Disentangling Effects of Freshwater Inflows on Coastal Fishes and Implications for Recreational Fisheries: Common Snook in the Florida Everglades

Desenredando los Efectos de los Flujos de Agua Dulce en los Peces Costeros y las Implicaciones para las Pesquerías Recreativas: Snook Común en los Everglades de Florida

Effet Désordonné des Apports d'eau Douce sur les Poissons Côtiers et Implications pour la Iêche de Loisir: Snook Common dans les Everglades en Floride

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EXTENDED ABSTRACT

Alterations to the quantity, timing, and quality of water deliveries to coastal areas can negatively affect both the ecological integrity and the socioecological services coastal systems provide (Gillanders and Kingsford 2002). Of particular interest is the effect of freshwater inflows on economically-valuable fisheries that are estuarine-dependent (Gillson 2011). These effects may result via alterations to salinity regimes, nutrient fluxes, and other important physio-chemical regimes (e.g., oxygen), as well as via changes to habitat quality and quantity, and/or influences on primary and secondary production (reviewed by Gillson 2011). Further, effects of freshwater inflows on coastal fisheries production may result from several key mechanisms, including those that govern the abundance, distribution, and/or traits of estuarine fishes (e.g., Walsh et al. 2013). Key is understanding how fisheries and their attributes respond to changing flows (i.e., 'flow–ecology relationships', Rosenfeld 2017). The shape (slope, intercept, presence of nonlinearity and location of thresholds), and the sensitivity of these flow-fishery relationship to environmental change are integral to the robust management of environmental flows into the future and to examining tradeoffs between instream and out-of-stream uses (Poff and Zimmerman 2010, Rosenfield 2017, Poff 2018).

In this study, we quantified the effects of hydrological variation on the distribution and movement of a valuable recreational coastal fishery in Florida. We asks how does variation in freshwater inflows affect the distribution and movement of Common Snook *Centropomus undecimalis* in the coastal Everglades?. In Florida and the Everglades region, Common Snook is a popular tropical species that supports a substantial recreational fishery (2.1 million fish caught per year, 90% of which are released; Muller and Taylor 2012), and previous work suggests that their ecology is closely tied to freshwater inputs (Boucek and Rehage 2013, Boucek et al. 2016, Blewett et al. 2017, Stevens et al. 2018). We hypothesized that variation in freshwater inflows would cause important habitat shifts, and changes in the movement behavior of Snook that should affect their catchability by anglers and thus the productivity of the fishery.

We tracked the distribution and movement of Snook in the upper Shark River, located in the southwestern region of Everglades National Park, Florida, USA using electrofishing and acoustic telemetry. We conducted standardized boat-mounted electrofishing (January 2006-April 2017) along five headwater sites (depth = 1.26 m; salinity = 1.1 PSU; see Boucek and Rehage 2013 for sampling details). Sampling was conducted three times/year: November-December, February-March and April-May, corresponding to the wet, early and late dry seasons respectively. From replicate transects sampled at each site (n = 522 samples), we calculated Snook catch per unit effort (CPUE) as the number of Snook caught or shocked per 100 m of shoreline ([CPUE/distance travelled] × 100 m, Boucek and Rehage 2013). We tracked the distribution and movements of Snook using acoustic telemetry at also five upstream-most acoustic stations (river km 20-28, see Boucek *et al.* 2017 and Matich et al. 2017 for additional details, Figure 1). If a tagged Snook passes a listening station, the autonomous device recorded the unique tag ID and time/date of detection. From May 2012 to April 2016, we tracked the space use of 76 internally-tagged Snook (VEMCO V16 and V13 transmitters; mean interpulse delay = 120 seconds, Snook size range = 45-86 cm standard length). From these tracking observations and following Boucek et al. (2017), we calculated and standardized the daily proportion of tracked Snook that were detected in the upper portion of the river. We then obtained Snook movement rate (km moved/day) by calculating the daily distance moved for a randomly-selected subset of tagged Snook (45 fish detected between November 1, 2012 and September 30, 2015). We used simple linear regressions in R v3.2.5 (R Core Team, 2017) to examine the relationships between electrofishing CPUE (averaged to seasonal samples), the proportion of Snook detected at the headwaters, and movement rate (km/day) both smoothed over 11-day bins (Walsh et al. 2013), and river stage obtained from the closest hydrological station (USGS Bottle Creek).

Freshwater inflows explained a substantial portion of the space use of Snook in the coastal Everglades (all adjusted R^2 values > 0.40). Overall, we found a negative effect of river stage on the three Snook variables measured. Upper Shark River Snook abundance was highest, more snook were detected, and their movement rates were higher at lower freshwater inflows. Snook electrofishing CPUE was negative related to river stage, with the CPUE peaking at 4.47 fish/100m at low

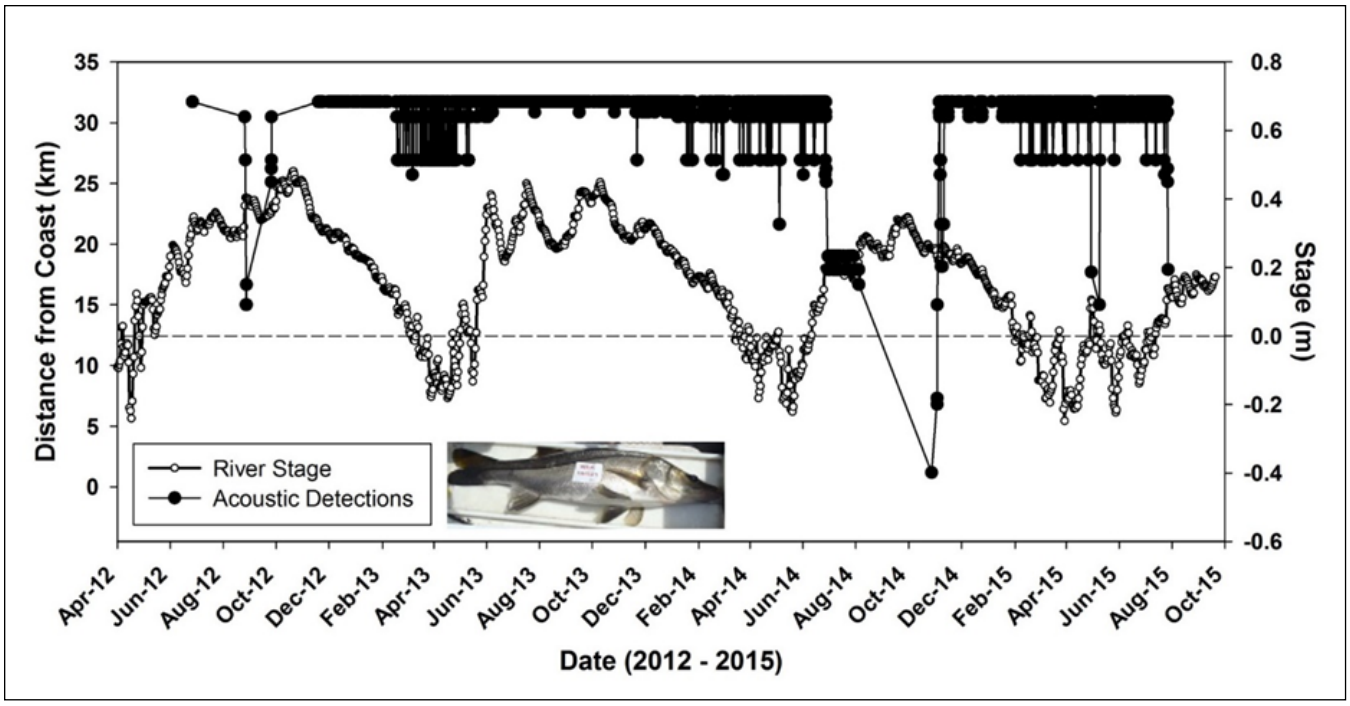

Figure 1. An example of a snook's acoustic detection record over from tagging (June 2012 to last detection in August 2015, plotted in relation to stage levels (m). Black symbols are daily detections for tag # 51318, while white symbols denote stage at the Bottle Creek hydrostation). Photo shows the snook when tagged.

flow conditions (β = -2.891, SE = 0.520, $F_{1,32}$ = 30.88, p < 0.0001, adjusted R^2 = 0.475, Figure 2A). Similarly for the acoustic data, the proportion of tagged Snook detected was also negatively related to river stage (β = -0.476, SE = 0.047, $F_{1,135}$ = 100.9, p < 0.0001, adjusted R^2 = 0.423). At low stage, up to 70% of the tagged Snook were detected in the upper reaches (Figure 2B). Last, the rate at which Snook moved also varied negatively as a function of stage (β = -2.322, SE = 0.280, $F_{1,95}$ = 68.83, p < 0.0001, adjusted R^2 = 0.414). Snook moved faster, approaching 2 km/day at the lowest stages of the peak of the dry season (Figure 2C).

These findings show how declines in freshwater inflows can result in local concentrations and alterations to the behavior of important recreational fisheries. We expect that the observed increased in Snook at the headwaters is driven by freshwater prey sources that pulse into the headwaters at low flows from drying marshes surrounding the headwaters (Boucek and Rehage 2013, Boucek et al. 2016). We hypothesize that the increases in movement rate at low flows reflect an increase in foraging activity at these localized high dry-season prey concentrations. Organisms are typically expected to increase prey search behavior, which has costs, as prey profitability increases (e.g., optimal foraging theory). Our results, along with previous work (Blewett et al. 2017), highlight two key points about the effects of flows on Snook. First, the effect appears to be mainly mediated by a trophic pathway (i.e., affecting prey abundance and availability), and not via effects of physico-chemical conditions (e.g. salinity or oxygen regimes). Second, as shown in previous work (Winemiller and Jepsen 1998), the effect of flow on prey is two-faceted: high flows are required for production, and low flows are needed for creating prey concentrations and increasing prey vulnerability, while extremely low flows are known to have negative effects on both prey production and consumers (Boucek et al. 2016, Blewett et al. 2017). Our study underscores the value of naturally-variable hydrological regimes to maintaining species populations, energy flow pathways and ecosystem processes in aquatic systems, and the importance of understanding the nonlinearities in flow-ecology relationships for key ecosystem service providers, such as economically-valuable recreational fisheries species (Poff and Zimmerman 2010, Rosenfeld 2017).

KEYWORDS: Recreational fisheries, freshwater inflows, management

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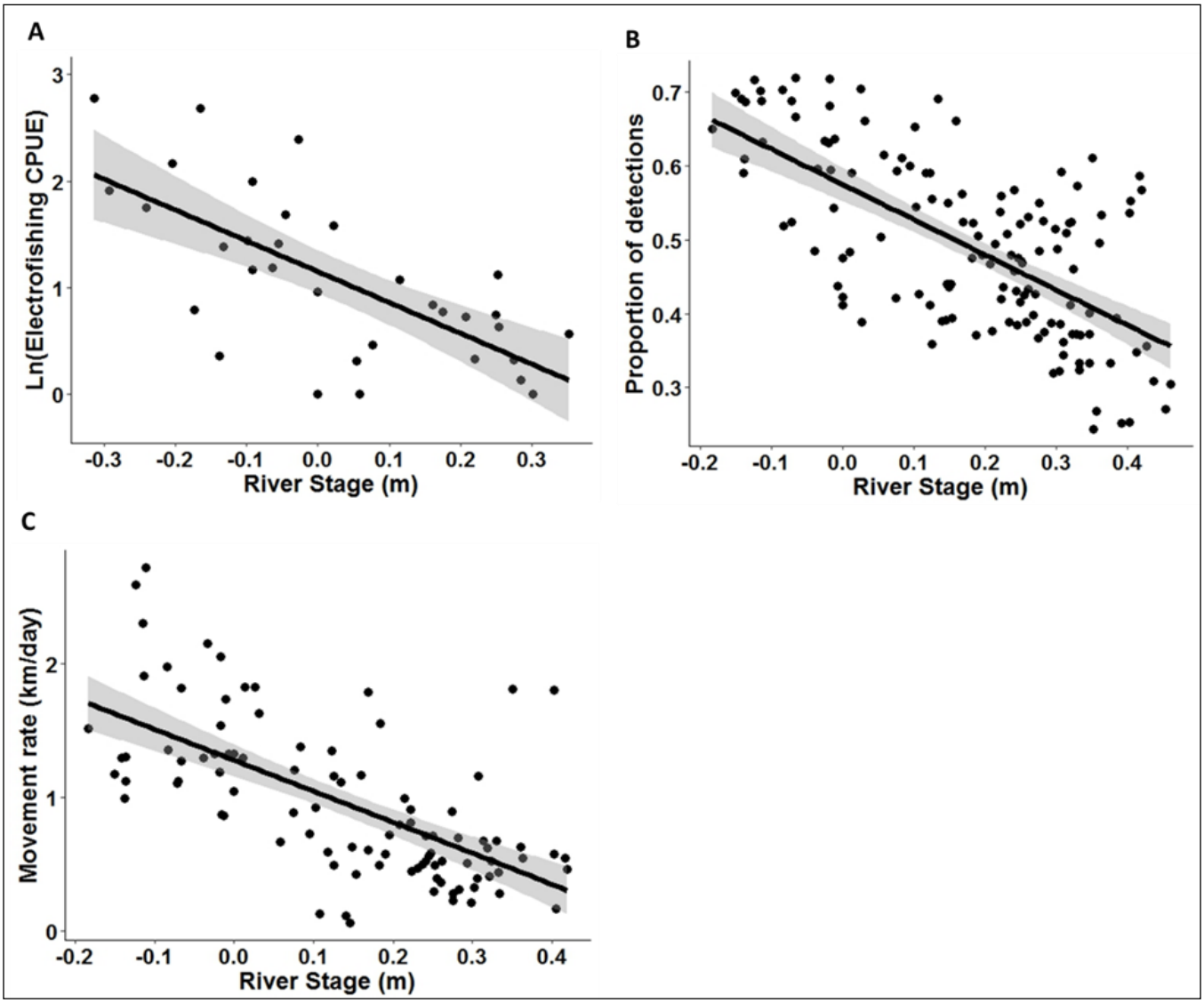

Figure 2. (A) Average snook CPUE in electrofishing samples (log-transformed), (B) proportion of fish detected in acoustic telemetry, and (C) average Snook movement rate (km/day) plotted as a function of river stage (m).