Fish and Invertebrate Communities of Short-hydroperiod Wetlands in the Rocky Glades:
Crayfish Population Dynamics and Dispersal

Final Report

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Project: Fish and Invertebrate Communities of Short-hydroperiod Wetlands in the Rocky Glades

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1. Executive Summary

Restoration efforts in Everglades National Park have focused on hydrology as the key factor for restoring the natural ecosystem. To evaluate the potential impacts of restoration options on the aquatic fauna, we studied the ecology of crayfish *Procambarus alleni* that have multiple functional roles in aquatic communities of the Everglades. This species is designated as an indicator species for evaluating restoration success. The objective of this study was to determine the factors that impact crayfish population dynamics in the marl prairie wetlands of the Rocky Glades where the seasonal hydropattern has been severely disrupted. Research on crayfish ecology was initiated in 1998. Experiments and monthly monitoring of the crayfish population were conducted during the flood season at nine sites in representative habitats that vary in hydroperiod, vegetation composition, and other environmental conditions.

I first developed and evaluated a quantitative method for sampling crayfish in these heterogeneous habitats. Using this methodology, we determined that high densities of crayfish were consistently supported in habitats characterized by hydroperiods longer than seven months and groundwater levels less than 0.5 m over the dry season. The longer hydroperiod habitats had large surface areas suitable for crayfish burrows (e.g., substantial peat overlay or large numbers of shallow soil-filled solution holes). Deep solution holes with little or no vegetation supported few crayfish, despite the presence of surface water after surrounding areas had dried. Field and laboratory experiments showed that growth rates were also significantly higher in longer hydroperiod habitats. Dispersal during flooding was directed at opportunistic colonization of newly flooded habitat, but

during the drydown, crayfish constructed or occupied local burrows rather than seeking deeper water. Mark-release-recapture studies on crayfish showed that crayfish survival over the dry season was significantly higher in habitats with longer hydroperiods and higher groundwater levels.

A spatially-explicit stage-structured population model was used to assess crayfish population viability and persistence under environmental conditions measured in marl prairie habitat. A habitat suitability index was developed using the association between local crayfish density, hydroperiod, and vegetation composition quantified using a GIS. Calculations indicated that large expanses of shorter hydroperiod areas of the marl prairie currently function as population sinks. Results from simulated habitat changes that might occur if hydrology is restored to pre-drainage conditions suggested that the crayfish population size would increased by an order of magnitude following an increase in population source habitat. Using the GIS habitat classification, we also calculated changes in crayfish annual productivity due to growth and reproductive output in different habitats. Comparisons of the annual turnover ratios (biomass:productivity) showed that the crayfish population is not replacing itself across most of the marl prairie habitat associated with shorter hydroperiods.

Our research to date has revealed valuable insights into the patterns and mechanisms of the impacts of disrupted hydropatterns on crayfish ecology in the Florida Everglades. Our data has shown how environmental changes associated with shortened hydroperiod have affected crayfish growth, survival, dispersal, and productivity. Furthermore, this work has provided quantitative estimates of changes that might occur under habitat restoration options or following further degradation of key wetland habitats. Because crayfish represent a key component of this aquatic community, these changes that we demonstrated will have far-reaching consequences throughout the Everglades trophic system.

2. Introduction

Changes in the hydrology of the Everglades are believed to be negatively impacting all levels of the faunal community. Longer dry seasons, lower groundwater levels, and overdrainage of wetlands have adversely impacted fish and macroinvertebrate abundances in most freshwater habitats of Everglades National Park (Loftus et. al 1992; Gunderson and Loftus 1994). Densities of other fauna dependent on marsh productivity are lower than historical densities and densities predicted by habitat area (e.g, piscivorous wading birds, Ogden 1994). The impacts of increasing the length of drydown periods are believed to be especially severe in the marl prairies of the eastern Everglades (Rocky Glades) where the wet/dry seasonality has been drastically altered by drainage (Loftus et al. 1992).

The aquatic habitat of the Rocky Glades is comprised of seasonally-flooded marl prairie with rock solution holes and shallow soil-filled depressions that support aquatic and semi-aquatic vegetation. This habitat grades into sawgrass marshes on peat substrate on the approach to Shark River Slough in the west and Taylor Slough in the southeast (Gunderson 1994). The aquatic fauna cope with drydowns in different ways. The deeper solution holes in the Rocky Glades may function as dry season refuges for fishes and some invertbrates to the extent that surface water remains in the holes (Loftus et al 1992). However, longer drydowns and lower groundwater levels may cause higher mortality and lower densities. Restoration efforts for these disturbed wetlands are aimed at increasing the productivity in aquatic populations (Davis and Ogden 1994).

The crayfish *Procambarus alleni* is an important component of the Everglades food web (Kushlan and Kushlan 1979), but little is known of the ecology of the species. Crayfish density is highest in marshes with high vegetation biomass, but low densities are found in deeper sloughs (Kushlan and Kushlan 1979; Jordan et. al 1996; Rhoads 1976) and solution holes (Loftus et. al 1992). Kushlan and Kushlan (1979) suggested that crayfish do not migrate to deeper water (e.g., in solution holes) but, instead, may survive the dry season by burrowing to the groundwater. Spatial and temporal comparisons of crayfish distribution from these studies are difficult because of differences in sampling methods and scale (Loftus and Eklund 1994). Among the major questions that remain

unanswered are how do crayfish cope with the changes in hydropattern and what population-level effects will be manifested by changing hydroperiod in the Rocky Glades during efforts to restore historical hydropatterns.

3. Objectives

The overall aim of this project is to study population ecology of crayfish *Procambarus alleni* in the seasonal wetlands of the Rocky Glades so that we can quantify the impacts of altered hydropatterns on crayfish population dynamics and predict how hydrological restoration will affect crayfish populations. The main objectives are designed to investigate dispersal in crayfish as a mechanism for surviving drydowns and to describe crayfish population dynamics in a heterogeneous landscape influenced by hydroperiod. Specific objectives are:

3.1 To develop a quantitative and standardized sampling method for estimating crayfish density and experimental mark-recapture parameters.

3.2 To monitor the distribution and abundance of crayfish in marl prairie habitats and evaluate spatio-temporal patterns under different hydrological and habitat conditions.

3.3 To study dispersal and colonization patterns in flooded marsh habitats so that their roles in population redistribution can be assessed.

3.4 To measure growth, reproductive output, and standing stock biomass under different environmental conditions and calculate differences in productivity associated with habitat and hydroperiod.

3.5 To model crayfish population dynamics as a function of habitat distribution and to simulate environmental changes so that restoration impacts can be assessed quantitatively.

4. Research Results

4.1. Population monitoring[1]

Marl prairie habitat was surveyed in 1998, and nine sites were selected for use as crayfish monitoring sites. Selection criteria for sites were relative length of hydroperiod, dominant vegetation, and type of substratum; fluctuation in water stage was monitored at nearby hydrological monitoring stations. Sites consisted of long-hydroperiod rock solution holes (A13.1), long-hydroperiod peat-overlayed rock with cypress and sawgrass marsh (NP62), medium-hydroperiod marl-overlayed rock with sawgrass and shallow depressions (CR2.1, CR2.2, A13.2, NP44), and short-hydroperiod marl-overlayed rock with sawgrass/muhlygrass marsh and shallow depressions (R158, NTS14, DO1). The ground surface elevations at hydrological stations were used for estimating the depths that crayfish must burrow to reach the water table in a given area during the dry season.

Measurements taken at each site during monthly sampling included water depth, temperature, dissolved oxygen, pH, and conductivity. Except for water depth, none of these measurements was associated with crayfish density at sites. Sampling was discontinued when surface water level fell below 4 cm (i.e., the height of openings to a crayfish trap). A quantitative and standardized sampling method was developed from mark-recapture experiments[1]. During sampling, crayfish were captured using minnow traps, measurements were taken (carapace length, weight, sex), and they were released at each site.

4.1.1 Sites A13.1 and A13.2

Site A13.1 and A13.2 are located in habitats dominated by rock solution holes in the north Pinelands (Long Pine Key). A13.1 has deep solution holes (0.7 – 1.2 m depth) that generally hold surface water the longest as the dry season progresses. The surrounding habitat is marl with a low density of solution holes. Crayfish density at this site is among the lowest of all sites. No crayfish have been recaptured within a wet season or between wet and dry seasons. The low density of crayfish there may be due to poor water quality near the bottom of the solution holes in which dissolved oxygen is

usually very low. These solution holes may act as sinks for crayfish seeking refuge during drydowns.

Site A13.2 consists of shallow, soil-filled solution holes or depressions. Crayfish density consistently averages 400 animals per hectare, which is about medium density among all sampling sites. Crayfish have been recaptured both within wet seasons and between wet seasons, indicating that survival in this habitat is relatively high. Dispersal out of these shallow solution holes occurs quickly with flooding, but dispersing crayfish do not move long distances. Comparison of the ground surface elevation and lowest water levels during the dry season shows that burrows may have to be up to two feet deep to contact groundwater.

4.1.2 Sites CR2.1 and CR2.2

These sites on Context Road have shallow soil-filled solution holes surrounded by high rocky substrate. Crayfish densities are at a medium level among all sites, and the recapture rate is generally high with limited dispersal as flooding occurs. The habitat and crayfish dynamics of this area appear to be similar to that at site A13.2. Groundwater levels were near the surface during the past two dry seasons. This indicates that crayfish survival may be linked to microhabitat features and not solely to the presence of water in solution holes.

4.1.3 Site R158

This site is located east of Taylor Slough near the Pinelands. The habitat contains numerous small and a few large shallow depressions surrounded by rocky substratum. The surface elevation is low and water level falls rapidly during drydowns. This area has a medium hydroperiod among marl prairie sites but is also affected by periodic flooding by the pump stations on the L31W Canal. Crayfish density is generally low but increases during the late wet season mostly due to colonization from other areas.

4.1.4 Site NTS14

This site is located west of Taylor Slough and north of the Pinelands. The habitat has few shallow soil-filled solution holes of various sizes and undergoes a short

hydroperiod. When flooded, crayfish occur in low densities. Recapture rates indicate that most of these crayfish are colonizers from other areas, so this habitat may function as a sink for animals isolated during drydowns.

4.1.5 Site P44

This site located west of the Pinelands undergoes a longer hydroperiod (9 mo) among Rocky Glades sites. The habitat consists of a high density of shallow solution holes and depressions. Crayfish density was consistently high compared to all other sites, despite the fact that ground water in this area fell to very low levels during the dry season.

4.1.6 Site P62

This site in the Pa-hay-okee peat overlay marshes is characterized as a longer hydroperiod (9-10 mo) among the sample sites. The highest densities of crayfish occur in this area as well as the largest adults and the highest density of juveniles during the June recruitment event. The characteristics of this habitat may represent an ecotone between the higher elevation marl prairie and Shark River Slough, both of which have lower densities of crayfish.

4.1.7 Site DO1

This site in the southern Pinelands ("Finger Glades") undergoes a short hydroperiod. The habitat consists of shallow solution holes of various sizes. Ground water levels fluctuated widely and were generally very low during dry seasons. Crayfish density was highly variable and may be related to the rate of colonization from nearby habitats.

4.2. Growth[2]

The suitability of a given habitat for survival and growth often depends on the foraging returns of that habitat which may be indicative of the level of environmental

stress. The growth dynamics of crayfish were studied to develop a simple analytical method for comparing growth processes and to assess whether growth is associated with differing hydrological conditions over the marl prairie wetlands[2]. The objectives were: 1) to describe growth of *P. alleni* on an optimal diet in the laboratory, 2) to relate growth processes to changes in carapace length and weight, 3) to compare length-weight patterns between crayfish on a laboratory diet to subpopulations at different field sites, and 4) to explore the associations between growth patterns and local hydroperiod.

In the laboratory, the frequency of molting in crayfish decreased with increasing size (range: 1 - 3 wk in juveniles; 4 - 6 wk in adults). The incremental increases in size and weight following ecdysis were greater in older individuals and were similar between males and females fed an optimal diet in the laboratory. This suggests that the length-weight relationship is conserved in this crayfish species, and this simple relationship is useful for analyzing growth rates among subpopulations. The Hiatt growth diagrams for pre-molt versus post-molt measurements showed no inflections that would suggest changes in growth patterns with the onset of maturity.

For the field growth study, measurements and weights were obtained for crayfish collected from seven areas of the marl prairie of eastern ENP during the on-going monitoring project. Regression analyses were used to determine if the length-weight relationships differed among field sites and from the laboratory population. The carapace length (independent variable) and the wet weight (dependent variable) were plotted for males and females at each site and from the laboratory population. Results showed that growth slopes were significantly steeper at sites with longer hydroperiods than at sites with shorter hydroperiods. Furthermore, the growth in the laboratory subpopulation was similar to that of crayfish growth at the long hydroperiod sites. Differences in growth did appear to be associated with environmental and habitat factors. Growth of crayfish on a high-protein diet in the laboratory was similar to growth in sites with longer hydroperiods (seven to ten months of inundation). These growth rates were significantly different from those for crayfish in sites where the hydroperiod was only two to four months. The duration of flooding impacts the marl prairie by influencing substrate composition, algal growth, and marl deposition which, in turn, impact aquatic productivity.

4.3. Dispersal and Survival[3]

During drydown periods, dispersal by crayfish to areas with longer hydroperiods, such as sloughs or deep solution holes, might be an alternative strategy to burrowing for surviving droughts. However, our studies showed that this did not occur, but instead, crayfish opportunistically colonized all flooded habitat[3]. At the start of the flood season, crayfish dispersed to colonize newly-flooded habitats where, presumably, resources were abundant. From on-going mark-recapture studies at monitoring sites, the scale of seasonal population redistribution was estimated to be on the order of less than 1 km^2. This dispersal pattern was random with no directional movement. However, the drydown did not induce a marked reversal of this pattern, in which crayfish would retreat to habitats with deeper water as predicted. Instead, crayfish movement was abbreviated as they instead searched for burrow space, occupied existing burrows, or constructed new burrows. The role of dispersal in the *P. alleni* population, instead, appears to function primarily for colonization to exploit resources in newly-flooded habitats. During drydowns, crayfish switched from horizontal movement to vertical movement by burrowing.

To compare survival in burrows during the dry season in areas with different hydroperiods, outplant mark-recapture experiments were conducted using field enclosures at the sites used for dispersal experiments. Survival of resident crayfish was significantly different among marl prairie sites differing in hydroperiod. There were no survivors among all replicates at short hydroperiod sites, whereas survival was significantly higher at medium and longer hydroperiod sites. The proportions of survivors were similar at medium and long hydroperiod sites. Although recolonization occurred at all sites, the consistent presence of marked, free-ranging crayfish from the previous flood seasons confirms the results from the enclosure experiments that some resident crayfish survived the dry season at the longer hydroperiod sites. Burrows in the short-hydroperiod areas must be over 1 m in depth to reach lowest groundwater levels during the dry season. This depth is substantially below the average depth of crayfish burrows (0.5 m) in this rocky substrate (Rhoads 1976). Low or no survival in short-

hydroperiod marl prairie appears to be linked to the low groundwater levels (> 1 m) during the unnaturally long dry season.

4.4 Population Model[4,6]

To assess how the crayfish population would respond to further changes in environmental conditions, crayfish population data and habitat maps were used to model the effects of simulated changes. A habitat suitability index was formulated using the relationship between crayfish density and dominant vegetation types at the marl prairie monitoring sites. Vegetation types were quantified using a geographic information systems (GIS) map and were weighted based on hydroperiod or length of inundation (Schomer and Drew 1982). Crayfish densities were then regressed against weighted habitats. Vegetation types were weighted from 0 for upland vegetation (no habitat) to 5 for aquatic vegetation found in longer-hydroperiod marshes and deeper solution holes (e.g., *Rhynchospora tracyi*, *Eleocharis cellulosa*, and *Panicum hemitomon*). The expansive shorter-hydroperiod areas of muhly grass *Muhlenbergia* was weighted as 3, and sawgrass was weighted as 4. Regression analysis showed that the total habitat weights at sampling sites were positively associated with local crayfish density, indicating that the habitat suitability index adequately represented environmental conditions impacting crayfish population dynamics.

A females-only, spatially-explicit, stage-structured population model (PATCH) was used to track population-level responses to simulated changes in critical habitat. The model overlays GIS habitat maps with population data and tracks population fluctuation through a time series of simulated habitat changes. Parameters of the model were estimated using population data from field studies on density, survival, fecundity, and dispersal that scaled with habitat quality.

The initial population size was set at the density expected if all suitable habitats were occupied, calculated from the GIS map of weighted habitats. The population model was then run for 50 yr under the current habitat conditions. At year 50, a new GIS map of vegetation habitat was inserted into the model. In this new habitat map, the effects of

hydrological restoration was simulated by converting *Muhlenbergia*-dominated habitat (3 mo hydroperiod) to *Cladium*-dominated habitat (7 mo hydroperiod). The distribution of all other habitat types was assumed to be unchanged. The model was run for an additional 50 yr under these environmental conditions. Preliminary results from the model indicated that the crayfish population size initially decreased up to year 10, but stabilized thereafter at a density at about 30% that of the initial population. Following the simulated restoration of pre-drainage hydroperiod and consequent changes in habitat conditions, the population increased rapidly in an exponential manner over the years 50 to 100 where it appeared to stabilize near the initial density. Fecundity initially declined but stabilized near original levels, even after the simulated habitat restoration. Survival of both adults and juveniles also remained relatively stable through 100 years, after intial fluctuations. These results appear to be the direct consequence of changing habitat distribution as population source habitats expanded following hydroperiod restoration, whereas population sinks were reduced to isolated patches.

To continue to refine this modeling approach, I assessed a spatially-explicit population model (RAMAS Metapopulation) that directly uses output from hydrological models as predictors of fluctuations in crayfish productivity. Results from preliminary simulations were promising in that some differences in population trends were apparent between outputs from two scenarios of the Natural Systems Model and the South Florida Water Management Model. Because of the complex data requirements of this approach, some crayfish life history parameters were only roughly estimated, and similar runs were conducted under the two hydrological model outputs. Despite the low resolution of the GIS coverages and estimated crayfish parameters, the simulations indicated differences in fluctuations in crayfish density under the two hydrological scenarios. Differences in population distribution among habitat patches and the extinction probabilities of local sub-populations were also apparent. This may be associated with the greater degree of fragmentation of high-quality aquatic habitats under the SFWMM. These preliminary analyses indicated a good potential for spatially-explicit models of habitat and hydroperiods on the population dynamics of crayfish and other target organisms such as apple snail and fishes. However, more data on life history parameters are necessary to increase the reliability and sensitivity of these model outputs.

4.5 Productivity[5]

Using the data from crayfish monitoring and growth experiments, I estimated annual productivity across the marl prairie habitat in terms of growth of different size classes of crayfish and production of young-of-the-year by different size classes of adult females. Estimates of crayfish density, standing crop biomass, and production were then compared among the nine sites. Crayfish density was calculated from monitoring data, and standing crop biomass was calculated as the sum of the wet weights of crayfish at each site, standardized per unit area (hectare) from density estimates. Production of new biomass was estimated as the sum of annual growth of all crayfish plus annual egg production by adult females. Annual growth was calculated separately for three size classes for each site: recruit (< 18 mm CL), subadult (18 – 24 mm CL), and adult (> 24 mm CL). Given that the average life span of the species is three years, growth from one size class to another was assumed to occur in one year (flood/dry season). Production of eggs by adult females was estimated for three size classes of females (24-27, 28-32, >32 mm CL) by conducting a regression analysis on data for number of eggs found per female size in an unpublished report by Rhoads (1970). The number of eggs produced ranged from 123 to 270 over the range of female sizes.

Annual productivity increased with hydroperiod in sites containing suitable burrowing habitat, except in habitats consisting of deep solution holes even though these holes held water for long periods of time. However, the turnover index (productivity: biomass ratio) quantitatively demonstrated that patterns of environmental stress in the marl prairie were associated with shorter hydroperiods. Turnover in long hydroperiod sites was near 1, indicating that these subpopulations are replacing themselves and that much annual productivity was being exported to other habitats. Turnover in short hydroperiod sites was much less than 1, indicative of severe stress in these areas.

5. Synopsis

I developed sampling and experimental protocols for studying the ecology of crayfish in the stressed east Everglades marl prairies. Crayfish distribution and abundance over the Rocky Glades varied temporally, most likely in response to hydroperiod (surface water during the wet season), ground water levels during the dry season, and associated habitat characteristics (vegetation and surface area suitable for burrowing). Growth rates for all crayfish size classes were significantly higher in longer hydroperiod sites, indicating that these areas provide a greater foraging return. Results of crayfish dispersal studies suggest that movement and colonization occur on localized scales without long-distance migrations. Survival was significantly greater in sites with longer hydroperiods (> 7 months) and higher groundwater levels (> 0.5 m). Crayfish productivity in a given area may be predictable if landscape features of the marl prairie wetlands can be quantified. Field data from these studies were used to model crayfish population viability and to simulate changes in productivity if pre-drainage hydrology is restored in the Rocky Glades. Results indicated that crayfish population productivity would increase substantially if hydroperiods are increased by 3 - 4 months in the marl prairie wetlands.

6. Publications

[1]Acosta, C. A. and S. A. Perry. 2000. Effective sampling area: a quantitative method for sampling crayfish populations in freshwater marshes. **Crustaceana** 73:425-432.

[2]Acosta, C. A. and S. A. Perry. 2000. Differential growth of crayfish *Procambarus alleni* in the seasonal wetlands of Everglades National Park, in relation to hydrological conditions. **Aquatic Ecology** 34:389-395.

[3]Acosta, C. A. and S. A. Perry. 2001. Impact of hydropattern disturbance on crayfish

Procambarus alleni in the seasonal wetlands of Everglades National Park. **Aquatic Conservation: Marine and Freshwater Ecosystems** 11:45-57.

[4]Acosta, C. A. and S. A. Perry. Manuscript in review. Spatially-explicit population responses of crayfish to hydropattern restoration in the marl marshes of Everglades National Park, USA.

[5]Acosta, C. A. and S. A. Perry. Manuscript in review. Spatio-temporal variation in secondary productivity as an indicator of environmental stress in the Florida Everglades.

[6]Acosta, C. A. and S. A. Perry. 2000. Restoring crayfish populations in the stressed wetlands of Everglades National Park. (Abstract) Greater Everglades Ecosystem Restoration (GEER) Science Conference, Naples, Florida.

7. Literature Cited

Davis, S. M. and J. C. Ogden. 1994. Toward ecosystem restoration. In: S. M. Davis & J. C. Ogden (eds.), Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida. pp 769-796.

Gunderson, L. H. 1994. Vegetation of the Everglades: determinants of community composition. In: S. M. Davis & J. C. Ogden (eds.), Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida. pp 232-340.

Gunderson, L. H. and Loftus, W. F. 1993. 'The Everglades', in Martin, W. H., Boyce, S. G. and Esternacht, A. C. (Eds), Biotic Communities of the Southeastern United States, Wiley & Sons, New York, 199-255.

Jordan, F., K. J. Babbitt, C. C. McIvor, and S. J. Miller. 1996. Spatial ecology of the

crayfish *Procambarus alleni* in a Florida wetland mosaic. *Wetlands* 16: 134-142.

Kushlan, J. A. and M. S. Kushlan. 1979. Observations on crayfish in the Everglades, Florida, U.S.A. *Crustaceana* (Supple.) 5: 115-120.

Loftus, W. F. and A. M. Eklund. 1994. Long-term dynamics of an Everglades small fish assemblage. In: S. M. Davis & J. C. Ogden (eds.), Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida. pp 461-463.

Loftus, W. F., R. A. Johnson, and G. H. Anderson. 1992. Ecological impacts of the reduction of groundwater levels in short-hydroperiod marshes of the Everglades. In: J. A. Stanford & J. J. Simons (eds.), Proceedings of the First International Conference on Groundwater Ecology. Tampa, Florida. pp 199-208.

Rhoads, P. B. 1976. Aspects of the life cycle and ecology of *Procambarus alleni* in the Everglades (Crustacea: Decapoda: Astacidae). *ASB Bulletin* (abstract) 23: 90.