to allow sometimes not very sightly equipment boxes, cameras or wiring to be in place for over a year on their otherwise scenic docks. Ms. Sandra Fournier of Marion County parks was always timely and helpful in answering various river recreation questions and providing information on KP Hole County Park's users.

In Gainesville, Dr. Ting-Bing Wu, post-doctoral assistant to Steve Holland, spent hundreds of hours viewing thousands of hours of tape, patiently recording the various user type counts. She was patient, accurate and relentless in getting the counts completed. Several short-term graduate students were hired to assist in counting the tapes and Dr. Wu trained them and monitored their output to assure quality. When some count did not seem correct, she was willing to locate the questionable day and camera tape and review it to either verify or revise that count. Her work ethic is commendable and a major component of the production of the results of this study. Ms. Erika Banks-Payne and Ms. Dorothea Roebuck processed and monitored the project's paperwork and budget as well as guided the proposal submission process through the University of Florida's Division of Sponsored Research.

The environmental field work was accomplished by Jesse Stephens, Dana Bigham, Doug Colle, Amanda Croteau, Geoff Smith, Kimberly Orren, Sharon Fitz-Coy, and Dylan Scott. Jesse, Doug, Sharon, and Dylan processed the aquatic plant and water samples in the laboratory. Jesse made sure that all sampling equipment was constructed, procured, and ready for use for the field sampling. Amanda played a major role in data entry, analysis and interpretation, and preparation of this final report. The county staff at the KP Hole, in particular Sandra Fournier, were very cooperative and provided assistance as needed. Jeff Sowards (Manager, Rainbow Springs Aquatic Preserve) allowed us to conduct the study on properties under his jurisdiction and cooperated in all ways with the project, including sample design and data collection.

In Tallahassee, Zack Wetzel and Albert Gregory, of Florida State Parks, Office of Park Planning, were very helpful in proposal discussions and meetings, scoping out the foci of the project, and various budget discussions. Later, Adam Straubinger and Meghan Mesler became our points of contact for the project deadline extension, deliverable submissions, review of the final report, and final processing.

We would especially like to acknowledge the Rainbow River residents and visitors who shared their thoughts with us throughout the study. We hope this study will contribute to maintaining or enhancing the quality of their river experiences in the future.

We thank them all! CC and SH

TABLE OF CONTENTS

Appendices are available as a separate document in support of this final report. These include:

- Individual grid data for each of the 26 plant transects sampled in May 2011, September/October 2011, and April 2012,
- Recreational user count data, collected during each of the 10 days during which water chemistry and drifting plant net sampling was conducted,
- Total, inorganic, and organic suspended solid data for each of the 10 days during which water was collected concurrent with recreational user counts and drifting plant net sampling,
- Weight of individual plant species, collected by each net and time, during each of the 10 days during which drifting plants were collected concurrent with recreational user count and water sampling,
- Boater observation data, including date of observation, boat type, length, engine HP, amount of damage observed, and if behavior was responsible for observed damage, and
- Width and length measurements for each prop scar sampled in the fall of 2011 and spring of 2012.

List of Tables

Table

List of Figures

Figure

EXECUTIVE SUMMARY

Rainbow River is a large, high volume spring-fed river with substantial ecological significance and scenic beauty. Although the State of Florida and Marion County own small tracts of land along the river, most of the riverbank is under private ownership. In recent years, recreational use of the river has increased. As a result, the potential conflicts between user groups and between landowners and tourists have arisen. In addition, there is concern that excessive recreational use may damage the water quality and biological environment of the river. By scientifically documenting (1) the types, locations, and degree or recreational use and (2) the effect of recreational use on the natural environment, results from this project can aid natural resource personnel in making sound management decisions. The methods and main conclusions from this study by task are:

Human Dimensions Study

River use was documented using six time lapse camera-recorders in place from May 11, 2011 to May 10, 2012 stationed along the river. Three were above KP Hole County Park and three were below. The northernmost camera was about 600 feet (183 m) south the headsprings park boundary and just south of the Rainbow Springs residence beach and boat ramp. The southernmost camera was about 150 feet (46 m) north of the Highway 484 bridge across the river. The video tapes were reviewed in slow motion to count the users and record daily summary counts for six use types: canoes, kayaks, motorboats, commercial scuba boats, divers, snorkelers & swimmers, and flotation tubes. Weekly summary counts per camera and activity are included in this report.

Task 1 - Type, location, and quantity of recreational use

1. The highest total recreational use of the river was between May 24 and August 22.
2. The spring, March 20 to April 23, period saw use equivalent to about 25% of the highest use days in the summer months.
3. In the post Labor Day period, the three weeks after Labor Day (~22% highest summer week's use), Thanksgiving week (~14%), and the week between Christmas and New Year's Day (~16%) were the busiest weeks.
4. The least total recreational use occurred the week after New Year's Day and the second week of February.
5. The highest total use across the entire river occurred during these weeks: (1) June 14-20 (designated 100% level), (2) July 19-25 (97%), (3) July 26-Aug. 1 (94%), (4) Aug. 2-8 (90%), (5) June 28-July 4 (90%), (6) July 12-18 (87%), (7) June 21-27 (86%), (8) June 7-13 (81%), (9) Aug. 16-22 (76%), and (10) Aug. 9-15 (75%).
6. During higher use summer periods (but not holiday Monday weeks) Mondays accounted 9.8% of use, Tuesdays 8.4%, Wednesdays 8.8%, Thursdays 9.4%, Fridays 12.8%, Saturdays 28.5% and Sundays 22.3% of weekly use. These sum to 50.8% of use occurring on Saturdays and Sundays and 49.2% occurring on weekdays.
7. During higher use summer periods (excluding holiday Monday weeks), the upper river proportion of total use was 28% and lower proportion was 72%. Not including tubers, the proportion of use for the upper river is 56% and the lower river is 44%.

8. The highest five-week average use (5 peak weeks average) recorded for each activity is: canoes 353, kayaks 467, motorboats 244, scuba boats 46, swimmer/divers 497 and tubers 5,757.
9. Comparing peak use days during 2011/12 with peak use days recorded in 1994, results in these comparisons: the number of tubers on peak use days has more than tripled (~3.7 times as many), the number of motorboats has increased by about 46% and about a 60% increase in canoe/kayaks on peak use days.
10. Estimating annual total use based on six cameras is fraught with potential for overestimates due to the likelihood of counting the same users twice. In an attempt to make some estimate, the highest total use for each activity, regardless of which camera it appeared on is summarized here (meaning these users were only counted once, unless they made multiple trips past the same camera on the same day). Estimated total annual number of canoes was about 5,500, kayaks about 11,000, motorboats 6,600, swimmers/divers about 9,000, scuba boats about 1000, and tubers about 84,000.
11. Comparing these annual use estimates with the annual estimates of a 1994 user count, the following growth increases are observed across the 17 year time span between the two studies. For tubers, there has been a 400% increase in number of tube trips, ~228% increase in number of motorboat trips and a ~15 times increase in the number of canoe/kayak trips or about 1500%.

Environmental Study

Task 2 - Geographic and temporal differences in aquatic plant communities

1. Eighteen species of aquatic macrophytes , along with Chara sp., Lyngbia spp., and other filamentous algae, were sampled in 26 fixed transects.
2. Sagittaria kurziana, Hydrilla verticillata, Vallisneria americana, Potamogeton illinoensis, Utricularia spp., and Fontinalis sp. had mean coverage (areal coverage per grid) of at least 15 percent in all three sampling events in 2011 and 2012
3. Strap-leaf sagittaria (S. kurziana) was the most dominant (areal coverage greater than 50 percent in 10 of 26 transects over all seasons.
4. Strap-leaf sagittaria, along with H. verticillata and Najas guadalupensis were the most common (occurring in 22 to 25 of the 26 transects over all seasons) submersed plant species in the Rainbow River.
5. V. americana was widespread (occurring in 16 to 20 of the 26 transects), but was never dominant in any single transect
6. Illinois pondweed (P. illinoensis) was found exclusively in the headsprings and was fairly common within this area during both our 1994-1995 study and in this current study. It was also found at transect 5.1, a new transect, located just below the State Park boundary.
7. Red ludwigia (Ludwigia repens) was found from transect 4 to 7, and most common at transects 5 and 5.1.
8. The nuisance exotic plant species hydrilla was found to be widespread throughout the river, occurring in 25 of 26 transects. It was absent from transect 2 in all three sampling events. Hydrilla has thus expanded its range within the Rainbow River between the 1994-1995 study (15 of 20 summer 1994 transects; 16 of 20 fall 1994 transects; 17 of 20 spring 1995 transects) and the present study.

9. In 1994-1995, hydrilla mean coverage for any single transect exceeded 25 percent only at transects 1 and 3 in the headsprings. In 2011 and 2012, hydrilla was never found to exceed 25% coverage at any transect. Abundance (percent coverage) declined in the headspring and downstream areas, while increasing somewhat in the midstream portions of the river.
10. Very few areas throughout the river appeared to be devoid of vegetation due to recreational activity. Shallow areas were prone to propeller damage.
11. In the transect data calculations, bare substrate represented areas covered by sand, rock, concrete, or detrital materials. All transect samples had a mean coverage of bare substrate of at least 2.5 percent. Nearly all (67 of 78) had a mean coverage of at least ten percent. Most often, submersed macrophytes seemed to be absent due to unsuitable bottom substrate, such as limestone outcroppings.
12. Bare substrate, due to motorboats (propeller scars), was observed in the Rainbow River. However, far less than one percent of bare substrate was caused by propeller damage.
13. Mean coverage for strap-leaf sag (Sagittaria kurziana) was greatest below the KP Hole County Park (transects 11 and 12), an area characterized by shallow depths, sandy substrate, and high recreational use.
14. Areas purposely cleared of vegetation (i.e., near boat docks, swimming areas) tend to be rapidly colonized by hydrilla.
15. Mean percent coverage and percent occurrences of major plant taxa were similar among all three transect data sets (spring 2011, fall 2011, and spring 2012). This indicates temporal (seasonal) stability of the submersed aquatic plant community.

Task 3 - Human activity and water quality relationships

1. Dissolved oxygen concentrations ranged from a low of 4.55 mg/L to a high of 10.2 mg/L, with a mean of 6.75 mg/L. Concentrations increased throughout each of the 10 sampling days, with highest values being recorded in midafternoon (3 to 4:30 pm).
2. Lowest dissolved oxygen readings were always recorded prior to the presence of recreational users and throughout the night during the diurnal samples, negating the belief that recreational use has a negative effect on dissolved oxygen concentrations in the river as a result of stirring up bottom sediments.
3. River water temperatures ranged from a low of 22.6 C to a high of 25.3 C, with an overall mean of 23.5 C.
4. Water clarity, measured using the horizontal Secchi technique, ranged from a low of 39 feet (11.9 m) to a high of 84 feet (25.6 m), with an overall mean of 63.5 feet (19.4 m).
5. The relationship between the change in water clarity and recreational use is unclear.
6. The change in total suspended solids (difference between late morning and afternoon concentrations from the early morning concentrations) was significantly and positively correlated to the number of motorized boats upstream from the sampling sites during the prior 15 and 30 minutes, respectively.
7. Change in total suspended solids was not found to be significantly correlated to the abundance of any other user group (tubers, canoes, kayaks, or paddlers [canoes + kayaks]) observed upstream of the sampling sites during the prior 15 and 30 minutes.
8. Change in inorganic suspended solids (difference between late morning and afternoon concentrations from the early morning concentrations) was significantly and positively correlated to

the number of motorized boats upstream from the sampling sites during the prior 15 and 30 minutes, respectively and significantly and positively correlated to the number of canoes and paddlers upstream from the sampling sites during the prior 30 minutes.

9. Change in organic suspended solids was not found to be significantly correlated to any user group or time period examined.
10. Based on the analyses of the suspended solids data, it appears that motorized boats have the greatest effect. Although these relationships were statistically significant, the relationships were not particularly strong, as motorized boats upstream of the sampling sites during the prior 15 and 30 minutes, accounted for only 7 to 15 percent of the change in total suspended solids, and 22 to 32 percent of the change in inorganic suspended solids, respectively. Sediments, disturbed by motorized boats, were observed to quickly settle from the water column.

Task 4 - Human activity and aquatic plant relationships

Net Sampling:

1. S. kurziana comprised 89.2 percent by weight of all plants collected, almost identical to the 88.6 percent in 1994-1995 (Holland and Cichra 1995). V. americana and H. verticillata were the next most abundant, comprising approximately 6 and 2 percent of the total weight, respectively. These two species represented approximately 4 percent each in 1994-1995.
2. Composition of drifting plants was similar on all ten sampling days except for the 24 August 2011 sample, when H. verticillata represented 11 percent of the submersed plants collected by the nets.
3. The composition of plant taxa collected with the nets was similar to the composition of plants found upstream of the sampling site, indicating that recreational activity is not selectively damaging any particular submersed plant species.
4. Early morning values for wet weight of plants collected were almost always less than 200 grams/net-hour.
5. During high-use days, the biomass of damaged plants increased throughout each sampling day as user activity increased. The mean wet weight of damaged plants reached much higher levels, up to 3400 grams/net-hour on high-use days.
6. The biomass of drifting plants, collected in the nets, was significantly and positively correlated to the number of tubers, power boats, canoes, and kayaks observed upstream from the nets. Motorized boats had the strongest relationship.
7. When examining increase in drifting plant biomass (i.e., plant damage), only motorized boats were found to have a significant relationship.
8. Although plant damage is occurring due to recreation, the amount of damage is insignificant in comparison to the total biomass of plants in the river.
9. Because the recreational activity of several different user groups (i.e., tubers, boaters, canoes, and kayaks) occurred at the same time, it is difficult to determine which user group was responsible for the observed plant damage. However, the strongest association with drifting plants, as well as observational evidence, indicates that the majority of the damage is likely due to power boats.
10. The behavior of a small number of irresponsible boaters resulted in a large amount of damage to the aquatic plant community.

Direct Observation of the Effects of Motor Boating on the Aquatic Plants:

1. A total of 269 motorized boats were observed during 2011 and 2012, and categorized into eleven "boat types" . The most common boats observed were pontoon, Jon, and bay boats (82 percent).
2. No damage was observed from any of the Gheenoe / Ganoe, inflatable, air boat, skiff / flats boat, or jet ski categories.
3. Pontoon boats are by far the most popular boat type on the Rainbow River. Of the 126 pontoon boats recorded, 86.5 percent were not observed to cause damage to the aquatic plants.
4. Minimal to substantial damage, however, was caused by 17 pontoon boats.
5. Most of the damage caused by this type of boat was due to behavior of the operator - operating the boats in shallow areas and/or not having the motor trimmed, among others.
6. Of the 49 Jon boats that were recorded, only one of the boats was observed to cause damage, and it was minimal in nature.
7. Of the 46 bay (small to medium, center or side console) boats that were recorded, 11 caused plant damage (3 minimal, 4 medium, and 4 substantial). Most of this damage was due to large motor size, which often caused the boats to ride low in the rear.
8. Eighteen bass boats were recorded. Of these five caused plant damage. The worst case (substantial damage) occurred when the operator drifted into shallow water while fishing. When attempting to leave the shallow area, the operator simply started the engine, without trimming it up, causing the damage.
9. Two near shore (walk-around, cuddy-cabin, or large center console) boats were recorded on the river. Both caused plant damage (1 minimal and 1 substantial). As with the cruisers, the operators attempted to stay in the deeper portion of the river channel, but due to their draft, they still caused damage.
10. When all recorded boats are combined, regardless of type, as boat size (length) increases, the percent of boats that caused damage increased. No damage was observed for the 36 boats less than 15 feet in length. For boats from 16 to 20 feet, 12.4 percent caused damage, while 20.5 percent of boats 21 feet or longer caused damage.
11. When all recorded boats are combined, regardless of type or length, the overall percentage of boats causing damage and the degree of damage increased. The highest percentage of damage was for boats with 76 to 100-HP engines. Within this category, 4 of the 7 boats, that caused plant damage, caused it due to operator behavior and not simply due to the size of the engine. Having a large engine does not necessarily lead to plant damage.

Prop Scars:

Number and Location:

1. A total of 61 prop scars were recorded and analyzed. The average depth of the scars was 3.02 feet (0.92 m). Within the KP Hole County Park boat launch buffer (1,000 feet [305 m]), 16 scars (26.2%) were observed. Only the State Campground tuber take out point had prop scars near it. Within that tuber take out point buffer (1,000 feet [305 m]), 14 scars (23.0%) were recorded. Between the points at which tubers enter and exit the river, 17 scars (23.0%) were recorded. Of the remaining 13 prop scars not accounted for in the tuber zone of the river or either launch or take-out buffer, eight were north of the KP Hole launch buffer, and five were south of the tuber take-out buffer.

2. Currently, the river has not been mapped for depth, so the concentrations of scars that were recorded may simply be because those are the shallowest stretches of the river.
3. Many of the scars occurred at the inside bends of the river where the water was shallow. A number of scars were located near boat docks.
4. Other areas, with high densities of scars, were large shallow expanses of water, with no well-defined deep channel, in particular downstream of the KP Hole County Park and downstream of the State Park tuber take out. Behavioral observations of boaters in these congested areas, while sampling plant transects (Task 2) and drifting plants (Task 4 – net sampling and SCUBA), found that some boaters created these scars while trying to avoid tubers, while others were formed simply in the course of normal navigation through shallow areas.

Regrowth of scars:

1. The 61 prop scars had a mean length of 18.6 m and mean width of 0.47 m in the fall of 2011. While observing the scars, it was apparent that regrowth of some of the scars had already commenced.
2. For the 26 prop scars, that were resampled in Spring 2012, the Fall 2011 mean length was 16.5 m and the Fall 2011 mean width was 0.37 m. The mean length and mean width of these 26 prop scars decreased to 0.14 m and 6.4 m, respectively in Spring 2012.
3. Over the winter, mean width decreased for 10 of the scars, increased for 2 scars, and stayed the same for 2 scars. Eleven of the scars completely closed in with regrowth from the surrounding plants, primarily Sagittaria kurziana. Total length decreased for 10 scars, increased for 1 scar, and stayed the same for 3 scars. As with width, 11 scars completely filled in with plants, and had zero length.

SCUBA:

Diver and Snorkeler Activity:

1. Observations were collected from the KP Hole and north to the headwaters of the Rainbow River.
2. Diver and snorkeler activity consistently occurred from 8 a.m. until 4 p.m, with a peak of activity occurring at 8 a.m.
3. Divers and snorkelers entered the water at the same locations by assistance of transportation boats (e.g., Rainbow Water Taxi or American Pro Dive Center on these dates). Two locations were identified where the transportation boats had designated drop locations for both divers and snorkelers.
4. The first site was near the shore and included a rock bottom with no submersed vegetation within the drop location, yet surrounded by Sagittaria kurziana and Valisneria americana beds. The second site was the Devil's Elbow, an area about 10m in depth with numerous small vents.
5. Diver activity occurred at both the surface of the water and under the water, while snorkeler activity occurred only at the surface of the water.
6. Diver and snorkeler activity at the surface was similar as both user groups drifted along the surface of the water. Frequently, the drift activity was observed to stop with the participants surfacing and sometimes standing in macrophyte beds to rest.
7. Average length of the drift activity was about 90 minutes, but ranged from 30 minutes to 120 minutes for both divers and snorkelers.

8. The average length of time under the water was 40 minutes, with the length of a dive ranging from 15 minutes to 90 minutes.

User Behavior:

1. Divers were not found to consistently cause damage (i.e., uprooting vegetation or breaking off pieces of vegetation) associated with use of the river. Although during periods of high use, divers were observed to move to vegetated areas of the river to limit congestion, such as the vegetated islands in the middle of the river or shallow, littoral vegetated areas.
2. The movement of divers to avoid areas of congestion was the only observed behavior with potential to damage vegetated areas of the river.
3. The most noted and obvious damage to vegetation was from boats. On a low-use day (i.e., low number of divers, snorklers, and other users), boats would stay in the deeper parts of the river causing no damage to vegetation.
4. On a high-use day (i.e., high number of river users), to navigate the river, boats had to move into shallow areas of the river to avoid kayakers, divers, snorkelers, other boats, etc. The movement to shallow areas, along with movement up or downstream, to avoid other river users, uprooted vegetation. Sometimes large mats of uprooted vegetation were observed to flow down the river after a boat had passed.
5. Comparatively, during this observation period, the movement of boats into vegetated areas produced more damage to emergent, floating, and submersed aquatic macrophytes than the movement of divers into the same, vegetated areas.

Management Suggestions

Of all of the recreational user groups, motor boaters have the greatest impact on the river. Damage is done by a small percentage of this user group. Some of the damage is due to the specific configuration of the boats and their engines, but operator behavior has a far greater impact on how much damage occurs. Based on this, the best way to minimize damage to the river is by educating the boating community. This can be done by:

1. Providing educational pamphlets:

   - To boat owners at the major points of entry to the river – the KP Hole County Park boat ramp and the Highway 41 boat ramp on the Withlacoochee River in Dunnellon
   - To residents, living on the river, via mail
   - To individuals who rent boats via boat rental operators

2. Providing educational kiosks or signage (with photos), at the KP Hole County Park boat ramp and the Highway 41 boat ramp on the Withlacoochee River in Dunnellon, indicating such items as:

   - Proper way to trim one's motor
   - Staying out of shallow areas of the river

- What damage can be done to the plants (photos of prop scars)
- Value of the plants to fish and wildlife and water quality of the river
- A map showing major areas of prop scarring

3. Holding meetings with local boating groups or individuals interested in the management of the river such as the Rainbow River and Florida Conservation Coalition. Staff from FDEP or the University of Florida can present updates, based on continued monitoring of the river, on an annual basis to better inform the public. Agency staff, university researchers, and interested stakeholders should get together on an annual basis to assess the environmental status and management of the river.

4. Working with boaters and other user groups to develop alternative management options for cases where their activities lead to localized damage to the river. For instance, boats tie up at the State Park tuber take out and canoes and kayaks often pull up onto the tuber take out, making it difficult for tubers to exit the river, thus leading to damage to the aquatic plants at the take-out area. One management option that could be considered is to restrict boaters from tying up their boats to the take-out structure, and to restrict canoes and kayaks from pulling up onto the structure.

The survey of the prop scars in the river identified two areas that had high densities of damage. These were the areas immediately downstream from the KP Hole County Park and the area downstream from the State Park tuber takeout. These areas should be marked as "shallow areas" with signage in the river. Prop scars occurred throughout much of the remainder of the river. Occasional signage could be placed in the river, warning boaters of shallow areas.

Given that the Rainbow River is a state-designated aquatic preserve, that warrants protection, law enforcement should be present on the river, warning boaters not to damage the aquatic plants. If allowed, warning citations should be given on the first violation, followed by tickets on subsequent violations. The threat of being fined will often change the behavior of boaters. This could easily be focused in the area immediately downstream from the KP Hole County Park. This area has easy access for law officers, via the KP Hole County Park boat ramp, and is an area where prop damage to the plants commonly occurs. Currently, Florida law protects seagrasses, located within marine aquatic preserves, from "scarring" by motor boats – see:
http://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0200-0299/0253/Sections/0253.04.html This section of the F.A.C. indicates that "A person operating a vessel outside a lawfully marked channel in a careless manner that causes seagrass scarring within an aquatic preserve established in ss. 258.39-258.399, with the exception of the Lake Jackson, Oklawaha River, Wekiva River, and Rainbow Springs aquatic preserves, commits a noncriminal infraction, punishable as provided in s. 327.73. Each violation is a separate offense." ""Seagrass" means Cuban shoal grass (Halodule wrightii), turtle grass (Thalassia testudinum), manatee grass (Syringodium filiforme), star grass (Halophila engelmannii), paddle grass (Halophila decipiens), Johnson's seagrass (Halophila johnsonii), or widgeon grass (Ruppia maritima)." ""Seagrass scarring" means destruction of seagrass roots, shoots, or stems that results in tracks on the substrate commonly referred to as prop scars or propeller scars caused by the operation of a motorized vessel in waters supporting seagrasses." This law could be changed to include the Rainbow Springs Aquatic Preserve, along with the other

freshwater aquatic preserves. "Seagrasses" could be expanded to include native freshwater species of aquatic plants such as S. kurziana and V. americana.

In May and June of this year (2012), water levels in the Rainbow River were extremely low due to the lack of rainfall in the area. Water levels reach almost historic lows. As a result, a large amount of damage occurred to the aquatic plants in the river. Levels were so low, that it was almost impossible to traverse portions of the river without damaging the plants. If such an event occurs in the future, action should be taken to potentially close portions of the river to motorized boat traffic to prevent or minimize damage to the river. Based on the findings of this study, if limited access were allowed, it should be provided to small boats with small engines. Extremely large boats, such as cruisers, should not be allowed on the river.

As indicated above, tubers do cause heavy damage in areas where they enter and exit the river while out of their tubes. This occurs in limited shallow areas of the river. Any attempt to restrict tubers from these areas will simply cause the tubers to find other nearby areas in which to loaf. The area adjacent to and downstream from the KP Hole County Park is denuded of vegetation in the peak summer recreational season. Hydrilla, an exotic invasive plant species, was observed to quickly grow within the damaged areas during the low recreational-use period.

Canoers and kayakers caused minimal damage to the river, occasionally pulling up a plant or stirring up the bottom sediments when they entered shallow areas. They readily used the ramps present on the river, often not getting into the water to enter or exit their boats. It is recommended that the access ramps, for these users, be maintained.

Many individuals, encountered on the river, felt that SCUBA divers were often blamed for damage to the river. The vast majority of diving activity is conducted upstream from the KP Hole County Park. During our observations, that focused on diving activities, both of the divers and of the dive boat operators, we did observe damage to aquatic plants, but it was limited in nature. A greater amount of damage was done by recreational boaters who were trying to avoid large groups of divers. At this time, no suggestions are made as to management of diving on the river.

On several occasions, and at several locations along the river, homeowners or individuals working for homeowners were observed pulling up or cutting aquatic plants along the river. Some of this was legal, being permitted work. In several cases, hydrillla was being pulled up and allowed to float down the river. If not already done, homeowners could be educated as to what they could and should be doing. This information could be provided to homeowners on the river, along with the information that is discussed above in regards to boating activities on the river. It was common for nearshore shaded disturbed areas to regrow with hydrilla.

Several key questions, examined in our 1994-1995 study, are responded to in the next few pages:

1. **Is there a carrying capacity on the river for tubing and will it be environmentally sound?**

Environmentally, tubing has little to no impact on aquatic plants and water quality, except potentially in the immediate location of tuber entry and exit (where shoreline erosion and plant damage will likely occur) or in areas where tubers physically come in contact with the plants or bottom (which seldom occurs). Direct observation of thousands of tubers, during sampling below the KP Hole County Park, indicate that most tubers are up onto their tubes soon after entry into the water. Empirical support for minimal tuber impact exists at the KP Hole County Park which experiences thousands of tubers, while exhibiting minimal environmental impact (except for shoreline erosion). Currently, tuber use of the river is far below any potential environmental carrying capacity for the river.

There is something to be said for the approximate use zoning of the river. Currently, most tubers use the river south of the State Campground and KP Hole County Park, while most canoers and boaters use the north part of the river, where there is less tuber traffic. This has advantages in safety and in providing users with alternative density types in different areas of the river.

2. **Can the river sustain more recreation?**

From an environmental perspective, currently, the answer is cautiously yes. Many people, encountered during the field sampling for this study, objected to divers using the river, by far the most objected to use. We did not observe any significant impact on the river by the divers. We did, however, observe situations in which boaters had a difficult time maneuvering in the river, while trying to avoid divers, especially in several narrow sections of the river located above the State Campground. It is recommended that ongoing agency monitoring of this system be continued. In the future, portions of this study could be conducted to assess the quantity of recreational use and the impact of potentially increased use on the aquatic plants within the river.

The application of the carrying capacity concept has been successful in limiting environmental degradation in aquatic ecosystems such as the Ichetucknee River, Florida. However, the Rainbow River greatly differs from such a system in that the Rainbow River has a much larger volume of flow, deeper water, larger width, and greater light availability. Though both systems have large numbers of tubers, the Rainbow River does have the presence of large numbers of motorized boats. The Rainbow River seems to not be as environmentally sensitive to recreational activity. Therefore, at current or moderately increased use, we would predict no long-term environmental impacts by recreational users on the water quality or aquatic plant community of the Rainbow River. The water chemistry of the river, primarily nitrates, has been changing. With changes in the water chemistry, such as increasing nitrates, effects of recreational use on the river may change over time.

3. **Is canoe and kayak use allowable from both recreational and environmental points of view, based on carrying capacity. What about the safety factor?**

Environmentally, canoes and kayaks (paddlers) have little impact on the water quality and aquatic plants due to the depth and width of this river. Paddlers seldom come in contact with the stream bottom and plant damage was observed to be minimal. These users should, however, be encouraged to restrict their use to open-water areas of the river. Currently restricted areas (roped off areas) should be maintained if deemed necessary by DEP staff.

Canoe and kayak use is allowable from the recreational perspective also. There seem to be limited safety concerns given the "no wake" regulations. The major safety factor is probably more take out points needed because of frequent afternoon severe weather and lightning in summer months. Given the expense and transportation logistics of canoes and kayaks, and in particular canoes, it seems unlikely that canoe and kayak use will dramatically increase to a point that will substantially affect carrying capacity. Far more canoes and kayaks were encountered during 2011 to 2012 than observed during 1994 to 1995. These users often were observed in social groups.

4. **Based on all data collected from the environmental study, what carrying capacity is recommended for the Rainbow River?**

It was not the purpose of this study to set a carrying capacity. Establishing a carrying capacity is a complex issue (see prior literature review which is included in this report). In addition, the high levels of use, witnessed during the summer of 2011, provided little evidence of substantial impact on the environment, except for damage from a small portion of motorized boats. With observed impact levels so low, it is speculative to suggest what the highest acceptable use level might be.

In the State Park area, the allowed uses are canoeing, swimming and snorkeling. Given the regulated environment of the park with monitoring to control environmentally impacting behaviors such as climbing on trees or banks or removing plants, etc., there is less likelihood of damage than might occur in non-regulated areas. It would seem that the primary damage is from swimmers denuding the aquatic vegetation in the swimming area and causing downstream sand transport due to sediment disturbance. Canoeing causes almost no damage, if there is a dock to which to tie up.

Estimates of recreational carrying capacity in specific portions of the river, such as in the State Park, could be generated by using spatial planning standards such as dividing the water area by use guidelines, such as 100 square feet (9.3 m^2) per snorkeler, 200 square feet (18.6 m^2) per canoe, and 50 square feet (4.6 m^2) per swimmer; times the user turnover rate per day.

For the entire river, with some rough estimate calculations on the environmental side, it was found that there is plant damage, especially from motorized boats, but the potential growth recovery rates of the plants (prop scars) is so high, that the net effect is negligible. There is substantially more capacity for plants to recover than the damage caused by current use. With many millions of gallons of spring water flowing through the river per day, there is almost no feasible recreational use level that could substantially impact water quality. Low flow does, however, reduce water depth, allowing increased damage to occur especially from boat traffic. This was observed during the low-river-flow period in early summer 2012.

Introduction

Rainbow River (Blue Run) is one of the largest spring-fed rivers in Florida with substantial ecological significance and scenic beauty. It has been designated as a National Natural Landmark, an Outstanding Florida Water, and an aquatic preserve by the state of Florida. The headspring and river is located in southwest Marion county, flowing about 5.7 miles through Dunnellon into the Withlacoochee River and out to the Gulf of Mexico, near Yankeetown (Figure 1).

Historically, the headspring area and part of the river have been privately owned and operated as a commercial recreation facility with overnight accommodations, flower gardens, rides, zoo, aviary and glass-bottom boats. This commercial operation ceased operation in 1974. In 1990, the state of Florida acquired the headspring area and established a state park in 1991. However, this state park encompasses only 0.3 mile of the river on the west bank and 0.7 mile on the east bank. Another stretch of about 1 mile is owned by the state further down the river on the east side. The state operates a public campground on this site. Most of the remainder of the river bank is owned by private landowners either directly or through homeowner associations, except for a small county-owned park (KP Hole) on the west bank of the river and a tube take-out park for the campground tubers on the east bank approximately half-way between the KP Hole County Park and the 484 bridge.

Recreational use of the river has increased steadily with motor boating, tubing, swimming, canoeing, kayaking, snorkeling, fishing, and SCUBA diving being the primary active uses. Warm weather weekend use has become intense with the potential for inter-user conflict, homeowner versus tourist conflict, perceptions of overcrowding, displacement, water quality and biological impacts. As with other popular natural resource sites, the question of public access to a common property resource which is largely surrounded by private lands, is continuously raised.

The overall purpose of this project was two-fold: 1) to determine the present condition of the aquatic environment of the Rainbow Springs Aquatic Preserve, and to compare the present condition to that recorded in 1994-1995 using identical methods and 2) to document the effects that various levels of current human activity have on the Rainbow Springs Aquatic Preserve.

The specific objectives of this study were:

1) To determine the type, quantity, and location of aquatic recreational use throughout the year.

2) To continue the long-term data base on aquatic plants.

3) To determine both geographic and within-year and long-term temporal differences in the aquatic plant communities.

4) To determine the short-term effect of specific human activities (boating, diving, tubing, etc.) on the water quality and the aquatic plant community.

5) To determine if any damage to the aquatic plant community due to human activity during the high-use period recovers during the off-season.

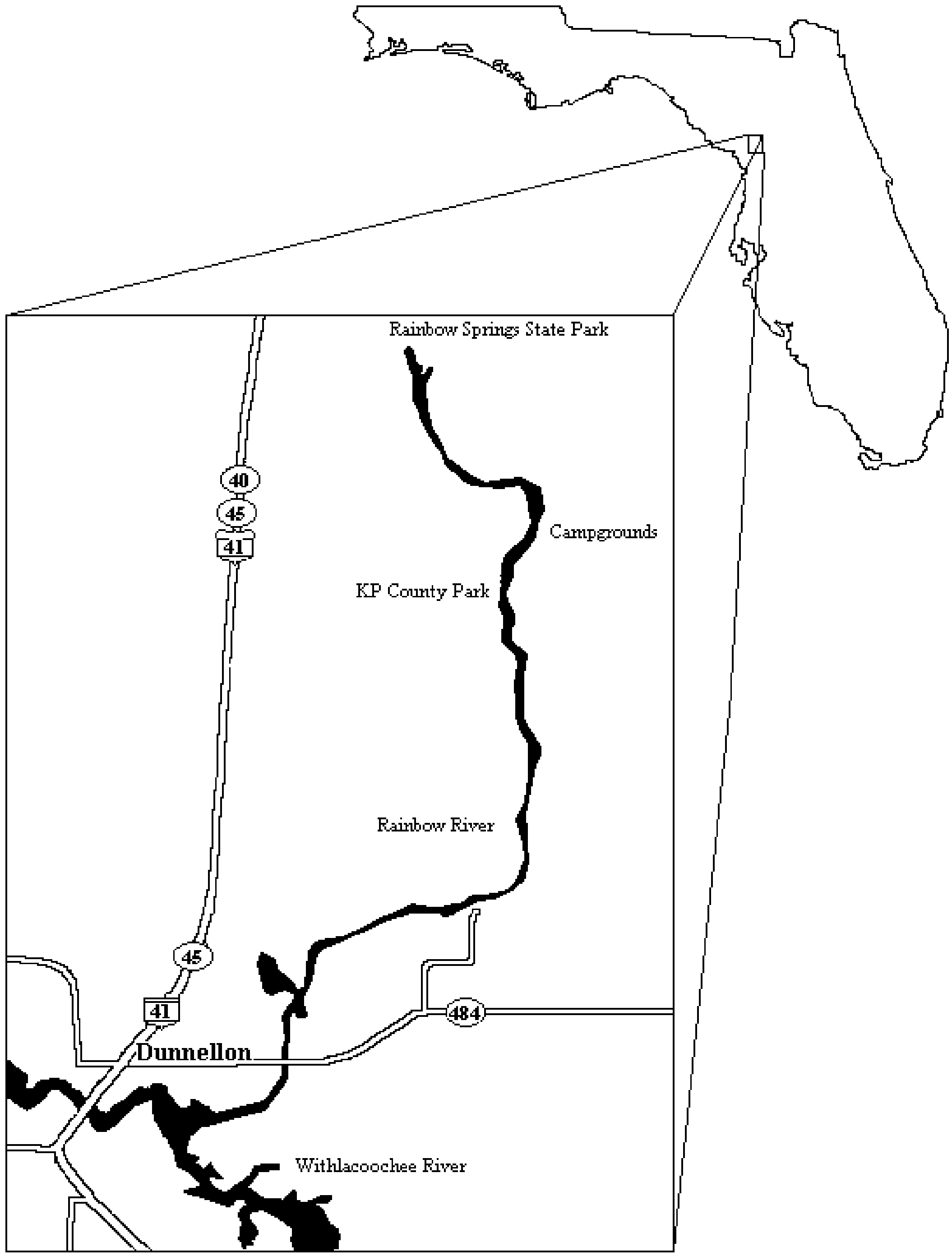


Figure 1. Location of Rainbow River in the State of Florida (Taken from Mumma 1996).

Literature Review

As we enter the 21st century, participation in outdoor recreation activities continues to rise. Because of changing lifestyles, new recreational technology and improved economic conditions, both the activities themselves and the patterns of participation are more diverse (Jubenville & Twight, 1993). Outdoor activity, especially outdoor recreation, is a renewing experience; a welcome change from the pressures of the work world and domestic routine.

Recreational visits to the National Parks have increased from 169 million in 1973 to 274 million in 1994. This is not only a national trend, but one which has also affected the state and local levels as well. The State of Florida Park System logged over 11 million visitors for the year 1993-1994; this is a 15% increase from a decade ago. Easier access to parks, increasing population, and growth in popularity of outdoor recreation are likely to increase both the number of participants (users) and the number of activities in the future. Because undisturbed, natural resources are limited, it is imperative that policies are created which will carefully allocate their use. Maximum satisfaction for participants in a wide spectrum of recreational experiences should be provided, within the constraints of preserving and protecting the parks physical environment (Randall, 1977).

Growth of recreational pursuits has led to the overuse of facilities and abuse to quality sites and recreational experiences. Additional problems parks face today include the need for new recreational opportunities, upgrades in existing ones, and maintaining existing opportunities. The provision of satisfying recreation opportunities is widely accepted as the overriding goal of recreation planning and management (Knudson, 1980). It is a goal which is responsive to the needs of the participants. One way to attain this goal is to examine and understand the different elements which affect the overall quality and satisfaction of participants in different types of recreation activities, and the recreational experience as a whole. Elements of park use which can be quantified include: levels of use, density, encounters, satisfaction, and perceived crowding.

Description of the Problem

The Florida State Park system is one of the largest and most extensively used recreation systems in the nation (FDNR, 1991). The system represents a major commitment by the state to preserve its natural resources, while providing quality recreation experiences for the public. The popularity of the parks has resulted in increased visitations. The system, like its national counterparts, is facing the problem of adopting policies which will allow recreationists to obtain a meaningful experience as well as to preserve the parks in their natural states.

To effectively handle visitor use in the context of preservation, park planners need to be aware of the entire range of outdoor activities in which people participate, as well as the nature, or character of the experience engendered by each activity (Randall, 1977). This is not an easy task. Each unit in the system has its own variety of problems, visitors, habitats, and characteristics. This makes each site unique. The Florida State Park Service was founded on the premise of "managing the properties under its jurisdiction to provide opportunities for Floridians and visitors to experience a variety of resource-based outdoor recreational activities, while ensuring the preservation and restoration of important natural and cultural resources on those lands" (FDNR, 1991). For the state to achieve its goal, each unit in the system must design and implement a policy which is tailored to their specific needs and wants and more specifically the needs and wants of the visitors.

The Rainbow River and Rainbow Springs Park is an area used for various outdoor recreation activities. The river is a viable resource, used by a wide variety of recreationists. Increased use, and the fact that the river plays host to many different activities, has led to the problem of user conflict. User conflict usually occurs because different recreation groups (tubers, motorized boaters, non-motorized boaters) have different ideas on what constitutes a quality recreation experience. Although the river is capable of handling multiple users, is there evidence that suggests limiting use would result in improving quality recreation experiences?

Introduction

Increasing use and demand for outdoor recreation areas has generated concern over management policies. The areas most affected are natural settings which have high participation rates of outdoor recreationists. Problems and effects associated with use impacts are not limited to the physical-biological environment, but also concern the visitor's experience. Traditionally, research has focused on the impacts recreation has on natural resources and areas. However, during the last twenty-five years an increasing number of studies have focused on how increased use affects the quality of a recreation experience. Managers of highly used recreation areas are attempting to set reasonable limits on the number of visitors a particular setting can withstand without seriously effecting the natural environment, as well as the recreation experience.

These limitations are referred to as the "carrying capacity" of an area (Stankey, 1973). Carrying capacity is a subject which is very complex. There is not one number or policy which can be used for all recreation settings and locations. Virtually all relevant recent articles suggest that carrying capacity is not an absolute value waiting to be discovered, but is rather a range of values which must be related to specific management objectives for a given area (Graefe, Vaske, & Kuss, 1984). Social carrying capacity is a component of carrying capacity that is even harder to understand, synthesize, and implement. Attempts to establish social carrying capacities for natural areas have intrigued, mystified, and burdened managers and researchers for at least the last twenty years (Graefe, Vaske, & Kuss, 1984).

Several factors are studied and analyzed when deciding whether or not to implement a social carrying capacity for a specific site. They include: density, encounters, use level, satisfaction, and perceived crowding, all which are intertwined. Adaptation of the concept of carrying capacity and particularly the expansion of the concept to include a social carrying capacity component provide a convenient foundation on which to base theoretical and empirical crowding research (Manning, 1985).

The remainder of this chapter will document and examine the history of carrying capacity, especially social carrying capacity. It will also show how use levels, density, and encounters affect a recreationist opinion of perceived crowding and satisfaction. This section will also look at how different recreation activities can cause different reactions to perceived crowding and satisfaction. Finally, similar studies on carrying capacity will be documented.

Carrying Capacity History

Giovanni Botero, in 1588, suggested "human populations did not grow, because the environmental resources were insufficient to support a larger population" (as cited in Smith, 1966). Thomas Robert Malthus, an English clergyman and economist, in 1798 developed carrying capacity as a wildlife ecology theory. It was defined as:

> the maximum number [of organisms] that can be in a given habitat. Once a population has reached or approached this level, it tends to fluctuate about it.... Only a certain density of any species can be supported by the resources available in any environment (as cited in Smith, 1966).

According to Burch (1984), in the areas of wildlife management and ecology, the theory of carrying capacity is quantifiable and precise. It allows ecologists to predict growth rate and size of a population. For example, if a certain population size was less than the carrying capacity of an environment, the population growth rate would increase. However, if the population size exceeded the carrying capacity of the environment, the population would decline until the carrying capacity was met (Wilson, 1975).

From its inception, carrying capacity has been adapted and used for other management areas and purposes. Outdoor recreation is one of the areas which have adopted, modified, and implemented carrying capacity as a managerial technique. It was in 1942, that Sumner became the first to use the concept of carrying capacity in a recreation setting. Carrying capacity, at the time, was thought as the "recreational saturation point", which was defined as: "the maximum extent of the highest type of recreational use which a wilderness can receive consistent with its long-term preservation" (as cited in Stankey & McCool, 1984).

Although this definition was first used in recreation management in 1942, the use of such a concept as it pertained to recreational settings was developed at an earlier time. In 1865, concerned about the overuse of the Yosemite Valley as a recreational site, Frederick Law Olmsted, stated, "an injury to the scenery so slight that it may be unheeded by any visitor now, will be of deplorable magnitude when its effects upon each visitor's enjoyment is multiplied by the millions {of visitors}" (Olmsted, 1865, reprinted in Landscape Architecture, 1955).

In 1916, because of concerns over the potentially threatening and damaging effects of recreation on natural resources, the National Parks Act and National Park Service were established. The mission of this agency by statutory authority was to:

> ...conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations (NPS Index, 1994).

This decree fostered the idea of carrying capacity by stating that the enjoyment of the parks was to be encouraged, in manner that "will leave them unimpaired for the enjoyment of future generations" (NPS Index, 1994). Growing popularity and demand for outdoor recreation and park areas during the 20th century, and the problems of overuse and resource damage have threatened to destroy the appeal that initially drew visitors to these areas (Alldredge, 1973; Frissel et al., 1980). Because of this, methods of user control were needed, such as, the concept of recreational carrying capacity.

Early recreational carrying capacity research suggested two facets of the carrying capacity concept: ecological and social (e.g., Forster, 1973; Peterson, 1983; Graefe et al., 1984; Kania, 1985; Shelby & Heberlein, 1986). The ecological aspect of carrying capacity relates to the environmental damage which is caused by users and to the preservation of the natural resources. The social aspect relates to the visitor experience and can include visitor preferences, number and type of encounters with others, size of groups encountered and perceived crowding. Various studies have identified additional dimensions which include physical carrying capacity, and facilities carrying capacity (Alldredge, 1973; Shelby & Herblein, 1984; NPS, 1987). In the following pages specific types of carrying capacity will be reviewed.

Recreational Carrying Capacity

Recreational carrying capacity can be defined as "the level of use beyond which impacts exceed acceptable levels specified by evaluative standards" (Shelby & Herblein, 1984). By using this definition, the evaluative standards can help determine the level of impact that is tolerable or the most desirable (the optimum), (Shelby & Herblein, 1984; 1986). Other recreational carrying capacity definitions which are used, describe carrying capacity types that deal with specific issues or problems.

Physical Carrying Capacity

This capacity type, also known as space carrying capacity or space standards (Buecher, 1971; Van Wagtendonk, 1985), describes the amount of space necessary to support a recreational activity. It is often used as a guideline to aid in planning. It helps define deficiencies in the provision of adequate recreation areas for various activities (Buecher, 1971). The number of acres per mile of hiking trail, the number of campers per campsite, and the square foot area of beach per swimmer are all examples of physical carrying capacity determinants. Participants in recreational activities often times have specific space requirements. Thus, the physical capacity of an area gives an initial impression about what maximum use level the activity will hold.

Facility Carrying Capacity

This type of carrying capacity is used to serve the visitor's facility needs. Examples are: parking lots, restrooms, developed campsites, fishing piers, and welcome centers. Facility carrying capacity is defined as "the maximum number or sustained flow of recreationists which can be contained in, or “processed” by the installed visitor facilities at one time or during some given period" (Alldredge, 1973).

Examples of measures of facility carrying capacity are, the number of campsites per unit area, number of people per vehicle, vehicles per parking lot, number of people per picnic table or per picnic area. Facility carrying capacity is easier to determine and establish than the rest of the capacity types. It involves taking an inventory of the available facilities, times the turnover rate for that particular facility, which in turn yields the number of users a particular facility can process or contain per time period (Alldredge, 1973). For example, 36 picnic tables times 6 users per table will yield a total use of 216 users per time period.

Ecological Carrying Capacity

Ecological carrying capacity is also referred to as resource-based carrying capacity (Alldredge, 1973). It is one of the original dimensions identified in early carrying capacity research. It focuses on how use levels affect plant, soil, animal, water, and air quality. Alldredge (1973), states "ecological carrying capacity is the maximum instantaneous number, or sustained flow, of recreationists such that the natural resources of the park will not be irreparably impaired for future public use".

In determining ecological carrying capacity, several indicators are used. They include: amount of soil compaction and erosion, quantity of observable plants or wildlife, and percent cover by specific plants. The determination of ecological carrying capacity is fairly straight forward in theory, but it is both delicate and time-consuming in practice (Alldredge, 1973).

Social Carrying Capacity

Social carrying capacity is also referred to as visitor carrying capacity (Alldredge, 1973). It is the second dimension identified in early recreation carrying capacity research. It is defined as "the level of human impact which if exceeded would cause a deterioration in the quality of outdoor recreational experience" (Forester, 1973). The most important element of social carrying capacity is congestion or crowding (Alldredge, 1973), but encounters with others and user satisfaction are also vital to understanding this capacity (Stankey, 1980; Stankey & McCool, 1984).

Social Carrying Capacity Framework

Many attempts have been made to formalize a process for social carrying capacity determination (Stankey & McCool, 1984). One of the main reasons for the lack of success is the difficultly involved in establishing a predictable link between use levels and experiential impact (Graefe et al., 1984; Stankey & McCool, 1984). Despite this, Graefe, et al. (1984) and Shelby & Heberlein (1986) have identified conditions that are imperative in order to establish a social carrying capacity. They are as follows:

1. A known relationship between use levels or other management parameters and experience parameters.

2. Agreement among relevant groups about the type or recreation experience to be provided.

3. Agreement among the relevant groups about the appropriate levels of experience parameters.

Along with the three conditions, Shelby & Heberlein (1986), also developed a conceptual framework to determine social carrying capacity. Their framework consists of a descriptive and evaluative component.

The descriptive component reveals how a recreation system works by providing answers to the following types of questions: What happens if 500 people per day enter a backpacking area? Do they spread out and never see each other, or do they crowd trails, get in each other's way at visitor attractions, and compete for campsites (Shelby & Heberlein, 1986)? The descriptive component describes what is going on in a particular system. The evaluative component defines what recreational opportunities the system should provide.

The descriptive component describes how a recreation system works. According to Shelby and Heberlein (1986) descriptive data focus on objective characteristics of recreation systems, and they specify the different states produced by different management alternatives. At this level, data collected in studies of recreation capacity are analogous to those collected in animal studies. The data describes observable behavior and the measurable consequences of that behavior. The descriptive component involves management parameters, impacts, and the relationship between the two.

The evaluative component defines how a system should be managed. To establish a social carrying capacity, specific judgments about levels of impact must be made. These judgments result in an evaluating standard. According to Shelby & Heberlein (1986), evaluative standards determine the level of impact that is tolerable (the maximum) or most desirable (the optimum). Evaluative standards are yardsticks for determining how much is too much. For example, suppose it is discovered that four parties launching a day result in two river encounters, while nine per day produce six encounters. Changes in management parameters (use levels) can produce different amounts of impact (river encounters). To establish a social carrying capacity, one must know which number of encounters is desirable, an evaluative standard.

Use Levels and Encounters

Social carrying capacity specifies a number for a single management parameter, use level, and focuses on impacts described in terms of encounters with other groups (Shelby & Heberlein, 1986). In order to measure use levels, the question: How many people are using the resource? is asked and answered.

Use level figures by themselves do not prove much. They cannot tell how many people recreationist see, where encounters happen, or to what extent congestion occurs. Encounters on the other hand can. When measuring social impacts in terms of experience parameters, it is important to note that it can be extended to variables other than encounters (e.g. time spent waiting to run a rapid). The best strategy is to use a variety of measures, focusing on whatever forms of impact have the greatest relevance for the experience in question (Shelby & Heberlein, 1986).

Satisfaction

Previous research and discussions of social carrying capacity involve visitor satisfaction (Wager 1964, 1966; Lucas 1964; Lime, 1977; Lucas & Stankey 1974). Lucas (1964), defines "the capacity of a recreational area" as the area's ability to provide satisfaction. Lime (1977), describes the goal of recreation management as providing "enjoyment and benefits for the people." Researchers often argue that "the goal of recreation management is to maximize user satisfaction" (Lucas & Stankey, 1974).

Research which has investigated social carrying capacity traditionally hypothesized that increasing visitor use levels would cause a corresponding decrease in visitor's satisfaction with their experience (Stankey, 1972).

Much of this theory was based upon work done by an economist, Alldredge (1973). Stankey's model, suggests that as visitors are added to a particular site, satisfaction of an individual will be lowered because of crowding. However, increasing numbers of people will increase the total or aggregate satisfaction. This process continues until the marginal satisfaction of the nth visitor no longer exceeds the drop in satisfaction of previous visitors. It is at this point which defines the optimal visitor density (social carrying capacity) of an area. The main component of this model is based on an assumed inverse relationship between use density and satisfaction. For the visitor, increased density causes decreased satisfaction. This approach to crowding has been called the "satisfaction model" (Heberlein & Shelby, 1977).

Social psychological literature has generated numerous hypotheses in outdoor recreation, which illuminated the relationship between density and satisfaction (Manning, 1985). These hypotheses along with empirical testing have expanded Alldredge's satisfaction model into a comprehensive model.

This model stems from Alldredge's input/output model. Substituting recreation visits for input and satisfaction for output, the model contends that visitor satisfaction can be used to determine use limits (Heberlein & Shelby, 1977; Manning & Ciali, 1980).

Both models have inherent problems and should not be used solely in determining social carrying capacity. The effect of crowding on visitor satisfaction is difficult to quantify. Since recreation is a voluntary activity, those dissatisfied with crowding will move or become displaced to less crowded areas. On the other hand, visitors "with norms more tolerant of higher densities" may opt to remain in an increasingly congested area (Heberlein & Shelby, 1977).

Increasing density may cause modifications of the recreational experience, which can in turn affect other variables of the area. Satisfaction is related to variables other than density which should be addressed. The satisfaction model does not do this, thus making the model "nearly unworkable for management" (Shelby & Heberlein, 1986).

To determine social carrying capacity and hence user satisfaction for a particular location, user parameters are surveyed (Stankey & McCool, 1984). The frequency of encounters with other parties, the size and type of the encountered groups and the number of visitors at the attraction site are all representative data.

Tolerance of specific user groups determines satisfaction for a specific recreational experience. Table 3 illustrates generalizations regarding the various sensitivities recreationists have. Most of the examples show conflict between motorized and non-motorized user groups (Graefe, et al., 1984).

The literature generally assumes that for user satisfaction to occur, few encounters are preferred over many, and that small groups are preferred to large ones (Lucas, 1964; Stankey, 1980; Kania, 1985). Wagar (1964; as cited in Stankey & McCool, 1984) argues that recreation satisfaction is also a function of user motivation. For example, if a user wants to meet new people, his/her satisfaction would be low if his/her encounters with others were low, but a visitor who wants solitude prefers no or very few encounters. A visitor who is exercising may show no preference for the number of encounters. This has been explained in terms of different groups holding different normative standards (Heberlein, 1977). Norms, or commonly held expectations and preferences, may be shared by a particular group of recreationist. For example, a group of bird watchers will have different expectations than a group of hunters. If each group has different ideas about densities and behaviors for a specific area, if it apparent why their perception about crowding might be different at the same density.

Crowding

The effects and problems that crowding can cause has been a major concern for outdoor recreation managers. A survey of managers of wilderness and related areas (Washburn & Cole 1983) found that two-thirds of all areas were considered to be used beyond capacity in at least some places and at some times. In most cases (53%), the overuse problems were considered to be of a social or crowding nature as opposed to resource damage.

Crowding refers specifically to a reaction to numbers of people. There is a difference between density and crowding. Shelby & Heberlein (1986), believe perceived crowding is a better evaluative standard than satisfaction. If there are too many people in a particular setting, the situation that is described by users and managers is "crowded" or "overcrowded".

Crowding is defined as a negative evaluation of a certain density or number of encounters (Desor, 1972; Stokols, 1972; Altman, 1975; Schmidt & Keating, 1979). Most theorists recognize that there is a difference between density and crowding, (Desor, 1972; Stokols, 1972; Lawrence, 1974; Altman, 1975; Rappoport, 1975; Stockdale 1978), but even scientists sometimes use the word "crowding" when they mean high density. Density is a descriptive term that measures the number of people per unit. It is measured objectively. Crowding is a negative evaluation of density. It involves value judgments that specifies a certain number as too many. It is subjective and situation-specific. Perceived crowding is a negative evaluation of density and is often used to emphasize the subjective or evaluated nature of the subject.

Shelby & Heberlein (1986), theorize that use levels influence contacts, while contacts influence perceived crowding. If these relationships hold, it would be possible to determine the use and encounter levels which produce a certain level of perceived crowding. Social carrying capacity could be established if there were an evaluative standard for perceived crowding.

Perceived crowding is related to various social psychological factors. Often times these factors have more influence on perceived crowding than use levels or encounters. "Perceived crowding is a psychological dimension which exists in the mind of individuals" (Manning, 54). Perceived crowding is usually measured by self-report techniques. In most studies visitors are asked how crowded they felt during their recreation experience. Responses are logged on a scale. In this scale seven of the nine points label the experience as crowded to some degree. This scale is useful because it is able to put the question "were you crowded today" into a response which has a quantifiable format and can pick up even slight degrees of perceived crowding.

Perceived crowding can be used as evaluative standard in determining carrying capacity. For example, suppose there are 200 people in an area. If 199 felt "not crowded at all" and one felt "slightly crowded", social carrying capacity probably has not been reached. If everyone feels "extremely crowded", social carrying capacity probably has been exceeded.
Perceived crowding is a better evaluative element than satisfaction in determining social carrying capacity, because it refers to numbers of people. Shelby and Heberlein (1986), cite the lack of a clear standard for

determining the point of crowding before it reaches unacceptable levels is caused by personal, social, and situational factors.

Similar Studies

In recent years, researchers have been conducting studies on how use levels, encounters, density, perceived crowding, and satisfaction effect a recreationists overall experience. They have also used these factors in determining whether social carrying capacity should be implemented at various recreation locations.

Summary

Decisions on carrying capacity can only be made once management standards and objectives are stated and clearly understood. These standards can and should address issues which concern social and ecological conditions appropriate for a given recreational area, the amount and type or use a particular area should receive, and finally the degree to which social or ecological change will be accepted.

In determining social carrying capacity, the management standard usually sought is providing quality experiences for participants. There are several elements which must be studied and examined. They include: use levels, encounters, density, perceived crowding and enjoyment/satisfaction. These elements are either evaluative or descriptive in nature. Often times it is hard to pinpoint specific numbers or feelings a visitor has. Because of this there is not a specific element which can define social carrying capacity for a particular location. Social carrying capacity, once determined is neither a fixed or inherent value (Phrases et al., 1980). Conditions defined as acceptable can evolve and lead to situations where conditions, once intolerable, become the norm (Stankey & McCool, 1984; Shelby & Heberlein, 1986).

Methods

Task 1 - Type, location, and quantity of recreational use

User Count Methods

River recreational users were counted utilizing six time-lapse VCR recorders and video cameras custom installed for this study spaced along the length of the river. The recorders were programmed to start recording about 8:00 to 8:30 am to near sunset. The northernmost recorder was just below the Rainbow Springs beach and boat launch area, or several hundred feet below the Rainbow River state park boundary sign and the southernmost recorder was about 150 feet (46 m) north of the Hwy 484 bridge. All cameras were on the west side of the river (Figures 2 and 3). More specifically, the camera and recorders were located (north to south):

1. 1st house south of Rainbow Springs beach
2. middle of east-west leg of river
3. across from State Park campground tuber input
4. 3rd house south of KP Hole
5. just north of State Park tuber exit
6. 2nd house north of CR 484 bridge

The recording began in mid-March of 2011; however, since the Hwy 484 tuber exit was undergoing construction until May 10, a decision was made to restart the 12-month user-count window. Thus, the user counts reported in this report extend from May 11, 2011 to May 10, 2012 – 366 days. The recorders recorded one frame of video about every 2 seconds and each video tape was able to tape for about two months of time. The tapes were replaced approximately every two months. They recorded less than two months during months with longer days and more in months with shorter days. Local assistants would check the recorders periodically; especially around the 6 to 7-week time frame to determine how much time was left before the tape needed to be changed. When extracted, the tapes were labeled with start and end dates and stored in Gainesville until viewing and counting could occur.

User counts were conducted by the co-PI and project assistants viewing the video tapes using slow viewing while utilizing several hand counters to click as each type of user passed downriver past the camera. Six types of users were counted: kayaks, canoes, motorboats (all types; e.g., pontoons, outboard small boats, boats with visible trolling motors, etc. [excluding commercial dive boats]), SCUBA dive boat company pontoon boats, swimmers/snorkelers/divers visible on water surface, and tubers/large flotation devices. During denser use days, the tape would be paused to count the users in

Figure 2. Aerial view of the Rainbow River, Dunnellon, Florida, showing the locations of the six cameras in 2011-2012.

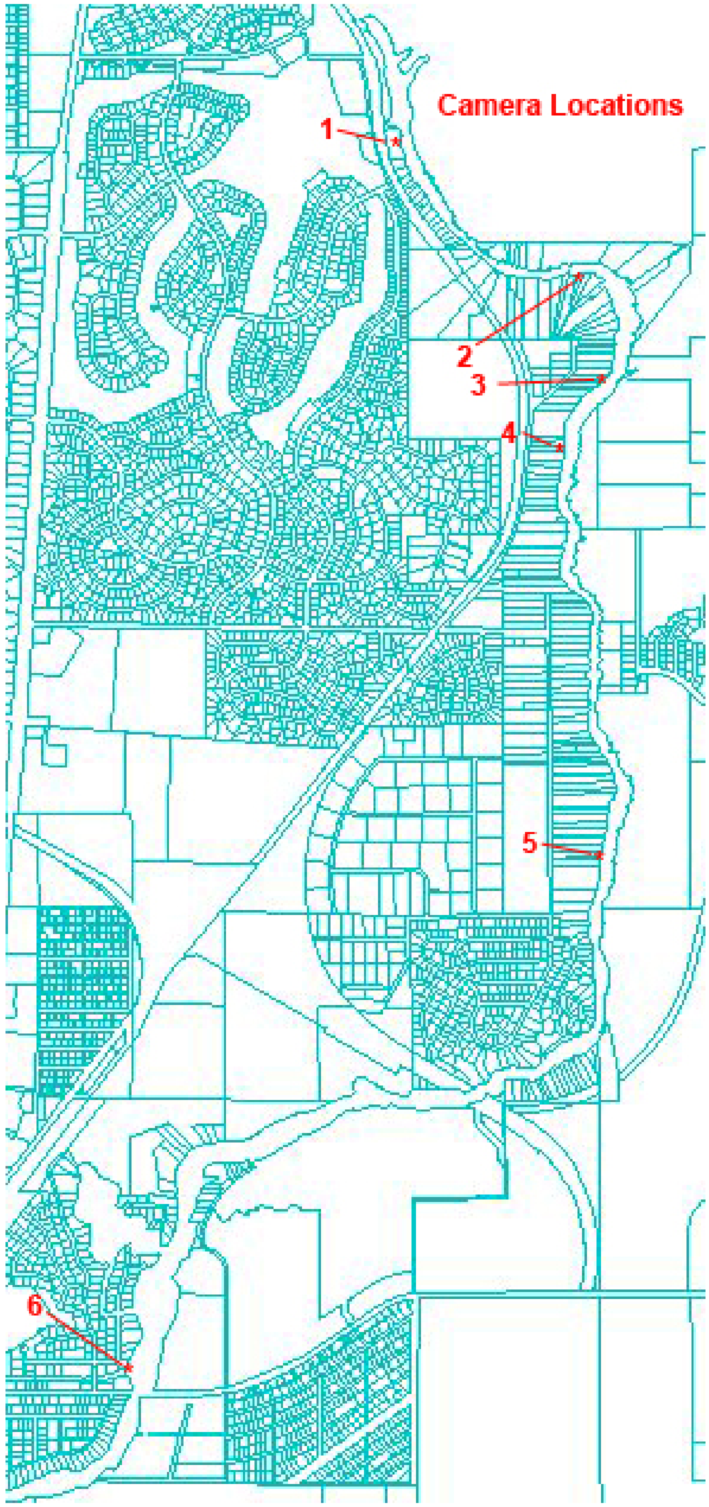


Figure 3. Map of the Rainbow River, Dunnellon, Florida, showing the locations of the six cameras in relation to property boundaries, 2011-2012.

view of camera and then advanced 2 to 5 frames and counted again until the day was completed. As each day's six users types were counted, the daily totals were recorded, and the next day was then counted. Shorter and slower use days generally took about 8-10 minutes to count while the heavier user days could take over an hour to count. Daily counts were aggregated into weekly totals reported in a table, by camera. They have been aggregated into a table showing weekly totals, with a week being Tuesday through Monday; so that three-day Monday holidays would be included with their associated weekend. Generally, Tuesday was the slowest day of the week, making a good start day for weekly counts. The descriptive text also mentions the highest daily counts observed. During less dense use times, a slow constant playback of the tape was adequate to count users.

Intervening Factors

Field research is known to have many factors that can affect it, unlike studies conducted in a controlled laboratory which are rarely, if ever, possible for public recreation user studies. Most days, the video recording performed well and counts were straightforward. However, intermittent power failures (more frequent than expected), sunlight glaring off a metal canoe or the water surface blinding the camera for a few seconds to a half-hour or so, morning fog, strong wind rippling the water making it difficult to see, much less count, swimmers or divers in the water, a large spider periodically sitting on the camera lens of camera two, off and on for several weeks, and an inexplicable occurrence of three recorders (2, 4, and 5) not recording on various days (not the same dates) between Aug. 31 and Sept. 9 (while the other 3 recorders ran fine). There likely was some electrical grid surge or anomaly about Aug. 31 or Sept. 1 that resulted in this unusual event. Recorder 2 was down the entire month of September, but started up on its own, the morning of October 1. It is unknown if electrical circuit breakers perhaps tripped due to storms, or the homeowner associated with that dock inadvertently turned off the dock circuit, or someone unplugged the power plug? Only one known case of sabotage occurred when someone misdirected camera five to point vertically down at the water (losing any ability to count users) for almost 4 weeks from mid-December to mid-January, when it was discovered and corrected.

Fixed camera limitations also caused complexities in counting. For example, if a pontoon boat was anchored in such a way that it substantially blocked a portion of the river, it may not have been possible to count smaller boats, tubers or swimmers passing on the other side of it, as long as the boat stayed in that position. Or, if a larger boat was drifting with the current, if there were tubers or swimmers, or even a kayak drifting with the current on the hidden side of the larger boat, they would not have been counted, unless they emerged while still in view of the camera. If swimmers were exiting and getting on a boat on the far side, it was difficult and sometimes impossible to see them. These occurrences were not common, but they happened, lasting from 20 minutes to about 2 hours for an anchored boat. Especially for camera 5, which was lower than the others, for tubers on the far side of the river (just above the state park take-out), on some occasions, it was not always possible to tell if there were 3 tubes or 4 or 5, if they were lined up (as many are, even tied together) so that the nearest two tubes hid those on the other side. Camera 3 (across from state park campground put in) had a view across a large swath of aquatic plants on the west side of the river, and those plants hid the water line for about 6-8 feet (1.8-2.4 m) on the western rim of river, making counts of through swimmers, snorkelers and divers on the west side of the river difficult to impossible. It was possible to count people swimming in the roped-off state park swimming area and the swimmer counts on camera 3 are primarily those swimmers. Other user types were elevated enough above the aquatic plant level to be able to count them on camera 3. In addition, on very busy days, many tubers would launch, en masse, from two different points of the state park shoreline, and it was difficult to get a precise count on tubers when virtually dozens of them would enter the water at the same time, almost all with the same color tubes. Counters made their best estimates.

Swimmers, divers and snorkelers were generally not easy to count even under good conditions on most cameras as they often were mostly in or under the water, in groups, swimming around each other, making it hard to know if one was counting the same swimmer twice or not, with multiple limbs splashing, and sometime hidden behind other crafts. In order to provide at least one solid count, for camera two swimmer counts, the numbers recorded there are not the number counted on the video tape, but are the number of paid divers/snorkelers for which a fee was paid at KP Hole County Park. Very few private through swimmers were apparent on that camera, so, since all dive boats use the north part of the river, and generally discharge their clients somewhere between cameras 1 and 2 (occasionally, they could be seen at camera 1, and were recorded there if so), it was judged that camera 2 would be the best place to substitute paid snorkelers/diver counts for what would have been flawed (since getting a good count of people submerged in water was near impossible) counts based on camera interpretations.

Intermittent electrical problems occurred throughout the year. One or two cameras had GFI caused stoppages. Others lost power off and on, for unknown reasons. On at least two occasions (cameras 1 and 6) repairs were undertaken (in one case using a licensed electrician) to make the power source more reliable. Apparently, there were also storm caused outages, on occasion. Since the recorder would resume working when the power was restored, these occurrences were difficult to know about until that tape was viewed, as the recorders were running when the tapes were changed. It should be noted that the recorders used were excellent at starting back up as soon as electricity was restored. A small battery retained the programming for weeks if needed to restart the recording whenever electricity was restored. The camera 2 September shut down is a total mystery, with the best guess a defective electronic chip or electrical surge that affected the September programming. That recorder was programmed the same way as all the others the previous three months, and one would think that a deliberate re-programming to specifically exclude September would have been needed to make that happen, which was not done. This recorder was in a locked box, so tampering is not a feasible explanation. That recording ended at dark on August 31 and restarted itself at dawn on October 1. The September loss of data on camera 2 was not discovered until months later when that tape was viewed and counted. Camera 3 counts would likely be the closest proxy to substitute, except for tubers, which virtually all go south from the camera 3 site. In future studies, it would be wise to budget for and utilize solar cells and back up batteries, to supplement grid electrical sources, to minimize downtimes.

Despite these issues, given that there were six cameras, there was redundancy to get an idea of what river use was on all days; and if needed, comparable use days for a down camera could be estimated based on other camera data. If users were not always able to be counted with 100% accuracy to document reality, for the purposes of this study, best estimates are sufficient. Would water or benthic environmental quality really substantially vary if an estimate indicated 350 tubers instead of 390 tubers? Or 38 swimmers instead of 50 swimmers? Probably not! It is likely that counting errors cancelled each other out, with some being high and others low. And to reiterate, the vast majority of days, all six cameras were functioning. For example, from January through May 2012, all cameras and recorders functioned well, except for the sabotaged camera 5 for 15 days in early January (a low use time) and an electrical issue for 13 days on camera 6 in April.

Another point that should be made is that it is known that some tubers and watercrafts were known to make more than one trip down the river in a day. In most cases, they would have been counted twice (when they proceeded down river, both times (not when they traveled up-river)). In obvious cases when an identifiable pontoon boat or motorboat went by the camera several times in the span of an hour (or less), or a pack of identifiable kayaks (e.g., 3 florescent green, 1 blue an 2 red) went by over a span of 2-3 hours (sometimes more than twice), they would not be recounted. But, most of the time there was simply too much river traffic or the time span was too long between passes or there was no way to keep track of tubers who may have made 2 trips past the cameras five hours apart. Thus, these counts of user occasions are not necessarily equal to number of distinct users. But, they do reflect the volume of use of the river, which is most relevant to impact assessments.

Task 2 - Geographic and temporal differences in aquatic plant communities

Sampling Design:

Data were collected and analyzed to determine geographic (upstream to downstream) and within-year and long-term temporal differences in aquatic plant communities. Within-year seasonal changes in vegetation are influenced by plant growth rates and human disturbance, so strategically located transects were used to document both "recovery of vegetation" during the low-use fall/winter period and "loss of vegetation" during high-use summer period. Transects, located within the headspring area, were sampled to document changes resulting from the relocation of the swimming area, while the lower headspring transects served as long-term "controls" as there has been limited recreational use within this area. Comparison of the data collected in this study with historical data from the 20 previously established (1994-1995) transects quantifiably document changes in plant type and coverage over the past 17 to 18 years, as recreational use has increased.

Sampling/Test Locations:

Twenty fixed aquatic plant transects (transects 1 through 20), originally sampled in 1994-1995 (Holland and Cichra 1995 – Final report to FDEP), along with six new transects, were sampled from May 19 to May 26 2011, 23 September to 5 October 2011, and 11 to 24 April 2012. Figure 4 shows the approximate locations of the 26 sites, while Table 1 gives the actual GPS coordinates of each site. Locations of the original 20 transects were initially established based on human activity patterns, water depth, substrate type, aquatic plant communities, and input from Florida Department of Environmental Protection (FDEP) staff. All 20 transects were successfully relocated in May 2011, based upon archived video footage, taken during the original 1994-1995 study. The six new transects were established using similar criteria, with two of the new transects placed in the upper portion of the river – one immediately downstream from the headspring park boundary (transect 5.1) and the second in an area of high SCUBA-diving activity (transect 5.2). The remaining four new transects were placed in the lower portion of the river upstream (transects 17.1, 17.2, and 17.3) and downstream (transect 17.4) of the State Campground tuber take out, located on the east side of the river between transects 17 and 18, which were sampled in the 1994-1995 study.

Field Testing Activities and data analysis:

The 2-m wide transects traversed the headspring area and river from bank to bank. A 2-m x 2-m PVC quadrat was placed on the bottom at the edge of the river (Figure 5). The percent coverage of each plant species within the quadrat was recorded, along with the percent coverage of bare bottom. The quadrat was then flipped over and placed on the bottom. The coverage of each plant species and bare bottom was recorded for this and all subsequent quadrats, until the opposite side of the river was reached. A compass bearing and landmarks were used to ensure that each transect followed a straight line from start to finish.

GPS coordinates were established at the end of each transect and recorded on field sheets. Water depth, to the nearest 0.1m, was recorded at the ends of each transect, and at approximately ¼, ½, and ¾ of its length.

Data Analysis:

These data were analyzed to determine the abundance (percent coverage and percent occurrence) of each submersed species at each transect location. A mean percent coverage of each species at each transect location was calculated from the individual grid percent coverage values. Percent occurrence of each species at each transect location was calculated from the number of grids containing the species and the total number of grids sampled along the transect, which varied according to stream width.

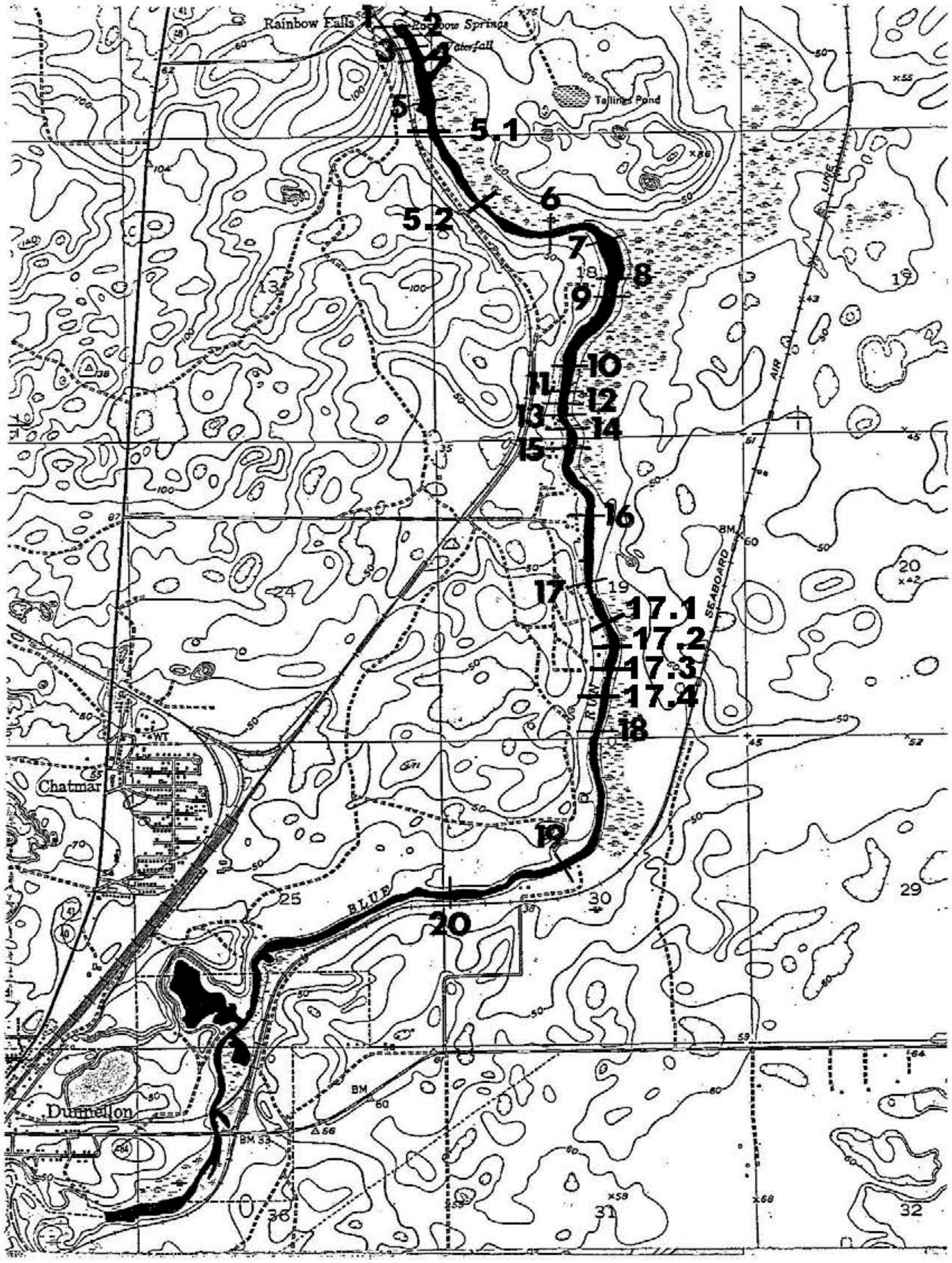


Figure 4. Location of 26 fixed submersed aquatic plant sampling transects, Rainbow River, Florida.

Table 1. GPS coordinates of the 26 aquatic plant transects on the Rainbow River, Florida in 2011-2012.

Transect	West Side			East Side	
1	N 029 06 08.8	W 082 26 15.9		N 029 06 09.3	W 082 26 15.3
2	N 029 06 06.9	W 082 26 14.5		N 029 06 07.6	W 082 26 13.7
3	N 029 06 05.1	W 082 26 13.3		N 029 06 05.9	W 082 26 12.0
4	N 029 06 03.2	W 082 26 13.0		N 029 06 03.5	W 082 26 11.1
5	N 029 05 67.7	W 082 26 11.4		N 029 05 58.3	W 082 26 10.1
5.1	N 029 05 50.6	W 082 26 10.2		N 029 05 51.6	W 082 26 07.9
5.2	N 029 05 33.3	W 082 25 53.1		N 029 05 34.5	W 082 25 52.1
6	N 029 05 34.2	W 082 25 41.5		N 029 05 35.2	W 082 25 41.3
7	N 029 05 33.2	W 082 25 37.0		N 029 05 33.7	W 082 25 36.4
8	N 029 05 31.6	W 082 25 36.5		N 029 05 34.4	W 082 25 34.7
9	N 029 05 19.7	W 082 25 37.3		N 029 05 18.7	W 082 25 35.7
10	N 029 05 16.6	W 082 25 40.0		N 029 05 15.5	W 082 25 39.0
11	N 029 05 14.0	W 082 25 42.8		N 029 05 13.5	W 082 25 41.2
12	N 029 05 09.0	W 082 25 44.3		N 029 05 09.1	W 082 25 42.1
13	N 029 05 02.3	W 082 25 45.6		N 029 05 02.6	W 082 25 43.7
14	N 029 05 02.0	W 082 25 43.8		N 029 05 00.5	W 082 25 43.4
15	N 029 04 57.9	W 082 25 42.9		N 029 04 57.6	W 082 25 41.4
16	N 029 04 45.2	W 082 25 39.7		N 029 04 45.1	W 082 25 38.2
17	N 029 04 35.9	W 082 25 40.1		N 029 04 35.8	W 082 25 39.0
17.1	N 029 04 13.1	W 082 25 37.5		N 029 04 13.0	W 082 25 36.2
17.2	N 029 04 09.7	W 082 25 38.0		N 029 04 09.5	W 082 25 36.4
17.3	N 029 04 08.1	W 082 25 38.5		N 029 04 07.7	W 082 25 37.2
17.4	N 029 04 02.7	W 082 25 40.1		N 029 04 02.9	W 082 25 38.2
18	N 029 03 59.1	W 082 25 38.4		N 029 03 59.9	W 082 25 38.2
19	N 029 03 44.8	W 082 25 46.1		N 029 03 43.9	W 082 25 45.4
20	N 029 03 31.7	W 082 26 35.4		N 029 03 30.6	W 082 26 35.3

Figure 5. Jesse Stephens sampling plants in one of the 2m x 2m grids from transect 17.3 on 21 April 2011. This transect was located immediately upstream from the State Campground tuber take out. (DSCN1555)

Task 3 - Human activity and water quality relationships

Sampling Design:

Human activities within the river may change water chemistry by disturbing the bottom sediments, bringing this material up into the water column. To determine if this occurs, water was sampled during various levels of recreational use on 10 sampling events (28 May, 22 June, 12 July, 2-3 July, 19 July, 24 August, and 3-4 September 2011 and 6 February, 15 February, and 18 February, 2012). Data was analyzed to determine if water quality parameters differed significantly over the short term in response to the amount and type of human activity, as was done in the 1994-1995 study. Based on comments from various agency staff and the public, recreational use of this system has increased dramatically from when the initial study was conducted. During the 1994-1995 study, no significant changes in water quality (water chemistry and clarity) were observed. One can hypothesize that increased recreational use, possibly a three-fold increase, may result in greater changes in water quality (primarily higher concentrations of suspended solids and reduced water clarity). The collected data were examined to determine if this increased use (as documented by field observations) results in any changes in water quality.

Sampling/Test locations:

All sampling was conducted approximately 100 m downstream from the KP Hole Marion County Park, which is located on the west side of the river (Figure 6). Samples were taken at approximately ¼, ½, and ¾ of the width of the river. This site was used in the 1994-1995 study and was used again in this study so that current water chemistry values can be compared to historical values.

Sample Collection and Processing Methods:

Surface grab water samples were collected using DEP-SOP-001/01 FS2100. Samples were placed onto ice and transported to the laboratory for analysis for total suspended solids, inorganic suspended solids, and organic suspended solids via APHA standard method 2540 D. One blank sample (DI water) was processed concurrently with the 9 samples collected on each of the ten sampling days.

Field Testing Activities and Data Analysis:

All users, who were observed upstream from the sampling site, were recorded on a continuous basis during the day (minimum of seven hours). Users included tubers, motor boats, kayaks, canoes, walkers, swimmers, SCUBA divers, and paddle boarders, along with any others that were present. These were recorded by 15-minutes increments. Triplicate water samples were collected a minimum of three times on each day to detect possible differences/changes throughout the day. These triplicate water samples were taken immediately to the east side of each net used to collect drifting plants (see methods below for Task 4). The first set of triplicate water samples were taken early in the morning before users accessed the river. These “baseline” early-morning samples were compared to those collected later in the day during peak recreational activity, and after recreational activity subsided. Change (likely an increase, if we hypothesize that users will disturb the sediments on the river bottom) was determined by subtracting the initial values from those taken later in the day. Values were calculated for each net. Changes in suspended solids were compared among low, medium, and high use days.

Surface water temperature and dissolved oxygen were measured in the field using DEP-SOP-001/01 FT1400 and FT1500, respectively, using a YSI Model 85 dissolved oxygen-temperature meter. Water clarity was determined by measuring the horizontal upstream distance at which a 25-cm diameter black and white Secchi disc, held in a vertical position, could no longer be seen through the water column by an underwater observer.

Two of the 10 samples were diurnal samples (24 hours of sampling), with a sampling interval of 2 hours, conducted during the July 4th weekend (2 – 3 July 2011) and Labor Day weekend (3 – 4 September 2011), times of historical peak recreational activity on the river. During these diurnal samples, water clarity measurements were limited to daylight hours. Other sampling procedures were identical to those described above.

Data analysis:

The total, inorganic, and organic suspended solid concentrations (mg/L), measured during the first samples of the day were subtracted from the concentrations measured later in the day. This was performed by net as triplicate samples were collected. These differences were then plotted and statistically correlated/regressed against the number of tubers, motorized boats, canoes, kayaks, and paddlers (canoes + kayaks) observed upstream of the collection sites during the 15-minute and 30-minute periods, immediately prior to collection of the water samples.

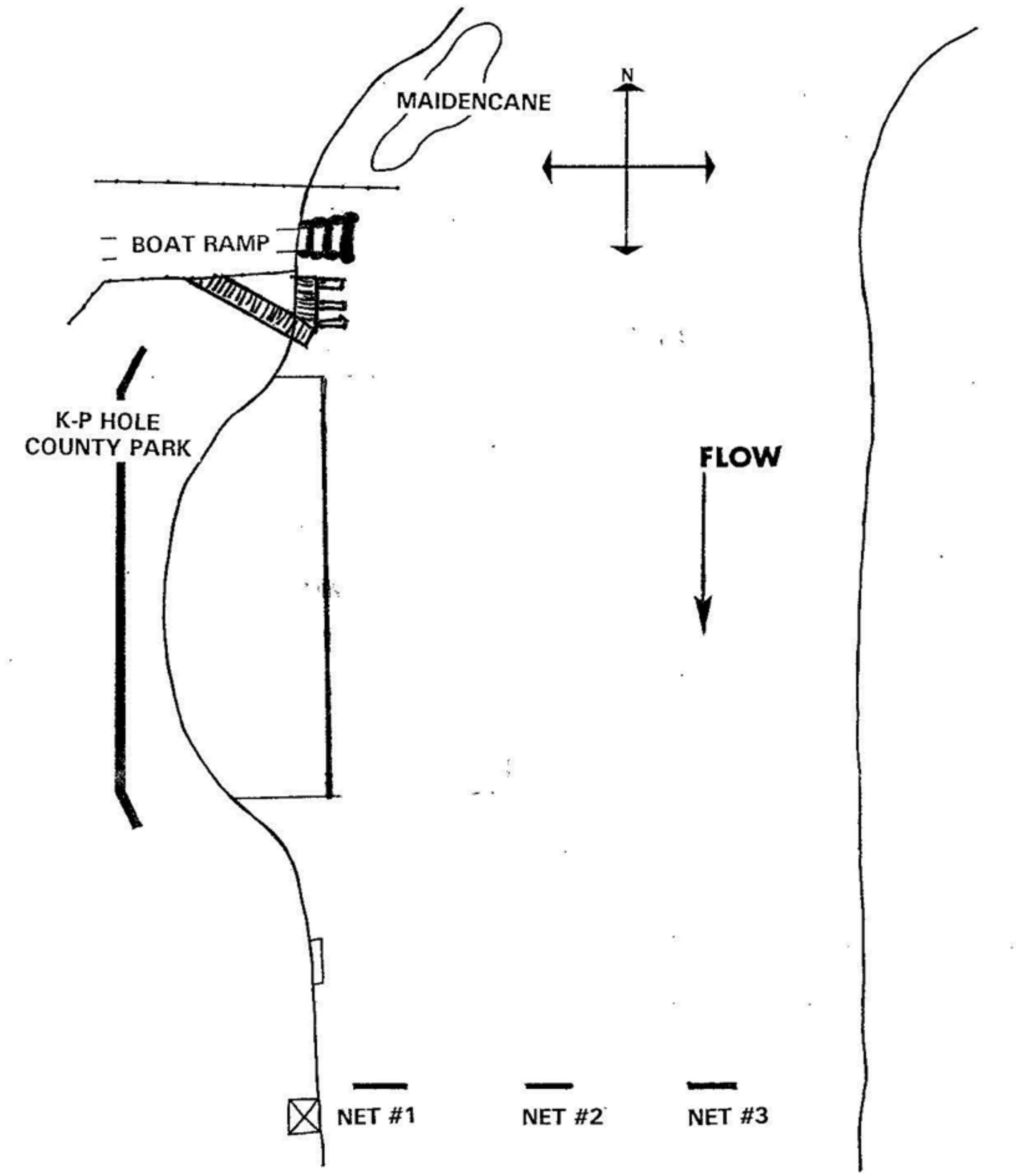


Figure 6. Location of triplicate user-based water quality and drifting aquatic plant sampling sites, located downstream from the KP Hole County Park, Rainbow River, Florida, 2011-2012.

Task 4 - Human activity and aquatic plant relationships

Net Sampling:

Sampling Design:

Human activities within the river can affect the aquatic plant community by physically damaging (tearing and uprooting) plants, sending them floating downstream. This portion of our study was designed to determine the type and degree of damage to the aquatic plant community in response to the amount and type of human activity occurring on the Rainbow River. Plant samples were collected on eight occasions (28 May, 22 June, 12 July, 19 July, and 24 August 2011 and 6 February, 15 February, and 18 February, 2012), each with a various degree of user activity. Two additional diurnal samples, (24 hours of sampling), with a sampling interval of 2 hours, was conducted during the July 4th weekend (2 – 3 July 2011) and Labor Day weekend (3 – 4 September 2011), times of historical peak recreational activity on the river, for a total of 10 sampling occasions. This sampling was conducted concurrently with the water quality sampling described in Task 3, which is described above.

The weight and type of vegetation collected via drift nets were analyzed in conjunction with the amount and type of human activity, upstream of the sampling site, to determine the effect of human activity on the aquatic plant community. Due to the downstream drift rates of the plants, only the activity that was recorded during the first 45 minutes of plant sampling and during the 15-minute period preceding plant sampling were used for analyses. This time period was determined during the 1994-1995 study and published in Mumma et al. (1996). In addition to absolute wet weight of plants collected, the change in plants (mean wet weight of plants per net per hour) was calculated by subtracting the 08:00 or 09:00 values from the 12:00 or 13:00 (peak-use) values. Wet weight and change in wet weight of drifting plants were then be plotted, correlated, and regressed against the type and quantity of human activity observed (tubers, motorized boats, canoes, kayaks, and paddlers [canoes + kayaks]) upstream from the nets.

One can hypothesize that, with increased recreational use of the river over recent years, there should be increased plant damage (rate of cut and uprooted plants passing down the river per hour). The collected data were examined to determine if this increased use (as documented by field observations during periods of plant sampling) results in a change (possible increase) in the rate of uprooted and cut plants that are floating downstream, as compared to that documented in the earlier 1994-1995 study.

Sampling/Test locations:

All sampling was conducted approximately 100 m downstream from the KP Hole County Park, which is located on the west side of the Rainbow River at the identical locations used for Task 3 to sample water (Figure 6). Samples were taken at approximately ¼, ½, and ¾ of the width of the river. This site was used in the 1994-1995 study and is being used again in this study so that current plant damage estimates can be compared to historical values.

Sample Collection and Processing Methods:

Triplicate plant samples were collected a minimum of four times throughout each day on a 2 to 3-hour schedule from early morning (prior to human activity) to midafternoon (after most recreational activity ceased). Each replicate sample consisted of collecting all floating vegetation passing through a 2-meter wide x 1-meter deep, 6-mm nylon mesh drift net during an approximate 60-minute period (Figure 7). Exact beginning and ending times were recorded for each sample. All vegetation, collected in each net, was placed into pre-labeled plastic bags and immediately placed on ice. These were returned to the UF Fisheries and Aquatic Sciences Laboratory, where vegetative material was identified and sorted to species. In addition, Sagittaria kurziana and Vallisneria americana was also sorted according to the type of damage (tearing vs. uprooting). All vegetation groups were then weighed (wet weight) and recorded. The weights were adjusted to wet weight per 60-minute period (wet weight/net hour) based on the number of minutes that each net actually sampled. Of the 168 samples, only one sample was lost (Net 1, between the hours of 23:00 to 24:00, on 3 September 2011). This sample was lost when the net became untied.

Figure 7. Jesse Stephens removing plants collected by Net 2, one of the 2m x 1m drift nets, set midstream and downstream from the KP Hole County Park on 28 May 2011. Net 3 is shown in the background, collecting plants. (DSCN1555)

Direct Observation of the Effects of Motor Boating on the Aquatic Plants:

Sampling Design:

Motor boating activities can directly impact the aquatic plants by cutting off their upper portions or by completely dislodging plants from the substrate. While on the river, UF staff observed and documented motor boating activity and plant damage in an attempt to determine if the quantity of plant damage was related to specific types / sizes of boats / motors or to operator behavior. To minimize future prop damage to plants, specific areas (based on water depth) of the river could be placed off limits to motor boats. A maximum water-surface to bottom-of-prop restriction or boat / motor type / size could also be developed and designated for the river, similar to mandating the no-wake designation. The information obtained in this study could also be used to target motor boaters for whom an educational program could be developed and implemented.

Sampling/Test locations:

Boating activity was observed on the entire river, while sampling the other components of this study (26 plant transects [spring and fall 2011 and Spring 2012], 61 prop scars [fall 2011 and spring 2012], 10 water / user / plant samples [28 May 2011 through 18 February 2012], and SCUBA divers), which encompassed most of the length of the river. The majority of the motor boating activity sampling was restricted to the area downstream from the KP Hole County Park while sampling water, recreational users, and aquatic plants associated with Tasks 3 and 4 (see methods above).

Field Testing Activities:

While on the river, an attempt was made to observe all passing motor boats and to take digital images of the facing side and stern of each boat. The location, date, and time of observation was recorded, along with the make, model, length, and type of each boat, if available; the make and horsepower of each motor; the type of activity (motoring, fishing, drifting, etc.); the direction of movement (up-stream, down-stream, cross-stream); location within the channel; the extent of plant damage (none, minimal, medium, and maximum); operator behavior; and any reasons as to why the damage or lack of damage occurred. The field sheets had most of the pertinent data directly recorded on them. The digital images were viewed to complete the data set for each boat, as is was often difficult to completely record all of the data in the field, given the high recreational use that occurred at times.

Prop Scars:

Sampling Design:

Motor boating activities can directly impact the aquatic plants by cutting off their upper portions or by completely dislodging plants from the substrate. Propeller scars (prop scars) from boats, have been characterized as paths within which vegetation has been removed from the sediments (Bell et al, 2002). This type of scarring removes both the above ground and below ground portion of the plant. In the Rainbow River this is a particular concern, since in addition to potential habitat loss, decreased productivity, and increases in sedimentation and erosion (Uhrin and Holmquist, 2003), the removal of native submerged vegetation is believed to aid in the colonization of hydrilla, an invasive aquatic plant species (Mumma et al., 1996). The submersed aquatic plant community was sampled to assess the direct impact of motor boating on the Rainbow River. By quantifying the location, type, and depth of propeller (prop) scars, we can assess what submersed plant beds of the Rainbow River are vulnerable to boating damage. To minimize future prop damage to plants, specific areas (based on water depth) of the river could be placed off limits to motor boats. A maximum water-surface to bottom-of-prop restriction could also be developed and designated for the river, similar to mandating the no-wake designation. The information obtained in this study could also be used to target motor boaters for whom an educational program could be developed and implemented.

Field Testing Activities:

Prop scars were located along the entire length of the Rainbow River by visual examination of the submersed plant beds during October and November 2011. Due to the large number of propeller scars, sampling targeted those scars for which damage down to the substrate had occurred (N=61). Once a scar was located, the beginning and ending locations of the scar were marked with either long stakes, placed into the stream bed, or with floats, anchored to the bottom with small weights. Paired GPS coordinates and water depths were collected from a moving motorized boat, using a Trimble GPS (Trimble Unit Pro XRS with a TSC1 data logger) and a Lowrance depth finder (LMS350A), and stored electronically for later analysis.

Species of plants damaged, along with length and width of scars were recorded. Water depth (to the nearest 0.1m) was manually recorded (surface to top of substrate) at each end and at the midpoint of each scar to determine a plant-damage to water-depth relationship. This was also performed as a quality check of the data generated by the electronic Lowrance depth finder. Water surface-to-stream-bottom and water-surface-to-top-of-plant depth were also recorded 5 meters out from the end of each scar. Scar width (to the nearest 0.1m) was manually recorded at 3 locations equally distributed along the length of each scar.

A subsample (N=26) of specific prop scars was examined in April 2012 to determine recovery rate (change in scar width and length) and factors affecting recovery (e.g., water depth, plant species, location within the channel).

Scars were selected so that they could specifically be identified and linked to the earlier data that were collected. Overlapping scars and scars in open-water areas, where multiple scars were located, were not sampled (e.g., immediately below the KP Hole County Park and rocky shoal area downstream from the State Campground tuber take out), as it was impossible to determine the individual scar identification. April 2012 length and mean width of the 26 scars were compared to their October and November 2011 lengths and mean widths.

GIS Analysis of Prop Scar Locations:

The following data were analyzed using ArcGIS 10:

Layers	Format	Data source	Purpose of the data layer	Management and analysis performed
Example layer	Shape file	http://www.fgdl.org	Needed to derive correlation between wildfires and forests	Clipped out area of interest. Joined fire table data. Buffered.
River map	Shape file	Florida Department of Environmental Protection	Needed to map all feature classes, and determine prop scar locations	Used as base layer to map prop scars
State Park boundaries	Shape file	FL DEP	Needed to remove the zone of the river by the headsprings where motorized boats are not allowed to enter	
Boat launches	Feature class	FL DEP	Needed to conduct buffer analysis around congestion points	Created 1000-foot (305-m) buffer
Tuber take-out point	Feature class	Google Earth	Needed to conduct buffer analysis around congestion points	Created 1000-foot (305-m) buffer
Prop scars	Feature class	Field collection Oct-Nov 2011	Needed to map prop scar locations	Converted from Mercator meters, merged files (from 61 individual to 1 total), removed lines with 0s from x-y fields using select, conducted statistics on depth, used buffer analysis

Steps taken:

1. Data were retrieved from collection unit (Lowrance LCX-28C HD) and converted to .csv files (61 total scars, labeled 1-62, label “7” was skipped during field collection)
2. Individual .csv files were converted to feature classes (using x,y coordinates and a defined projection to convert from Mercator meters) in ArcCatalog
3. The prop scar feature classes (61 total) were merged into 1 feature class to make analysis and data management easier
4. There were lines with multiple 0,0 for x,y coordinates (each time the Lowrance unit was unable to make a good connection). To remove these, the Select tool was used to select lines that were non-zero (position x,y)
5. When data were collected, the depth measurements were taken at 1 foot (0.3 m) below the surface. To determine the total depth of the scar a field was added to the prop_scar feature class (Total_Depth), and calculated as Total Depth = [Depth] + 1.0
6. Symbology for the Prop_scar layer was modified to reflect total depth, with measurements of 2, 3, 4, 5, 6
7. A buffer of 5 feet (1.52 m) was created around the scar points so that shapes of individual scars would still be able to be displayed with the depth measurements for each point on top of them
8. 1000-foot (305-m) buffers were created around the boat launch and both of the tuber take outs to determine the number of scars around these congestion points.
9. To determine the number of scars in various sections of the river, the  tool was used to select the following areas: 1) north the boat launch, 2) south of the tuber take-out, and 3) zone between the boat launch and the tuber take-out (where both boaters and tubers interact)
10. Statistics were run to determine mean depth of the prop scars.

SCUBA:

Sampling Design:

An attempt was made to document if any particular type of dive activity (e.g., offloading or loading of divers, location of dive boats, anchoring of dive boats, standing of divers in shallows while receiving instructions, and actual diving) can be related to type or quantity of plant damage. Observations were made whenever dive boats and their divers were encountered. It was impossible to assign a sample size to this portion of the study, as we were dependent upon the diver activity and dive boat operations. There is little consistency as to the number of dive boats and divers on the Rainbow River within and among days. UF staff worked closely with FDEP and Marion County personnel to determine peak areas and times of diving (SCUBA and snorkeling) activity on the river so as to increase our probability of encountering divers.

Sampling/Test locations:

All observations were made upstream from the KP Hole County Park, as this is where the vast majority of divers had been encountered in past visits to the river and based on input from local residents and FDEP and county park staff. Dive boat operators launched their boats at the KP Hole County Park boat ramp (American Pro Diving Center, Bird's Underwater, etc.) or kept their boats docked on the river (Rainbow Water Taxi – immediately downstream of the KP Hole County Park; Crystal Lodge Dive Center – Upstream of the KP Hole Park). No dive boats were ever encountered downstream of the KP Hole Park.

Sample Collection Methods:

Only observational samples of diver activity were collected. No physical samples were collected so as not to interfere with the divers. UF staff recorded occasional diving activity as it was encountered while sampling other components of this study (transects, prop scars, user/water/plant sampling). In addition, UF staff visited the Rainbow River on suspected high-use days (9 to 11 March 2012) in an attempt to observe the effects of dive boat and diver activity on the aquatic plants. An un-marked (no UF markings) boat was used, so as not to alert the divers or dive boat operators of our activity.

The date and time of each dive party encountered was recorded, along with the dive company, including the length of the boat, size of motor, number of crew, and number and approximate age of the divers. The location of the diver drop off was recorded, along with the description of the area within the river and estimated depth and bottom type. Both diver and boat operator (anchoring, motoring, drifting, power loading) behaviors were recorded, along with any observation of plant damage. If plants were dislodged by the divers, attempts were made to determine the type and extent of damage.

Results

Task 1 - Type, location, and quantity of recreational use

About 93% of the 312[1] weeks of recorded data were recorded without recorder or camera problems. The remaining weeks had at least 1 day or in some cases all seven days of missing information. Table 2 presents the weekly use counts by date and camera, using only data from days when the equipment was functional. The results presented in the text below utilize these data, though a few weeks with missing information are included that likely would have been notable, based on extrapolating from cameras near the malfunctioning ones (see footnote 2). The busiest user weeks on the river, based on aggregating data across the six recording stations and all use types were between May 24 through August 22. These dates generally correspond to the time when K-12 schools are out of spring and fall sessions, and, of course, the warmest weather. During the spring months, March 20 through April 16 were the busier weeks, though at river use levels about 25% that of the highest summer weeks. In the post Labor Day period, the three weeks after Labor Day (~22% of the highest summer week's use), Thanksgiving week (~14%) and the week between Christmas and New Year's Day (~16%) were the busier weeks. The least used weeks were the week after New Year's Day (even with substituting the missing values from the tampered with camera 5 with data from camera 4) and Feb. 7-13 (though this was likely mostly determined by when the coldest weather weeks are, and may vary by a few weeks each year).

The higher overall weeks for total recreational use of the river in the time frame of this study (if incomplete data that was adjusted for[2] was used, it is denoted with asterisk)) were (1) June 14-20 (designated 100% level), (2) July 19-25 (97%*), (3) July 26-Aug. 1 (94%), (4) Aug. 2-8 (90%), (5) June 28-July 4 (90%*), (6) July 12-18 (87%*), (7) June 21-27 (86%*), (8) June 7-13 (81%*), (9) Aug. 16-22 (76%), (10) Aug. 9-15 (75%), (11) July 5-11 (71%*), (12) May 24-30 (Memorial Day weekend included) (67%), (13) Aug. 30-Sept. 5 (Labor Day weekend included) (59%*), (14) May 31-June 6 (55%*) and (15) Aug. 23-29 (52%). No other weeks during the year were above 50% of the highest week's use level. It should be kept in mind that a series of atypical weather days (e.g., 4 days of severe thunderstorms each afternoon in a row; or 2 all day rain days (esp. if over a weekend)) could easily vary a given week's percent level by more than 5-10%, so future projections of use per given week based on these results should be tempered with that in mind. The time period of this study was during a drought period with lower than average rainfall, with no major tropical systems affecting the Rainbow River area, so, if there is a general weather effect bias, it probably would be the results of this study being higher in use levels than a typical year which might be expected to have more summer rain days and 1-2 tropical systems (for the record, tropical storm Debby occurred after the time frame for this project in June 2012).

---

[1] 52 weeks x 6 cameras = 312

[2] Missing data was adjusted for by using the previous week's same day of the week data, or in some cases, averaging the day before and day after. In cases where an entire week's data was missing, either the previous or following weeks where complete data was available for that camera was temporarily substituted, to calculate specific data points for this discussion. In some cases, data from the nearest camera up river was substituted. Whichever of these approaches was the most justifiable was utilized for a specific case of missing data.

Table 2. Weekly use counts by camera station and activity.

		wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10	wk 11	wk 12
	2012	1/3-9	1/10-16	1/17-23	1/24-30	1/31-2/6	2/7-13	2/14-20	2/21-27	2/28-3/5	3/6-12	3/13-19	3/20-26
Cam 1													
	Canoes	16	10	56	32	44	33	64	40	55	98	198	154
	Kayaks	107	103	131	157	122	98	176	167	246	231	470	403
	Motor Boats	19	29	22	12	15	13	14	6	20	30	58	49
	Scuba Boat	0	3	13	9	11	8	11	2	6	1	2	2
	Swim + Divers	11	15	7	46	29	16	20	22	27	29	63	129
	Tubers	0	1	2	16	6	17	8	3	15	13	91	100
Cam 2													
	Canoes	18	26	74	76	61	34	62	49	83	111	193	159
	Kayaks	107	105	125	117	103	110	121	138	193	248	396	211
	Motor Boats	37	53	45	59	67	42	56	52	37	44	88	78
	Scuba Boat	16	34	29	24	41	27	63	47	5	2	0	2
	Swim + Divers	151	427	286	222	487	242	682	491	48	41	33	43
	Tubers	0	0	26	43	40	7	25	5	10	28	71	67
Cam 3													
	Canoes	21	30	38	28	30	15	22	22	29	37	64	26
	Kayaks	71	74	116	144	132	103	128	152	143	239	466	370
	Motor Boats	29	30	41	60	72	34	36	43	59	71	182	109
	Scuba Boat	16	35	29	25	42	27	63	47	5	3	1	2
	Swim + Divers	0	0	24	48	151	64	55	87	7	65	131	68
	Tubers	0	0	0	0	0	0	0	0	0	0	13	25

		wk 1	wk 2	wk 3	wk 4	wk 5	wk 6	wk 7	wk 8	wk 9	wk 10	wk 11	wk 12
	2012	1/3-9	1/10-16	1/17-23	1/24-30	1/31-2/6	2/7-13	2/14-20	2/21-27	2/28-3/5	3/6-12	3/13-19	3/20-26
Cam 4													
	Canoes	45	31	17	16	14	18	25	16	24	20	77	56
	Kayaks	79	80	39	39	28	21	27	29	50	57	229	137
	Motor Boats	46	68	60	32	47	38	73	62	54	47	117	89
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	0	0	0	0	0	0	0	0	0	0	9	15
	Tubers	0	14	2	0	0	0	6	5	28	214	667	695
Cam 5													
	Canoes		0	19	29	37	26	36	24	67	51	143	68
	Kayaks		0	64	94	68	72	92	77	148	150	224	165
	Motor Boats		3	35	27	26	18	29	23	35	53	87	59
	Scuba Boat		0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers		0	0	2	0	0	0	2	5	2	18	28
	Tubers		0	6	0	3	0	6	5	28	210	661	684
		S***	S***										
Cam 6													
	Canoes	8	9	58	48	54	49	51	51	38	50	57	62
	Kayaks	70	78	127	118	166	86	112	87	86	139	168	160
	Motor Boats	66	70	69	108	68	59	79	72	73	99	96	109
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	0	0	2	1	0	0	0	0	0	0	0	0
	Tubers	0	0	6	0	6	0	10	5	34	212	656	672

S = camera tampered with rendering it unable to view users; *** = major loss of data

		wk 13	wk 14	wk 15	wk 16	wk 17	wk 18	leftover
								2 days
	2012	3/27-4/2	4/3-9	4/10-16	4/17-23	4/24-30	5/1-7	5/8-9
Cam 1								
	Canoes	93	157	92	73	86	88	16
	Kayaks	350	569	451	186	353	283	53
	Motor Boats	90	68	87	23	51	50	15
	Scuba Boat	6	13	8	4	6	8	1
	Swim + Divers	108	96	68	30	59	77	9
	Tubers	48	80	30	9	61	59	7
Cam 2								
	Canoes	58	74	74	41	65	60	7
	Kayaks	343	500	367	192	341	273	45
	Motor Boats	143	146	111	43	115	73	13
	Scuba Boat	10	33	22	21	18	16	7
	Swim + Divers	124	321	196	181	164	128	62
	Tubers	34	17	15	1	85	44	0
Cam 3								
	Canoes	47	84	46	21	40	38	3
	Kayaks	284	475	312	149	297	289	49
	Motor Boats	142	132	103	37	101	81	17
	Scuba Boat	5	33	22	21	18	16	7
	Swim+ Divers	69	145	67	27	26	64	10
	Tubers	113	146	181	84	210	256	0

		wk 13	wk 14	wk 15	wk 16	wk 17	wk 18	leftover
								2 days
	2012	3/27-4/2	4/3-9	4/10-16	4/17-23	4/24-30	5/1-7	5/8-9
Cam 4								
	Canoes	44	41	24	70	57	23	1
	Kayaks	153	301	239	131	188	97	31
	Motor Boats	118	84	69	29	48	49	17
	Scuba Boat	0	0	0	0	0	0	0
	Swim + Divers	8	3	12	0	13	7	0
	Tubers	774	1097	843	315	889	1152	131
Cam 5								
	Canoes	44	6	5	4	14	2	1
	Kayaks	229	298	185	102	159	122	34
	Motor Boats	90	76	62	35	63	54	10
	Scuba Boat	3	0	0	0	0	0	0
	Swim + Divers	7	5	6	2	11	5	0
	Tubers	767	1078	834	310	887	1131	128
Cam 6								
	Canoes	63	93	35	0	5	46	12
	Kayaks	205	249	176	0	54	118	22
	Motor Boats	129	106	65	0	30	90	21
	Scuba Boat	0	0	0	0	0	0	0
	Swim + Divers	25	22	9	0	4	17	0
	Tubers	672	971	647	0	361	913	131
				IC*	IC***	IC***		

IC = incomplete data on some (or all) days of that week due to technical problems with recorder

* = minor loss of data,   ***=major loss of data

		wk 19	wk 20	wk 21	wk 22	wk 23	wk 24	wk 25	wk 26	wk 27	wk 28	wk 29	wk 30
	2011	5/10*-16	5/17-23	5/24-30	5/31-6/6	6/7-13	6/14-20	6/21-27	6/28-7/4	7/5-11	7/12-18	7/19-25	7/26-8/1
Cam 1													
	Canoes	150	116	113	194	346	407	226	351	246	313	350	313
	Kayaks	255	293	233	265	148	173	113	259	151	202	302	241
	Motor Boats	53	42	92	54	99	64	46	96	60	34	31	37
	Scuba Boat	12	11	9	7	16	28	9	9	10	13	19	17
	Swim + Divers	88	105	160	103	19	55	110	80	75	61	54	34
	Tubers	78	163	276	154	99	164	148	263	195	214	271	347
					IC*	IC*							
Cam 2													
	Canoes	146	199	126	198	264	216	116	224	100	208	239	227
	Kayaks	210	204	207	251	367	564	323	361	246	286	269	259
	Motor Boats	75	79	157	69	139	190	106	191	151	184	286	202
	Scuba Boat	32	13	17	16	20	43	18	13	19	20	22	24
	Swim + Divers	283	99	159	148	175	398	161	111	153	143	171	202
	Tubers	100	132	249	102	206	209	118	243	98	145	119	180
Cam 3													
	Canoes	94	137	111	155	70	135	76	141	72	133	160	170
	Kayaks	200	287	218	270	173	326	248	317	204	268	219	191
	Motor Boats	85	125	191	119	78	159	92	188	102	177	184	143
	Scuba Boat	31	13	14	16	21	45	17	12	19	18	21	25
	Swim + Divers	4	5	3	0	0	0	0	0	0	0	0	0
	Tubers	195	243	1352	1658	2824	3716	3080	3194	2209	3305	3703	3348

IC = incomplete data on some (or all) days of that week due to technical problems with recorder

Note: * May 10 only was a 2012 count, the rest of the week was 2011 count; * = minor loss of data

		wk 19	wk 20	wk 21	wk 22	wk 23	wk 24	wk 25	wk 26	wk 27	wk 28	wk 29	wk 30
	2011	5/10*-16	5/17-23	5/24-30	5/31-6/6	6/7-13	6/14-20	6/21-27	6/28-7/4	7/5-11	7/12-18	7/19-25	7/26-8/1
Cam 4													
	Canoes	63	73	173	104	56	91	90	130	61	76	91	80
	Kayaks	224	127	187	174	229	322	231	388	246	342	390	280
	Motor Boats	60	61	95	49	97	125	85	154	87	98	131	97
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	28	9	82	31	47	53	57	57	54	87	114	120
	Tubers	1226	1563	3613	3018	4933	5978	5417	5133	3830	5307	6263	5794
Cam 5													
	Canoes	11	43	89	85	66	98	68	89	23	0	62	97
	Kayaks	226	186	282	222	217	299	210	274	83	0	167	213
	Motor Boats	53	83	119	63	121	102	79	135	42	0	106	87
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	28	65	89	53	25	9	10	59	4	0	73	65
	Tubers	749	1527	3561	3012	4867	5991	5411	5140	1835	2198	5460	5760
										IC**	IC***	IC**	
Cam 6													
	Canoes	68	85	167	125	93	86	2	39	59	98	105	154
	Kayaks	256	247	339	233	307	392	24	83	221	324	378	299
	Motor Boats	136	145	262	174	220	233	8	64	161	165	243	196
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	0	0	0	2	0	0	0	0	6	0	0	4
	Tubers	1169	1341	2589	1536	2342	2367	224	441	1812	2119	2589	2450
								IC***	IC***				

IC = incomplete data on some (or all) days of that week due to technical problems with recorder

** = moderate loss of data; *** = major loss of data

Note: * May 10 only was a 2012 count, the rest of the week was 2011 count

		wk 31	wk 32	wk 33	wk 34	wk 35	wk 36	wk 37	wk 38	wk 39	wk 40	wk 41	wk 42
	2011	8/2-8	8/9-15	8/16-22	8/23-29	8/30-9/5	9/6-12	9/13-19	9/20-26	9/27-10/3	10/4-10	10/11-17	10/18-24
Cam 1													
	Canoes	308	102	56	39	60	66	41	21	29	0	31	25
	Kayaks	324	314	313	200	253	98	120	61	121	0	175	128
	Motor Boats	47	142	110	91	212	93	92	103	95	0	25	26
	Scuba Boat	14	5	10	9	3	2	13	10	2	0	1	0
	Swim + Divers	38	33	45	58	32	7	10	8	19	0	13	28
	Tubers	313	180	112	33	191	46	44	34	8	0	0	2
											IC***		
Cam 2													
	Canoes	243	59	48	27	6	0	0	0	26	9	20	10
	Kayaks	299	280	277	179	34	0	0	0	88	101	176	94
	Motor Boats	223	138	122	105	13	0	0	0	71	48	84	51
	Scuba Boat	21	10	12	13	1	0	0	0	5	12	19	12
	Swim + Divers	126	96	111	84	51	66	92	81	61	122	150	88
	Tubers	159	140	113	35	3	0	0	0	10	3	0	0
						IC***	IC***	IC***	IC***	IC***			
Cam 3													
	Canoes	127	64	29	31	67	62	40	30	51	46	10	27
	Kayaks	173	301	374	226	242	83	119	80	126	63	58	118
	Motor Boats	131	161	190	129	185	116	121	121	113	129	46	40
	Scuba Boat	21	7	12	11	5	10	14	10	6	12	19	12
	Swim + Divers	0	0	0	0	7	0	0	0	0	0	0	0
	Tubers	3036	2650	2789	2141	2146	471	615	537	41	0	6	0

IC = incomplete data on some (or all) days of that week due to technical problems with recorder

*** = major loss of data

		wk 31	wk 32	wk 33	wk 34	wk 35	wk 36	wk 37	wk 38	wk 39	wk 40	wk 41	wk 42
	2011	8/2-8	8/9-15	8/16-22	8/23-29	8/30-9/5	9/6-12	9/13-19	9/20-26	9/27-10/3	10/4-10	10/11-17	10/18-24
Cam 4													
	Canoes	53	33	30	45	24	34	37	27	21	9	67	9
	Kayaks	273	229	159	139	102	118	205	116	120	82	138	118
	Motor Boats	102	90	100	62	37	53	73	26	47	20	62	114
	Scuba Boat	0	0	0	0	0	1	0	2	0	0	2	0
	Swim + Divers	118	27	63	12	10	6	8	0	6	0	2	10
	Tubers	5442	4680	4745	3222	3374	815	1413	1034	286	40	28	15
Cam 5													
	Canoes	83	89	79	91	44	22	32	17	16	6	49	6
	Kayaks	248	208	176	140	200	88	196	119	113	65	125	74
	Motor Boats	114	197	243	221	235	70	148	110	104	35	65	35
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	68	17	38	12	18	6	2	5	5	0	0	3
	Tubers	5424	4676	4736	3217	3608	794	1416	1035	287	40	30	17
						IC**	IC***						
Cam 6													
	Canoes	92	33	43	14	39	23	26	14	19	5	54	9
	Kayaks	353	200	264	195	325	135	192	147	165	46	59	73
	Motor Boats	212	173	154	161	184	89	107	90	77	19	87	93
	Scuba Boat	0	0	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	5	0	0	0	0	0	0	0	0	0	2	2
	Tubers	2492	2059	2027	1108	1573	439	856	526	253	43	25	17

IC = incomplete data on some (or all) days of that week due to technical problems with recorder

** = moderate loss of data; *** = major loss of data

		wk 43	wk 44	wk 45	wk 46	wk 47	wk 48	wk 49	wk 50	wk 51	wk 52
	2011/2012	10/25-31	11/1-7	11/8-14	11/15-21	11/22-28	11/29-12/5	12/6-12	12/13-19	12/20-26	12/27-1/2*
Cam 1											
	Canoes	19	28	16	28	34	11	1	8	30	39
	Kayaks	138	159	161	148	235	85	70	76	210	308
	Motor Boats	27	27	33	33	51	17	4	15	45	52
	Scuba Boat	0	0	0	2	1	0	0	0	0	3
	Swim + Divers	34	16	14	36	19	12	2	5	30	30
	Tubers	0	0	1	0	1	0	0	2	9	1
Cam 2											
	Canoes	17	11	14	28	57	17	7	7	48	68
	Kayaks	118	130	118	129	242	93	60	71	204	312
	Motor Boats	47	50	69	62	92	29	26	34	45	77
	Scuba Boat	17	9	26	15	11	20	19	17	9	38
	Swim + Divers	143	58	229	127	89	167	166	140	72	326
	Tubers	0	0	0	0	1	0	0	0	0	0
Cam 3											
	Canoes	24	14	11	32	51	12	3	14	39	55
	Kayaks	88	93	108	121	226	74	53	67	177	263
	Motor Boats	43	44	67	54	93	24	27	26	43	71
	Scuba Boat	18	9	26	13	11	20	19	17	9	39
	Swim + Divers	0	0	0	0	0	0	0	0	0	0
	Tubers	0	0	0	0	1	0	0	0	0	0

Note: in week 52, Jan 1 and 2 are in 2012

		wk 43	wk 44	wk 45	wk 46	wk 47	wk 48	wk 49	wk 50	wk 51	wk 52
	2011/2012	10/25-31	11/1-7	11/8-14	11/15-21	11/22-28	11/29-12/5	12/6-12	12/13-19	12/20-26	12/27-1/2*
Cam 4											
	Canoes	2	8	9	11	23	4	2	9	28	61
	Kayaks	114	164	116	99	150	114	117	99	99	141
	Motor Boats	124	116	101	100	98	71	58	36	42	60
	Scuba Boat	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	0	15	3	22	0	11	4	0	0	0
	Tubers	0	0	2	2	0	0	3	0	0	2
Cam 5											
	Canoes	3	5	5	2	13	3	3	1		
	Kayaks	70	96	96	81	134	50	39	48		
	Motor Boats	29	17	35	31	91	22	21	18		
	Scuba Boat	0	0	0	0	0	0	0	0		
	Swim + Divers	0	0	0	0	0	0	0	0		
	Tubers	0	0	2	2	2	0	3	0		
									S**	S***	S***
Cam 6											
	Canoes	3	13	13	8	14	6	11	15	23	31
	Kayaks	100	178	122	95	183	51	38	72	124	206
	Motor Boats	76	77	83	89	107	47	47	65	103	129
	Scuba Boat	0	0	0	0	0	0	0	0	0	0
	Swim + Divers	0	0	0	0	0	0	0	0	0	0
	Tubers	0	0	0	2	2	0	3	0	0	2

S = camera tampered with rendering it unable to view users

** = moderate loss of data; *** = major loss of data

Note: in week 52, Jan 1 and 2 are in 2012

Daily proportions of total weekly use (based on five use weeks (not including any holiday Monday weeks)[3] with complete (or almost complete) data, all above 80% of the highest use week, were: Mondays 9.8%, Tuesdays 8.4%, Wednesdays 8.8%, Thursdays 9.4%, Fridays 12.8%, Saturdays 28.5% and Sundays 22.3% of weekly use. This averages to 50.8% of use occurring on Saturdays and Sundays and 49.2% occurring on weekdays.

Regarding total use of the upper river (north of KP Hole County Park) contrasted with total use of the lower river (south of KP Hole Park), for the same five higher use weeks denoted in footnote 2, the upper river proportion of total use was 28% and lower proportion was 72%. Clearly, the primary difference is the larger number of tubers on the lower river. When all tuber counts are removed, the proportion of use for the upper river is 56% and the lower river is 44% for the five weeks referenced in footnote 2. This is likely due to the heavy tuber traffic on the lower river either influencing other users of the lower river to not participate or displacing them to upper river areas.

Since this study is mostly focused on issues associated with higher use levels, the highest five use week counts for each activity are summarized in Table 3.

Table 3. Five highest use weekly counts by activity.

Rank	1	2	3	4	5	Highest 5 weeks average	River
Activity							Section
Canoes	407	351	350	346	313	353	UR
Kayaks	569	564	466	367	367	467	UR
Motor Boats	286	243	235	233	223	244	UR + LR
Scuba Boats	63	47	45	42	35	46	UR
Swim & Divers	682	491	487	427	398	497	UR
Tubers	6263	5978	5794	5442	5307	5,757	LR

UR = Upper River LR = Lower River

The highest daily counts of motorboats were: 93 (July 23), 71 (July 25), 70 (June 18), 68 (July 28), 65 (July 16), 64 (May 28), 62 (May 29) and 62 (May 30). The highest daily counts of tubers were: 1818 (June 18), 1656 (Aug 11), 1609 (July 16), 1609 (Aug. 6), 1607 (July 30), 1578 (July 11), 1539 (July 23), 1528 (Aug 27), 1507 (Aug 20), and 1439 (July 2). The highest daily counts of scuba boats were 20 (Feb. 18), 20 (Feb. 26), 18 (Feb. 19), 15 (Dec. 30), 14 (Feb. 6), 14 (Feb. 25) and 14 (June 16). The highest daily counts for canoes were 90 (July 3), 88 (July 4), 84 (May 29), 84 (July 23), 77 (May 30), 77 (Apr. 27), 74 (Apr. 29) and 43 (Apr. 7). The highest daily counts for kayaks were 117 (Apr. 14), 110 (Apr. 15), 107 (June 19), 105 (Aug. 13), 104 (Apr. 7), 101 (May 14), 99 (Apr. 5), 96 Apr. 28, 90 (July 23), 88 (May 30), 88 (July 3), 87 (Apr. 1), 86 (May 29) and 84 (Sep. 3). Comparing these with the 1994 study findings, the number of tubers on peak use days has more than tripled (3.7 times as many) and the number of motorboats has increased by about 46% (keep in mind

3 June 7-13, June 14-20, July 19-25, July 26-Aug. 1, Aug. 2-8

that the number of motorboats on peak use days is restrained by the tuber traffic on the river likely making the river too congested on the lower river to increase motorboat use much). Canoe/kayaks were counted in one category in 1994, so combining the current data to compare on peak use days indicates about a 60% increase in these watercrafts on peak use days.

Estimating total annual use by activity is complex with six cameras meaning there is a high likelihood of double counting if counts from more than one camera are summed. Thus, annual sums per camera are presented in Table 4, and the reader can select the annual use number for a selected activity per camera location that they deem appropriate. The highest count for each activity across the six cameras is shaded.

Table 4. Observed annual use counts by camera station and activity.

		52 week
Cam 1		Total
	Canoes	5,522
	Kayaks	10,988
	Motor Boats	3,014
	Scuba Boats	349
	Swim/Divers	2,294
	Tubers	3,947
Cam 2		
	Canoes	4,310
	Kayaks	10,587
	Motor Boats	4,820
	Scuba Boats	960
	Swim/Divers	9,177
	Tubers	3,237
Cam 3		
	Canoes	2,934
	Kayaks	10,147
	Motor Boats	5,243
	Scuba Boats	989
	Swim/Divers	1,127
	Tubers	44,278

Cam 4		
	Canoes	2,253
	Kayaks	8,107
	Motor Boats	4,020
	Scuba Boats	5
	Swim/Divers	1,123
	Tubers	84,011
Cam 5		
	Canoes	1,876
	Kayaks	7,028
	Motor Boats	3,616
	Scuba Boats	3
	Swim/Divers	747
	Tubers	74,707
Cam 6		
	Canoes	2,378
	Kayaks	8,647
	Motor Boats	6,600
	Scuba Boats	0
	Swim/Divers	101
	Tubers	37,711

It is possible that these counts are conservative for canoes, kayaks and motorboats, since counts from only one camera are highlighted, while some users of these watercrafts may tend to stay either on the upper or lower river, and those who use stay in the other end of the river would not be captured in the shaded counts. Also note that these use counts do not include any counts from visitors to the Rainbow Springs Headsprings state park (unless they canoed or kayaked from that park into the part of the river monitored in this study) nor any visitors to the Rainbow Springs state park campground or KP Hole County Park that did not utilize a longitudinal section of the river (i.e., if they only camped and did not enter the river; or they only swam in the swimming area of KP Hole park and did not go downriver; or if they only picnicked at KP Hole County Park and did not enter the river). Thus, due to these exclusions, these use counts are also conservative if total recreational use of the entire Rainbow River or its adjacent parklands is the number desired.

Counts from the 1994-1995 Rainbow River study conducted by Holland and Cichra (1995), were based on partial year observations and archived records and only 2 cameras (one on upper river and one on lower river) so it is not ideally comparable to this study. However, estimates were made in 1994 that a total of 21,000 tube trips, 2,313 motorboat trips, and 1,054 canoe/kayak trips occurred on the river annually. No count was made of swimmer/divers or scuba boats in that study (though scuba boats were included in the motorboat total). Rough comparisons are possible. If we take the highest annual estimates for these three types of users from the current 2011/2012 study numbers and compare them, the following growth increases are observed across the 17 year time span between the two studies. For tubers, there has been a 400% increase in number of tube trips, 228% increase in number of motorboat trips and a ~15 times increase in the number of canoe/kayak trips or about 1500%. Keep in mind; these are user occasions, meaning the increases are not necessarily based solely on increased numbers of people, but also likely reflect an increase in the number of trips that a given person takes. Thus, if more river residents purchased motorboats and kayaks over the last 17 years (likely), those residents may have substantially increased the number of such trips they take on the river. A river resident who has easy access to a motorboat on the river, might take multiple trips a week, and be counted multiple times that week, even though it is the same 2-4 people on that boat each trip. Yet, it is also clear that numbers of non-river residents renting tubes at the two parks that rent tubes have substantially increased, with more parking being needed to host them and more available tubes to rent compared to 1994. And, the number of commercial trips offered by dive boats has clearly increased, likely almost all non-resident users. Nevertheless, for purposes of this study, where potential environmental pressure on the river due to volume of river use is the main focus, it is the number of user events on the river that is relevant, regardless of whether it is 500 people taking 40 trips a year, totaling 20,000 user events, or if it is 5,000 people taking 4 trips per year, totaling 20,000 user events, the potential river environmental impacts would be about the same. The user occasion counts summarized in this study provide estimates of the amount of various types of recreational use on different segments of the river across time, to be used in conjunction with any environmental quality indicators that can be paired with these data to explore any relevant correlations.

Task 2 - Geographic and temporal differences in aquatic plant communities

Eighteen species of aquatic macrophytes, along with Chara sp., Lyngbia spp., and other filamentous algae, were sampled on the 26 0.1 to 3.5-m-deep (Tables 5 – 7) fixed sampling transects during spring and fall 2011 and spring 2012 (Table 8). Ten species of submersed aquatic macrophytes were sampled from 20 fixed sampling transects during summer and fall 1994 and spring 1995 (Holland and Cichra 1995). All ten submersed plant species were again sampled during this study, along with several emergent species that were not included in the earlier study. The submersed plant species, sampled in the 1994-1995 study, were also sampled by Water and Air Research (WAR) (1991). WAR also found variable-leaf (two-leaf) water-milfoil (Myriophyllum heterophyllum) present within the river. This species was not listed by WAR in a table of percentage of samples, indicating that mean coverage was less than 0.2 percent. It is possible that milfoil was so low in abundance that we did not observe it in our 1994-1995 study due to our limited sampling. We did find it in the headsprings in all three sampling events in 2011 and 2012 in up to 5 of the transects originally sampled in 1994-1995, and in transect 5.1, a new transect.

Of the 18 species sampled with transects, six (Sagittaria kurziana, Hydrilla verticillata, Vallisneria americana, Potamogeton illinoensis, Utricularia spp., and Fontinalis sp.) had mean coverage (areal coverage per grid) of at least 15 percent in all three sampling events in 2011 and 2012 (Tables 9 - 11).

Strap-leaf sagittaria (S. kurziana) was the most dominant (areal coverage greater than 50 percent in 10 of 26 transects over all seasons, Tables 9 - 11). This species, along with H. verticillata and Najas guadalupensis were the most common (occurring in 22 to 25 of the 26 transects over all seasons, Tables 12 - 14) submersed plant species in the Rainbow River. S. kurziana was also listed as the most common species encountered in 1990 by WAR (1991) and in our 1994-1995 study (Holland and Cichra 1995). Odum (1957b) cites S. kurziana as by far the most dominant submersed macrophyte within Silver Springs, Florida. When comparing the 1994-1995 data to the 2011-2012 data on a transect-by-transect basis, it is obvious that the abundance (percent coverage) of this species has decline over the period of record at most transects.

V. americana was widespread (occurring in 16 to 20 of the 26 transects), but was never dominant in any single transect, similar to our findings in 1994-1995 (14 of 20 transects). Henigar and Ray (1987) cited V. americana as the most dominant submersed macrophyte on Rainbow River. It is unlikely that a large scale shift in the submersed plant community occurred in such a short period of time in such a stable system. Therefore, we believe Henigar and Ray (1987) misidentified S. kurziana as V. americana. When comparing the 1994-1995 data to the 2011-2012 data on a transect-by-transect basis, the abundance (percent coverage) of this species has increased at some transects, while decreasing at others, with no regional trend in the river.

V. americana and S. kurziana are often found in association with one another within Florida springs. In Rainbow River, small patches of V. americana were often encountered within extensive patches of S. kurziana. Odum (1957b) mentions the competition between S. kurziana and V. americana as "one of the most fascinating, unsolved problems in [Florida] springs."

Illinois pondweed (P. illinoensis) was found exclusively in the headsprings (transects 1 through 5), and was fairly common within this area during both our 1994-1995 study and in this current 2011-2012 study. It was also found at transect 5.1, a new transect, located just below the State Park boundary.

In Florida, Illinois pondweed is frequently found in swift flowing spring-fed calcareous waters (Tarver et al. 1979). It is not known for certain why it was found exclusively in the headsprings. However, it is suspected that water chemistry may play some role. Pondweed was observed to be closely associated with certain spring vents. Additional water chemical testing of these vents in 1994-1995 revealed that water from these vents was substantially higher in total alkalinity (84-104 mg/L), total nitrogen (1.05-1.23 mg/L) and total phosphorus (0.28-0.34 mg/L) (Holland and Cichra 1995). Analysis of water chemistry data from over 300 Florida lakes reveals that Illinois pondweed tends to occur in alkaline, hardwater, nutrient-rich systems (Hoyer et al. 1996).

Red ludwigia (Ludwigia repens) was found from transect 4 to 7, and most common at transects 5 and 5.1. In 1990, WAR found pondweed and red ludwigia to occur only in a small section of the headsprings.

Hydrilla was found to be widespread throughout the river, occurring in 25 of 26 transects (Tables 12 - 14). It was absent from transect 2 in all three sampling events. Hydrilla has thus expanded its range within the Rainbow River between the 1994-1995 study (15 of 20 summer 1994 transects; 16 of 20 fall 1994 transects; 17 of 20 spring 1995 transects) and the present study. In 1994-1995, hydrilla mean coverage for any single transect exceeded 25 percent only at transects 1 and 3 in the headsprings. In 2011 and 2012, hydrilla was never found to exceed 25% coverage at any transect. In fact, it represented less than 3% coverage at both transects 1 and 3 in all three 2011 and 2012 sampling events. Hydrilla was first noticed in Rainbow River at the headsprings in the mid 1970s (Peter Sleszynski, past Manager, Rainbow Springs Aquatic Preserve, pers. comm.). Jeff Sowards (current Manager, Rainbow Springs Aquatic Preserve, pers. comm.) indicated that its abundance has gone down in much of the headspring area, as our transect data indicate. Additionally, when comparing the 1994-1995 data to the 2011-2012 data on a transect-by-transect basis, the abundance (percent coverage) of hydrilla has declined at the most downriver transects, while increasing at the midstream transects.

In the Rainbow River, hydrilla also tends to be more abundant along shorelines. It is not known for certain why this occurs. Some evidence suggests that species such as V. americana might have lower nutrient requirements than hydrilla, which may serve as a competitive advantage in low nutrient hydrosoils (Steward 1991). However, due to high concentrations of nutrients in this system, it is unlikely that nutrients are a growth limiting factor for hydrilla. In addition, Canfield and Hoyer (1988b) found that the abundance of aquatic macrophytes in Florida streams is typically not limited by nutrients (nitrogen and phosphorus). Rather, shading by riparian vegetation is often the dominant factor controlling the location and abundance of aquatic macrophytes. However, hydrilla is known to have extremely low light requirements (Bowes et al. 1977). Because canopy closure at Rainbow River was found to be only one percent (Duarte and Canfield 1990a) and water clarity during this study always exceeded ten meters, it is unlikely that light limits the growth of hydrilla in this system.

Butcher (1933) found water current to be the most important factor in determining the distribution of aquatic macrophytes in streams. It is commonly known that current flow is typically lower along the edges of moving water than at mid-stream. Differences in water current along the width of Rainbow River were not measured during this study. However, during transect sampling it was obvious that current along the sides of the channel were substantially less than in midstream. Species such as S. kurziana commonly occur in swift-flowing water (Tarver et al. 1979). This species, as well as others adapted to moving waters, tend to have well developed root systems and long, thin and flexible leaves which provide low resistance to current flow (Pitlo and Dawson 1989). Perhaps these features provide a competitive advantage over more lentic-adapted species such as hydrilla.

In the transect data calculations, bare substrate represented areas covered by sand, rock, concrete, or detrital materials. All transect samples had a mean coverage of bare substrate of at least 2.5 percent. Nearly all (67 of 78) had a mean coverage of at least ten percent. Most often, submersed macrophytes seemed to be absent due to unsuitable bottom substrate, such as limestone outcroppings. Another Florida spring system, Ichetucknee River, was noted as having similar limestone outcroppings unsuitable for macrophyte growth (Canfield and Hoyer 1988b). Other areas devoid of vegetation included areas near boat docks and swimming areas. Bare substrate, due to motorboats (propeller scars), was observed in the Rainbow River. However, far less than one percent of bare substrate was caused by propeller damage.

Mean percent coverage and percent occurrences of major plant taxa were similar among all three transect data sets (spring 2011, fall 2011, and spring 2012). This indicates temporal (seasonal) stability of the submersed aquatic plant community.

Table 5. Water depth taken at five locations along each of the 26 aquatic plant sampling transects on the Rainbow River, Dunnellon, Florida, May 2011.

Transect	Date	Depth (m)				
		West		Middle		East
1	5/26/2011	1.9	1.8	2.1	2.2	2.0
2	5/26/2011	1.4	.	2.2	1.5	1.2
3	5/26/2011	1.4	2.1	2.5	2.1	1.6
4	5/26/2011	1.1	.	.	.	1.3
5	5/26/2011	1.0	1.9	1.5	1.9	2.0
5.1	5/25/2011	1.2	1.4	1.7	1.7	1.9
5.2	5/25/2011	0.1	1.4	1.6	1.1	0.5
6	5/25/2011	1.3	2.0	2.1	1.8	2.2
7	5/25/2011	2.4	>3.0	>3.0	1.6	0.9
8	5/24/2011	1.4	1.1	1.2	7.3	1.4
9	5/24/2011	0.5	0.8	1.3	2.2	0.8
10	5/25/2011	1.0	1.2	1.7	1.9	0.3
11	5/24/2011	1.0	2.1	1.3	1.1	0.2
12	5/25/2011	0.8	1.1	1.0	1.5	0.5
13	5/24/2011	0.8	0.9	1.5	2.9	0.7
14	5/23/2011	1.0	2.7	2.8	1.4	0.9
15	5/23/2011	0.7	1.2	3.7	3.5	1.2
16	5/23/2011	1.1	1.5	1.7	3.0	1.2
17	5/23/2011	0.7	1.3	1.5	1.5	0.3
17.1	5/19/2011	1.7	1.8	1.4	1.3	0.8
17.2	5/19/2011	0.8	0.9	1.7	1.8	1.1
17.3	5/19/2011	1.0	1.1	1.5	1.3	0.7
17.4	5/23/2011	1.2	1.5	1.2	0.9	0.6
18	5/20/2011	1.1	2.1	1.4	1.7	0.8
19	5/20/2011	0.6	1.4	1.8	1.7	1.0
20	5/20/2011	1.7	2.3	2.5	2.1	1.2

Table 6. Water depth taken at five locations along each of the 26 aquatic plant sampling transects on the Rainbow River, Dunnellon, Florida, September and October 2011.

		Depth (m)				
Transect	Date	West		Middle		East
1	10/5/2011	2.0	1.9	2.0	2.2	2.0
2	10/5/2011	1.7	1.7	2.1	1.4	.
3	10/5/2011	1.3	2.3	2.7	2.3	1.9
4	10/5/2011	1.4	2.0	1.3	1.3	1.3
5	10/5/2011	0.5	2.4	1.3	1.7	1.9
5.1	10/5/2011	1.5	1.2	1.0	1.7	1.8
5.2	9/30/2011	0.2	1.6	1.6	1.2	1.0
6	9/30/2011	1.2	2.0	2.1	1.6	2.2
7	9/30/2011	1.3	2.8	3.5	2.3	0.9
8	9/30/2011	1.4	0.9	1.5	>3.0	1.1
9	9/30/2011	0.5	1.0	2.0	2.9	0.8
10	9/30/2011	1.0	1.3	2.1	2.0	0.5
11	9/26/2011	0.9	1.8	1.4	1.1	0.4
12	9/30/2011	0.2	1.2	1.2	1.4	0.6
13	9/26/2011	0.6	1.3	2.0	2.7	0.8
14	9/26/2011	0.9	2.6	2.0	1.3	0.8
15	9/26/2011	0.8	1.1	1.6	3.3	1.3
16	9/26/2011	1.2	1.5	1.3	2.7	1.1
17	9/26/2011	0.6	1.0	1.4	1.3	0.5
17.1	9/23/2011	.	.	.	.	.
17.2	9/23/2011	0.9	1.1	1.4	1.6	0.8
17.3	9/23/2011	1.0	1.2	1.6	1.3	0.7
17.4	9/23/2011	1.0	1.3	1.0	0.8	0.7
18	9/23/2011	0.9	1.2	1.6	1.6	1.5
19	9/23/2011	0.8	1.6	1.8	1.6	1.3
20	9/23/2011	.	.	.	.	.

Table 7. Water depth taken at five locations along each of the 26 aquatic plant sampling transects on the Rainbow River, Dunnellon, Florida, April 2012.

Transect	Date	Depth (m)				
		West		Middle		East
1	4/24/2012	1.7	1.7	1.8	2.0	1.8
2	4/24/2012	1.5	1.5	1.9	1.4	0.9
3	4/24/2012	1.1	2.1	2.5	2.1	1.9
4	4/24/2012	1.3	1.8	1.3	1.2	1.3
5	4/24/2012	1.6	1.7	1.5	1.8	1.9
5.1	4/23/2012	.	.	.	.	.
5.2	4/23/2012	1.1	1.5	1.4	0.9	0.9
6	4/23/2012	1.3	1.9	2.2	2.0	1.9
7	4/23/2012	2.0	3.0	3.0	1.4	0.7
8	4/23/2012	1.1	1.1	>3.0	>3.0	1.3
9	4/17/2012	0.3	0.8	1.8	2.6	0.5
10	4/17/2012	0.9	1.2	2.3	2.1	0.3
11	4/17/2012	1.0	1.9	1.0	1.0	0.3
12	4/17/2012	0.3	0.7	1.2	1.0	0.2
13	4/17/2012	1.0	2.1	2.5	1.3	0.6
14	4/12/2012	0.6	2.3	1.7	1.0	0.5
15	4/12/2012	0.6	0.9	1.3	3.0	1.0
16	4/12/2012	1.3	1.2	1.6	2.9	1.4
17	4/12/2012	0.7	0.5	1.0	0.7	0.2
17.1	4/12/2012	1.2	1.5	1.1	1.0	0.9
17.2	4/11/2012	1.1	1.5	1.2	0.7	0.8
17.3	4/11/2012	0.7	1.0	1.5	1.0	0.7
17.4	4/11/2012	0.9	1.1	0.8	0.7	0.7
18	4/11/2012	0.7	0.9	1.2	1.3	1.4
19	4/11/2012	0.6	1.6	1.4	1.4	0.7
20	4/11/2012	1.6	2.1	2.1	1.5	0.9

Table 8. Scientific and common names of aquatic plants sampled along 26 transects on the Rainbow River, Dunnellon, Florida, in April, September, and October 2011 and May 2012.

Scientific Name	Common Name
Ceratophyllum demersum	Coontail/hornwort
Fontinalis sp.	Water-moss
Hydrilla verticillata	Hydrilla
Najas guadalupensis	Southern naiad
Potamogeton illinoensis	Illinois pondweed
Myriophyllum sp.	Milfoil
Sagittaria kurziana	Strap-leaf sag
Sagittaria sp.	Sagittaria
Utricularia spp.	Bladderwort
Vallisneria americana	Eelgrass/tapegrass
Ludwigia repens	Red ludwigia
Bacopa caroliniana	Lemon bacopa
Zizania aquatic	Wild rice
Scirpus validus	Soft-stem bulrush
Rhynchospora colorata	Star rush
Hydrocotyle sp.	Water pennywort
Panicum spp.	Panic grasses / maidencane
Polygonum sp.	Smartweed
Chara sp.	Muskgrass
Lyngbia spp.	Blue-green algae
Unknown spp.	Filamentous algae

Table 9. Mean percent coverage of major aquatic plant taxa observed along the Rainbow River, Dunnellon, Florida, based on Spring 2011 transects.

Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	61.0	15.4	0.0	0.0	0.0	0.2	0.0	0.0	23.3	0.0	0.0	0.0
2	56.9	6.3	0.0	0.0	0.0	0.0	1.7	23.7	11.0	0.6	0.0	0.0
3	23.2	5.7	0.3	0.0	1.2	2.9	10.4	19.2	34.1	2.1	0.0	1.1
4	16.1	7.4	0.2	0.2	0.8	1.1	1.8	27.8	23.0	8.8	10.6	2.2
5	31.3	3.7	0.3	0.0	3.6	1.6	4.2	15.4	0.0	19.5	15.8	4.6
5.1	46.7	7.3	0.0	0.1	0.2	7.7	0.0	33.1	0.0	1.1	0.2	3.6
5.2	62.0	4.0	0.2	0.8	2.0	7.6	3.4	18.1	0.0	0.2	0.0	1.7
6	55.0	5.0	0.2	0.0	0.4	3.8	0.0	35.7	0.0	0.0	0.0	0.0
7	56.3	4.1	3.3	0.0	2.7	5.8	0.8	27.2	0.0	0.0	0.0	0.0
8	35.3	2.8	0.7	2.4	1.8	3.6	13.9	39.5	0.0	0.0	0.0	0.1
9	14.9	12.9	1.1	1.1	4.5	16.0	10.1	39.4	0.0	0.0	0.0	0.0
10	2.9	11.4	2.8	0.1	12.4	2.8	3.3	64.2	0.0	0.0	0.0	0.1
11	13.8	1.7	0.9	0.0	0.4	9.4	0.0	73.8	0.0	0.0	0.0	0.0
12	12.5	9.5	0.1	0.0	3.9	9.8	0.0	64.2	0.0	0.0	0.0	0.0
13	2.5	10.5	0.0	0.8	5.0	6.4	24.6	50.1	0.0	0.0	0.0	0.1
14	10.0	9.2	0.0	0.0	0.6	17.3	0.0	62.9	0.0	0.0	0.0	0.0
15	4.5	8.3	0.0	0.5	10.3	20.1	0.8	55.5	0.0	0.0	0.0	0.0
16	13.8	20.4	0.0	7.0	10.3	10.4	6.1	32.1	0.0	0.0	0.0	0.0
17	16.6	8.7	0.0	0.1	6.1	12.6	0.0	55.9	0.0	0.0	0.0	0.0
17.1	20.7	12.6	7.4	1.2	0.0	8.2	21.1	28.9	0.0	0.0	0.0	0.0
17.2	19.7	20.0	3.3	2.3	3.5	5.2	0.0	45.9	0.0	0.0	0.0	0.0
17.3	31.1	27.6	3.6	0.1	2.4	5.2	6.5	23.4	0.0	0.0	0.0	0.0
17.4	25.7	9.1	1.0	0.0	1.8	6.1	0.4	56.0	0.0	0.0	0.0	0.0
18	35.1	19.7	4.4	0.0	0.1	3.1	0.0	37.5	0.0	0.0	0.0	0.0
19	32.9	46.8	5.3	1.0	2.1	0.7	1.9	9.4	0.0	0.0	0.0	0.0
20	12.4	73.1	8.9	0.8	0.0	0.7	0.0	4.0	0.0	0.0	0.0	0.0

Table 10. Mean percent coverage of major aquatic plant taxa observed along the Rainbow River, Dunnellon, Florida, based on Fall 2011 transects.

Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	66.7	14.2	0.0	0.0	0.0	0.4	0.4	0.0	18.3	0.0	0.0	0.0
2	41.5	15.0	0.0	0.0	0.8	0.0	2.9	25.8	10.3	1.6	0.5	1.6
3	13.8	14.1	0.0	1.5	2.9	0.9	15.9	16.2	25.9	6.2	0.0	2.6
4	10.9	11.7	0.0	0.5	1.3	1.7	5.6	22.1	20.6	7.3	9.6	8.8
5	27.8	4.1	0.4	0.0	3.2	1.0	2.4	21.0	0.0	18.8	17.0	4.2
5.1	23.6	10.8	0.0	0.2	1.4	8.7	1.7	49.0	0.0	0.9	1.5	2.2
5.2	52.4	9.7	0.2	1.9	3.0	4.9	0.7	26.5	0.0	0.0	0.0	0.8
6	46.1	3.3	0.4	0.3	0.8	10.8	10.0	28.2	0.0	0.0	0.0	0.0
7	58.4	3.9	0.0	1.8	1.2	2.1	2.4	30.1	0.0	0.0	0.0	0.0
8	32.4	3.4	0.0	2.8	1.2	3.5	13.6	43.3	0.0	0.0	0.0	0.0
9	19.8	1.6	0.1	1.8	7.9	16.6	13.7	38.6	0.0	0.0	0.0	0.0
10	16.7	4.7	6.5	0.0	10.5	3.1	0.7	58.0	0.0	0.0	0.0	0.0
11	13.3	2.8	1.7	0.1	6.1	10.5	0.0	65.2	0.0	0.0	0.0	0.4
12	7.4	9.9	0.1	0.1	2.6	16.9	0.0	63.0	0.0	0.0	0.0	0.0
13	3.2	18.3	0.0	2.0	6.4	11.1	22.0	37.0	0.0	0.0	0.0	0.2
14	9.4	10.4	0.0	0.6	0.4	16.2	0.0	63.1	0.0	0.0	0.0	0.0
15	7.5	25.4	0.0	1.6	9.1	12.6	3.8	39.5	0.0	0.0	0.0	0.5
16	8.3	31.5	0.0	4.8	9.1	19.5	9.6	17.3	0.0	0.0	0.0	0.0
17	26.2	6.3	0.0	0.0	7.7	17.4	0.0	42.4	0.0	0.0	0.0	0.0
17.1	18.4	17.9	3.2	0.0	4.7	6.8	17.9	31.1	0.0	0.0	0.0	0.0
17.2	10.1	26.8	4.0	1.0	2.9	5.1	0.0	50.1	0.0	0.0	0.0	0.0
17.3	30.7	20.8	2.4	0.0	1.8	5.8	9.8	28.7	0.0	0.0	0.0	0.0
17.4	26.5	15.7	0.6	0.0	2.9	9.5	0.4	44.4	0.0	0.0	0.0	0.0
18	33.0	8.0	5.8	0.0	2.3	4.2	0.0	46.2	0.0	0.3	0.0	0.2
19	38.6	40.3	5.0	0.3	0.6	2.9	6.2	6.1	0.0	0.0	0.0	0.0
20	13.1	66.1	6.8	10.3	1.0	0.4	1.9	0.4	0.0	0.0	0.0	0.0

Table 11. Mean percent coverage of major aquatic plant taxa observed along the Rainbow River, Dunnellon, Florida, based on Spring 2012 transects.												
Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	27.1	58.7	0.0	0.0	0.0	0.4	0.0	0.0	13.8	0.0	0.0	0.0
2	30.0	25.8	0.0	0.0	0.8	0.0	1.6	28.7	10.3	2.1	0.4	0.4
3	28.2	15.3	0.0	1.2	3.2	2.1	8.1	13.2	24.7	2.6	0.0	1.3
4	12.1	14.4	0.0	0.0	1.0	1.5	2.7	12.5	38.5	2.6	11.8	2.9
5	26.2	6.1	0.2	0.0	3.3	1.3	3.6	12.9	0.0	17.1	27.2	2.3
5.1	32.7	8.6	0.2	0.1	3.6	17.2	0.8	31.1	0.0	1.4	1.8	2.6
5.2	57.8	10.7	0.3	1.7	5.2	11.0	1.2	11.3	0.0	0.0	0.0	0.9
6	57.3	6.6	0.5	0.3	0.1	6.3	0.9	27.9	0.0	0.0	0.0	0.0
7	51.5	8.1	0.0	3.2	1.0	3.2	1.4	31.0	0.0	0.0	0.0	0.7
8	38.5	6.8	0.0	4.5	0.8	1.9	6.5	41.0	0.0	0.0	0.0	0.0
9	12.6	10.7	0.2	0.5	9.7	9.5	18.4	38.4	0.0	0.0	0.0	0.0
10	8.4	17.3	8.9	1.8	8.4	6.4	0.0	48.9	0.0	0.0	0.0	0.0
11	15.4	6.3	1.8	0.0	4.8	8.2	0.0	62.4	0.0	0.0	0.0	1.1
12	11.3	15.3	0.2	0.0	3.0	11.3	0.1	58.8	0.0	0.0	0.0	0.1
13	15.9	15.9	0.0	1.7	4.8	7.0	15.8	38.9	0.0	0.0	0.0	0.1
14	8.8	23.3	0.0	0.4	0.4	4.2	0.0	62.9	0.0	0.0	0.0	0.0
15	6.8	19.5	0.0	1.0	11.5	11.3	0.8	49.3	0.0	0.0	0.0	0.0
16	15.8	20.8	0.0	2.0	8.9	18.4	11.1	23.1	0.0	0.0	0.0	0.0
17	17.0	13.8	0.2	0.0	5.1	13.9	0.0	50.0	0.0	0.0	0.0	0.0
17.1	13.3	36.7	2.4	0.0	1.4	3.8	15.3	27.2	0.0	0.0	0.0	0.0
17.2	20.4	30.5	1.8	0.2	0.5	1.2	0.0	45.2	0.0	0.0	0.0	0.0
17.3	22.7	30.0	1.8	0.5	2.6	5.8	11.1	25.5	0.0	0.0	0.0	0.0
17.4	29.2	15.9	1.2	0.0	0.9	4.9	0.2	47.7	0.0	0.0	0.0	0.0
18	19.6	17.7	11.3	0.0	1.2	1.5	0.0	48.4	0.0	0.3	0.0	0.3
19	35.1	26.7	7.1	0.0	1.2	4.3	7.4	18.3	0.0	0.0	0.0	0.0
20	21.7	74.4	1.1	1.4	0.0	0.5	0.7	0.3	0.0	0.0	0.0	0.0

Table 12. Percent occurrence (percent of 2-m grids having plant present) of major aquatic plants observed along the Rainbow River, Dunnellon, Florida, based on Spring 2011 transects.

Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	83.3	75.0	0.0	0.0	0.0	8.3	0.0	0.0	58.3	0.0	0.0	0.0
2	94.4	44.4	0.0	0.0	0.0	0.0	33.3	88.9	55.6	5.6	0.0	0.0
3	47.4	47.4	5.3	0.0	15.8	42.1	36.8	100.0	63.2	31.6	0.0	21.1
4	36.0	12.0	8.0	8.0	20.0	20.0	28.0	80.0	56.0	60.0	48.0	24.0
5	64.3	39.3	7.1	0.0	28.6	17.9	57.1	96.4	0.0	57.1	71.4	42.9
5.1	90.6	43.8	0.0	3.1	6.3	56.3	0.0	87.5	0.0	21.9	3.1	40.6
5.2	88.5	26.9	3.8	19.2	19.2	53.8	15.4	42.3	0.0	3.8	0.0	30.8
6	78.6	42.9	7.1	0.0	14.3	35.7	0.0	71.4	0.0	0.0	0.0	0.0
7	81.3	37.5	31.3	0.0	37.5	62.5	18.8	75.0	0.0	0.0	0.0	0.0
8	67.6	48.6	16.2	29.7	29.7	43.2	62.2	62.2	0.0	0.0	0.0	2.7
9	53.6	67.9	10.7	10.7	35.7	92.9	60.7	92.9	0.0	0.0	0.0	0.0
10	33.3	83.3	16.7	4.2	62.5	54.2	33.3	91.7	0.0	0.0	0.0	4.2
11	91.7	8.3	20.8	0.0	12.5	25.0	0.0	100.0	0.0	0.0	0.0	0.0
12	48.6	68.6	2.9	0.0	42.9	42.9	0.0	82.9	0.0	0.0	0.0	0.0
13	33.3	66.7	0.0	25.0	45.8	75.0	33.3	79.2	0.0	0.0	0.0	4.2
14	69.2	30.8	0.0	0.0	15.4	100.0	0.0	100.0	0.0	0.0	0.0	0.0
15	21.1	78.9	0.0	10.5	31.6	84.2	21.1	89.5	0.0	0.0	0.0	0.0
16	35.0	75.0	0.0	15.0	55.0	90.0	45.0	60.0	0.0	0.0	0.0	0.0
17	87.0	43.5	0.0	4.3	30.4	82.6	0.0	87.0	0.0	0.0	0.0	0.0
17.1	63.2	42.1	47.4	15.8	0.0	57.9	63.2	78.9	0.0	0.0	0.0	0.0
17.2	66.7	62.5	41.7	29.2	37.5	75.0	0.0	87.5	0.0	0.0	0.0	0.0
17.3	90.9	68.2	22.7	4.5	40.9	72.7	27.3	77.3	0.0	0.0	0.0	0.0
17.4	59.3	77.8	22.2	0.0	22.2	48.1	3.7	74.1	0.0	0.0	0.0	0.0
18	100.0	76.5	35.3	0.0	5.9	41.2	0.0	76.5	0.0	0.0	0.0	0.0
19	77.8	88.9	22.2	11.1	22.2	33.3	44.4	66.7	0.0	0.0	0.0	0.0
20	55.6	94.4	55.6	16.7	0.0	22.2	0.0	22.2	0.0	0.0	0.0	0.0

Table 13. Percent occurrence (percent of 2-m grids having plant present) of major aquatic plants observed along the Rainbow River, Dunnellon, Florida, based on Fall 2011 transects.

Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	83.3	58.3	0.0	0.0	0.0	8.3	8.3	0.0	66.7	0.0	0.0	0.0
2	84.2	89.5	0.0	0.0	15.8	0.0	52.6	78.9	42.1	31.6	10.5	21.1
3	52.9	82.4	0.0	29.4	23.5	17.6	52.9	88.2	76.5	47.1	0.0	29.4
4	45.8	79.2	0.0	12.5	20.8	16.7	54.2	95.8	66.7	62.5	54.2	37.5
5	59.3	44.4	7.4	0.0	37.0	22.2	40.7	96.3	0.0	59.3	77.8	44.4
5.1	68.8	71.9	0.0	3.1	25.0	37.5	28.1	84.4	0.0	21.9	25.0	37.5
5.2	80.8	53.8	15.4	23.1	19.2	57.7	11.5	61.5	0.0	0.0	0.0	19.2
6	73.3	33.3	33.3	6.7	13.3	66.7	20.0	73.3	0.0	0.0	0.0	0.0
7	72.2	33.3	0.0	38.9	22.2	50.0	38.9	61.1	0.0	0.0	0.0	0.0
8	60.5	47.4	0.0	34.2	23.7	52.6	71.1	60.5	0.0	0.0	0.0	0.0
9	85.7	21.4	3.6	10.7	64.3	89.3	53.6	89.3	0.0	0.0	0.0	0.0
10	63.6	54.5	31.8	0.0	59.1	45.5	13.6	95.5	0.0	0.0	0.0	0.0
11	85.2	25.9	18.5	3.7	14.8	37.0	0.0	88.9	0.0	0.0	0.0	7.4
12	35.9	76.9	2.6	2.6	15.4	43.6	0.0	82.1	0.0	0.0	0.0	0.0
13	30.4	95.7	0.0	26.1	47.8	65.2	30.4	73.9	0.0	0.0	0.0	8.7
14	76.9	46.2	0.0	15.4	7.7	100.0	0.0	100.0	0.0	0.0	0.0	0.0
15	35.0	95.0	0.0	25.0	65.0	45.0	80.0	85.0	0.0	0.0	0.0	10.0
16	35.0	80.0	0.0	35.0	65.0	100.0	80.0	65.0	0.0	0.0	0.0	0.0
17	87.0	47.8	0.0	0.0	43.5	95.7	0.0	82.6	0.0	0.0	0.0	0.0
17.1	52.6	84.2	36.8	0.0	31.6	52.6	57.9	78.9	0.0	0.0	0.0	0.0
17.2	44.0	96.0	28.0	8.0	28.0	44.0	0.0	92.0	0.0	0.0	0.0	0.0
17.3	76.2	81.0	19.0	0.0	42.9	52.4	28.6	76.2	0.0	0.0	0.0	0.0
17.4	92.6	96.3	11.1	0.0	22.2	51.9	3.7	70.4	0.0	0.0	0.0	0.0
18	86.7	73.3	46.7	0.0	26.7	46.7	0.0	73.3	0.0	6.7	0.0	6.7
19	100.0	100.0	50.0	5.6	16.7	66.7	22.2	44.4	0.0	0.0	0.0	0.0
20	66.7	100.0	44.4	38.9	11.1	16.7	22.2	16.7	0.0	0.0	0.0	0.0

Table 14. Percent occurrence (percent of 2-m grids having plant present) of major aquatic plants observed along the Rainbow River, Dunnellon, Florida, based on Spring 2012 transects.

Transect Number	Bare Substrate	Filamentous Algae	Chara sp.	Ceratophyllum demersum	Najas guadalupensis	Hydrilla verticillata	Vallisneria americana	Sagittaria kurziana	Potamogeton illinoensis	Utricularia spp.	Fontinalis sp.	Other
1	83.3	100.0	0.0	0.0	0.0	8.3	0.0	0.0	66.7	0.0	0.0	0.0
2	89.5	94.7	0.0	0.0	10.5	0.0	26.3	89.5	42.1	31.6	10.5	10.5
3	64.7	94.1	0.0	17.6	17.6	23.5	47.1	76.5	70.6	23.5	0.0	17.6
4	72.0	88.0	4.0	4.0	20.0	20.0	32.0	68.0	80.0	48.0	64.0	20.0
5	69.0	62.1	10.3	3.4	41.4	24.1	69.0	86.2	3.4	58.6	82.8	34.5
5.1	70.6	70.6	8.8	5.9	35.3	55.9	14.7	82.4	2.9	20.6	29.4	29.4
5.2	80.8	57.7	11.5	19.2	30.8	46.2	15.4	57.7	0.0	0.0	0.0	19.2
6	70.6	47.1	23.5	5.9	5.9	64.7	17.6	70.6	0.0	0.0	0.0	0.0
7	72.2	50.0	0.0	44.4	22.2	33.3	27.8	66.7	0.0	0.0	0.0	16.7
8	65.8	57.9	0.0	28.9	26.3	31.6	57.9	63.2	0.0	0.0	0.0	0.0
9	62.1	86.2	3.4	10.3	51.7	75.9	75.9	72.4	0.0	0.0	0.0	0.0
10	59.1	95.5	27.3	22.7	31.8	36.4	0.0	95.5	0.0	0.0	0.0	0.0
11	88.9	18.5	25.9	0.0	18.5	40.7	0.0	85.2	0.0	0.0	0.0	14.8
12	55.0	75.0	7.5	0.0	17.5	40.0	2.5	82.5	0.0	0.0	0.0	2.5
13	52.2	82.6	0.0	17.4	39.1	52.2	43.5	69.6	0.0	0.0	0.0	4.3
14	58.3	100.0	0.0	8.3	8.3	75.0	0.0	100.0	0.0	0.0	0.0	0.0
15	55.0	90.0	0.0	15.0	35.0	55.0	15.0	95.0	0.0	0.0	0.0	0.0
16	25.0	90.0	0.0	35.0	55.0	90.0	55.0	60.0	0.0	0.0	0.0	0.0
17	90.9	90.9	4.5	0.0	18.2	81.8	0.0	90.9	0.0	0.0	0.0	0.0
17.1	55.6	100.0	33.3	0.0	27.8	38.9	77.8	77.8	0.0	0.0	0.0	0.0
17.2	56.5	91.3	26.1	4.3	17.4	21.7	0.0	91.3	0.0	0.0	0.0	0.0
17.3	68.2	72.7	22.7	9.1	27.3	45.5	54.5	86.4	0.0	0.0	0.0	0.0
17.4	63.0	96.3	14.8	0.0	18.5	37.0	3.7	74.1	0.0	0.0	0.0	0.0
18	62.5	93.8	62.5	0.0	31.3	31.3	0.0	68.8	0.0	6.3	0.0	6.3
19	68.4	94.7	47.4	0.0	21.1	42.1	36.8	52.6	0.0	0.0	0.0	0.0
20	61.1	100.0	22.2	16.7	0.0	27.8	16.7	11.1	0.0	0.0	0.0	0.0

Task 3 - Human activity and water quality relationships

Tubing, boating, kayaking, and canoeing were the principal activities recorded over all 10 sampling days (28 May 2011 – 18 February 2012). These four activities encompassed over 95 percent of total upstream recreational activity on the river during the sampling periods. The total number of all recreational users recorded upstream from the sampling sites during any one sampling day ranged from 80 on 15 February 2012 to 3,347 on 2-3 July 2011 (see Figures 12 – 17 of daily use in Task 4, pages 76 - 81).

Dissolved oxygen concentrations ranged throughout the study from a low of 4.55 mg/L to a high of 10.2 mg/L, with a mean of 6.75 mg/L (Table 15). Concentrations increased throughout each of the 10 sampling days, with highest values being recorded in midafternoon (3 to 4:30 pm). Highest readings were always recorded at this time at the western Net (#1), immediately downstream of the KP Hole County Park. Lowest readings were always recorded prior to the presence of recreational users and throughout the night during the diurnal samples, negating the belief that recreational use has a negative effect on dissolved oxygen concentrations in the river as a result of stirring up bottom sediments. In the 1994-1995 study of the Rainbow River (Holland and Cichra 1995), the highest dissolved oxygen levels occurred between noon and 2:00 p.m. This time period, incidentally, was also the time period of highest recreational use. As a result, dissolved oxygen levels were significantly and positively correlated with recreational activity over all time periods and user groups. Recreational activity, although positively associated with dissolved oxygen concentrations, would not cause a detectable increase in dissolved oxygen concentrations in such a large volume of water with such a high flushing rate. It is common knowledge that, in aquatic systems, dissolved oxygen concentrations increase throughout the day due to photosynthetic activity of the aquatic plants. The diurnal samples, collected during this study and during 1994-1995 study, clearly show the diurnal change that occurs in dissolved oxygen in the Rainbow River (Table 15).

River water temperatures ranged from a low of 22.6 C to a high of 25.3 C, with an overall mean of 23.5 C during the study (Table 15). As with dissolved oxygen, water temperatures likewise fluctuated throughout each sampling day, being lowest in the morning and highest in the late afternoon. One would not expect water temperature in such a large fast-flowing river to be affected by recreational use, but rather by solar heating of the water during the day and cooling at night due to loss of heat to the atmosphere. The diurnal samples clearly show the day-night fluctuation in water temperatures.

Water clarity, measured using the horizontal Secchi technique, ranged from a low of 39 feet (11.9 m) to a high of 84 feet (25.6 m), with an overall mean of 63.5 feet (19.4 m) (Table 15). The relationship between the change in water clarity and recreational use is unclear. On four of the sampling days (22 June, 3 July, and 12 July 2011 and 18 February 2012), water clarity diminished during the day as recreational use increased. This is the relationship that would be expected if recreational users were indeed stirring up the bottom sediments or disturbing the submersed aquatic vegetation, releasing periphyton (attached algae) into the water column from the plants, resulting in reduced water clarity. Contrary to this decrease in water clarity, on five of the sampling days (19 July, 24 August, and 4 September 2011, and 6 February and 15 February 2012), water clarity actually increased as recreational use increased. This indicates that recreational users are not having a negative effect on water clarity. One factor that is uncontrollable which can influence the water clarity readings is the availability of sunlight. Increased sunlight can lead to increased water clarity readings. Highest readings were often recorded at midday when the sun was at its highest point in the sky, regardless of the number of recreational users upstream from the sampling sites. Field notes also indicate that occasional reduced readings were recorded as cloud cover increased.

The change in total suspended solids (difference between late morning and afternoon concentrations from the early morning concentrations) was significantly and positively correlated ($r = 0.266$, $p = 0.040$ and $r = 0.390$, $p = 0.002$) to the number of motorized boats upstream from the sampling sites during the prior 15 and 30 minutes, respectively (Table 16). Change in total suspended solids was not found to be significantly correlated to the abundance of any other user group (tubers, canoes, kayaks, or paddlers [canoes + kayaks]) observed upstream of the sampling sites during the prior 15 and 30 minutes (Table 16). Figures 8 to 10 visually show the data for change in total, inorganic, and organic suspended solids concentrations versus numbers of tubers, motorized boats, and paddlers observed upstream from the sampling sites during the prior 30-minute period. The change in inorganic suspended solids (difference between late morning and afternoon concentrations from the early morning concentrations) was significantly and positively correlated ($r = 0.465$, $p < 0.001$ and $r = 0.562$, $p < 0.001$) to the number of motorized boats upstream from the sampling sites during the prior 15 and 30 minutes, respectively , and significantly and positively correlated to the number of canoes and paddlers upstream from the sampling sites during the prior 30 minutes ($r = 0.322$, $p = 0.012$ and $r = 0.263$, $p = 0.043$, respectively) (Table 16). The change in inorganic suspended solids was not found to be significantly correlated to any other user group or time period examined. The change in organic suspended solids was not found to be significantly correlated to any user group or time period examined (Table 16).

Based on these analyses of the suspended solids data, it appears that motorized boats have the greatest effect (highest and most significant correlation coefficients). This finding is substantiated as several of the boats, observed travelling through the study area, disturbed large quantities of bottom sediments with their propeller wash. Although these relationships were statistically significant (Ho: $R = 0$), the relationships were not particularly strong, as motorized boats upstream of the sampling sites during the prior 15 and 30 minutes, accounted for only 7 to 15 percent of the change in total suspended solids, and 22 to 32 percent of the change in inorganic suspended solids, respectively. Sediments, disturbed by motorized boats, were observed to quickly settle from the water column.

It is interesting to note that although recreational use increased during the day, the organic suspended solids did not increase (change). Research indicates that in some streams a pulse of phytoplankton can occur, typically between 10:00 a.m. and 3:00 p.m. (Blum 1954; Gustavsson et al. 1978). This peak is caused by the production of oxygen during photosynthesis as a result of the greater availability of light during midday hours. Oxygen bubbles formed within algae cells increase the buoyancy of the algae, therefore making them more susceptible to removal by water currents. Blum (1954) and Gustavsson et al. (1978) both attributed a peak in the abundance of benthic diatoms to a peak midday production of oxygen. On the Rainbow River, the detachment and rise of large mats of benthic algae (Lyngbya spp.) were observed during the afternoon in the 1994-1995 study, but was not apparent in this current study. This may explain why a midday pulse in stream algae would explain why the changes in organic suspended solids were correlated with recreation in 1994-1995, and possibly why we did not see an increase in 2011-2012. Odum (1957) attributes a diurnal pulse in chlorophyll in Silver Springs, Florida to boats as well as natural causes.

Table 15. Dissolved oxygen (mg/L), water temperature (C), and water clarity (as measured by Secchi disk in feet) at each net (1 = West; 2 = Middle; and 3 = East) located downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, in 2011 and 2012.

Date	Net	Time	DO (mg / L)	Temp (C)	Secchi (Feet)
28-May-11	1	9:25	5.83	23.2	.
28-May-11	2	9:28	.	.	.
28-May-11	3	9:31	.	.	.
28-May-11	1	12:35	7.35	24.3	39
28-May-11	2	.	.	.	.
28-May-11	3	.	.	.	.
28-May-11	1	16:35	8.59	25.3	39
28-May-11	2	.	.	.	.
28-May-11	3	.	.	.	.
22-Jun-11	1	10:32	.	.	58
22-Jun-11	2	10:23	.	.	58
22-Jun-11	3	10:13	.	.	61
22-Jun-11	1	13:07	.	.	56
22-Jun-11	2	13:13	.	.	58
22-Jun-11	3	13:27	.	.	59
22-Jun-11	1	15:14	.	.	55
22-Jun-11	2	15:10	.	.	53
22-Jun-11	3	15:02	.	.	57
22-Jun-11	1	16:58	.	.	54
22-Jun-11	2	.	.	.	49
22-Jun-11	3	.	.	.	56
2-Jul-11	1	19:28	7.64	24.3	48
2-Jul-11	2	19:15	7.64	24.5	52
2-Jul-11	3	18:58	7.70	24.5	52
2-Jul-11	1	10:00	6.61	.	.
2-Jul-11	2	10:05	6.43	.	.
2-Jul-11	3	10:12	6.30	.	.
3-Jul-11	1	0:02	5.90	.	.
3-Jul-11	2	0:08	5.60	.	.
3-Jul-11	3	0:14	5.50	.	.
3-Jul-11	1	2:01	5.28	.	.
3-Jul-11	2	2:08	5.10	.	.
3-Jul-11	3	2:12	5.97	.	.
3-Jul-11	1	4:02	4.62	22.9	.
3-Jul-11	2	4:06	4.61	22.9	.
3-Jul-11	3	4:10	4.55	22.9	.
3-Jul-11	1	6:06	5.00	22.8	.

Date	Net	Time	DO (mg / L)	Temp (C)	Secchi (Feet)
3-Jul-11	2	6:10	4.90	22.8	.
3-Jul-11	3	6:14	4.77	22.8	.
3-Jul-11	1	8:38	5.16	22.9	58
3-Jul-11	2	8:42	4.91	23.0	65
3-Jul-11	3	8:46	5.05	22.9	61
3-Jul-11	1	11:05	6.60	23.5	59
3-Jul-11	2	11:10	6.63	23.6	60
3-Jul-11	3	11:18	6.57	23.7	62
3-Jul-11	1	12:44	7.40	24.4	56
3-Jul-11	2	12:38	7.25	24.0	53
3-Jul-11	3	12:23	7.35	23.7	57
3-Jul-11	1	14:13	8.13	24.4	55
3-Jul-11	2	14:26	8.02	24.4	53
3-Jul-11	3	14:28	8.13	24.4	48
3-Jul-11	1	16:37	8.58	24.8	49
3-Jul-11	2	16:25	8.49	24.6	51
3-Jul-11	3	16:19	8.80	24.7	52
3-Jul-11	1	18:30	8.25	25.1	48
3-Jul-11	2	18:33	7.84	24.7	46
3-Jul-11	3	18:41	7.87	24.6	48
12-Jul-11	1	9:19	5.48	23.3	66
12-Jul-11	2	9:13	5.49	23.2	64
12-Jul-11	3	9:08	5.29	23.1	69
12-Jul-11	1	12:10	7.15	24.1	64
12-Jul-11	2	12:21	6.88	23.9	63
12-Jul-11	3	12:27	6.86	23.9	66
12-Jul-11	1	14:14	7.22	24.0	54
12-Jul-11	2	14:10	7.30	24.0	54
12-Jul-11	3	13:53	7.22	24.1	58
12-Jul-11	1	16:44	8.28	24.5	55
12-Jul-11	2	16:38	8.09	24.5	58
12-Jul-11	3	16:30	8.09	24.8	56
19-Jul-11	1	8:55	5.29	22.9	59
19-Jul-11	2	9:03	5.32	23.0	62
19-Jul-11	3	9:10	5.30	22.8	64
19-Jul-11	1	12:14	7.20	23.8	69
19-Jul-11	2	12:09	6.99	23.9	66
19-Jul-11	3	12:01	6.82	23.6	69
19-Jul-11	1	14:01	8.09	24.3	65
19-Jul-11	2	14:07	7.93	24.3	73
19-Jul-11	3	14:13	8.07	24.4	67
19-Jul-11	1	15:46	8.41	24.5	59

Date	Net	Time	DO (mg / L)	Temp (C)	Secchi (Feet)
19-Jul-11	2	15:55	8.24	24.5	72
19-Jul-11	3	16:05	8.33	24.6	70
24-Aug-11	1	9:14	5.73	23.1	60
24-Aug-11	2	9:05	8.85	23.1	61
24-Aug-11	3	8:52	5.20	23.0	59
24-Aug-11	1	10:35	6.77	23.4	70
24-Aug-11	2	10:46	6.48	23.4	76
24-Aug-11	3	10:50	6.36	23.4	80
24-Aug-11	1	12:27	7.97	24.0	70
24-Aug-11	2	12:23	7.79	23.9	69
24-Aug-11	3	12:37	7.70	23.9	84
24-Aug-11	1	14:25	9.01	24.5	61
24-Aug-11	2	14:38	8.78	24.4	72
24-Aug-11	3	14:45	8.80	24.5	75
3-Sep-11	1	19:30	8.20	24.0	.
3-Sep-11	2	19:39	7.72	24.0	.
3-Sep-11	3	19:42	7.68	24.0	.
3-Sep-11	1	21:06	7.08	23.8	.
3-Sep-11	2	21:09	6.94	23.7	.
3-Sep-11	3	21:12	6.75	23.7	.
3-Sep-11	1	23:00	6.12	23.4	.
3-Sep-11	2	23:03	6.00	23.4	.
3-Sep-11	3	23:05	5.92	23.4	.
4-Sep-11	1	1:04	5.22	23.2	.
4-Sep-11	2	1:02	5.30	23.2	.
4-Sep-11	3	0:58	5.43	23.2	.
4-Sep-11	1	3:02	4.86	23.1	.
4-Sep-11	2	3:01	4.95	23.0	.
4-Sep-11	3	2:59	5.00	23.0	.
4-Sep-11	1	5:08	4.76	23.0	.
4-Sep-11	2	5:05	4.80	23.0	.
4-Sep-11	3	5:01	4.93	23.0	.
4-Sep-11	1	7:07	4.72	23.0	.
4-Sep-11	2	7:04	4.79	23.0	.
4-Sep-11	3	7:01	4.87	23.0	.
4-Sep-11	1	10:25	5.55	23.1	63
4-Sep-11	2	10:23	5.47	23.1	62
4-Sep-11	3	10:21	5.53	23.1	62
4-Sep-11	1	13:10	6.92	23.4	56
4-Sep-11	2	13:27	6.83	23.4	62
4-Sep-11	3	13:31	6.97	23.4	63
4-Sep-11	1	16:19	7.85	23.8	65

Date	Net	Time	DO (mg / L)	Temp (C)	Secchi (Feet)
4-Sep-11	2	16:23	7.77	23.7	67
4-Sep-11	3	16:34	7.75	23.7	64
4-Sep-11	1	18:08	7.86	23.7	63
4-Sep-11	2	18:03	7.71	23.7	65
4-Sep-11	3	18:01	7.81	24.1	62
6-Feb-12	1	8:45	6.70	22.6	72
6-Feb-12	2	8:45	6.80	22.6	71
6-Feb-12	3	8:45	6.80	22.6	74
6-Feb-12	1	10:40	8.10	22.7	71
6-Feb-12	2	10:50	7.90	22.8	79
6-Feb-12	3	10:55	8.00	22.8	75
6-Feb-12	1	12:43	9.70	23.2	78
6-Feb-12	2	12:46	9.40	23.2	77
6-Feb-12	3	12:50	9.50	23.1	79
6-Feb-12	1	15:08	10.20	23.5	54
6-Feb-12	2	15:04	10.00	23.5	60
6-Feb-12	3	15:00	10.10	23.5	60
15-Feb-12	1	8:47	4.60	22.7	77
15-Feb-12	2	8:49	4.64	22.7	80
15-Feb-12	3	8:53	4.64	22.7	77
15-Feb-12	1	11:19	6.00	23.0	81
15-Feb-12	2	11:22	5.93	23.0	83
15-Feb-12	3	11:25	5.93	23.0	82
15-Feb-12	1	13:19	7.07	23.4	73
15-Feb-12	2	13:13	6.90	23.3	75
15-Feb-12	3	13:10	7.13	23.4	75
15-Feb-12	1	15:40	7.55	23.7	69
15-Feb-12	2	15:46	7.39	23.7	76
15-Feb-12	3	15:50	7.40	23.7	78
18-Feb-12	1	9:21	4.66	22.8	69
18-Feb-12	2	9:18	4.71	22.8	69
18-Feb-12	3	9:05	4.83	22.8	70
18-Feb-12	1	11:08	5.54	23.0	64
18-Feb-12	2	11:04	5.47	23.0	67
18-Feb-12	3	11:00	5.56	23.0	70
18-Feb-12	1	13:19	6.77	23.4	59
18-Feb-12	2	13:14	6.63	23.4	60
18-Feb-12	3	13:10	6.69	23.4	72
18-Feb-12	1	15:16	7.09	23.5	63
18-Feb-12	2	15:13	7.03	23.5	61
18-Feb-12	3	15:10	7.03	23.5	64

Table 16. Pearson correlation coefficients and P > |r| for the change in total (TSS Diff), inorganic (ISS Diff), and organic (OSS Diff) suspended solids versus the number of tubers, motorized boats, canoes, kayaks, and paddlers (canoes + kayaks) observed upstream during the prior 15 and 30 minutes on the Rainbow River, Dunnellon, Florida during 10 sampling days in 2011 and 2012 (N = 60 for each comparison). Values in bold are significant at the p = 0.05 level.

	TSS Diff	ISS Diff	OSS Diff
Tubers15	-0.11304	0.01979	-0.21294
	0.3898	0.8807	0.1024
Boat15	**0.26575**	**0.46477**	-0.09790
	0.0401	0.0002	0.4568
Canoe15	-0.02755	0.01329	-0.06664
	0.8345	0.9197	0.6129
Kayak15	0.12083	0.10392	0.07749
	0.3578	0.4294	0.5562
Paddle15	0.08565	0.08890	0.03475
	0.5152	0.4994	0.7921
Tubers30	-0.13279	-0.00506	-0.21437
	0.3118	0.9694	0.1000
Boat30	**0.38994**	**0.56162**	-0.00004
	0.0021	<0.0001	0.9998
Canoe30	0.21530	**0.32242**	-0.01992
	0.0985	0.0120	0.8799
Kayak30	0.06365	0.18511	-0.11037
	0.6290	0.1568	0.4012
Paddle30	0.13022	**0.26267**	-0.09079
	0.3214	0.0426	0.4902

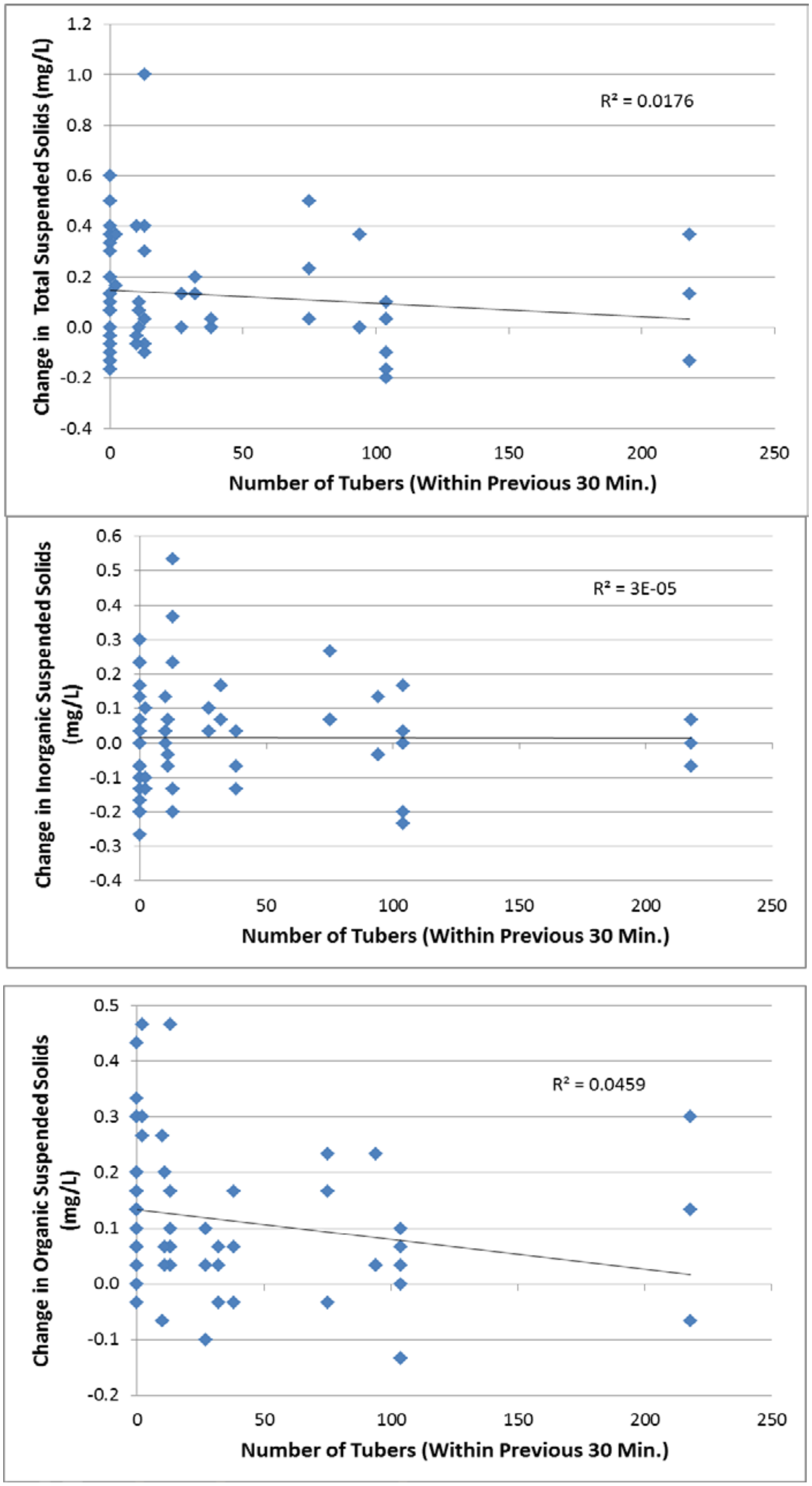


Figure 8. Change in total, inorganic, and organic suspended solids (mg/L) versus number of tubers during the prior 30 minutes of sampling below the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

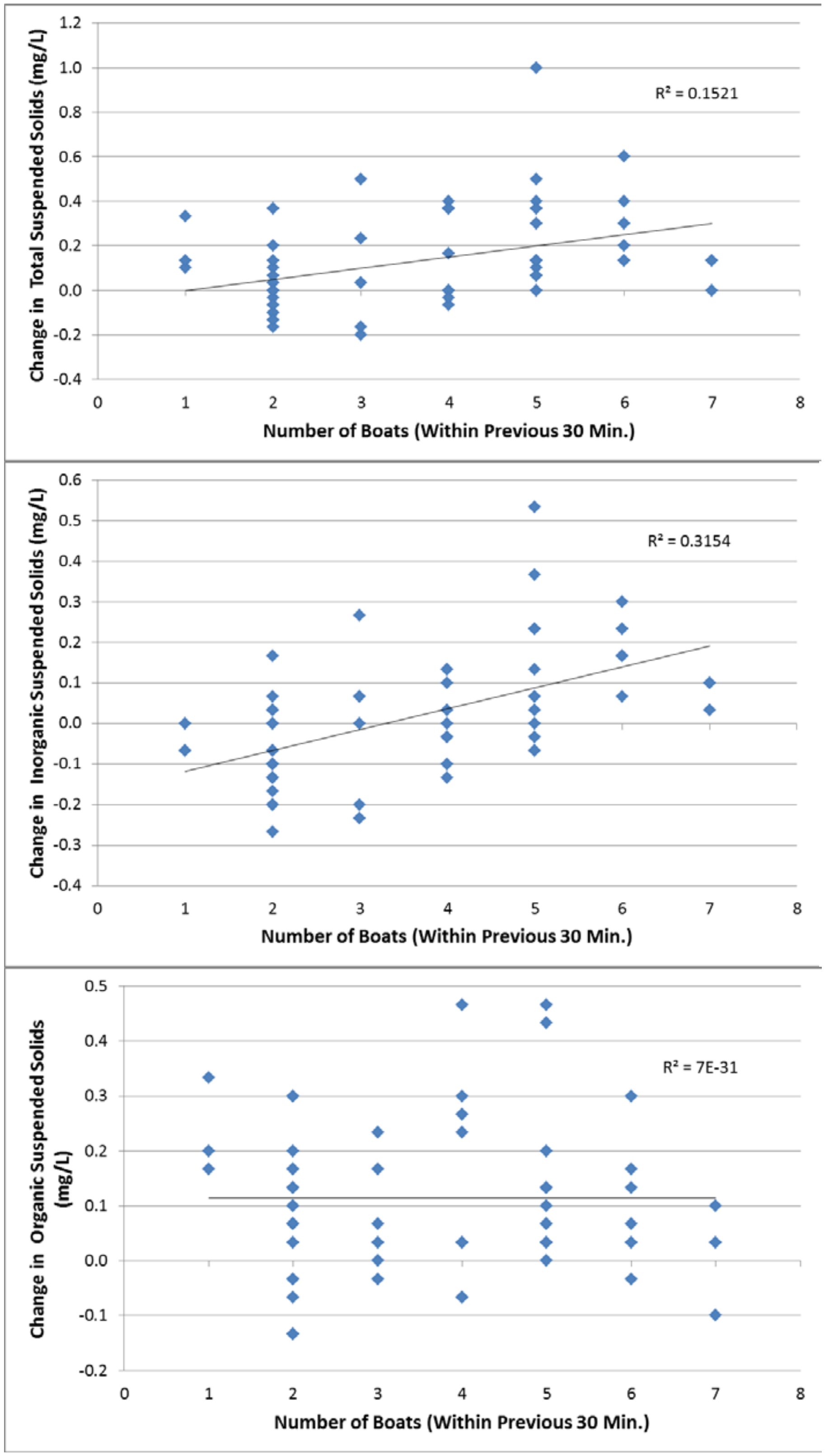


Figure 9. Change in total, inorganic, and organic suspended solids (mg/L) versus number of motorized boats during the prior 30 minutes of sampling below the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

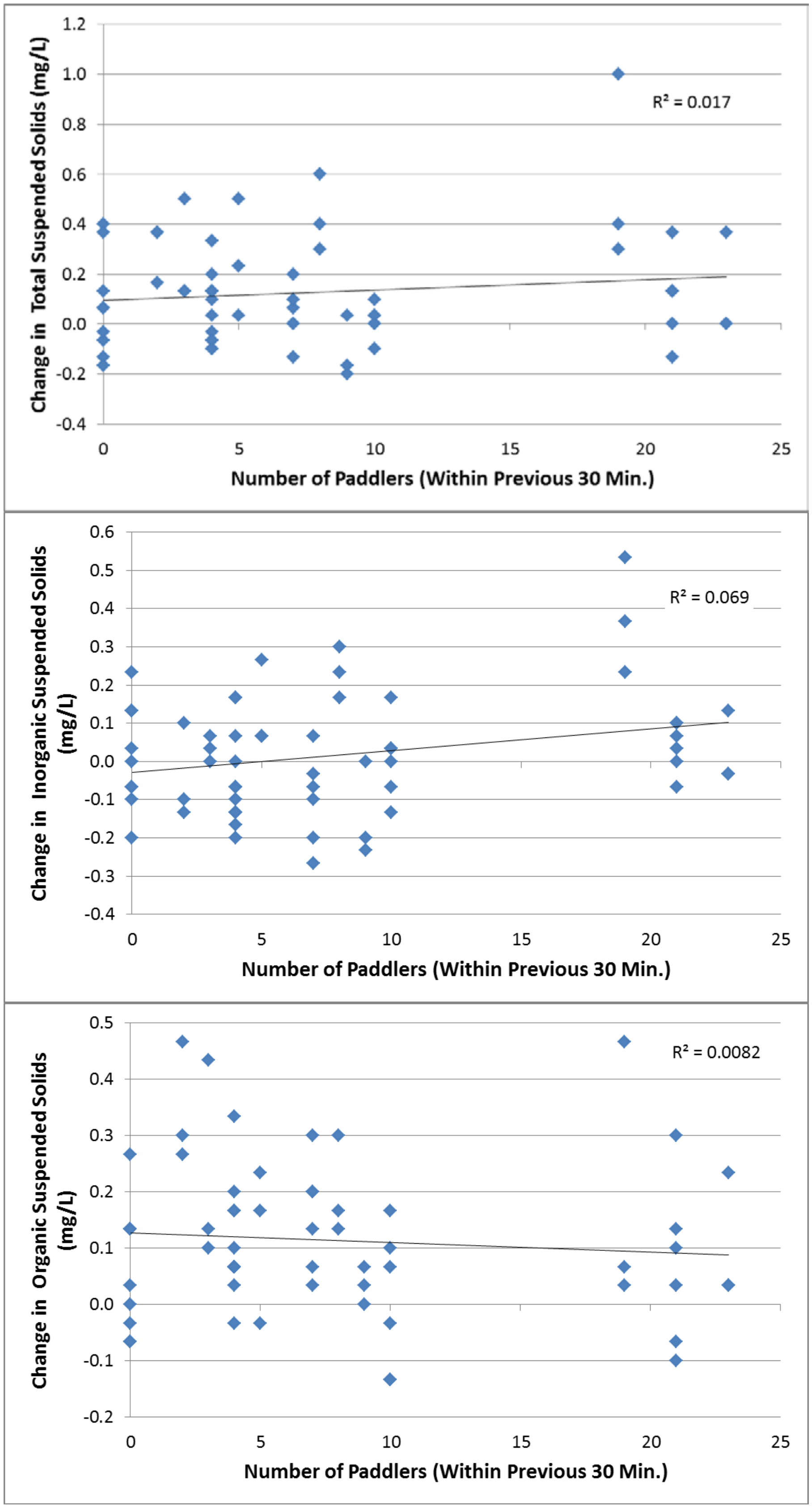


Figure 10. Change in total, inorganic, and organic suspended solids (mg/L) versus number of paddlers during the prior 30 minutes of sampling below the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

Task 4 - Human activity and aquatic plant relationships

Net Sampling:

Both uprooted and cut submersed plants were collected in conjunction with recreational user data. Underwater observation of drifting plants confirmed that nearly all of the damaged plants floated at or near the surface and all of these drifting plants were collected by the nets. S. kurziana comprised 89.2 percent by weight of all plants collected, almost identical to the 88.6 percent in 1994-1995 (Holland and Cichra 1995). V. americana and H. verticillata were the next most abundant, comprising approximately 6 and 2 percent of the total weight, respectively. These two species represented approximately 4 percent each in 1994-1995.

Composition of drifting plants was similar on all ten sampling days except for the 24 August 2011 sample, when H. verticillata represented 11 percent of the submersed plants collected by the nets (Figure 11). It is unclear as to why this species represented such a large proportion of the sample on this day.

The composition of plant taxa collected with the nets was similar to the composition of plants found upstream of the sampling site (Table 17 and Tables 9 - 14). This indicates that recreational activity is not selectively damaging any particular submersed plant species. A similar relationship was found in the 1994-1995 study.

The relationship between recreational activity patterns and the biomass of downstream drifting (damaged) plants is shown for each of the 10 sampling days in Figures 12 - 17. Early morning values for wet weight of plants collected were almost always less than 200 grams/net-hour. Night-time values, collected during the two diurnal sampling events (2 to 3 July 2011 and 3 to 4 September 2011) were slightly lower (Figures 13 and 16). During most days, the biomass of drifting plants remained relatively constant throughout the day except for one sampling period, which typically occurred at midday or midafternoon, as recreational use on the river increased (Figures 12, 14, and 15). During high-use days (28 May, 2 to 3 July, and 3 to 4 September 2011), the biomass of damaged plants increased throughout each sampling day as user activity increased (Figures 12, 13, and 16). The mean wet weight of damaged plants reached much higher levels, up to 3400 grams/net-hour on high-use days. In addition, peak plant weight levels did not necessarily occur during the time of highest recreational use, but often late in the day (after 16:00 hours), as use declined. The biomass of damaged plants decreased as recreational activity decreased, eventually returning to background levels (those observed during nighttime and early morning samples). This can best be observed for the two diurnal samples.

As the abundance of downstream drifting plants increased throughout the day, the species composition of damaged plants remained stable . Uprooted and cut/fragmented proportions of the two dominant species, S. kurziana and V. americana, also remained stable throughout the day.

The biomass of drifting plants, collected in the nets, was significantly and positively correlated to the number of tubers ($r = 0.277$, $p = 0.039$), power boats ($r = 0.553$, $p =< 0.0001$), canoes ($r = 0.0.347$, $p = 0.0088$), and kayaks ($r = 0.351$, $p = 0.008$) observed on the Rainbow River upstream from the nets (Table 18, Figures 18 - 22). Motorized boats had the strongest relationship. When examining increase in drifting plant biomass (i.e., plant damage), only motorized boats were found to have a significant relationship ($r = 0.378$, $p = 0.0027$) (Table 19 and Figure 19). These relationships support the belief that there is a positive relationship between plant damage and the amount of upstream recreational activity.

Although plant damage is occurring due to recreation, the amount of damage is insignificant in comparison to the total biomass of plants in the river. Based on our transect data, the 2.8 km length of the river upstream of the KP Hole County Park had a mean plant coverage of approximately 70 percent and a mean stream width of 50.7 m. Submersed plant biomass in this area ranges from 8.9 to 20.6 kg/m2 (Duarte and Canfield 1990). Thus, the total upstream submersed plant biomass ranges from 880,000 kg to 2,000,000 kg. The maximum damage rate to submersed plants of 3 kg/net-hour, on 28 May 2011, represents a total maximum hourly removal rate of 90 kg/hour (three 2-m wide nets, 60-m river width). Therefore, the biomass of plants removed during the highest levels of recreational activity represents only 4.5 to 9.9 x 10^{-5} percent of the total upstream plant biomass. However, recreation of the intensity needed to achieve this rate of plant damage only occurs during a few hours of each year (Holland and Cichra 1995 and Task 1 of this report). In addition, this estimate does not take into account plant regrowth and assumes all plants are accessible to damage by recreation.

Mean areal plant coverage, as measured by quadrat sampling, was highest below the KP Hole County Park over all four seasons in 1994-1995, often reaching 100 percent (Holland and Cichra 1995). If recreational activities on the river decrease plant abundance, then the area below the KP Hole County Park (the area which received the highest levels of recreational activity) would be expected to have had the lowest percent areal coverage rather than the highest. In addition, mean total coverage was not found to differ over time at the KP Hole County Park, despite the intense use of this area in the summer season. It is not known why plant coverage in the headsprings area decreased by 15 percent throughout the earlier study (spring 1994 through spring 1995) despite the fact that this area received almost no recreational activity (Holland and Cichra 1995).

Table 17. Abundance of plants, based on wet weight, collected by drift nets downstream from the KP Hole County Park on the Rainbow River, Dunnellon, Florida during 2011 and 2012. Data include all 10 sampling events. Sagittaria kurziana and Vallisneria americana are also listed as either uprooted plants or as cut or fragmented pieces of plants.

Plant Species	Frequency (in grams)	Percent	Cumulative Frequency (in grams)	Cumulative Percent
Uprooted Sag. kurziana	66650.37	50.70	66650	50.70
Cut/Frag Sag. kurziana	50636.87	38.52	117287	89.21
Cut/Frag Val. americana	6421.79	4.88	123709	94.10
Hydrilla verticillata	2534.82	1.93	126244	96.02
Uprooted Val. americana	1240.04	0.94	127484	96.97
Najas quadalupensis	1108.51	0.84	128592	97.81
Utricularia spp.	915.13	0.70	129507	98.51
Ceratophyllum demersum	790.75	0.60	130298	99.11
Potamogeton illinoensis	519.12	0.39	130817	99.50
Fontinalis sp.	212.44	0.16	131030	99.66
Ludwigia repens	177.64	0.14	131207	99.80
Zizania aquatica	67.00	0.05	131274	99.85
Scirpus validus	59.00	0.04	131333	99.90
Hydrocotyle sp.	47.88	0.04	131381	99.93
Bacopa caroliniana	45.03	0.03	131426	99.97
Chara spp.	25.80	0.02	131452	99.99
Myriophyllum sp.	15.61	0.01	131467	100.00
Terrestrial	2.71	0.00	131470	100.00
Lemna sp.	0.26	0.00	131471	100.00

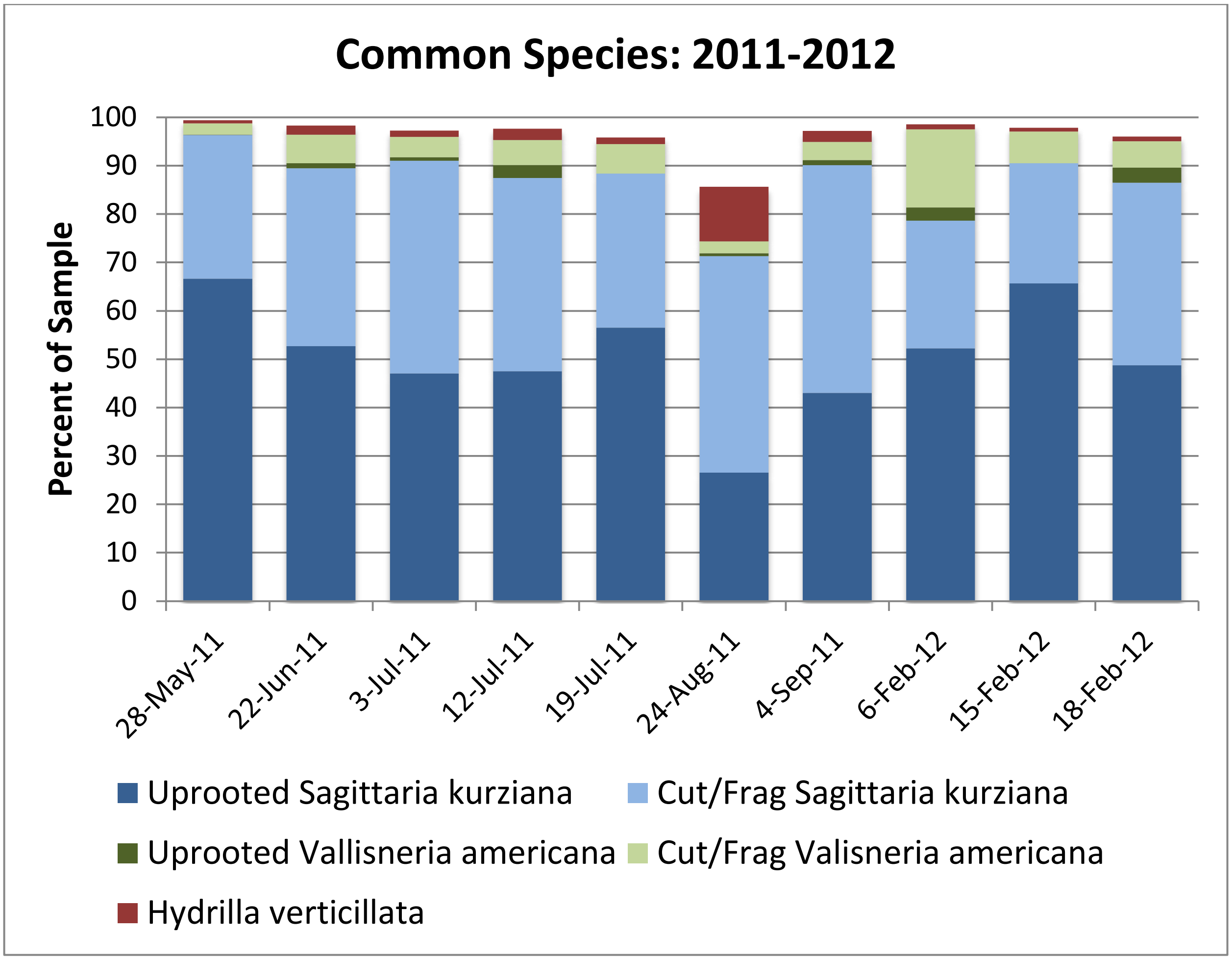


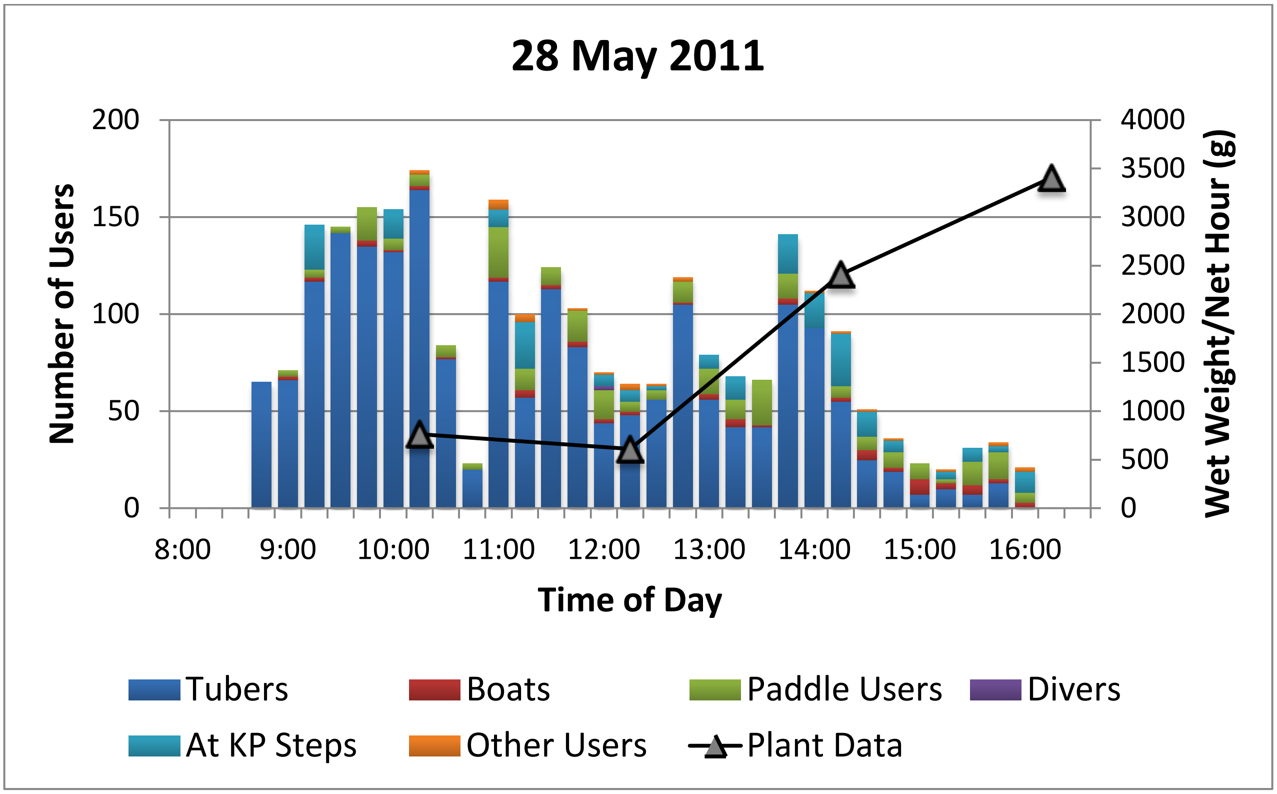
Figure 11. Relative abundance, based on wet weight, of the three most common aquatic plants collected by drift nets downstream from the KP Hole County Park on the Rainbow River, Dunnellon, Florida during 2011 and 2012. Sagittaria kurziana and Vallisneria americana are further listed as either uprooted plants or as cut or fragmented pieces of plants.

Table 18. Date and approximate ending times for the collection of drifting plants on the Rainbow River, Dunnellon, Florida, along with the mean weight, select mean weight, and change in weight of drifting plants collected per net hour, and the number of tubers, boats, canoes, kayaks, and paddlers (canoes + kayaks) upstream from the nets during the collection period.

Date	End time	Mean Weight	Select Mean Weight	Weight Change	Tubers	Boats	Canoes	Kayaks	Paddlers
28-May-11	1015	764	764	.	526	6	6	24	30
28-May-11	1215	611	611	-153	297	11	11	40	51
28-May-11	1415	2411	2411	1647	282	8	11	35	46
28-May-11	1615	3406	3406	2642	30	13	14	19	33
22-Jun-11	1030	224	224	.	86	6	20	2	22
22-Jun-11	1230	381	381	157	159	4	13	9	22
22-Jun-11	1430	607	607	383	96	5	1	4	5
22-Jun-11	1630	494	494	270	35	3	2	5	7
2-Jul-11	1945	620	.	.	2	7	1	2	3
2-Jul-11	2200	1183	.	.	0	1	0	0	0
2-Jul-11	2400	141	141	.	0	0	0	0	0
3-Jul-11	200	122	122	.	0	0	0	0	0
3-Jul-11	400	71	71	.	0	0	0	0	0
3-Jul-11	600	105	105	.	0	0	0	0	0
3-Jul-11	800	196	196	.	0	2	0	2	2
3-Jul-11	1000	783	783	587	344	9	7	24	31
3-Jul-11	1200	679	679	483	268	9	4	48	52
3-Jul-11	1400	904	904	708	313	17	16	53	69
3-Jul-11	1600	1640	1640	1444	195	15	10	10	20
3-Jul-11	1800	2058	2058	1862	0	17	2	14	16
12-Jul-11	945	237	237	.	23	4	0	22	22
12-Jul-11	1145	972	972	735	164	3	2	21	23
12-Jul-11	1345	411	411	174	65	6	5	7	12
12-Jul-11	1545	368	368	131	7	7	2	6	8
19-Jul-11	930	179	179	.	9	7	1	7	8
19-Jul-11	1130	603	603	424	129	6	5	21	26
19-Jul-11	1330	2618	2618	2439	127	4	4	12	16
19-Jul-11	1530	1434	1434	1255	40	10	1	9	10
24-Aug-11	945	215	215	.	0	2	0	3	3
24-Aug-11	1130	209	209	-6	20	2	1	5	6
24-Aug-11	1315	354	354	139	64	5	0	3	3
24-Aug-11	1500	1304	1304	1089	14	6	0	0	0

Table 18. Continued.

Date	End time	Mean Weight	Select Mean Weight	Weight Change	Tubers	Boats	Canoes	Kayaks	Paddlers
3-Sep-11	1945	1880	.	.	0	13	0	2	2
3-Sep-11	2200	750	.	.	0	2	0	0	0
3-Sep-11	2400	257	257	.	0	0	0	0	0
4-Sep-11	215	188	188	.	0	0	0	0	0
4-Sep-11	400	137	137	.	0	0	0	0	0
4-Sep-11	600	173	173	.	0	0	0	0	0
4-Sep-11	800	192	192	.	0	4	0	0	0
4-Sep-11	1000	1536	1536	1344	210	6	2	20	22
4-Sep-11	1200	1633	1633	1441	328	10	3	22	25
4-Sep-11	1400	1183	1183	991	271	3	10	19	29
4-Sep-11	1600	1105	1105	913	47	7	6	31	37
4-Sep-11	1800	1180	1180	988	0	6	3	6	9
6-Feb-12	930	278	278	.	0	1	0	0	0
6-Feb-12	1130	1322	1322	1044	0	1	1	5	6
6-Feb-12	1330	191	191	-87	0	7	2	6	8
6-Feb-12	1530	730	730	452	0	9	0	8	8
15-Feb-12	930	296	296	.	0	0	0	1	1
15-Feb-12	1130	240	240	-56	0	2	0	13	13
15-Feb-12	1330	401	401	105	0	4	1	2	3
15-Feb-12	1530	602	602	306	0	4	0	5	5
18-Feb-12	945	226	226	.	0	8	0	0	0
18-Feb-12	1145	649	649	423	8	11	1	14	15
18-Feb-12	1345	352	352	126	0	7	1	8	9
18-Feb-12	1545	1409	1409	1183	2	16	1	9	10



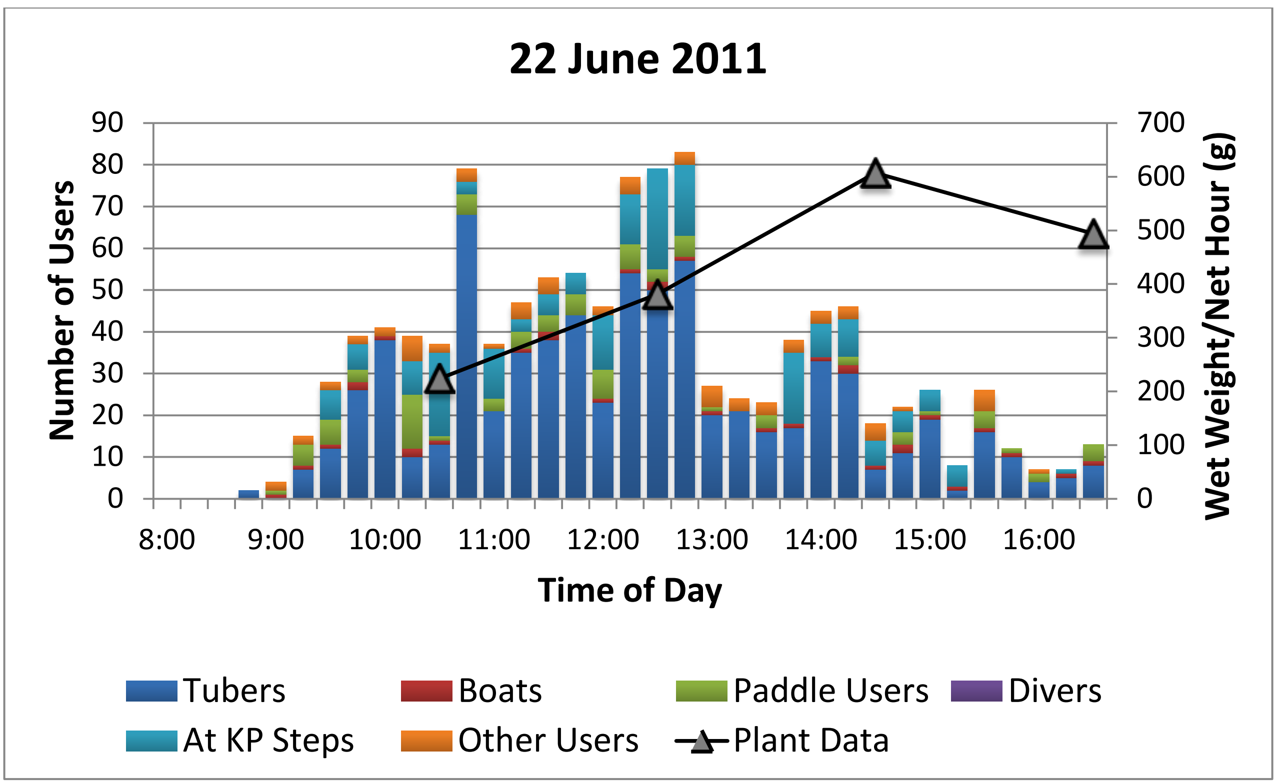


Figure 12. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 28 May and 22 June 2011, downstream from the KP Hole County Park, Dunnellon, Florida.

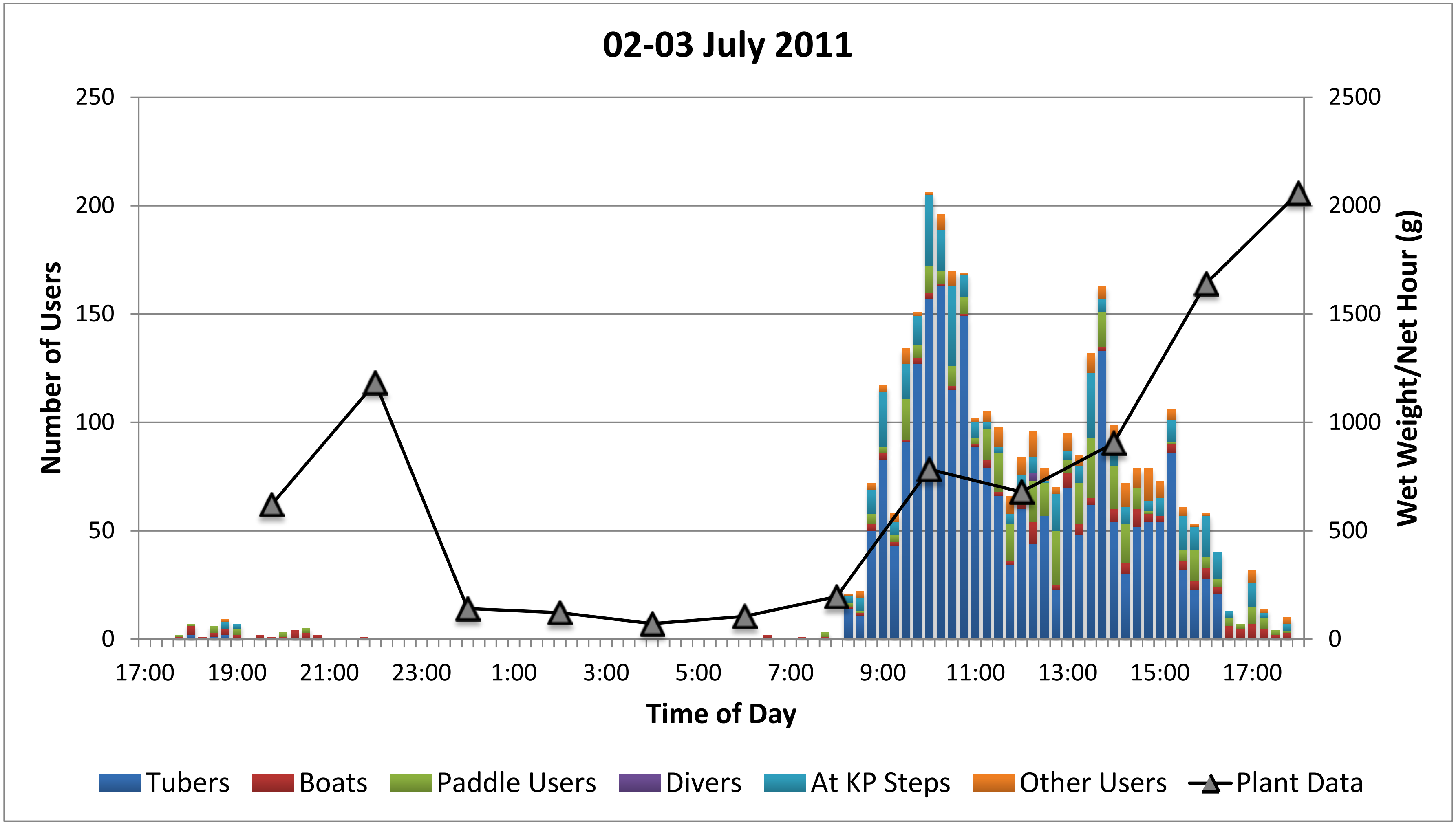


Figure 13. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 02 and 03 July 2011, downstream from the KP Hole County Park, Dunnellon, Florida.

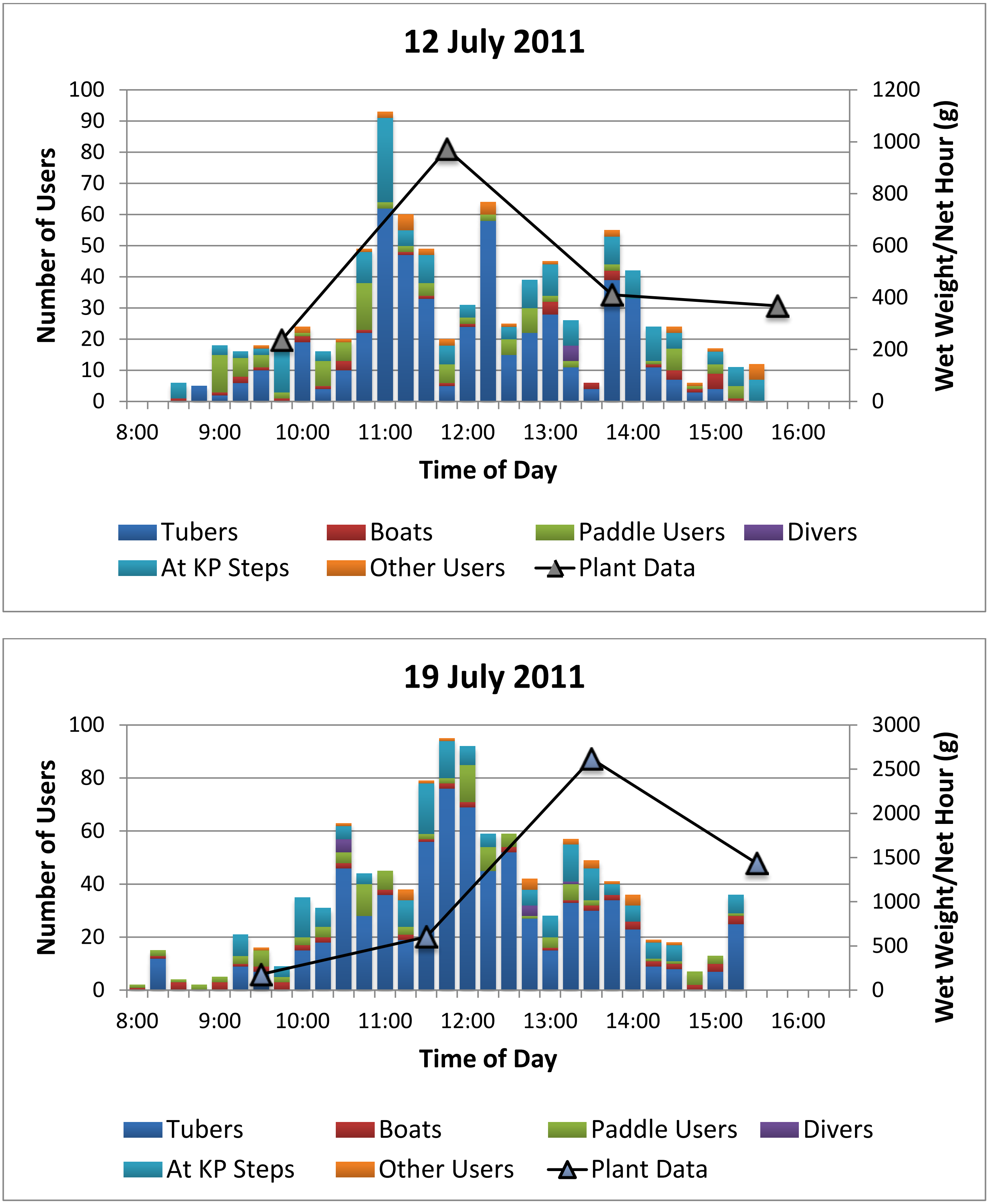
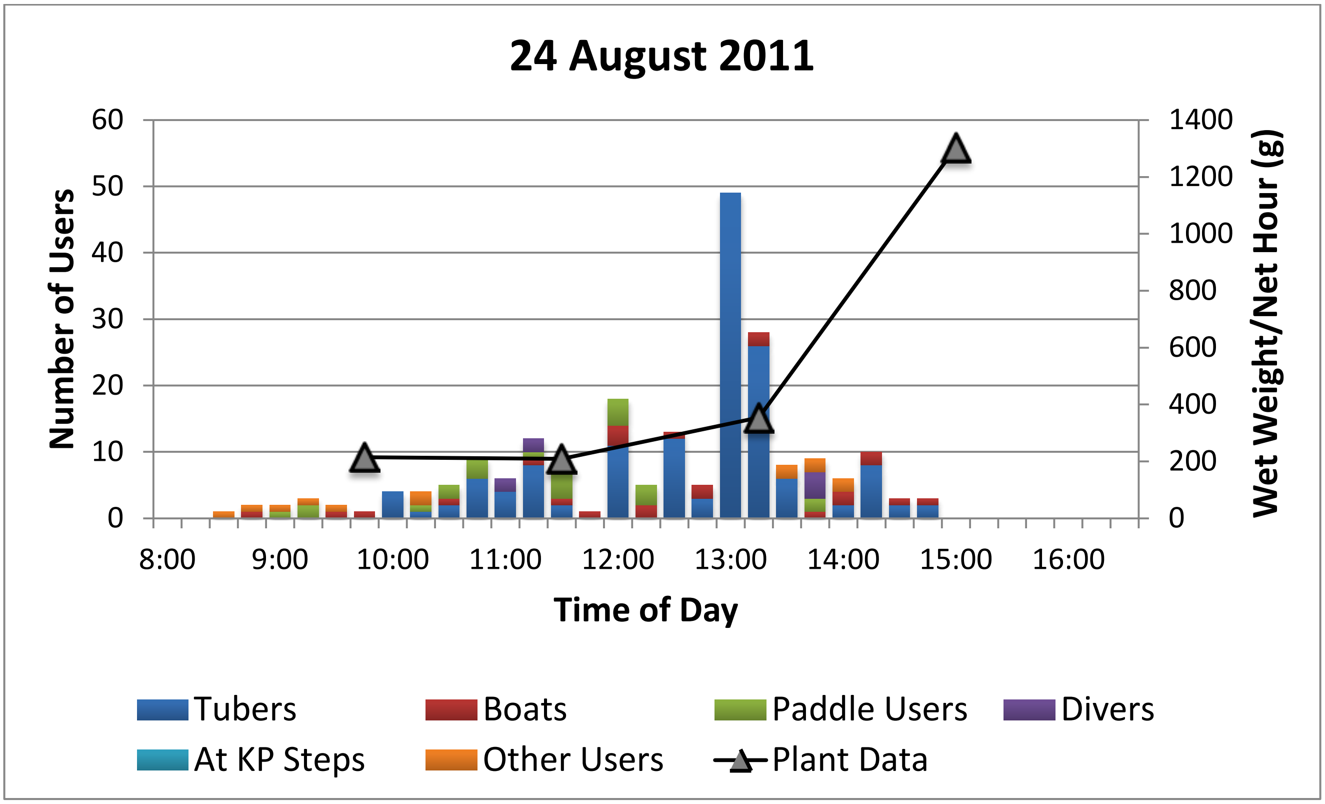


Figure 14. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 12 and 19 July 2011, downstream from the KP Hole County Park, Dunnellon, Florida.



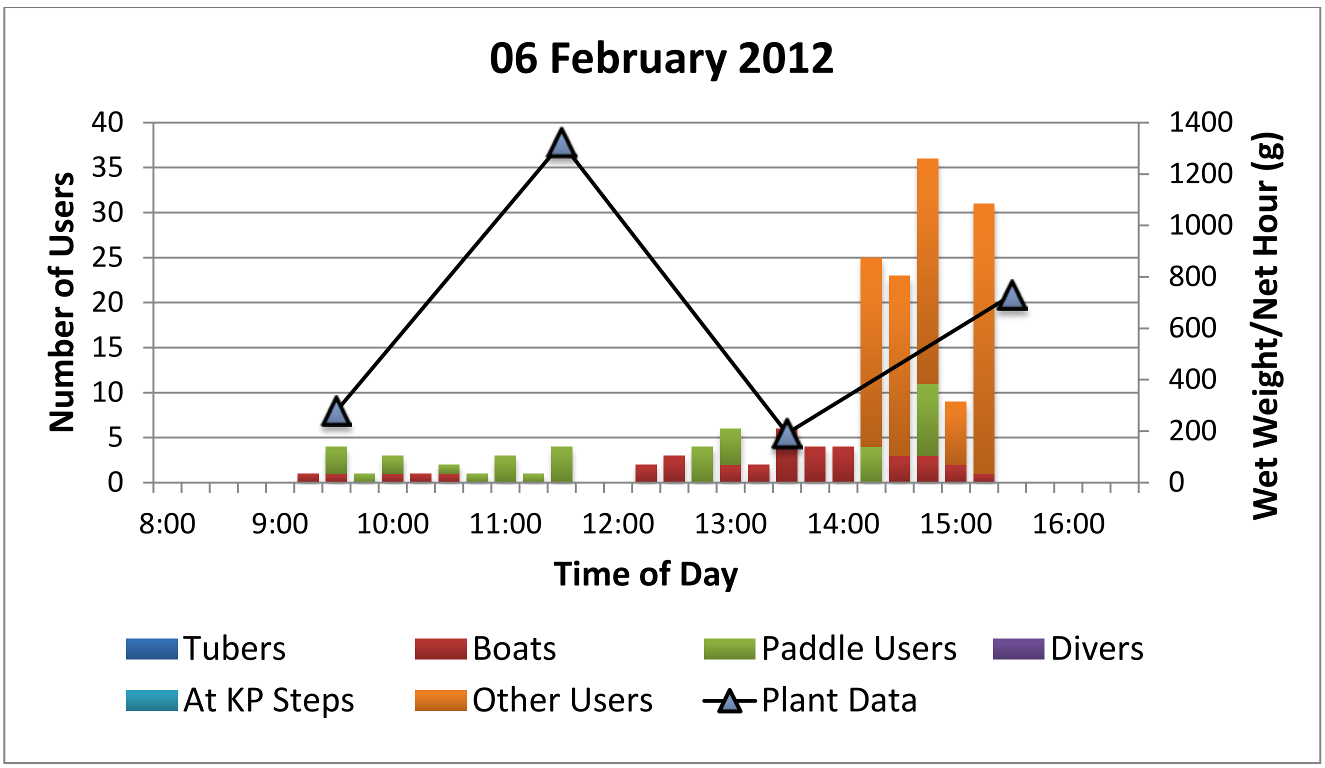


Figure 15. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 24 August 2011 and 06 February 2012, downstream from the KP Hole County Park, Dunnellon, Florida.

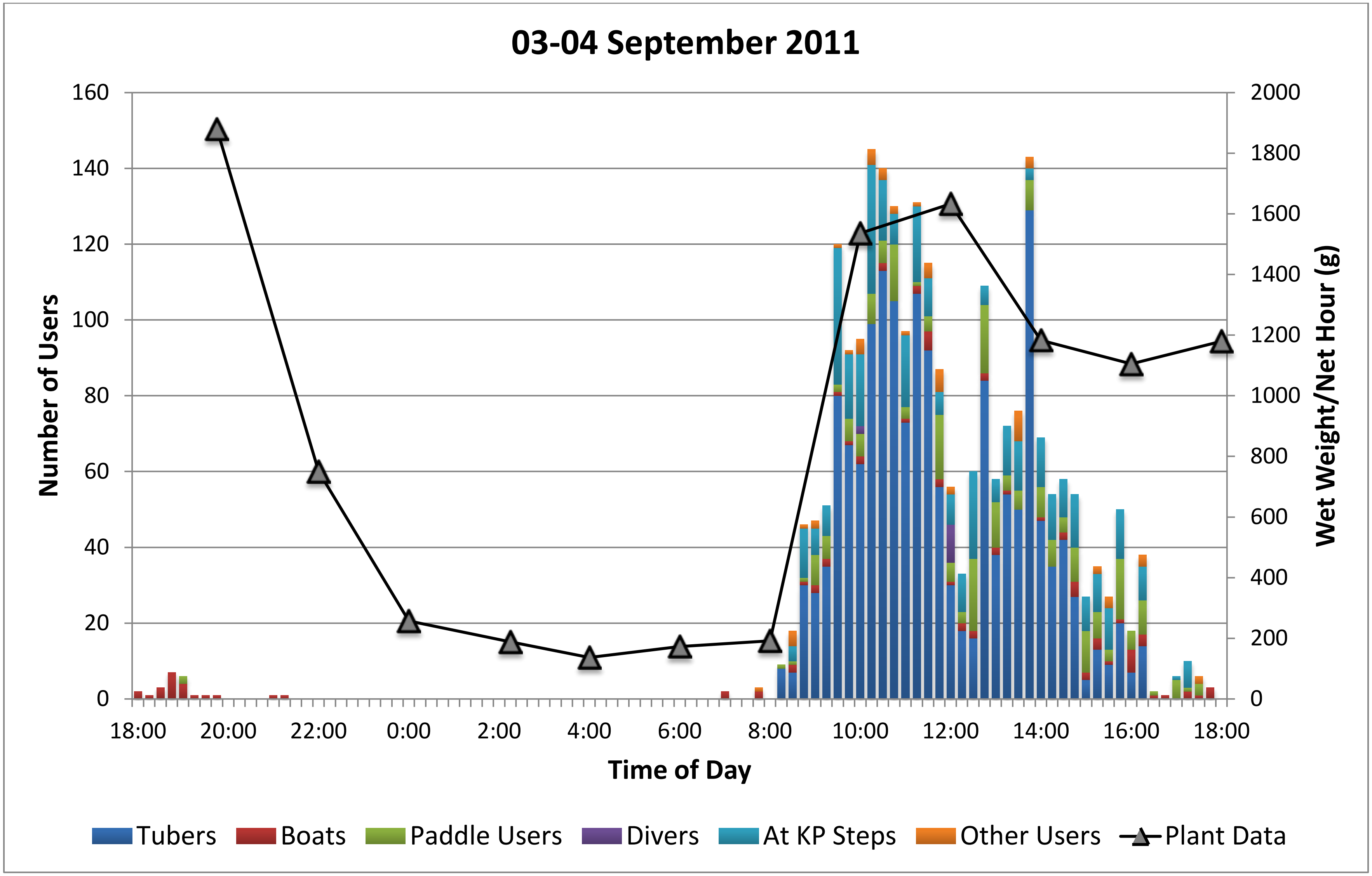
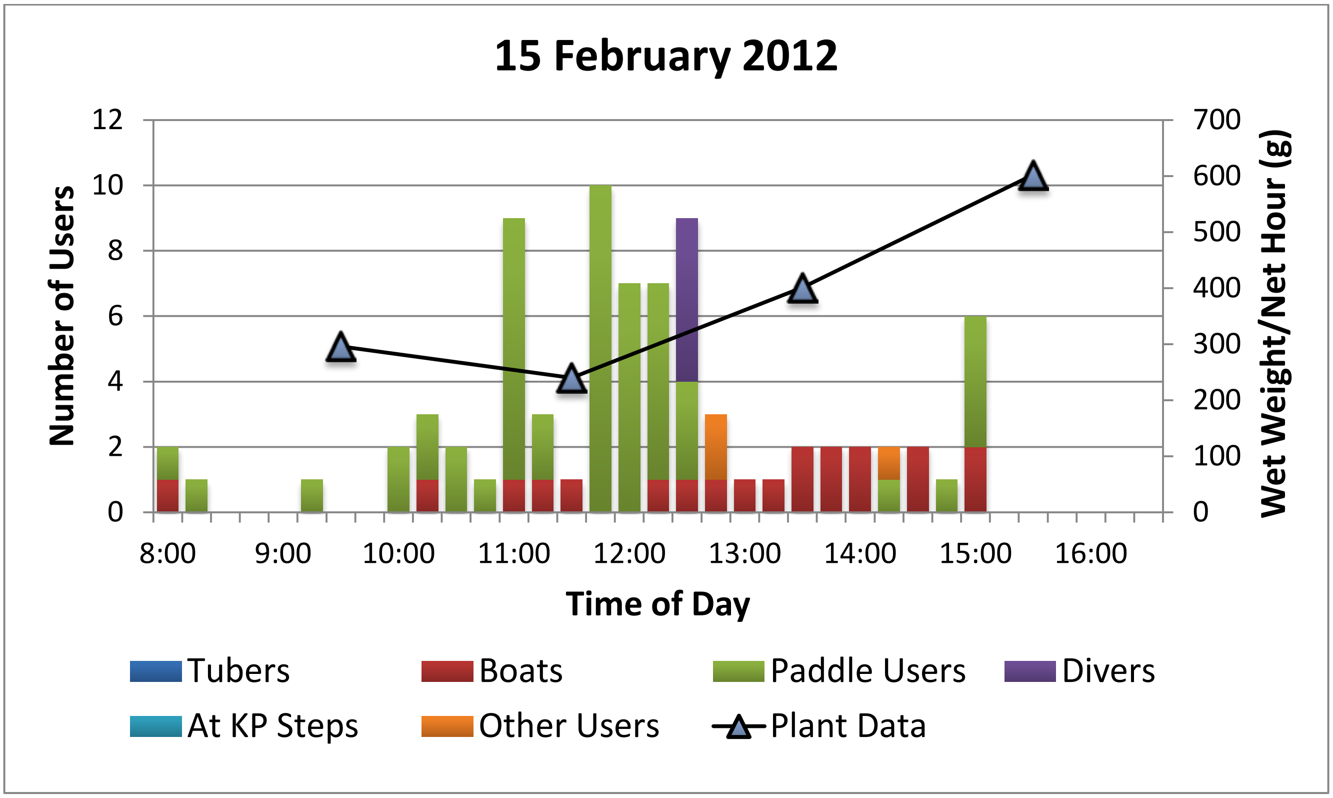


Figure 16. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 03 and 04 September 2011, downstream from the KP Hole County Park, Dunnellon, Florida.



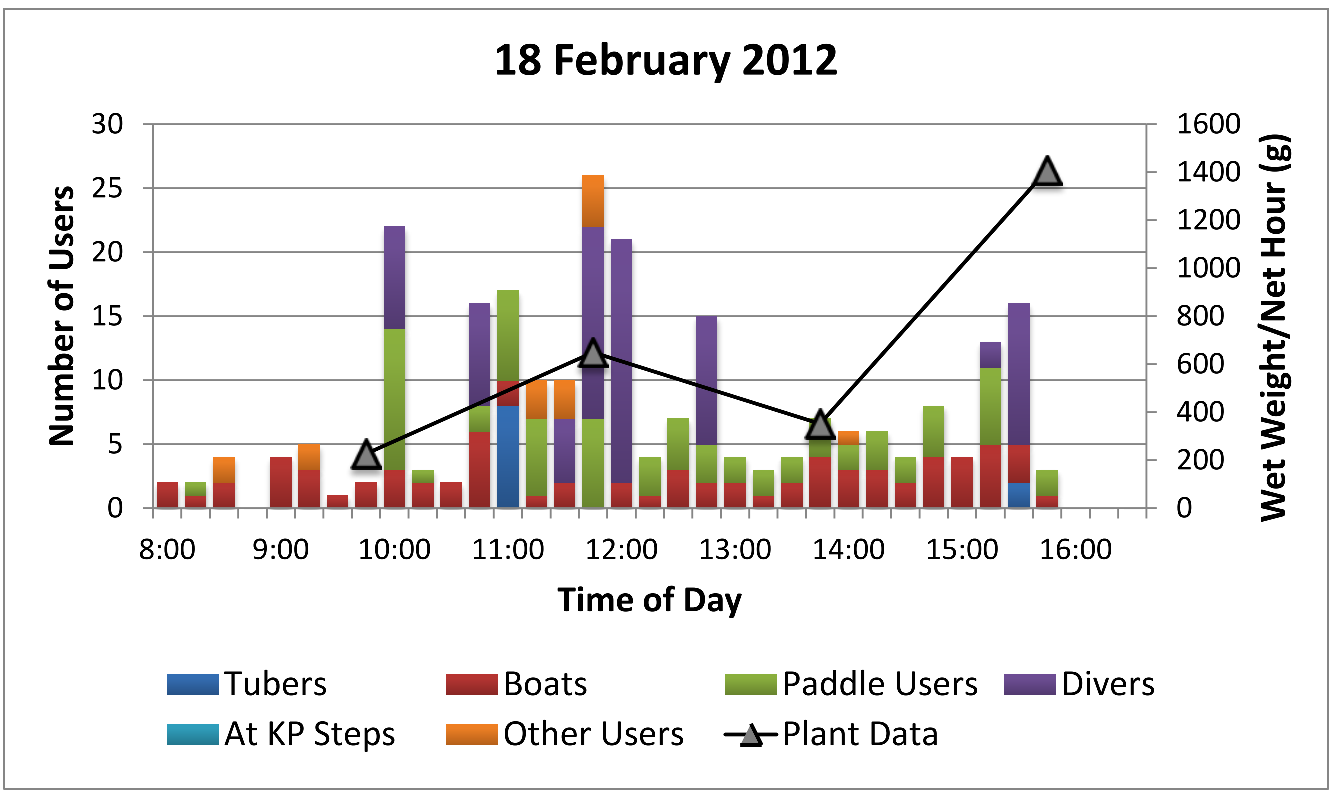
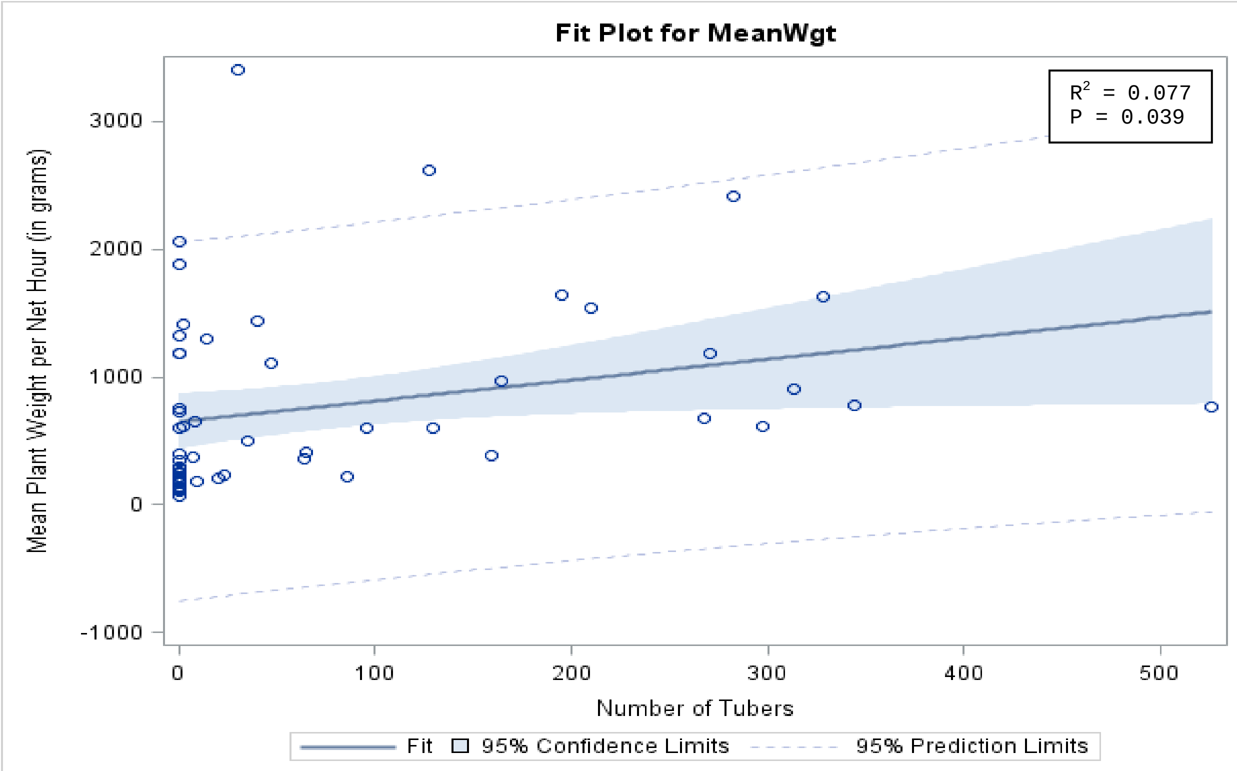


Figure 17. Number of each user group observed per 15-minutes (bars) upstream from sampling nets and mean wet weight of drifting plants collected on 15 and 18 February 2012, downstream from the KP Hole County Park, Dunnellon, Florida.

Table 19. Pearson correlation coefficients, along with P-values and sample sizes, for mean weight, selected mean weight, and change in weight of drifting plants collected per net hour for all 10 sampling dates combined. Four late-afternoon samples for the first day of the two diurnal sampling periods were not included in the "select mean weight" analysis, as plant weight were likely effected by earlier high use. This variable was analyzed to determine if these four samples affected the results. Values in bold are significant.

Pearson Correlation Coefficients Prob > |r| under H0: Rho=0 Number of Observations			
	Mean Weight	**Select Mean Weight**	**Weight Change**
Tubers	**0.27659** 0.0391 56	**0.31203** 0.0243 52	0.14536 0.4121 34
Boats	**0.55282** <0.0001 56	**0.55498** <0.0001 52	**0.37837** 0.0273 34
Canoes	**0.34703** 0.0088 56	**0.3873** 0.0046 52	0.27103 0.1210 34
Kayaks	**0.35071** 0.0080 56	**0.39611** 0.0037 52	0.13432 0.4488 34
Paddlers	**0.38479** 0.0034 56	**0.43497** 0.0013 52	0.18353 0.2988 34



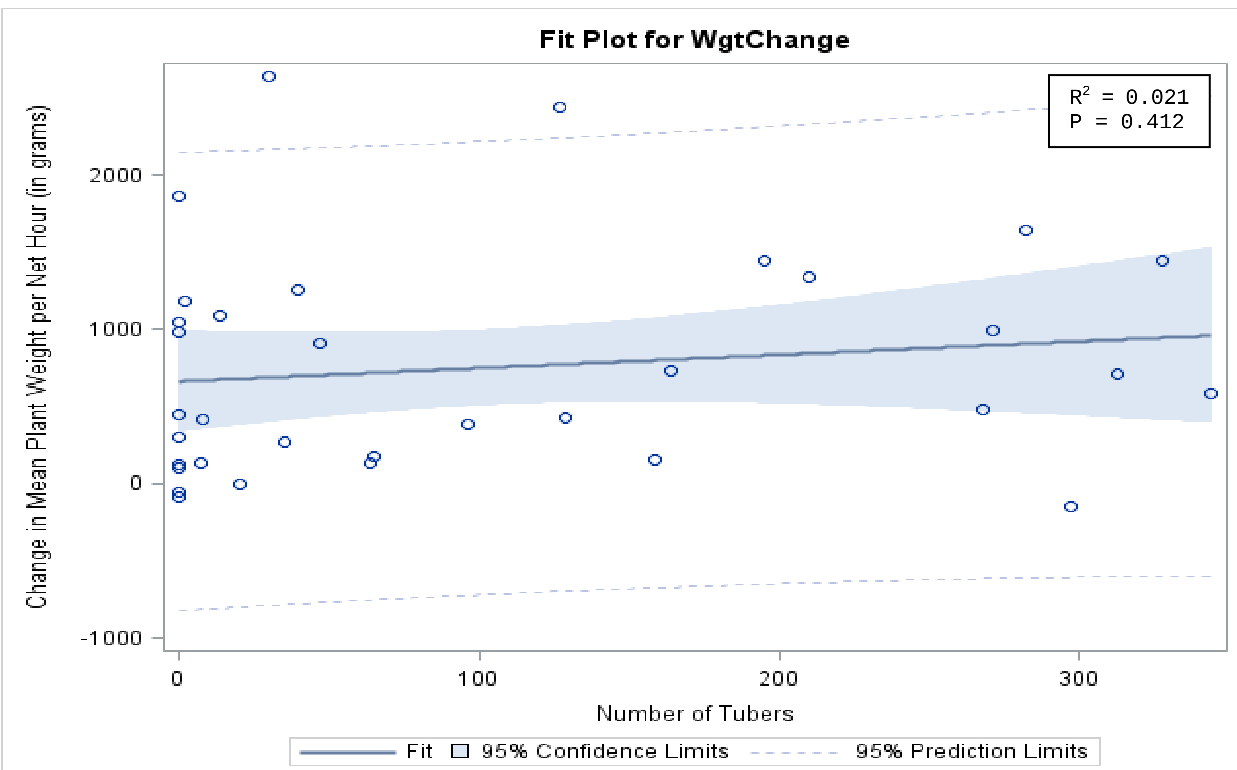


Figure 18. Plots of mean weight (in grams) and change in weight (in grams) of drifting aquatic plants collected per net hour versus number of tubers observed upstream from the nets during the 1-hour period of collection, just downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

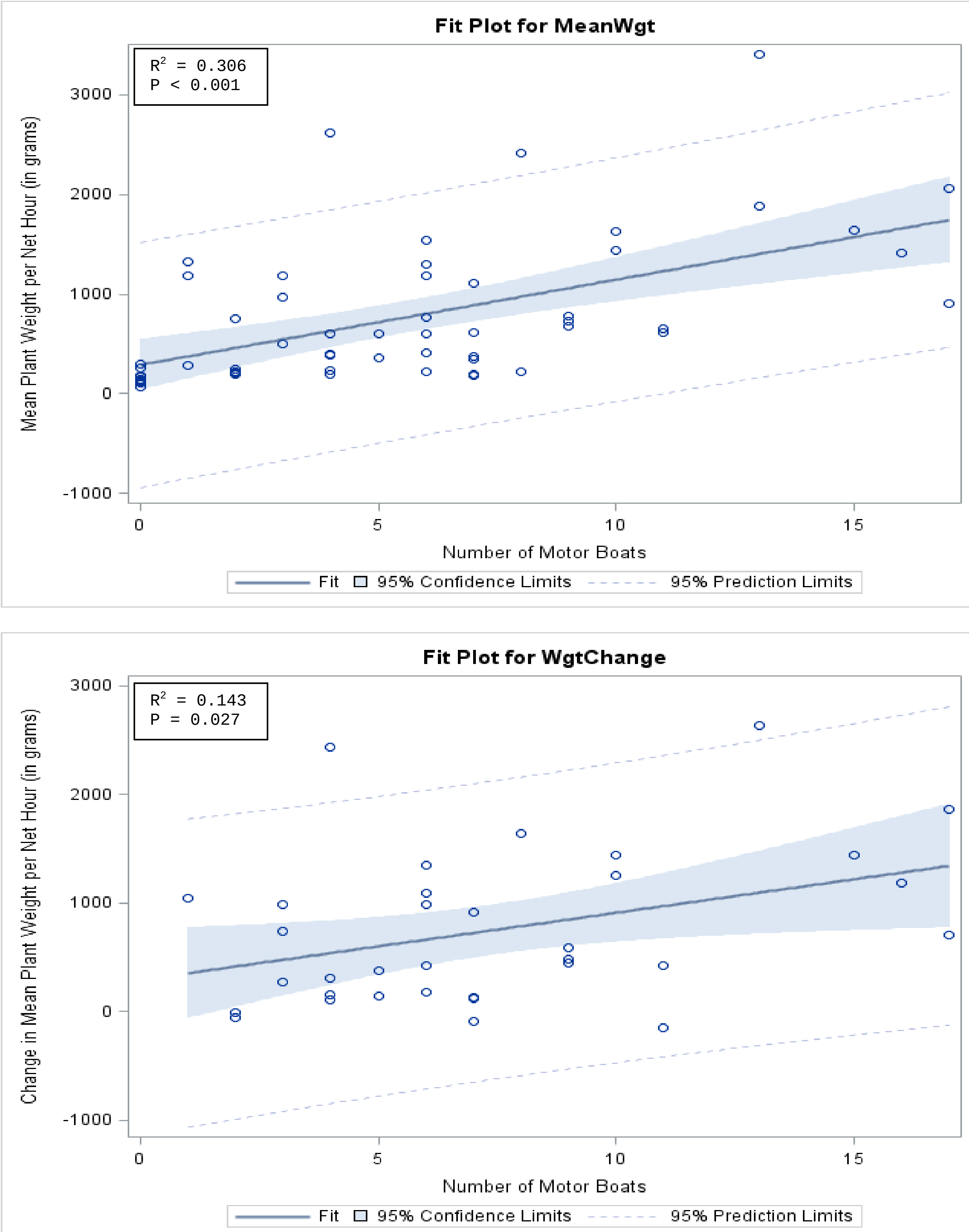
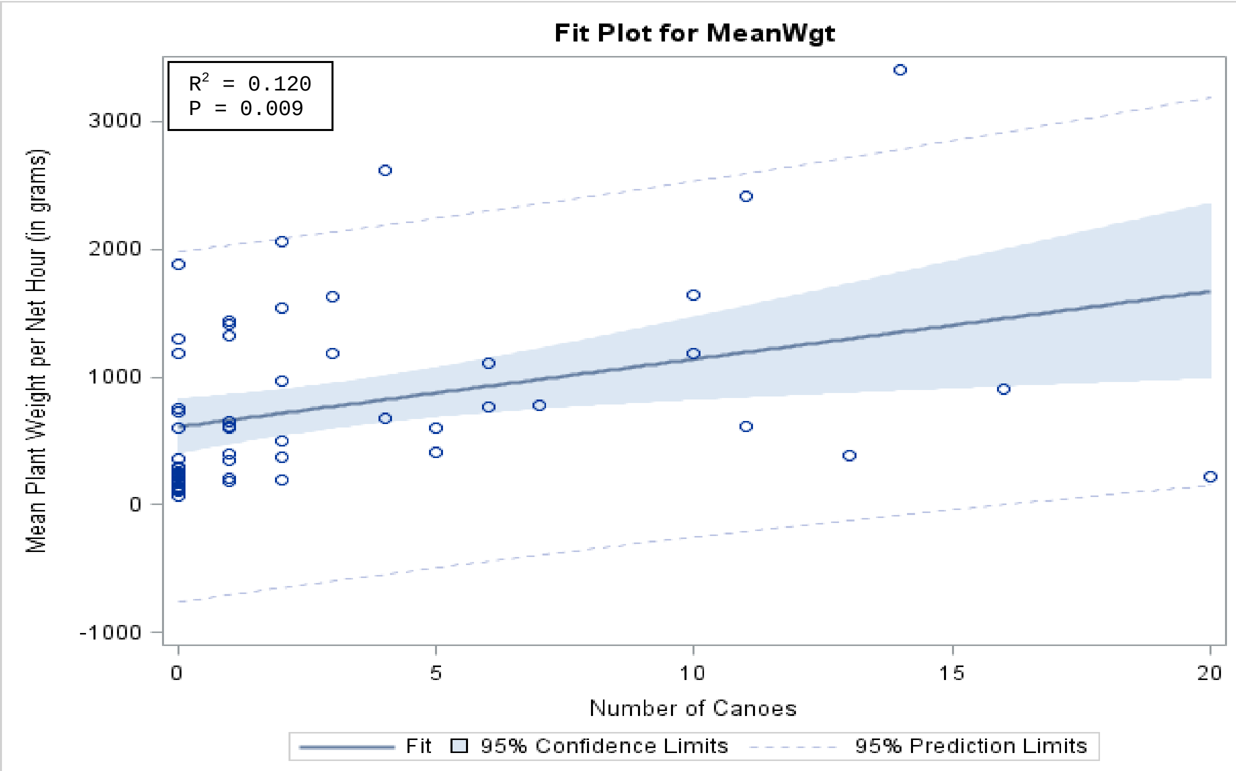


Figure 19. Plots of mean weight (in grams) and change in weight (in grams) of drifting aquatic plants collected per net hour versus number of motorized boats observed upstream from the nets during the 1-hour period of collection, just downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.



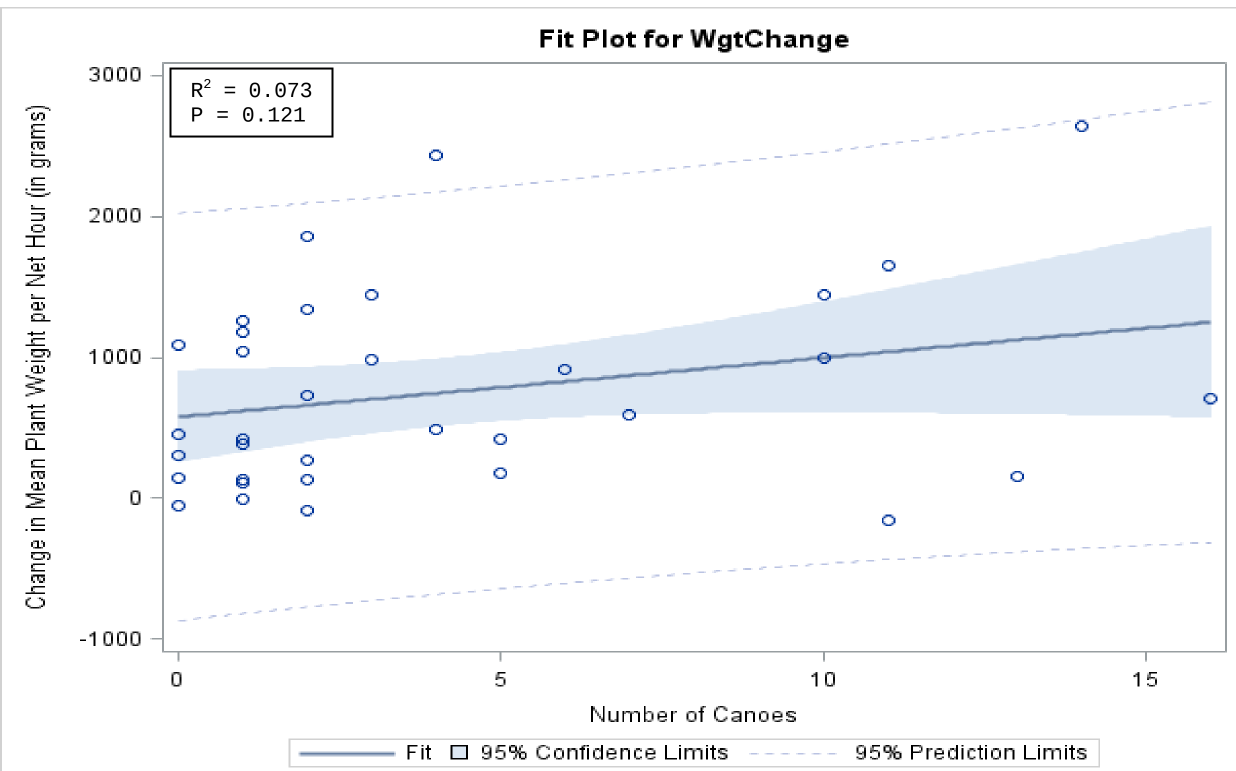
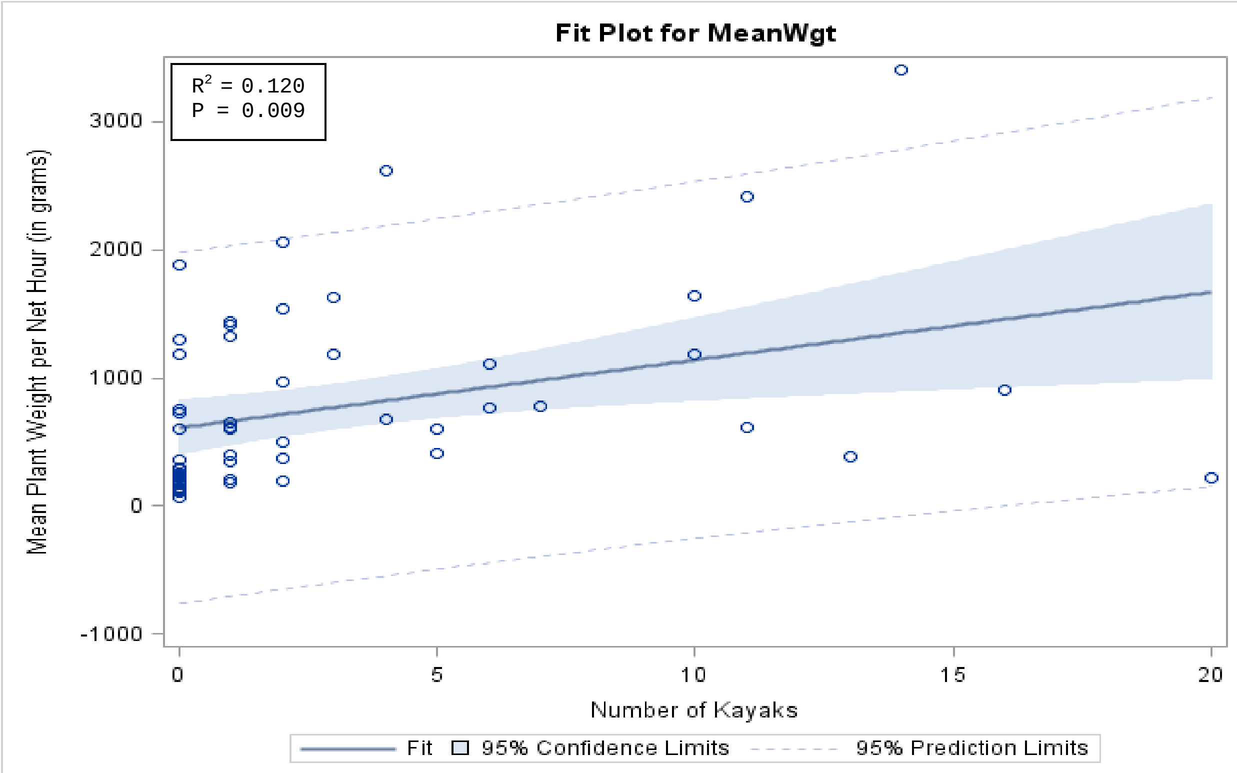


Figure 20. Plots of mean weight (in grams) and change in weight (in grams) of drifting aquatic plants collected per net hour versus number of canoes observed upstream from the nets during the 1-hour period of collection, just downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.



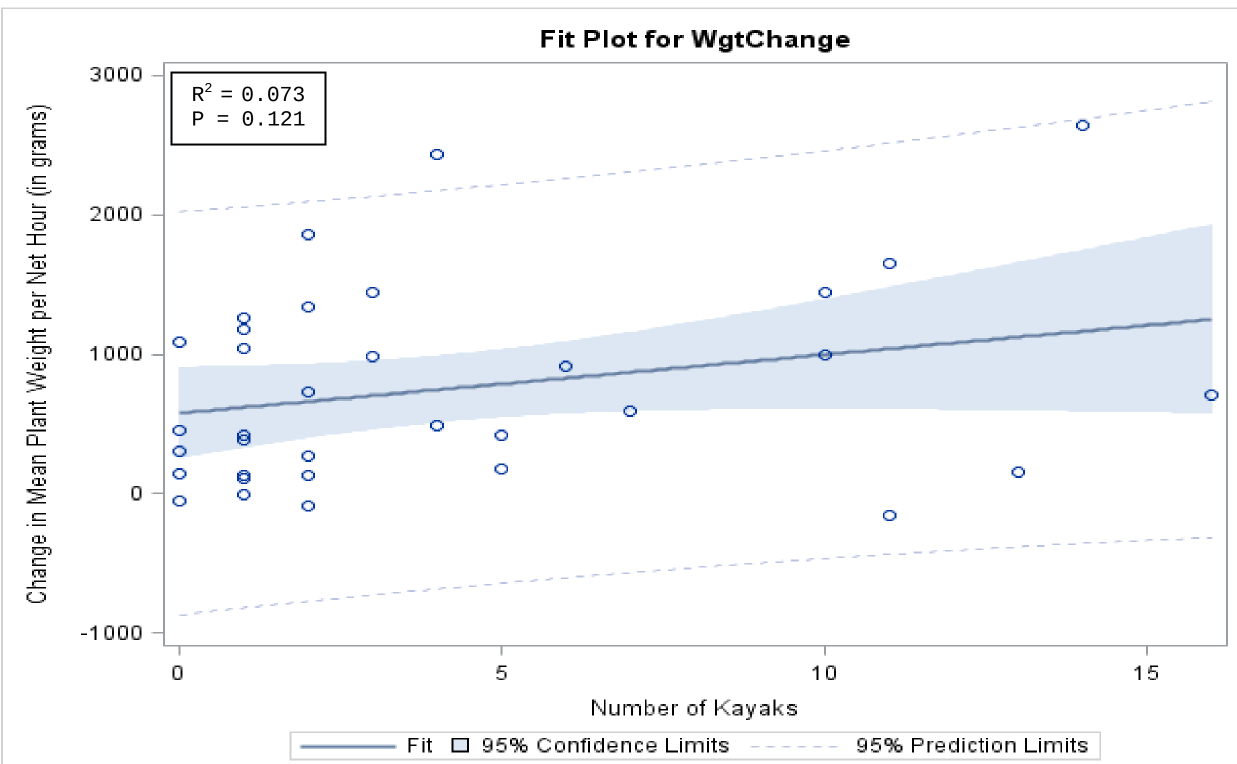


Figure 21. Plots of mean weight (in grams) and change in weight (in grams) of drifting aquatic plants collected per net hour versus number of kayaks observed upstream from the nets during the 1-hour period of collection, just downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

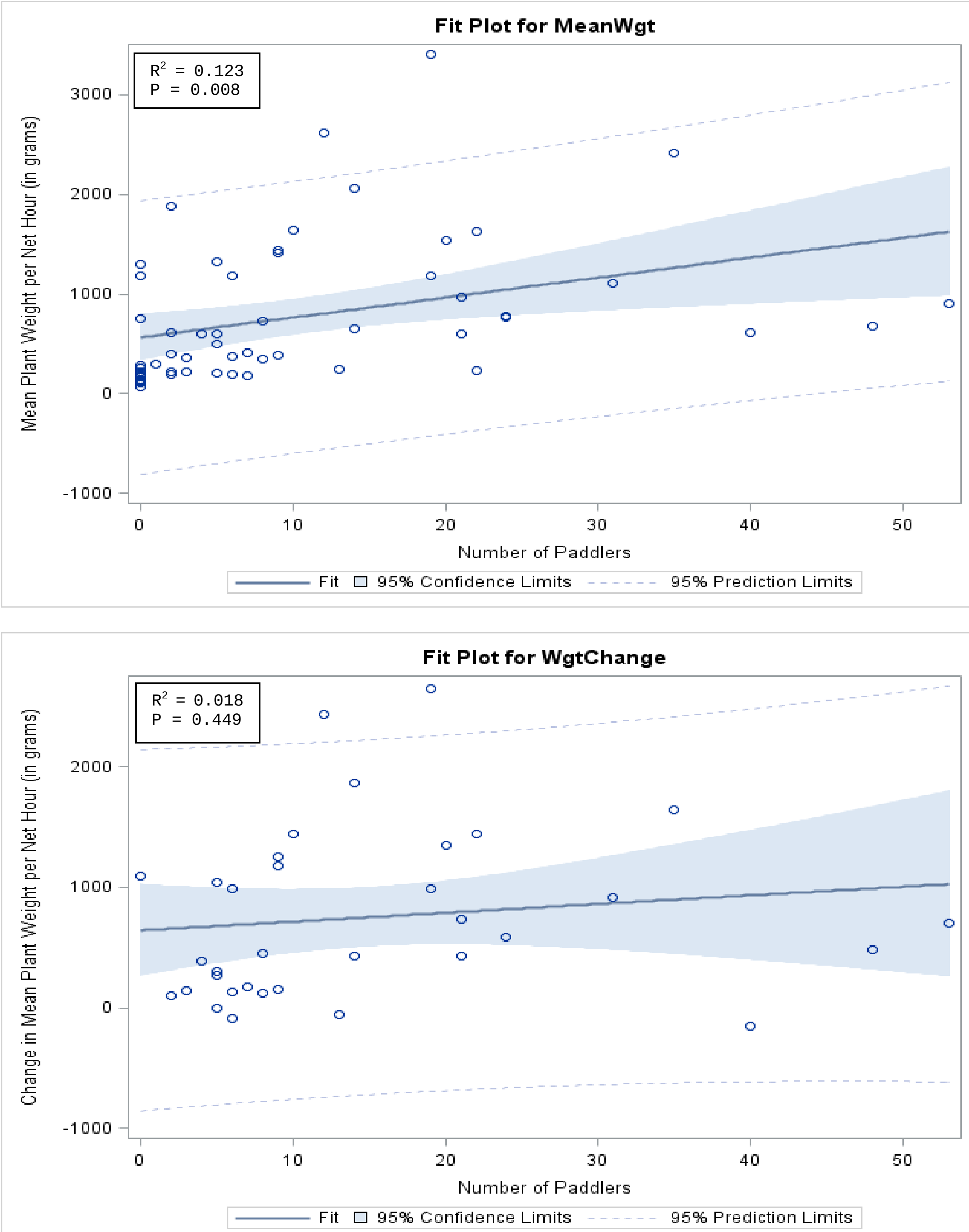


Figure 22. Plots of mean weight (in grams) and change in weight (in grams) of drifting aquatic plants collected per net hour versus number of paddlers (canoes + kayaks) observed upstream from the nets during the 1-hour period of collection, just downstream from the KP Hole County Park, Rainbow River, Dunnellon, Florida, 2011-2012.

Task 4 - Human activity and aquatic plant relationships

Direct Observation of the Effects of Motor Boating on the Aquatic Plants

A total of 269 motorized boats were observed during 2011 and 2012. These boats were categorized into eleven "boat types" (Figure 23). The most common boats observed were pontoon, Jon, and bay boats. These three boat types represented 82 percent of all recorded boats. Other types included bass boats, Gheenoe / Ganoe (generic version of Gheenoe), cruisers, inflatables, air boats, skiff/flats boats, nearshore, and jet ski.

No damage was observed from any of the Gheenoe / Ganoe, inflatable, air boat, skiff / flats boat, or jet ski categories. Four of these five categories had sample sizes of 4 or less, while 11 Ghenoes / Ganoes were observed.

Pontoon boats are by far the most popular boat type on the Rainbow River. Of the 126 pontoon boats recorded, 86.5 percent were not observed to cause damage to the aquatic plants. Minimal to substantial damage, however, was caused by 17 pontoon boats. Several pontoon boats had extremely large engines, and even though they stayed in the deepest portion of the river, they caused substantial damage (Figure 24). Most of the damage caused by this type of boat was due to behavior of the operator. The major cause of plant damage was operating the boats in shallow areas (Figure 25) and/or not having the motor trimmed. One boat was observed motoring along the shallow eastern shore, apparently to avoid tubers, causing substantial damage. One pontoon boat was observed backing up from a pier and turning around over a shallow plant bed. One boat motored through a shallow area with a motor that was mounted low on the boat, and all six passengers were seated on the back seat of the pontoon boat, causing it to ride low in the rear. The operator of one rental pontoon boat constantly tried to motor slowly through a dense patch of tubers, repeatedly stalling the engine. On all three occasions, when the operator restarted the engine and put it into gear, they gunned the engine, digging up submersed plants and bottom sediments, although they were in one of the deeper areas of the river at the time.

Of the 49 Jon boats that were recorded, only one of the boats was observed to cause damage, and it was minimal in nature. This boat had its engine down and went through a shallow plant bed.

Of the 46 bay (small to medium, center or side console) boats that were recorded, 11 caused plant damage (3 minimal, 4 medium, and 4 substantial). Most of this damage was due to large motor size, which often caused the boats to ride low in the rear. For two of the worst cases observed, producing substantial uprooted plant damage, the operator of the boat did not trim its engine or the operator damaged the plants trying to avoid a group of tubers. One large bay boat, a 24+-foot Hurricane deck boat, did not damage plants as it travelled upstream, but caused substantial damage as it came back downstream. No unusual behavior was noted for this boat/operator. One boat caused medium plant damage as it passed by, travelling at a fast rate of speed (faster than no wake). Other bay boats caused damaged, primarily due to the engines not being trimmed up.

Eighteen bass boats were recorded. Of these five caused plant damage. The worst case (substantial damage) occurred when the operator drifted into shallow water while fishing. When attempting to leave the shallow area, the operator simply started the engine, without trimming it up, causing the damage.

Cruisers were defined as being large enclosed boats, often referred to as cabin cruisers. Four of the six cruisers caused minimal (2 boats) or medium (2 boats) plant damage, even when operating in the deeper portion of the river.

Two nearshore (walk-around, cuddy-cabin, or large center console) boats were recorded on the river. Both caused plant damage (1 minimal and 1 substantial). As with the cruisers, the operators attempted to stay in the deeper portion of the river channel, but due to their draft, they still caused damage.

When all recorded boats are combined, regardless of type, as boat size (length) increases, the percent of boats that caused damage increased (Figure 26). No damage was observed for the 36 boats less than 15 feet in length. For boats from 16 to 20 feet, 12.4 percent caused damage, while 20.5 percent of boats 21 feet or longer caused damage.

When all recorded boats are combined, regardless of type or length, the overall percentage of boats causing damage and the degree of damage increased (Figure 27). The highest percentage of damage was for boats with 76 to 100-HP engines. Within this category, 4 of the 7 boats, that caused plant damage, caused it due to operator behavior and not simply due to the size of the engine. Having a large engine does not necessarily lead to plant damage. On several occasions, a boat mounted with a 200-HP engine was observed (Figure 28). This boat was never observed to cause damage, as the operator always had the engine trimmed up, the motor slowly idling, and the boat driven in the deeper portion of the river. Figure 28 also shows a second boat, with a 150-HP engine that likewise produced no damage due to the motor being well trimmed up.

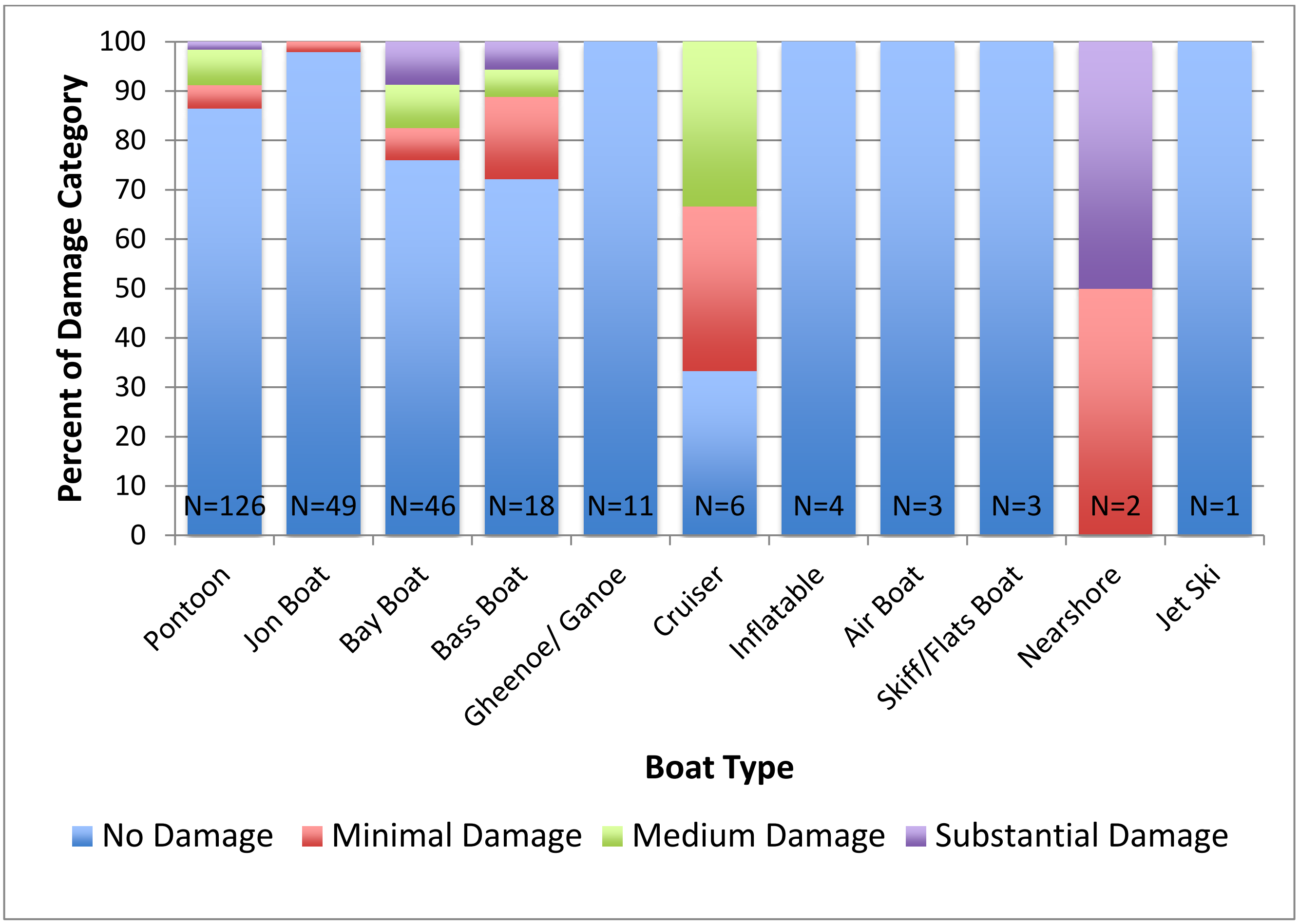


Figure 23. Relative damage to submersed aquatic plants produced by type of boat observed on the Rainbow River, Dunnellon, Florida, 2011 – 2012. Numbers in columns (N=#) are the number of boats of that type observed on the river.

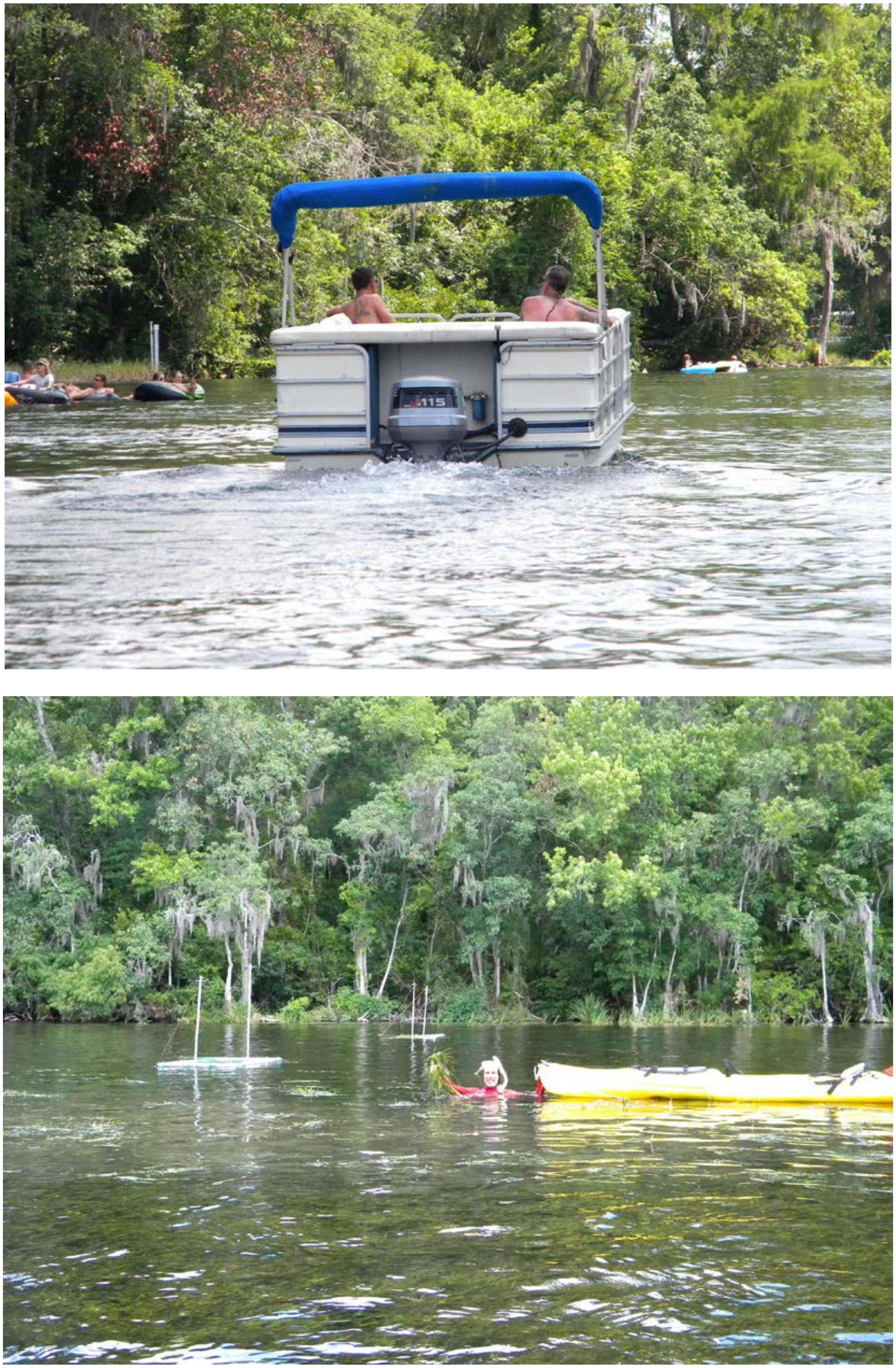


Figure 24. Photos of pontoon boat with 115-HP engine and associated plant damage and sediments caused by this boat, Rainbow River, Dunnellon, Florida, 28 May 2011. (DSCN2190 and DSCN2192)

Figure 25. Photos of pontoon boat motoring along shallow eastern shore (with motor not trimmed up) and associated uprooted plant damage caused by this boat, Rainbow River, Dunnellon, Florida, 28 May 2011. (DSCN2221 and DSCN2224)

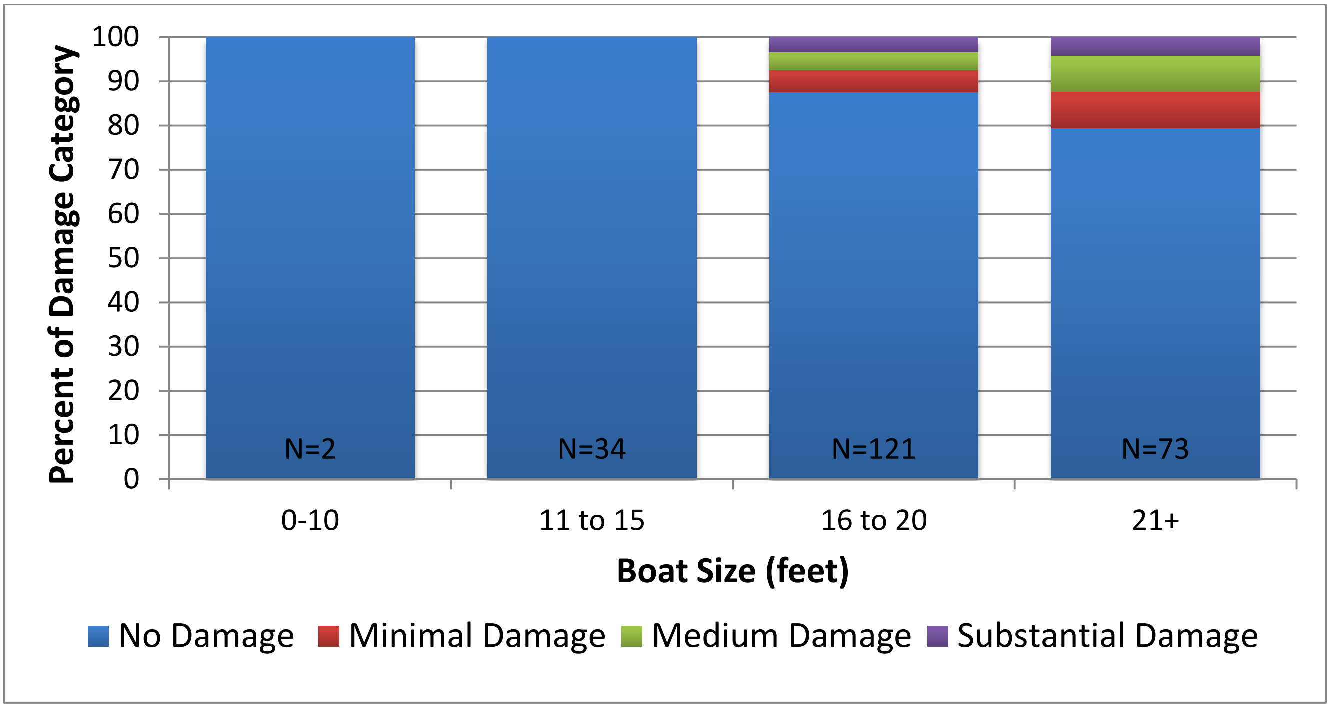


Figure 26. Relative damage to submersed aquatic plants produced by size of boat (length in feet) observed on the Rainbow River, Dunnellon, Florida, 2011 – 2012. Numbers in columns (N=#) are the number of boats of that size observed on the river.

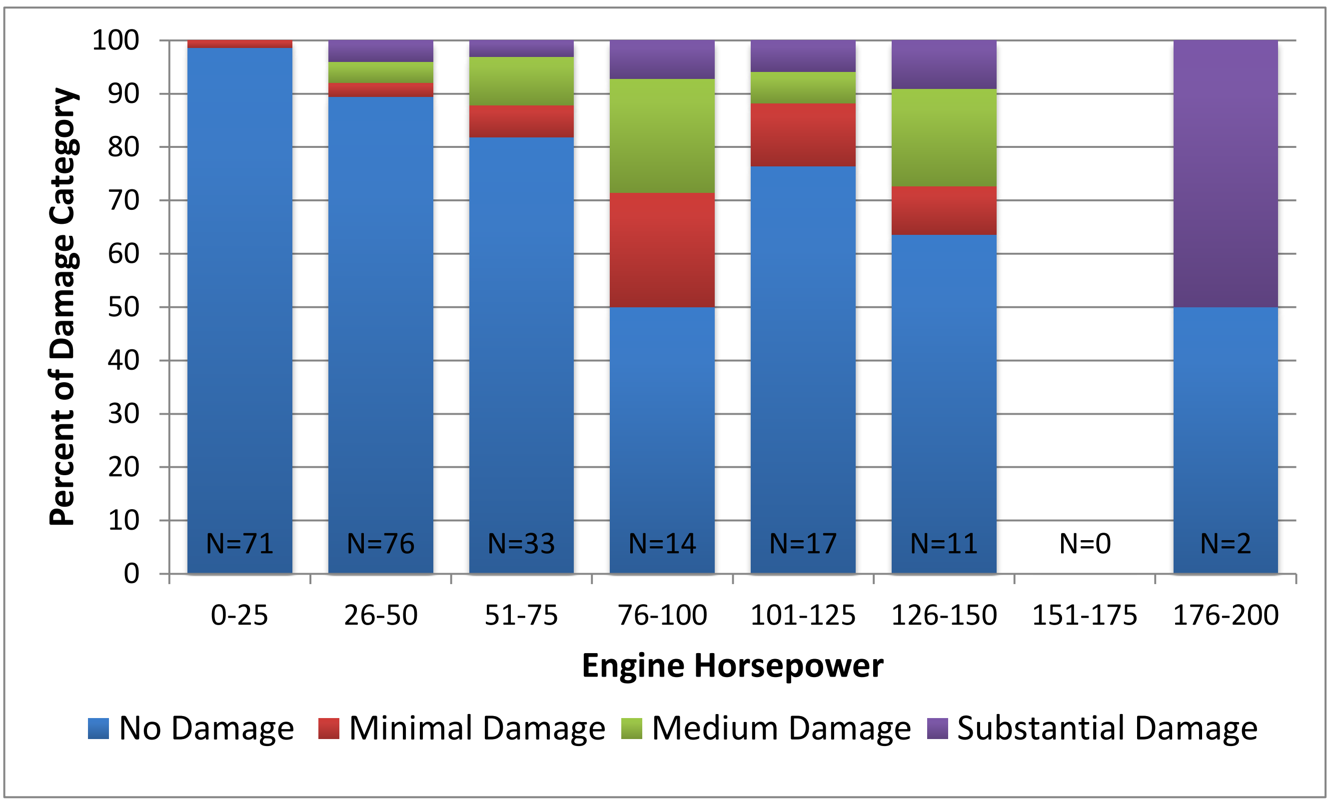


Figure 27. Relative damage to submersed aquatic plants produced by engine size (in horsepower) observed on the Rainbow River, Dunnellon, Florida, 2011 – 2012. Numbers in columns (N=#) are the number of boats with that engine size observed on the river.

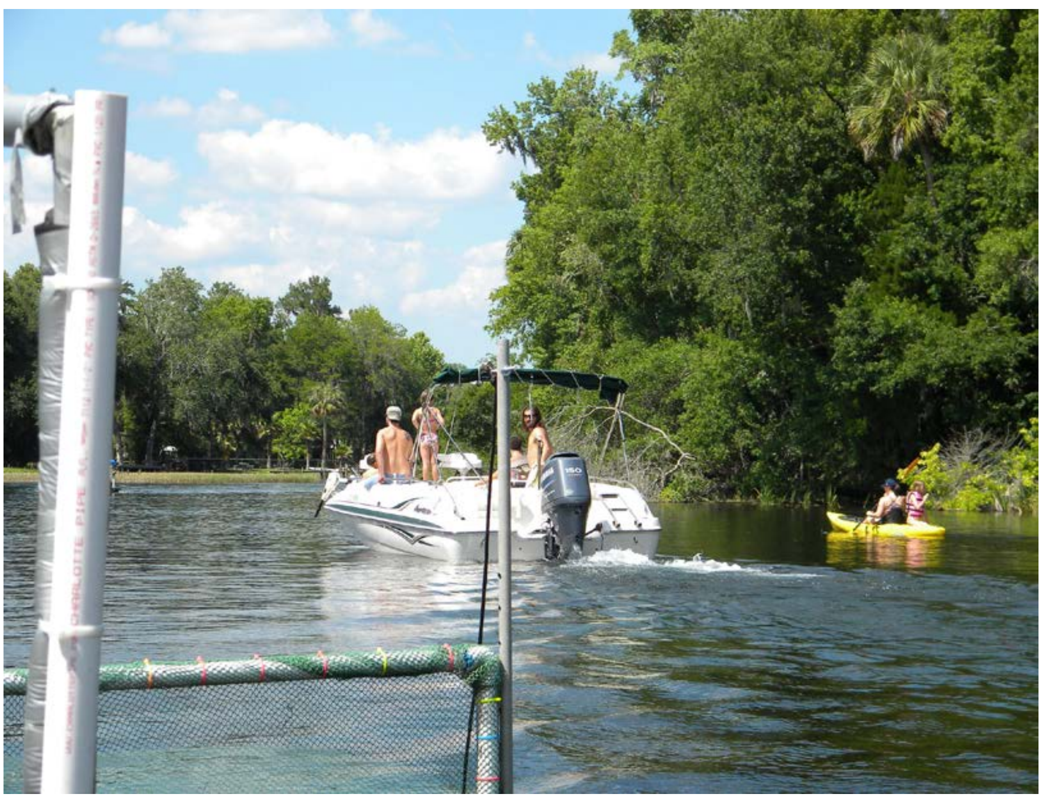


Figure 28. Examples of two boats, with trimmed-up 200 and 150-HP engines, travelling upstream due east of the KP Hole County Park, Rainbow River, Dunnellon, Florida, 28 May 2011. Neither of these boats were observed to damage plants on the river. (DSCN2155 and DSCN2209)

Task 4 - Human activity and aquatic plant relationships

Prop Scars

Number and Location:

A total of 61 prop scars were recorded and analyzed in this project (Figure 29). The average depth of the scars was 3.02 feet (0.92 m). Within the KP Hole County Park boat launch buffer (1,000 feet [305 m]), 16 scars (26.2%) were observed (Figure 31). Only the State Campground tuber take out point had prop scars near it. Within that tuber take out point buffer (1,000 feet [305 m]), 14 scars (23.0%) were recorded (Figure 33). Between the points at which tubers enter and exit the river, 17 scars (23.0%) were recorded (Figure 32). Of the remaining 13 prop scars not accounted for in the tuber zone of the river or either launch or take-out buffer, eight were north of the KP Hole launch buffer (Figure 30), and five were south of the tuber take-out buffer (Figure 34).

These data seem to indicate that there is potentially tuber-boater interactions, leading to prop scars, within these stretches of the river where these two user groups overlap. However, based on this investigation alone, we cannot definitively come to this conclusion for many reasons. First, prop scars can only occur in areas where there are vegetation beds to scar. Beyond the southernmost scar (Scar_ID: 23), beds of submersed aquatic vegetation were uncommon. Since the entire river is an aquatic preserve with a no-wake speed restriction, prop scars are primarily depth dependent (i.e., not related to velocity). Prop scars were recorded for depths ranging from 2 (0.61 m) to 6 feet (1.83 m) (an unusually deep value that resulted from a deep hole located within one of the scars), with an average of 3.02 feet (0.92 m). Currently, the river has not been mapped for depth, so the concentrations of scars that we recorded may simply be because those are the shallowest stretches of the river. Many of the scars occurred at the inside bends of the river where the water was shallow. A number of scars were located near boat docks. Other areas, with high densities of scars, were large shallow expanses of water, with no well-defined deep channel, in particular downstream of the KP Hole County Park and downstream of the State Park tuber take out. Behavioral observations of boaters in these congested areas, while sampling plant transects (Task 2) and drifting plants (Task 4 – net sampling and SCUBA), found that some boaters created these scars while trying to avoid tubers, while others were formed simply in the course of normal navigation through shallow areas.

Regrowth of scars:

The 61 prop scars had a mean length of 18.6 m and mean width of 0.47 m in the fall of 2011 (Table 20). While observing the scars, it was apparent that regrowth of some of the scars had already commenced. Jeff Sowards, Manager of the Rainbow Springs Aquatic Preserve, indicated that the scars indeed had already begun to regrow prior to our initial sampling in October and November of 2011. For the 26 prop scars, that were resampled in Spring 2012, the Fall 2011 mean length was 16.5 m and the Fall 2011 mean width was 0.37 m. The mean length and mean width of these 26 prop scars decreased to 0.14 m and 6.4 m, respectively, by Spring 2012 (Table 20). Over the winter, mean width decreased for 10 of the scars, increased for 2 scars, and stayed the same for 2 scars. Eleven of the scars completely closed in with regrowth from the surrounding plants, primarily Sagittaria kurziana. Total length decreased for 10 scars, increased for 1 scar, and stayed the same for 3 scars. As with width, 11 scars completely filled in with plants, and had zero length. In all cases, scar regrowth was from the adjacent plant community.

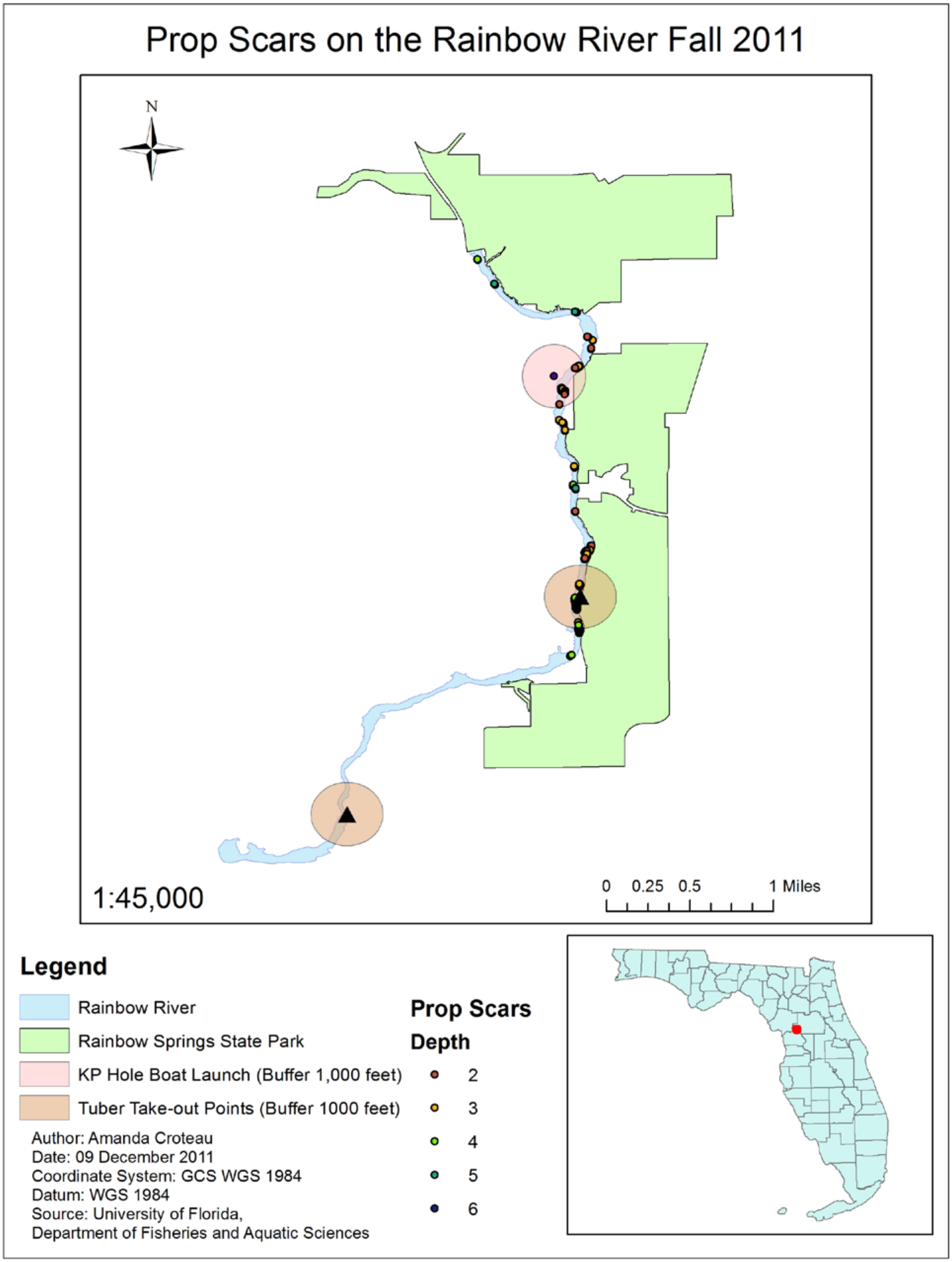


Figure 29. Map showing the location of the 61 prop scars in the Rainbow River, Dunnellon, Florida, fall 2011.

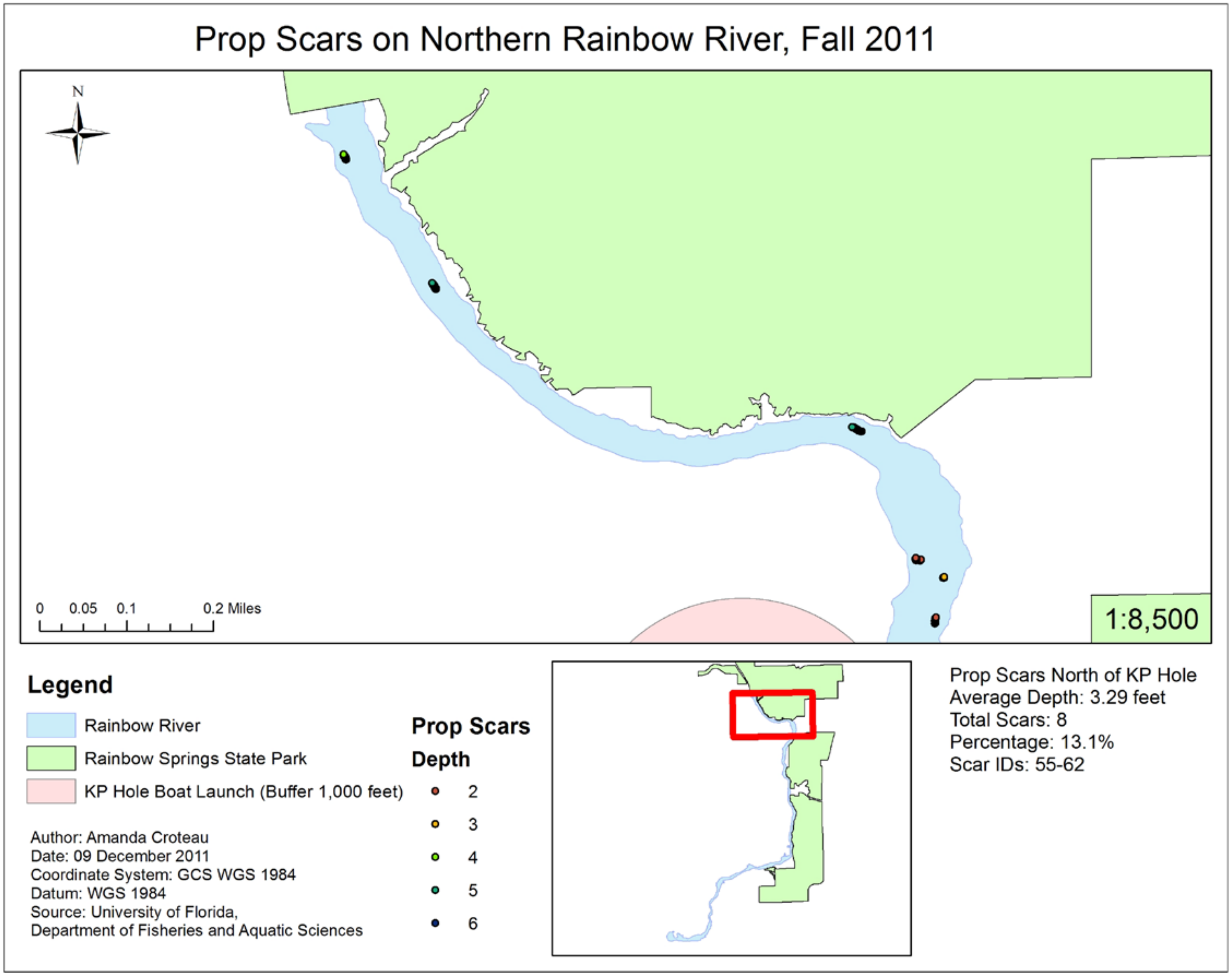


Figure 30. Map showing the location of the 8 prop scars in the uppermost portion of the Rainbow River, Dunnellon, Florida, fall 2011.

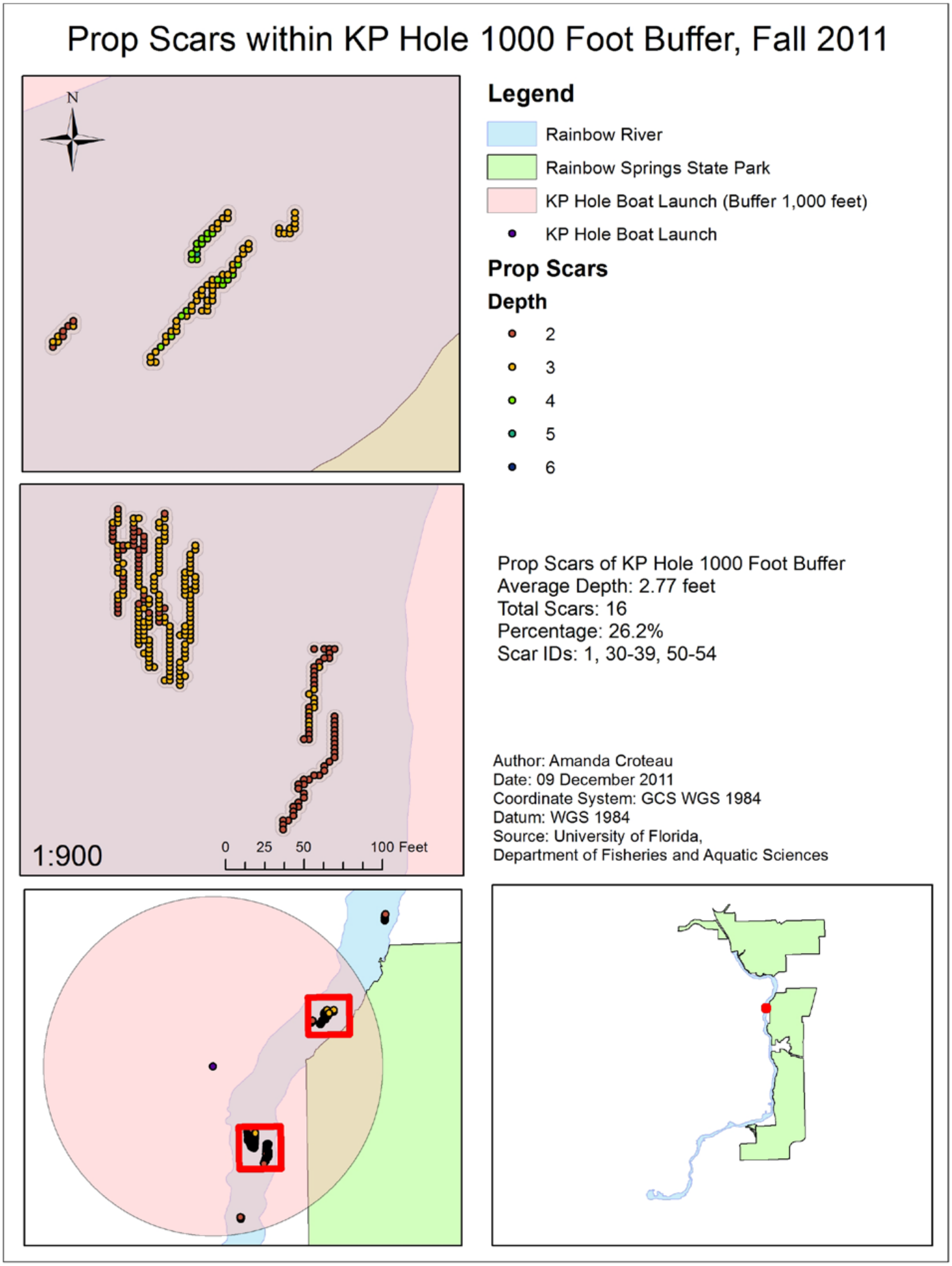


Figure 31. Map showing the location of the 16 prop scars located immediately upstream and downstream of the KP Hole County Park, on the Rainbow River, Dunnellon, Florida, fall 2011.

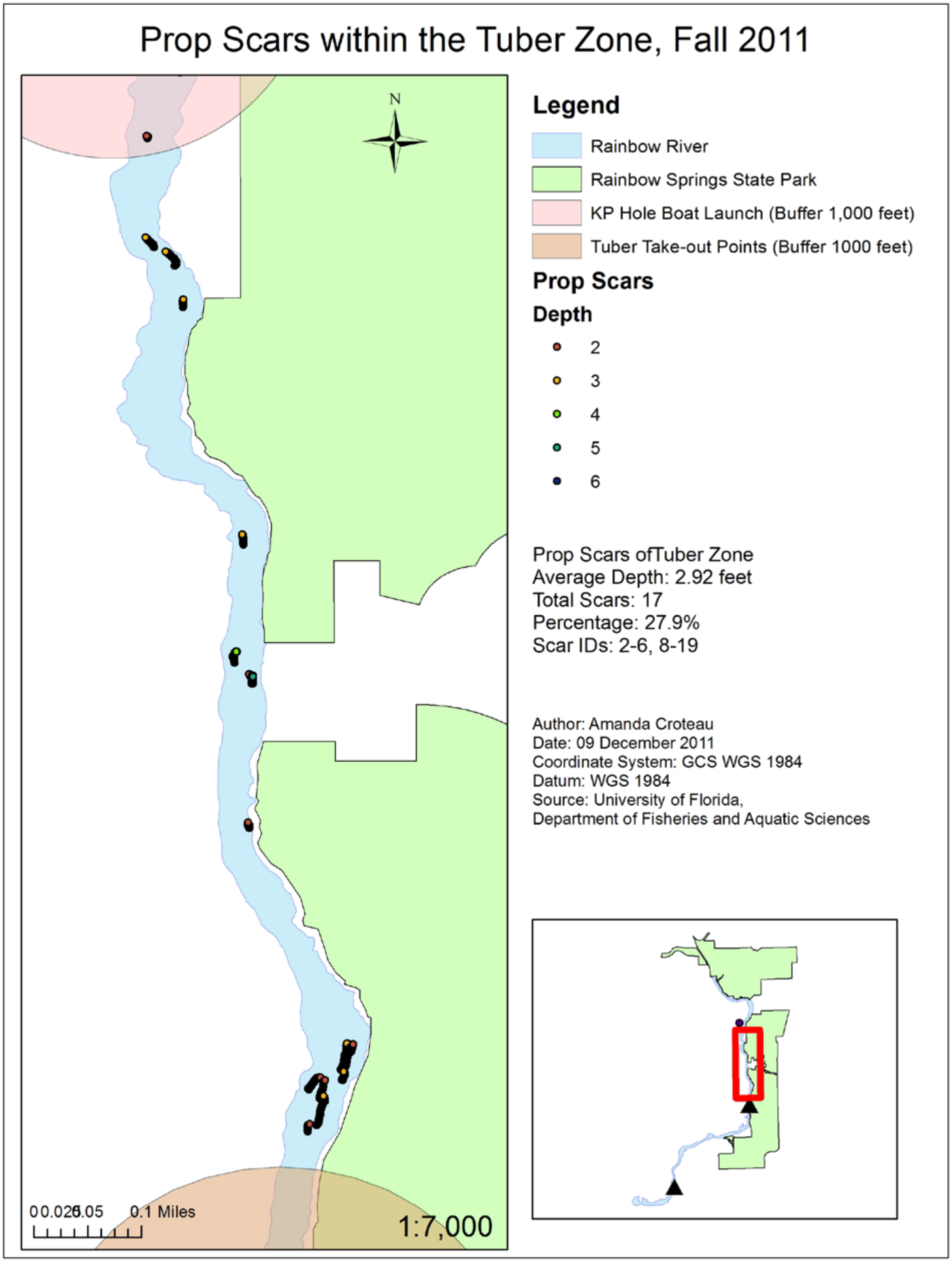


Figure 32. Map showing the location of the 17 prop scars located between the KP Hole County Park and the State Campground tuber take out on the Rainbow River, Dunnellon, Florida, fall 2011.

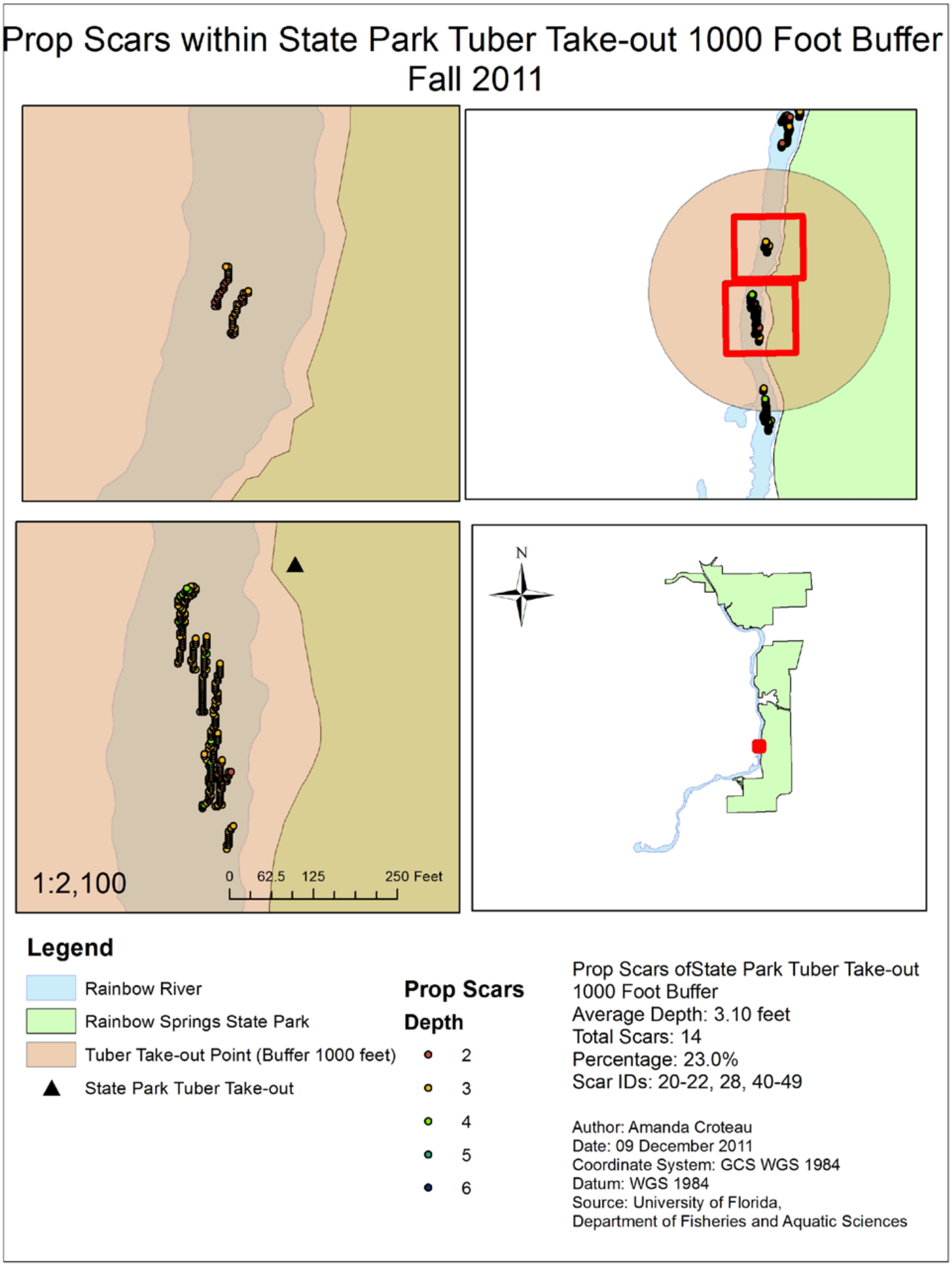


Figure 33. Map showing the location of the 14 prop scars located upstream and downstream from the State Campground tuber take out on the Rainbow River, Dunnellon, Florida, fall 2011.

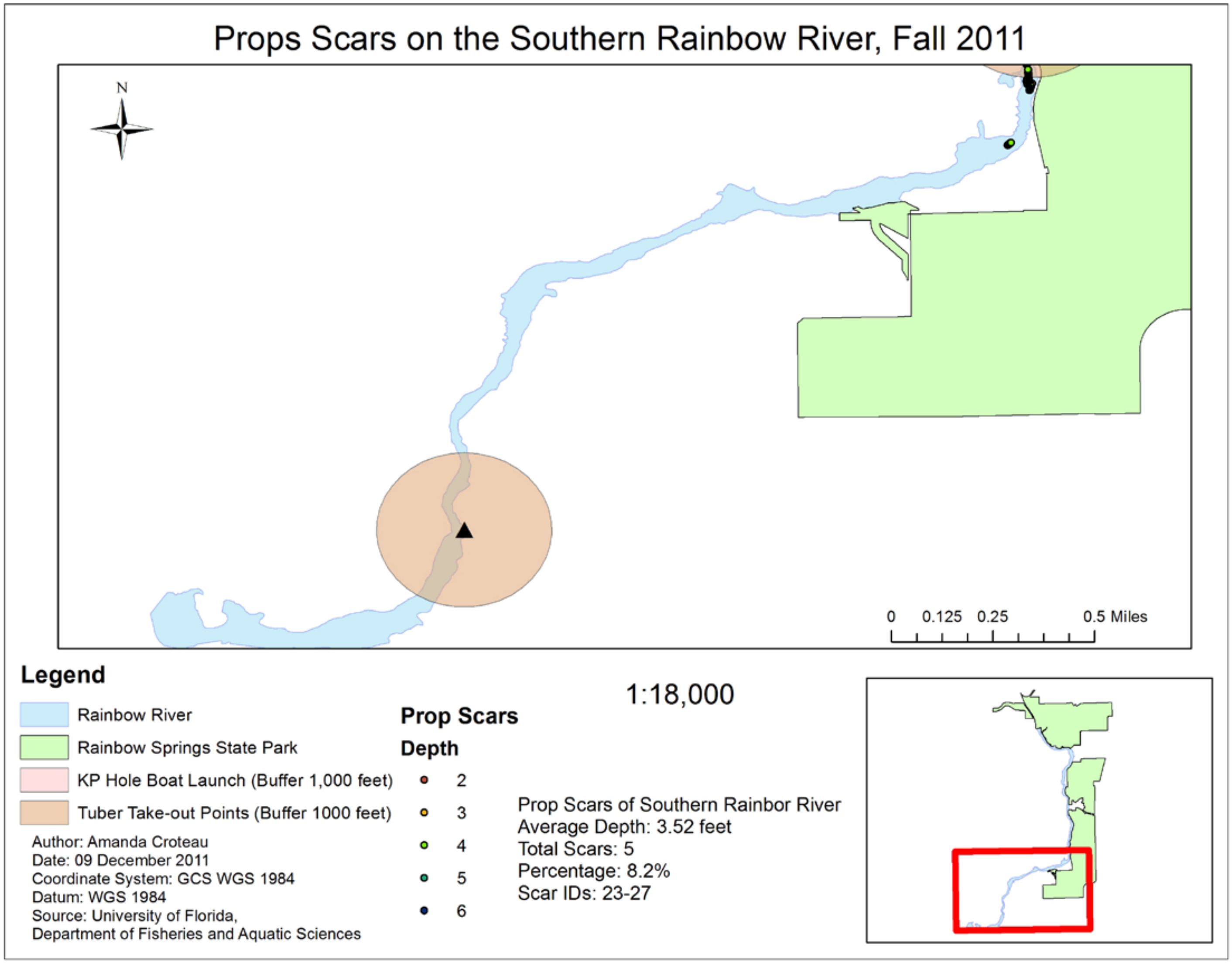


Figure 34. Map showing the location of the 5 prop scars located between the State Campground tuber take out and the Highway 484 bridge on the Rainbow River, Dunnellon, Florida, fall 2011.

Table 20. Total length and mean width for the 61 prop scars observed in Fall 2011 (October and November) and 26 prop scars resampled in Spring 2012 (April), Rainbow River, Dunnellon, Florida. *Prop scar 16 was sampled in Spring 2012, but due to the patchiness of the Hydrilla and filamentous algae in the area, it was impossible to identify the exact location of the scar, and thus its Spring 2012 width and length could not be accurately measured.

Scar ID	**Mean Width (m)**		**Length (m)**	
	Fall 11	**Spring 12**	**Fall 11**	**Spring 12**
1	0.43	0.20	4.9	4.9
2	0.37	0.33	16.8	9.1
3	0.35	.	24.7	.
4	0.47	0.00	11.6	0.0
5	0.37	0.27	12.8	11.9
6	0.53	0.33	20.7	20.1
8	0.40	0.00	11.3	0.0
9	0.33	0.00	5.2	0.0
10	0.30	0.00	8.2	0.0
11	0.30	0.30	6.4	6.4
12	0.50	0.00	51.2	0.0
13	0.33	0.00	47.5	0.0
14	0.43	0.00	12.8	0.0
15	0.47	.	19.2	.
16*	0.37	.	37.5	.
17	0.37	0.28	55.8	26.5
18	0.47	0.30	60.4	53.9
19	0.40	0.00	13.7	0.0
20	0.40	.	13.7	.
21	0.30	.	21.0	.
22	0.53	.	2.7	.
23	0.40	.	13.7	.
24	0.33	.	12.8	.
25	0.57	.	27.4	.
26	0.33	.	9.1	.
27	0.53	.	26.5	.
28	0.93	.	49.4	.
29	0.47	.	18.3	.
30	0.33	.	21.9	.
31	0.40	.	6.4	.
32	0.37	.	20.1	.
33	0.30	.	18.3	.
34	0.27	.	21.9	.

Table 20. Continued.

Scar ID	Mean Width (m)		Length (m)	
	Fall 11	**Spring 12**	**Fall 11**	**Spring 12**
36	0.23	.	21.0	.
37	0.20	.	15.5	.
38	0.33	.	17.4	.
39	0.40	.	21.9	.
40	0.37	.	9.1	.
41	0.40	.	22.9	.
42	0.73	.	35.7	.
43	0.47	.	12.8	.
44	0.27	.	2.7	.
45	0.53	.	39.3	.
46	0.53	.	36.6	.
47	0.33	.	11.0	.
48	0.47	.	33.8	.
49	0.50	.	17.4	.
50	0.37	0.00	4.0	0.0
51	0.43	0.00	8.2	0.0
52	0.33	0.00	10.1	0.0
53	0.33	0.33	24.7	13.7
54	0.30	0.23	6.4	6.4
55	0.30	0.06	10.1	2.0
56	0.43	0.04	3.7	0.6
57	0.27	0.20	2.3	1.7
58	0.23	0.50	2.3	2.7
59	0.20	0.23	2.3	0.9
60	1.00	.	11.9	.
61	2.83	.	12.8	.
62	1.80	.	17.4	.
Overall means of all scars	**0.47**	**0.14**	**18.6**	**6.4**

Task 4 - Human activity and aquatic plant relationships

SCUBA

Rainbow River Use Background:

A new aspect of research that was added to the scope of study for this 2011-2012 Rainbow River study was to gather information about the various types of SCUBA diver related activities on the river. Though the river itself is several miles long, and other forms of recreation use the river in its entirety, the majority of use by divers is concentrated in the half mile north of the KP Hole County Park and on the Devil’s Elbow area within that stretch. This area has some of the deeper sections (deepest just over 10 meters) in the river containing several small spring vents, a small cavern, and a large amount of sandy shoreline next to the primary dive site. Unlike the majority of freshwater springs used as dive sites throughout Florida, the primary zone of use on the Rainbow River is not within easy access to a diver from either the KP Hole County Park or the State Park, causing the need for a means of transportation to the sites. Both dive charter boats and water taxis are used for transportation upstream from the KP Hole County Park, with some divers being picked up and brought back to the KP Hole County Park and other divers swimming with the river current back to the KP Hole County Park.

Diver and Snorkeler Activity:

Diver and snorkeler activity was specifically targeted over a three-day period, 9 March 2012 through 11 March 2012. Observations were collected from the KP Hole County Park and north to the headwaters of the Rainbow River, diver and snorkeler activity was not documented, during this time, south of the KP Hole County Park. Over the period of observation, diver and snorkeler activity consistently occurred from 8 AM until 4 PM, with a peak of activity occurring at 8 AM (Figure 35). Divers and snorkelers entered the water at the same locations by assistance of transportation boats (e.g., Rainbow Water Taxi or American Pro Dive Center on these dates). Two locations were identified where the transportation boats had designated drop locations for both divers and snorkelers. The first site (N 29^{o}05’33.5” W 82^{o}25’52.7”) was near the shore and included a rock bottom with no submersed vegetation within the drop location, yet surrounded by Sagittaria kurziana and Valisneria americana beds. The second site (N 29^{o}05’34.1” W 82^{o}25’47.9”) was the Devil’s Elbow, an area about 10m in depth with numerous small vents. All transportation boats dropped divers and snorkelers off into the two noted locations.

Diver and snorkeler activity were similar and different. Diver activity occurred at both the surface of the water and under the water, while snorkeler activity occurred only at the surface of the water. Diver and snorkeler activity at the surface was similar as both user groups drifted along the surface of the water. Frequently, the drift activity was observed to stop with the participants surfacing and sometimes standing in macrophyte beds to rest. From the beginning (rock bottom location) to the end (KP Hole County Park), the average length of the drift activity was about 90 minutes, but ranged from 30 minutes to 120 minutes for both divers and snorkelers. However, diver and snorkeler activity differed, as diver(s) were under the water. The length of time the divers were under the water was of particular interest in this study due to the potential greater impact to the vegetation as divers have access to submersed beds. Among all observations of diver activity, the average length of time under the water was 40 minutes, with the length of a dive ranging from 15 minutes to 90 minutes. The total amount of time divers were under the water, over the three-day observation period, was 2290 minutes or about 38 hours. The 38 hours of underwater dive activity, however, overlapped and includes divers who made multiple dives (Table 21).

User Behavior:

Divers were not observed to consistently cause damage (i.e., uprooting vegetation or breaking off pieces of vegetation) associated with use of the river. However, it can be noted (Jeff Sowards, Manager, Rainbow Springs Aquatic Preserve, personal communication) that the two main areas of diver/snorkler drop off have shown impacts to the submersed aquatic vegetation communities over time. The near shore bare rock drop area has expanded into the Sagittaria bed approximately fifteen feet on the southern corner. The Devil's Elbow drop zone has shown an extensive decline of the shallow water near shore Valisneria bed. These areas exhibit little recovery due to their high use throughout the year by multiple user groups including boaters, kayakers, canoers, as well as diver/snorkeler groups. During periods of high use, divers were observed to move to vegetated areas of the river to limit congestion, such as the vegetated islands in the middle of the river or shallow, littoral vegetated areas. The observed movement was documented to occur at the surface of the water and under the water as well. The movement of divers to avoid areas of congestion was the only observed behavior with potential to damage vegetated areas of the river. The most noted and obvious damage to vegetation was from boats. On a low-use day (i.e., low number of divers, snorklers, and other users), boats would stay in the deeper parts of the river causing no damage to vegetation. On a high-use day (i.e., high number of river users), to navigate the river, boats had to move into shallow areas of the river to avoid kayakers, divers, snorkelers, other boats, etc. The movement to shallow areas, along with movement up or downstream, to avoid other river users, uprooted vegetation. Sometimes large mats of uprooted vegetation were observed to flow down the river after a boat had passed. Furthermore, vegetation was frequently noticed on boat props. Comparatively, during this observation period, the movement of boats into vegetated areas produced more damage to emergent, floating, and submersed aquatic macrophytes than the movement of divers into the same, vegetated areas.

Table 21. The recorded number of divers and the length (in minutes) of each dive completed (i.e., underwater time), the total dive time by the number of divers completing the same dive, and the total amount of dive time. These data reflect observations made over a three-day period (9 March 2012 through 11 March 2012).

	Number of Divers	Length of Dive (minutes)	Total Time (minutes)
	22	60	1320
	5	30	150
	5	30	150
	5	40	200
	5	20	100
	8	20	160
	8	15	120
	1	90	90
Total	59	305	2290

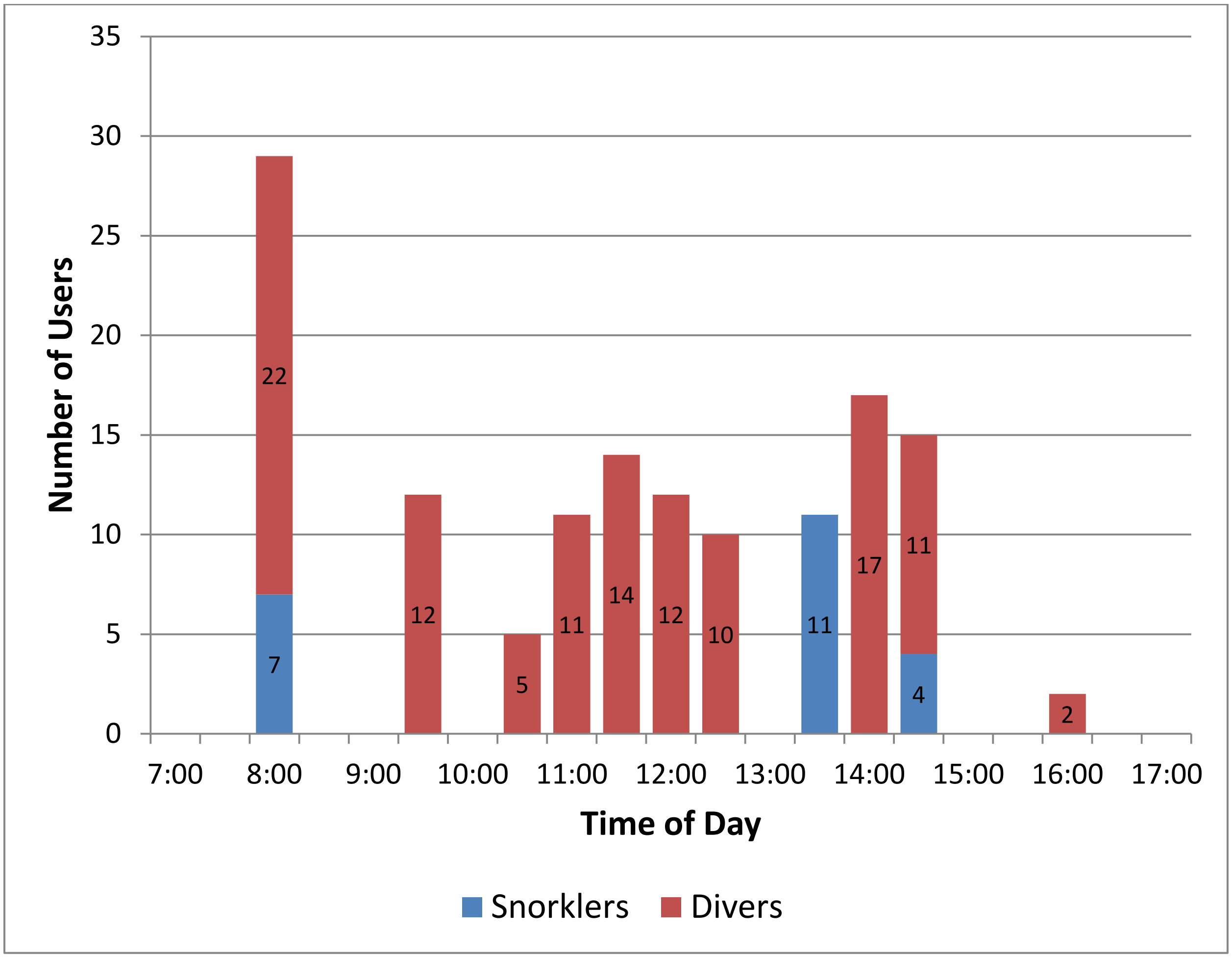


Figure 35. The cumulative number of divers and snorkelers by time of day, corresponding to entrance into the water, among the three-day period of observation from 9 March through 11 March 2012.

Management Suggestions for the River

Overview

The Rainbow River provides a scenic and relaxing recreation environment, which is sometimes punctuated by episodes of high use with multiple segments (tubers, motor boaters, divers, canoers, kayakers, and snorkelers) causing some inter-activity conflict situations. Such conflicts were apparent while observing large groups of SCUBA divers and snorkelers in the upper portion of the river, above the KP Hole County Park, an area heavily used for these activities. Several motor boat operators grew impatient, while travelling upstream. To avoid hitting the divers and snorkelers, and to speed up their passage upstream, the boat operators motored through shallow areas of the river. Likewise, downstream from the KP Hole County Park, motor boaters were observed going into shallow areas to avoid large groups of tubers. The boat operators were impatient. Had they waited 30 seconds or so, the tubers would have passed these boats, allowing them to proceed upstream. Based upon hundreds of interactions with the users of the river while sampling, overall, the visiting public in general seemed to be content with the state of the river, particularly the tubers. Some motor boaters were concerned about increased control, and at times, indicated that boating would be easier without all of the aquatic plants present on the river. Kayakers seemed to be most concerned about the status of the river and were extremely interested in our study. It does seem as if the river is reaching some kind of threshold of heavy use for some users , primarily boaters, who have a difficult time maneuvering the river on holiday weekends and in some areas of the river on other high-use weekends, but outside of that, use is at a tolerable level for most visitors.

River residents seem more pessimistic about the condition of the river, about the disturbance to their quality of experience during summer weekends, and about the trends towards more controls. Most seem to want to maintain their right to use motorized boats on the river. Many have a negative attitude toward SCUBA divers, likely due to their sometimes difficult passage on the river when SCUBA divers and snorkelers are present in large groups.

Much interest has arisen in applying the carrying capacity concept to aquatic systems based on environmental research. Application of this concept has been successful in limiting environmental degradation in some systems, such as in the case of the Ichetucknee River, Florida. However, due to a much larger volume of flow, deeper water, greater mean stream width, limited tree canopy, and nutrient-rich water, the Rainbow River seems to be not as sensitive to environmental degradation through human activity. During this study, sampling methodologies were designed and conducted to monitor and quantify any user-induced changes to the water quality and the aquatic plant community. Changes in water quality, principally total and inorganic solids, were primarily related to boating activity, while changes in water clarity, water temperature, and dissolved oxygen seemed to be unrelated to recreational use. Undoubtedly, certain human activities also damage a small portion of the aquatic vegetation in the river. Boaters were observed causing direct impact to the aquatic plant beds in the river, with larger boats and bigger engines causing greater damage. The river-wide survey of prop scars also documented this impact of boating on the aquatic plants and where it is occurring in the river. However, due to the physical and chemical characteristics of the system, no long-term impact by users on the water quality or aquatic plant communities is apparent at current user levels. Resampling of the plant transects found the aquatic plant community to be fairly stable over the past nearly 20 years since the last study of the river. Resampling, of the fall prop scars in the spring, also indicates that the plant damage quickly regrows during the winter, when boat traffic and other use of the river are light. A number of individuals, encountered on the river, had no clue as to what a prop scar was.

Damage to the aquatic plants of the river has been caused by tubers, walkers, and swimmers. This damage is extremely localized in nature, occurring near the points of entry and exit from the river. The damage often recovers in the off season (winter), but colonization of the damaged areas appear to be primarily by hydrilla. Regrowth of Vallisneria and S. kurziana does occur, but is slow.

In addition to addressing the effects of users on the river, this study continued to collect data to assess long-term changes of the aquatic plant community of the Rainbow River. Sampling methodologies developed during the 1994-1995 study continue to prove to be highly replicable. These data bases and methodologies will enable future researchers to collect data that will allow the identification of any future long-term changes that may occur.

One issue that should be addressed is the continued management of hydrilla in this aquatic system. Hydrilla is present throughout much of the river, and has expanded in portions of the river. Property owners were observed uprooting hydrilla from the river. This material was often allowed to freely float downstream, likely allowing further expansion of this exotic species throughout the river to occur. At times, property owners were observed uprooting native aquatic plants. It appears that the public must be better informed as to the potential long-term effects of their activities.

Management

Of all of the recreational user groups, motor boaters have the greatest impact on the river. Damage is done by a small percentage of this user group. Some of the damage is due to the specific configuration of the boats and their engines, but operator behavior has a far greater impact on how much damage occurs. Based on this, the best way to minimize damage to the river is by educating the boating community. This can be done by:

1. Providing educational pamphlets:

    - To boat owners at the major points of entry to the river – the KP Hole County Park boat ramp and the Highway 41 boat ramp on the Withlacoochee River in Dunnellon
    - To residents, living on the river, via mail
    - To individuals who rent boats via boat rental operators

2. Providing educational kiosks or signage (with photos), at the KP Hole County Park boat ramp and the Highway 41 boat ramp on the Withlacoochee River in Dunnellon, indicating such items as:

    - Proper way to trim one’s motor
    - Staying out of shallow areas of the river
    - What damage can be done to the plants (photos of prop scars)
    - Value of the plants to fish and wildlife and water quality of the river
    - A map showing major areas of prop scarring

3. Holding meetings with local boating groups or individuals interested in the management of the river such as the Rainbow River and Florida Conservation Coalition. Staff from FDEP or the University of Florida can present updates, based on continued monitoring of the river, on an annual basis to better inform the public. Agency staff, university researchers, and interested stakeholders should get together on an annual basis to assess the environmental status and management of the river.

4. Working with boaters and other user groups to develop alternative management options for cases where their activities lead to localized damage to the river. For instance, boats tie up at the State Park tuber take out and canoes and kayaks often pull up onto the tuber take out, making it difficult for tubers to exit the river, thus leading to damage to the aquatic plants at the take-out area. One management option that could be considered is to restrict boaters from tying up their boats to the take-out structure, and to restrict canoes and kayaks from pulling up onto the structure.

The survey of the prop scars in the river identified two areas that had high densities of damage. These were the areas immediately downstream from the KP Hole County Park and the area downstream from the State Park tuber takeout. These areas should be marked as "shallow areas" with signage in the river. Prop scars occurred throughout much of the remainder of the river. Occasional signage could be placed in the river, warning boaters of shallow areas.

Given that the Rainbow River is a state-designated aquatic preserve, that warrants protection, law enforcement should be present on the river, warning boaters not to damage the aquatic plants. If allowed, warning citations should be given on the first violation, followed by tickets on subsequent violations. The threat of being fined will often change the behavior of boaters. This could easily be focused in the area immediately downstream from the KP Hole County Park. This area has easy access for law officers, via the KP Hole County Park boat ramp, and is an area where prop damage to the plants commonly occurs. Currently, Florida law protects seagrasses, located within marine aquatic preserves, from "scarring" by motor boats – see:
http://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0200-0299/0253/Sections/0253.04.html This section of the F.A.C. indicates that "A person operating a vessel outside a lawfully marked channel in a careless manner that causes seagrass scarring within an aquatic preserve established in ss. 258.39-258.399, with the exception of the Lake Jackson, Oklawaha River, Wekiva River, and Rainbow Springs aquatic preserves, commits a noncriminal infraction, punishable as provided in s. 327.73. Each violation is a separate offense." ""Seagrass" means Cuban shoal grass (Halodule wrightii), turtle grass (Thalassia testudinum), manatee grass (Syringodium filiforme), star grass (Halophila engelmannii), paddle grass (Halophila decipiens), Johnson's seagrass (Halophila johnsonii), or widgeon grass (Ruppia maritima)." ""Seagrass scarring" means destruction of seagrass roots, shoots, or stems that results in tracks on the substrate commonly referred to as prop scars or propeller scars caused by the operation of a motorized vessel in waters supporting seagrasses." This law could be changed to include the Rainbow Springs Aquatic Preserve, along with the other freshwater aquatic preserves. "Seagrasses" could be expanded to include native freshwater species of aquatic plants such as S. kurziana and V. americana.

In May and June of this year (2012), water levels in the Rainbow River were extremely low due to the lack of rainfall in the area. Water levels reach almost historic lows. As a result, a large amount of damage occurred to the aquatic plants in the river. Levels were so low, that it was almost impossible to traverse portions of the river without damaging the plants. If such an event occurs in the future, action should be taken to potentially close portions of the river to motorized boat traffic to prevent or minimize damage to the river. Based on the findings of this study, if limited access were allowed, it should be provided to small boats with small engines. Extremely large boats, such as cruisers, should not be allowed on the river.

As indicated above, tubers do cause heavy damage in areas where they enter and exit the river while out of the tubes. This occurs in limited shallow areas of the river. Any attempt to restrict tubers from these areas will simply cause the tubers to find other nearby areas in which to loaf. The area adjacent to and downstream from the KP Hole County Park is denuded of vegetation in the peak summer recreational season. Hydrilla, an exotic invasive plant species, was observed to quickly grow within the damaged areas during the low recreational-use period.

Canoers and kayakers caused minimal damage to the river, occasionally pulling up a plant or stirring up the bottom sediments when they entered shallow areas. They readily used the ramps present on the river, often not getting into the water to enter or exit their boats. It is recommended that the access ramps, for these users, be maintained.

Many individuals, encountered on the river, felt that SCUBA divers were often blamed for damage to the river. The vast majority of diving activity is conducted upstream from the KP Hole County Park. During our observations, that focused on diving activities, both of the divers and of the dive boat operators, we did observe damage to aquatic plants, but it was limited in nature. A greater amount of damage was done by recreational boaters who were trying to avoid large groups of divers. At this time, no suggestions are made as to management of diving on the river.

On several occasions, and at several locations along the river, homeowners or individuals working for homeowners were observed pulling up or cutting aquatic plants along the river. Some of this was legal, being permitted work. In several cases, hydrillla was being pulled up and allowed to float down the river. If not already done, homeowners could be educated as to what they could and should be doing. This information could be provided to homeowners on the river, along with the information that is discussed above in regards to boating activities on the river. It was common for nearshore shaded disturbed areas to regrow with hydrilla.

References

Absher, J. D., and R.G. Lee. 1981. Density as an incomplete cause of crowding in back country settings. Leisure Sciences, 4: 231-247.

Alldredge, R. 1973. Some capacity theory for parks and recreation areas. Trends, Oct-Dec, 20-30.

Altman, I. 1975. The environment and social behavior. Brooks Cole Company, Monterey, California.

Babbie, E. 1992. The practice of social research. Wadsworth Publishing Company, Belmont, California.

Bell, S.S., M.O. Hall, S. Soffian, and K. Madley. 2002. Assessing the impact of boat propeller scars on fish and shrimp utilizing seagrass beds. Ecological Applications 12(1): 206-217.

Blum, J.L. 1954. Evidence for a diurnal pulse in stream phytoplankton. Science 119:732-734.

Bowes, G., T.K. Van, L.A. Garrand, and W.T. Haller. 1977. Adaptation to low light levels by hydrilla. Journal of Aquatic Plant Management 15: 32-35.

Buecher, R.D. 1971. National Parks recreation and open space standards. National Recreation and Park Association, Washington D.C.

Bultena, G. L., Field, W., and D. Albert. 1981. Closing the gates: A study of backcountry use-limitations at Mount McKinley National Park. Leisure Sciences, 4: 249-267.

Burch, W.R., Jr. 1984. Much ado about nothing - some reflections on the wider and wilder implications of social carrying capacity. Leisure Sciences, 6: 487-496.

Butcher, R.W. 1933. Studies on the ecology of river. I. On the distribution of macrophytic vegetation in the rivers of Britain. Journal of Ecology 21: 58-91.

Canfield, D.E., Jr. and M. V. Hoyer. 1988. Influence of nutrient enrichment and light availability on the abundance of aquatic macrophytes in Florida streams. Canadian Journal of Fisheries and Aquatic Science 45:1467-1472.

Christopher, S. 1991. Carrying capacity determination of resource based recreation for the Florida Park System. Unpublished master's thesis, University of Florida, Gainesville, Florida.

Desor, J.A. 1972. Toward a psychological theory of crowding. Journal of Personality and Social Psychology, 21(1): 79-83.

Duarte, C.M. and D. E. Canfield, Jr. 1990. Macrophyte standing crop and primary productivity in some Florida spring-runs. Water Resources Bulletin 26(6): 927-934.

Florida Department of Natural Resources. 1991. History of the Florida State Park System. Unpublished Report. Department of Natural Resources, Tallahassee, Florida.

Forester, R.R. 1973. Planning for man and nature in National Parks: Reconciling participant use. (IUCN Publication New Series). International Union for Conservation of Nature and Natural Resources. Morges, Switzerland.

Frissell, S., Lee, R., Stankey, G., and E. Zube. 1980. A framework for estimating the consequences of alternative carrying capacity levels in Yosemite valley. Landscaping Plan, 7: 151-170.

Graefe, A.R., Vaske, J.J., and F.R. Kuss. 1984. Social carrying capacity: An integration and synthesis of twenty years research. Leisure Sciences, 6: 395-431.

Gustavsson, K., P. Marvan, and A. Muller-Haeckel. 1978. Diel drift of diatoms in an equatorial river. Oikos 31:38-40.

Hammitt, W.E., McDonald, C. D., and F.P. Noe. 1992. Use levels and encounters: Important antecedents of perceived crowding among non-specialized recreationists. USDI National Park Service Southeast Regional Office and USDA Forest Service Southeastern Forest Experiment Station.

Heberlein, T. 1977. Density, crowding, and satisfaction: Sociological studies for determining carrying capacities. In USDA Forest Technical Report NC-28, Proceedings: River Recreation Management and Research Symposium (pp.67-76. North Central Forest Experiment Station, St. Paul, Minnesota.

Heberlein, T., and B. Shelby. 1977. Carrying capacity, values, and the satisfaction model: a reply to Greist. Journal of Leisure Research, 9(2): 142-148.

Henigar and Ray. 1987. Rainbow River Management Plan, Summary Report, Phase I. Henigar and Ray Engineering Associates, Inc., Crystal River, Florida.

Holland, S.M., and C.E. Cichra. 1995. Human and environmental dimensions of the recreational use of Blue Run and Rainbow Springs State Park, Dunnellon, Florida. University of Florida, Gainesville, Florida.

Hoyer, M.V., Canfield, Jr., D.E., Horsburgh, C.A., and K. Brown. 1996. Florida freshwater plants: A handbook of common aquatic plants in Florida lakes. Special Publication SP 189. University of Florida, Gainesville, Florida.

Jubenville, A., and B. Twight. 1993. Outdoor recreation management. Venture Publishing, Inc. , State College, Pennsylvania.

Kania, M. R. 1985. A site analysis for determining wilderness carrying capacity. In R.C. Lucas (Ed.), National Wilderness Research Conference: Current Research (pp. 462-470). Intermingling Research Station, Ogden, Utah.

Knudson, D. 1980. Outdoor recreation. MacMillian Publishing Company, New York, New York.

Lawrence, J. 1974. Science and sentiment: Overview of research on crowding and human behavior. Psychological Bulletin, 8: 712-720.

Lee, R. G. 1975. The management of human components in the Yosemite national park ecosystem. The Yosemite Institute, Yosemite, California.

Lee, R. G. 1977. Alone with others: The paradox of privacy in wilderness. Leisure Sciences, 1: 3-19.

Lime, D.W. 1977. Research for river recreation planning and management. In USDA Forest Service, General Technical Report, NC-28, River Recreation Management and Resource Symposium Proceedings (pp. 202-209). North Central Forest Experiment Station, St. Paul, Minnesota.

Lucas, R.C. 1964. Wilderness perceptions and use: the example of the boundary waters canoe area. National Resource Journal, 3: 394-411.

Lucas, R.C., and G. Stankey. 1974. Social carrying capacity for backcountry recreation resources: Applying the results. USDA Forest Services, General Technical Report, NC-9. North Central Forest Experiment Station, St. Paul, Minnesota.

Lucas, R.C. 1980. Use patterns and visitor characteristics, attitudes, and preferences, in nine wilderness and other roadless areas. USDA Forest Service Research Paper INT-253. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Manning, R. 1985. Studies in outdoor recreation. Oregon State University Press, Corvallis, Oregon.

Manning, R., and C.P. Ciali. 1980. Recreation density and user satisfaction: A further exploration of the satisfaction model. Journal of Leisure Research, 12: 329-345.

Mumma, M.T. 1996. Effects of recreation on the water chemistry and submersed plant community of Rainbow River, Florida. Unpublished master's thesis, University of Florida, Gainesville, Florida.

Mumma, M.T., C.E. Cichra, and J.T. Sowards. 1996. Effects of recreation on the submersed aquatic plant community of Rainbow River, Florida. Journal of Aquatic Plant Management 34: 53-56.

National Park Service. 1987. The carrying capacity of Lake Powell: A management analysis of capacity for boater recreation, Glen Canyon national recreation area AZ/UT. Rocky Mountain Regional Office, Denver, Colorado.

Odum, H.T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecological Monographs 27: 55-112.

Peterson, G. L. 1983. Rationing and redistribution of recreational use of scarce resources with limited carry capacity. In S. R. Leiber and D. R. Fesenmaier (Ed.), Recreation planning and management (pp. 286-302). Venture Publishing, State College, Pennsylvania.

Pitlo, R.H. and F.H. Dawson. 1989. Flow-resistance of aquatic weeds. Pages 74-84 in: A.H. Pieterse and K.J Murphy, eds. Aquatic weeds: The ecology and management of nuisance aquatic vegetation. Oxford University Press, Inc., New York, New York.

Randall, J. 1977. The windshield experience: Visitor satisfaction in a drive through Dunes Park. Unpublished master's thesis, University of Wisconsin, Madison.

Rappoport, A. 1975. Toward a redefinition of density. Environment and Behavior, 7: 133-158.

Schmidt, D., and J. Keating. 1979. Human crowding and personal control: An integration of the research. Psychological Bulletin, 36: 680-700.

Shelby, B. 1980. Contrasting recreational experiences: Motors and oars in the Grand Canyon. Journal of Soil and Water Conservation, 35(3):, 129-131.

Shelby, B., and T. Heberlein. 1984. A conceptual framework for carrying capacity determination. Leisure Sciences, 6: 433-451.

Shelby, B., and T. Heberlein. 1986. Carrying capacity in recreation settings. Oregon State University Press, Corvallis, Oregon.

Shelby, B., Heberlein, T., Vaske, J., and G. Alfano. 1983. Expectations, preferences, and feeling crowded in recreation activities. Leisure Sciences, 6: 1-14.

Shelby, B., Vaske, J., and T. Heberlein. 1989. Comparative analysis of crowding in multiple locations: Results from fifteen years of research. Leisure Sciences, 6: 269-291.

Smith, R. L. 1966. Ecology and field biology. Harper and Row Publishers, New York, New York.

Stankey, G. 1971. Wilderness: Carrying capacity and quality. The Naturalist, 22(3): 7-13.

Stankey, G. 1972. A strategy for the definition and management of wilderness quality. In J.V. Krutilla (Ed.), Natural environments studies in the theoretical and applied analysis. John Hopkins Press, Baltimore, Maryland.

Stankey, G. 1973. Visitor perception of wilderness recreation carrying capacity. USDA, Forest Service Research Paper, INT-142. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Stankey, G. 1980. Carrying capacity: Management and resource progress in the United States. Landscape Research, 5(3): 6-10.

Stankey, G., and S. McCool. 1984. Carrying capacity in recreational settings: Evaluation appraisal and application. Leisure Sciences, 6: 453-473.

Steward, K.K. 1991. Competitive interaction between monoecious hydrilla and American eelgrass on sediments of varying fertility. Florida Scientist 54: 135-137.

Stockdale, J. E. 1978. Crowding: Determinants and effects. In L. Berkowitz (Ed.), Advances in experimental social psychology. Academic Press, New York, New York.

Stokols, D. 1972. On the distinction between density and crowding: Some implications for future research. Psychology Review, 79: 275-277.

Tarver, D.P., J.A. Rodgers, M.J. Mahler, and R.L. Lazor. 1979. Aquatic and wetland plants of Florida. Second Edition. Bureau of Aquatic Plant Research and Control, Florida Department of Natural Resources, Tallahassee, Florida.

Titre, J., and A.S. Mills. 1982. Effect of encounters on perceived crowding and satisfaction (Miscellaneous Publication 18). University of Minnesota, Forest and River Recreation, Agricultural Experiment Station, Minneapolis, Minnesota.

Uhrin, A.V., and J.G. Holmquist. 2003. Effects of propeller scarring on macrofaunal use of the seagrass Thalassia testudinum. Marine Ecology Progress Series 250: 61-70.

U.S. Department of the Interior. 1993. The National Parks index 1994. Department of the Interior, Washington D.C.

Van Wagtendonk, J.W. 1985. The determination of carrying capacity for Yosemite wilderness. In R.C. Lucas (Ed.), National Wilderness Research Conference: Current Research (pp. 456-461). Intermountain Resource Station, Ogden, Utah.

Vaske, J. J., Graefe, A. R., and A. Dempster. 1982. Social and environmental influences on perceived crowding. In Proceedings of the Wilderness Psychology (pp. 211-227). West Virginia University, Morgantown, West Virginia.

Wagar, J.A. 1964. The carrying capacity of wildlands for recreation (Forest Service Monograph No. 2). Society of American Foresters, Washington D.C.

Wagar, J.A. 1966. Quality in outdoor recreation. Trends in Parks and Recreation, 3: 9-12.

Washburn, R.F., and D.A. Sole. 1983. Problems and practices in wilderness management: A survey of managers. USDA Forest Service Resource Paper, INT-304.

Water and Air Research. 1991. Diagnostic studies of the Rainbow River. Prepared for Southwest Florida Water Management District. Water and Air Research, Inc., Gainesville, Florida.

West, P. C. 1982. Effects of user behavior on the perception of crowding in backcountry forest recreation. Forest Science, 28(1): 95-105.

Wilson, E.O. 1975. Sociobiology: The new synthesis. Harvard University Press, Cambridge, Massachusetts.

Wirth, C. 1955. The landscape architect in National Park work: His projects, opportunities, problems, and obligations. Landscape Architecture, 46(1): 13-18.

Womble, P., and S. Studekaker. 1981. Crowding in a national park campground. Environment and Behavior, 13: 557-573.