Wetlands (2014) 34 (Suppl 1):S175–S187
DOI 10.1007/s13157-012-0362-0

HYDROLOGIC RESTORATION

Recent Fish Introductions Into Everglades National Park: An Unforeseen Consequence of Water Management?

Jeffrey L. Kline · William F. Loftus · Kevin Kotun · Joel C. Trexler · Jennifer S. Rehage · Jerome J. Lorenz · Michelle Robinson

Received: 28 August 2012 / Accepted: 7 December 2012 / Published online: 17 January 2013

Abstract Non-native fishes present a management challenge to maintaining Everglades National Park (ENP) in a natural state. We summarized data from long-term fish monitoring studies in ENP and reviewed the timing of introductions relative to water-management changes. Beginning in the early 1950s, management actions have added canals, altered wetland habitats by flooding and drainage, and changed inflows into ENP, particularly in the Taylor Slough/C-111 basin and Rocky Glades. The first non-native fishes likely entered ENP by the late 1960s, but species numbers increased sharply in the early 1980s when new water-management actions were implemented. After 1999, eight non-native species and three native species, all previously recorded outside of Park boundaries, were found for the first time in ENP. Several of these incursions occurred following structural and operational changes that redirected water deliveries to wetlands open to the eastern boundary canals. Once established, control non-native fishes in Everglades wetlands is difficult; therefore, preventing introductions is key to their management. Integrating actions that minimize the spread of non-native species into protected natural areas into the adaptive management process for planning, development, and operation of water-management features may help to achieve the full suite of objectives for Everglades restoration.

Keywords Non-native fishes · Cichlids · Everglades · Canals · Wetlands · Water management · Restoration

Electronic supplementary material The online version of this article (doi:10.1007/s13157-012-0362-0) contains supplementary material, which is available to authorized users.

J. L. Kline (✉)
South Florida Natural Resources Center,
Everglades National Park, 40001 State Road 9336,
Homestead, FL 33034, USA
e-mail: Jeff_Kline@nps.gov

W. F. Loftus
Aquatic Research & Communication, LLC, 5600 Dominica St,
Vero Beach, FL 32967, USA

K. Kotun
South Florida Natural Resources Center,
Everglades National Park, 950 N. Krome Avenue,
Homestead, FL 33030, USA

J. C. Trexler
Department of Biological Sciences,
Florida International University, 3000 NE 151 St,
North Miami, FL 33181, USA

J. S. Rehage
Earth & Environment Department, Southeast Environmental
Research Center, Florida International University,
11200 SW 8th Street, ECS 337,
Miami, FL 33199, USA

J. J. Lorenz · M. Robinson
Audubon Florida, Tavernier Science Center,
115 Indian Mound Trail,
Tavernier, FL 33070, USA

Introduction

The introduction of non-native and translocated native species is a major challenge facing natural-resource-management agencies, including the U. S. National Park Service (NPS; Loope 2004). Established to "conserve the scenery and the natural and historic objects and the wild life therein and… leave them unimpaired for the enjoyment of future generations" (Organic Act of 1916), the NPS has a long history devoted to invasive-species management (Courtenay and

Fuller 2004; Drees 2004). Although early NPS fisheries management included stocking non-native and translocated native fishes to develop fisheries, the practice was halted in 1968 (Courtenay and Fuller 2004), and management now focuses on native species while limiting introductions of non-native fishes (USNPS 2007). Aquatic-habitat restoration, restoration of native fishes (Moore and Larson 1990; Baker et al. 2008), understanding the impacts of and removal of non-native fishes (Koel et al. 2006; Tronstad et al. 2010), and minimizing the risk of spreading invasive species by federal actions (Executive Order 13112) are now emphasized.

In 1947, Everglades National Park (ENP) became the first US national park established primarily to protect biological resources by preserving the "unique flora and fauna and the essential primitive natural conditions now prevailing in this area" (48 Stat 816 Everglades National Park Enabling Legislation 1934). Later, ENP was expanded to "maintain the natural abundance, diversity, and ecological integrity of native plants and animals" (Everglades National Park Protection and Expansion Act of 1989). Those directives emphasize the protection of native species and natural conditions of ENP.

In south Florida, the native freshwater fish assemblage is derived from the temperate North America ichthyofauna (Loftus and Kushlan 1987). Despite high fish biodiversity in the southeastern United States (Warren et al. 2000), the native freshwater assemblage in the Everglades region is relatively species-poor (32 taxa; Loftus 2000) due to zoogeographic and habitat factors (Loftus and Kushlan 1987; Gunderson and Loftus 1993; Gleason and Stone 1994). Large areas of shallow ridge-and-slough wetlands define the historic freshwater Everglades landscape (McVoy et al. 2011). Although natural dry-season refuge habitats include alligator holes (Kushlan 1974; Loftus and Kushlan 1987; Parkos et al 2011), solution holes (Loftus et al. 1992; Kobza et al. 2004; Rehage et al. in press), and headwaters of tidal creeks (Rehage and Loftus 2007), harsh conditions during the dry season likely limit the ability of species to persist through to the wet season (Kushlan 1974; Loftus and Kushlan 1987; Kobza et al. 2004; Schofield et al. 2007; Rehage et al. in review).

The large-scale construction of canals that drain the Everglades began in the 1880s (Light and Dineen 1994; Godfrey and Catton 2011; McVoy et al. 2011), creating deep-water habitats uncommon in south Florida prior to development (Gunderson and Loftus 1993). Water-management actions beginning with the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF) in the early 1950s constrained the Everglades within an eastern protective levee (50 % wetland loss), created a series of reservoirs in the northern Everglades, developed an interconnected canal system, and allowed direct delivery of canal waters into ENP (Light and Dineen 1994; Merritt 1996; SFNRC 2005).

Besides altering flow and water levels, canals are conduits for pollutants, nutrients, and biota (Gunderson and Loftus 1993; Doren et al. 1997; Mills et al. 1999; Kolar and Lodge 2000; Childers et al. 2003; Carriger et al. 2006). South Florida canals provide deep-water refuges from seasonal drying and occasional cold temperatures that allow species of tropical origin to persist (Shafland and Pestrak 1982; Loftus 1988; Trexler et al. 2000; Harvey et al. 2010). The connectivity of the canal system permits both non-native and native species to spread rapidly across large areas of south Florida (Courtenay and Robins 1973; Courtenay and Miley 1975; Loftus and Kushlan 1987; Loftus 1988; Nico 2005; Gandy et al. 2012). The use of canals as corridors to natural habitats deserves attention because Everglades restoration projects (e.g., The Comprehensive Everglades Restoration Plan; CERP 1999) will alter water deliveries from canals to natural areas and further increase connectivity, providing additional opportunities for invasion and range expansion.

Here we review the timing of introductions of all non-native and three new native fishes with relation to water-management changes to ENP. We document an increase in the number to fishes introduced since 1999 and provide a review of each new species. In addition, we use long-term sampling data to examine patterns in introduced fish distribution and relative abundance, and update the studies reported by Trexler et al. (2000).

Methods

We developed a timeline for introductions of non-native freshwater fish species into ENP based on sampling efforts, literature, and observations, and grouped fish invasions within the context of four time periods that reflect major changes in the canal landscape and hydrologic management: pre-C&SF (before 1950), C&SF (1950–1977), South Dade Conveyance System (SDCS; 1978–1999), and Interim Structural Operational Plan/Interim Operational Plan (ISOP/IOP; 1999–2012). We contrasted this with a statewide timeline of invasions for the 34 non-native species reproducing in Florida as of 2007 (Shafland et al. 2008). We used Trexler et al. (2000) as a baseline study to document changes in the number of species collected by long-term sampling. Relative and total abundance were evaluated across various sampling techniques and key habitats and regions: freshwater wet prairies and alligator ponds of northern and southern Shark River Slough (SRS-N and SRS-S, respectively), Taylor Slough (TS), marl prairies adjacent to the C-111 Canal (C-111W), in the Rocky Glades (RG, including solution holes), and west of SRS (WMP), and mangrove-dominated marshes/creeks of the C-111/TS and SRS-S (Odum et al. 1982; Loftus and Kushlan 1987; Loftus et al. 1992; Gunderson and Loftus 1993; Fig. 1).

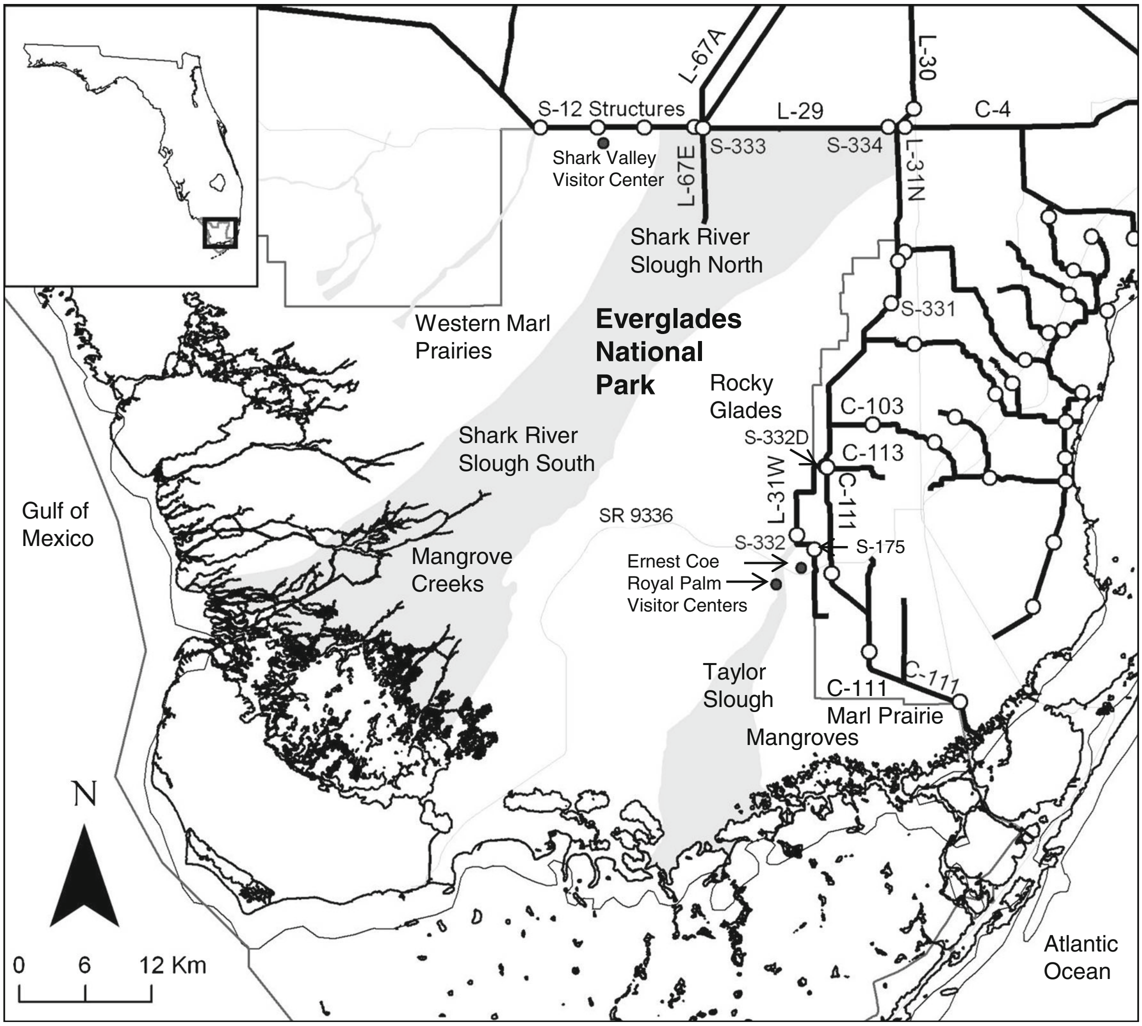

Fig. 1 Map of south Florida with the canals (labeled C- or L-), water-management structures (labeled S-), and habitat regions of Everglades National Park. Acronyms in text: SRS-N = northern Shark River Slough, SRS-S = southern Shark River Slough, TS = Taylor Slough, C-111W = C-111 wetlands, RG = Rocky Glades, WMP = western marl prairies

Sampling Techniques

We updated non-native distribution and abundance records for ENP studies from Trexler et al. (2000) and summarized data from newer studies through May 2012. Studies using 1-m^2 throw traps (Jordan et al. 1997), 9-m^2 drop nets (Lorenz et al. 1997), and electrofishing in wet prairies and alligator ponds (Chick et al. 2004; Parkos et al. 2011) reported by Trexler et al. (2000) were updated (Table 1) and new studies reported. Throw-trap collections from 1978 to 1984 were not reported by Trexler et al. (2000) but were added by us to create a time-series of fish collections in SRS-N from 1978 to 2012. Trexler et al. (2000) and Kobza et al. (2004) collected fishes with wire-mesh minnow traps in solution holes of the RG during the 1999 and 2000 dry seasons. A study concurrent with Kobza et al. (2004) sampled seven sites in the RG from June 1999–2012 (JLK unpublished data), and five other projects that included almost all freshwater areas of ENP, used minnow traps at various times between 2000 and 2012 (Table 1). Drift fences were used to collect small fishes moving across the marsh surface by funneling them into three to eight minnow traps placed at the center of an ‘X’ with 12 m wings of silt fencing prior to 2009 (Obaza et al. 2011; Goss et al. in press) and 3-m wings from 2009 to 2012. Electrofishing in mangrove creeks of SRS-S was started in 2004 (Rehage and Loftus 2007) and continued through 2012.

Visual observations and anecdotal records that have been vetted by the authors are included with species accounts. Voucher specimens deposited in the Florida Museum of Natural History (UF) are cited in the text.

Data Presentation

To compare our results to data collections prior to 2000 (Trexler et al. 2000), we report the catch of non-native fish

Table 1 The total catch, catches of non-native and new native species, and relative abundance of non-native fishes reported by sampling method and location.

Habitat and method	N	Study period	Total fishes	Non-native species															Non-native (%)	New natives	
				BA	WC	BT	O	MC	ST	BP	PK	JG	AJ	OS	BH	PE	AE	UC		PP	RP
Throw traps in wet prairies																					
SRS-N*	4778	1996–2012	55133	33	1	2	0	78	1	0	38	0	3	0	2	0	0	0	0.3	16	23
SRS-S*	4051	1997–2012	89906	9	10	16	2	217	40	0	86	0	44	0	1	0	0	0	0.5	76	8
TS*	5406	1997–2012	44927	6	3	6	0	217	12	0	37	0	36	0	1	0	0	0	0.7	0	0
C-111	881	2008–2012	2260	5	0	0	0	13	0	0	5	0	6	0	0	0	7	0	1.6	0	0
Minnow traps																					
SRS-N	1145	2000–2012	10583	15	0	2	0	90	11	0	16	5	63	1	0	0	0	0	1.9	2	5
SRS-S	377	2002–2012	2499	2	0	0	0	13	0	0	9	0	19	0	0	0	0	0	1.7	0	2
TS	252	2004–2012	1795	2	0	1	0	42	0	0	19	0	124	0	0	0	0	0	10.5	0	0
Rocky Glades	16827	2000–2012	75286	1731	531	66	2	1046	88	0	868	211	12703	0	32	7	2	0	23.0	13	22
Western Marl Prairie	454	2002–2012	3679	5	0	0	0	12	0	0	31	0	37	0	0	0	0	0	2.3	1	0
C-111	133	2004–2012	618	25	0	0	0	15	0	0	3	2	16	0	0	1	2	0	10.4	0	0
Mangroves	293	2004–2012	1674	1	0	0	0	145	14	0	8	0	27	0	0	0	0	0	11.6	1	1
Drift fence																					
SRS-N	1131	2003–2012	17214	14	0	39	0	107	9	0	24	0	23	0	2	0	0	8	1.3	19	2
SRS-S	742	2003–2012	10124	4	0	7	0	34	0	0	10	0	6	0	1	0	0	0	0.6	30	4
Rocky Glades	2954	2000–2012	192717	581	51	611	1	1351	109	0	1265	21	3790	4	49	0	0	1	4.1	15	6
L-31 W and C-111	659	2009–2012	11198	9	0	3	0	62	4	0	35	0	203	0	0	0	0	6	2.9	0	0
Electrofishing in wet prairies																					
SRS-N*	447	2000–2012	239	0	2	0	0	9	2	0	1	0	0	0	5	0	0	0	7.9	0	2
SRS-S*	962	2000–2012	576	0	10	37	0	48	51	0	1	0	0	0	12	0	0	0	27.6	0	9
TS*	660	2000–2012	188	0	9	10	0	26	6	0	1	0	0	0	1	1	0	0	28.7	0	1
C-111	125	2007–2012	53	0	4	3	0	1	1	5	1	0	0	0	0	3	27	0	84.9	0	0
Electrofishing in ponds and creeks																					
SRS*	488	1997–2012	8821	2	31	29	0	49	23	0	64	0	0	1	15	0	0	0	2.4	0	4
TS	261	1997–2012	648	0	8	7	0	3	3	0	3	0	0	0	0	35	0	0	9.1	0	0
C-111	13	2008–2012	22	0	0	1	0	0	2	0	0	0	0	0	0	1	0	0	18.2	0	0
SRS-S-mangrove creeks	735	2004–2012	15032	0	1	474	0	387	63	0	8	0	24	4	0	276	0	9	8.3	0	0
Drop nets in mangroves																					
C-111/TS Original*	1413	2000–2011	62197	0	6	7	0	3006	135	0	32	0	5	0	0	17	2	0	5.2	0	0
C-111/TS new	973	2005–2011	34512	2	4	21	0	1335	143	0	76	0	311	0	0	1	1	0	5.5	0	0
SRS-S	618	2005–2011	26889	0	13	0	0	1481	130	0	50	0	315	0	0	0	0	0	7.4	0	0

* indicate continuations of projects reported by Trexler et al. (2000). Species codes: *BA* black acara, *WC* walking catfish, *BT* blue tilapia, *O* oscar, *MC* Mayan cichlid, *ST* spotted tilapia, *BP* butterfly peacock, *PK* pike killifish, *MT* Mozambique tilapia, *JG* jaguar guapote, *AJ* African jewelfish, *OS* Orinoco sailfin catfish, *BH* brown hoplo, *BC* banded cichlid, *PE* peacock eel, *AE* Asian swamp eel, *VS* vermiculated sailfin catfish, *UC* unidentified Cichlidae, *PP* pirate perch, *RP* redfin pickerel

vs. the total catch. The relative abundance of non-native fish and the total number of non-native species collected annually and cumulatively for three of the longest data records (Throw traps in SRS-N 1978–2012, drop nets in C-111/TS 1990–2011, minnow traps in RG 1999–2012) are displayed. Despite the limitations of a non-statistical approach taken here and by Trexler et al. (2000), results from long-term projects in combination with various collection methods and observations over widespread locations allow for a robust and comprehensive overview of invasion dynamics in ENP.

Results

Invasions Across Water-Management Periods

Before 1950, when few non-native fishes were established in Florida (Fig. 2), water flowed south into SRS-N from the northern Everglades across a borrow canal and through culverts and bridges under the Tamiami Trail (built in 1927; Merritt 1996; Fig. 3a). In the early 1950s, construction of canals and levees as part of the C&SF Project began (Light and Dineen 1994; Merritt 1996). After 1950, introductions of non-native species that established reproductive populations (Shafland et al. 2008) increased steadily in Florida; however, introductions lagged in ENP (Fig. 2). Studies from the 1950s reported no non-native species within the Greater Everglades (Hunt 1953; Kilby and Caldwell 1955). In 1962, inflows into ENP from the northern Everglades were severed by levee construction, and restored in 1965, but constrained to the northwestern portion of SRS from the enlarged L-29 Canal (Fig. 3b). Quantitative fish sampling in ENP wetlands beginning in 1965 found no non-native species (Higer and Kolipinski 1967; Kolipinski and Higer 1969; Kushlan 1980), but black acara (*Cichlasoma bimaculatum*) were collected in the Big Cypress Swamp west of ENP (Kushlan 1972), and Dineen (1974) collected black acara and walking catfish (*Clarias batrachus*) upstream of ENP. Those were the first non-natives to colonize ENP in the late 1960s to early 1970s (Loftus 1988). Along the eastern boundary of ENP, the L-31W and the C-111 canals were constructed in the late 1960s (Merritt 1996). Blue tilapia (*Oreochromis aureus*) was observed in 1977 in the discharge of an aquaculture facility into a marsh bordering lower L-31W Canal (D. Koehl, unpub. data). In 1978, blue tilapia was observed in the lower L-31W Canal, and later that year was collected in the Royal Palm ponds inside ENP (Loftus and Kushlan 1987; Loftus 1988; Fig. 1).

After 1978, the SDCS expanded the capacity of C&SF canals to move water south, and in 1981, pumped water directly into TS from L-31W Canal (Light and Dineen 1994; Merritt 1996; Kotun and Renshaw in review; Fig. 3c). Soon

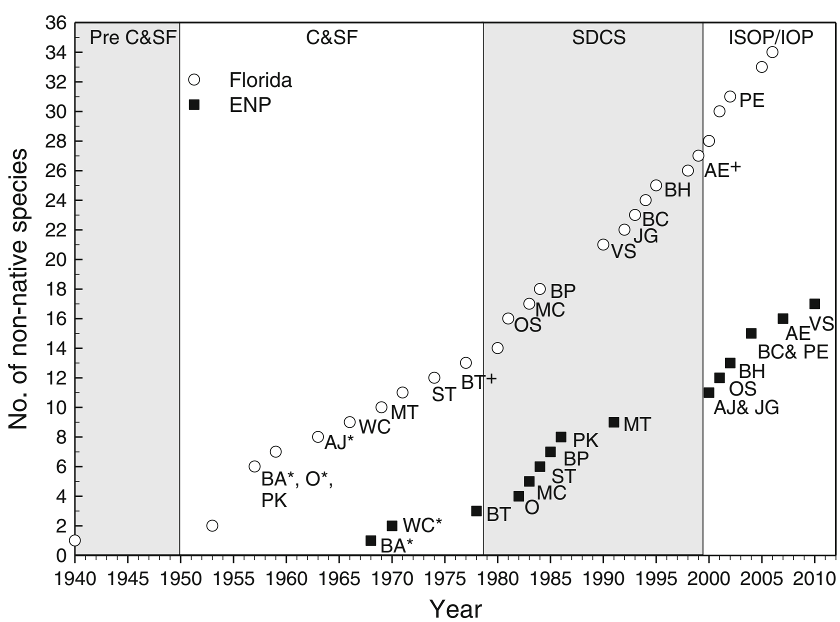

Fig. 2 Timelines of the first introductions of non-native species reproducing in Florida contrasted with introductions into ENP. Water-management time periods are alternatively shaded for pre-C&SF (Before 1950), C&SF (1950–1977), SDCS (1978–1999), and ISOP/IOP (1999–2012). Species found in ENP are labeled on points when first introduced. * indicates estimated first observation dates for species; + indicates dates of introductions separate from the original introductions in Florida. Timeline for Florida from Shafland (1996), Shafland et al. (2008) and citations therein; timeline for ENP from Loftus (1987), Loftus (1988), and data reported herein. Species codes: BA-black acara, WC-walking catfish, BT-blue tilapia, O-oscar, MC-Mayan cichlid, ST-spotted tilapia, BP-butterfly peacock, PK-pike killifish, MT-Mozambique tilapia, JG-jaguar guapote, AJ-African jewelfish, OS-Orinoco sailfin catfish, BH-brown hoplo, BC-banded cichlid, PE-peacock eel, AE-Asian swamp eel, VS-vermiculated sailfin catfish

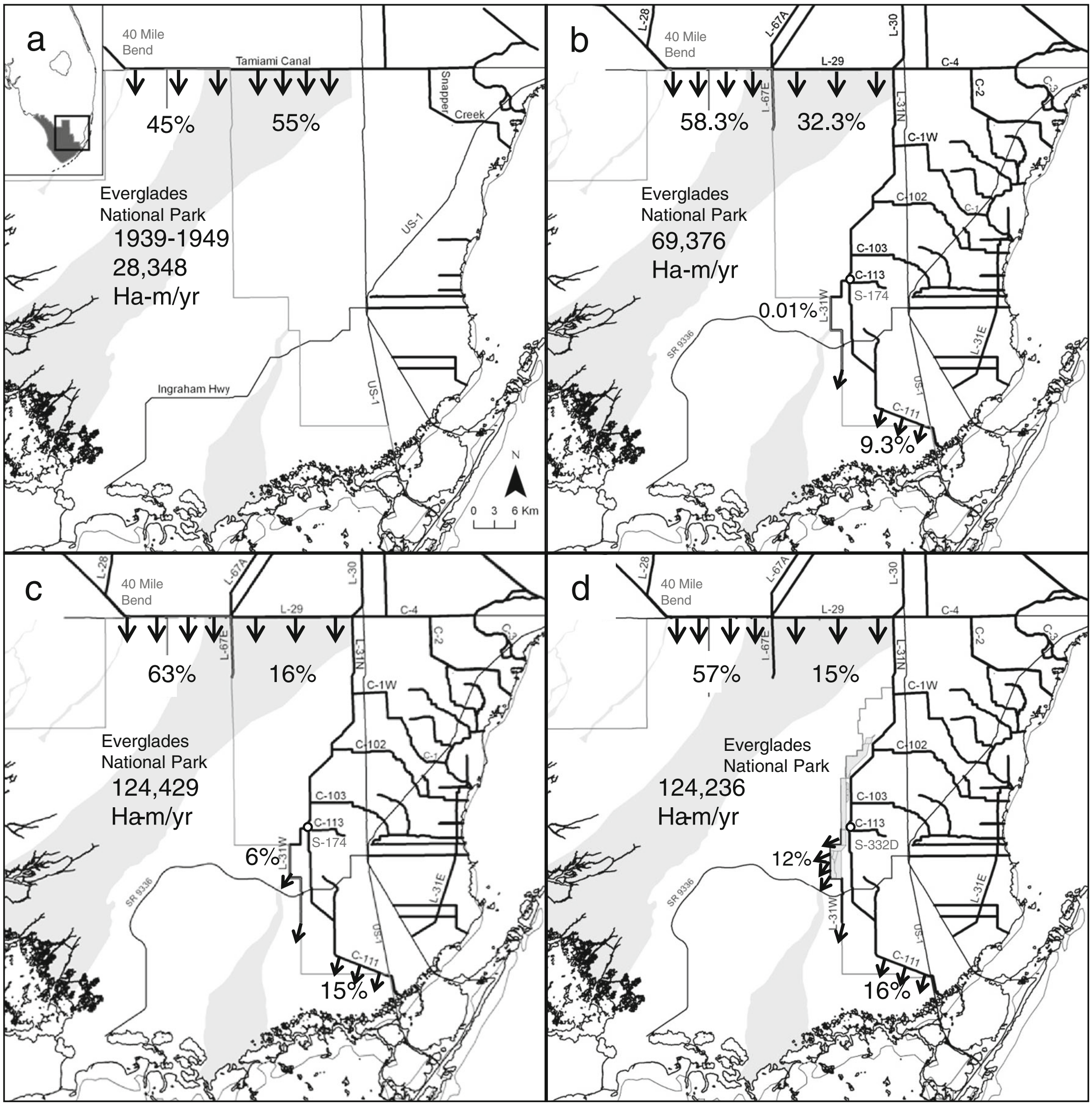

Fig. 3 Diagrams of primary inflows from, and connectivity of canals to ENP marshes (*arrows*) during water-management periods: **a** pre-C&SF (before 1950); **b** C&SF project (1950–1978); **c** SDCS (1978–1998); and **d** ISOP/IOP (1999–2012). The average annual inflow volume (hectare-meters: Ha-m) and relative percentage of flow toward ENP for each period were estimated along the northern boundary into northwestern (from 40 mile bend to the current location of the L-67 canals) and northeastern (from the L-67canals to the current location of the L-30 Canal) Shark River Sough using data from USGS (2012) and along the eastern boundary into the L-31W Canal (via S-174 or S-332D structures) and the eastern panhandle via the C-111 Canal (via S-18C structure) using data from SFWMD (2012). Diagrams modified from Merritt (1996)

afterwards, six new non-native fishes were found in the eastern sections of ENP: oscar (*Astronotus ocellatus*; 1982), Mayan cichlid (*Cichlasoma urophthalmus*; 1983), spotted tilapia (*Tilapia mariae*; 1984), pike killifish (*Belonesox belizanus*; 1986) and Mozambique tilapia (*Oreochromis mossambicus*; 1991; Loftus 1987; Loftus 1988, WFL, pers. obs; Fig. 2). Butterfly peacock (*Cichla ocellaris*) was observed near the Shark Valley Visitor Center of ENP in 1985, but it and Mozambique tilapia failed to establish in ENP (Loftus 2000).

In late 1999, ISOP/IOP management began to route additional water from the north through the SDCS to the eastern side of ENP (SFNRC 2005; Kotun and Renshaw in review). Direct pumping into TS was halted and instead water was pumped into the L-31W Canal (and later into a detention area), raising canal water levels which overflowed into the southeastern RG/upper TS (USACE 2002; SFNRC 2005; Kotun and Renshaw in review; Fig. 3d). Between 2000 and 2012, eight new non-native (Fig. 2) and three new native species were found in ENP along the eastern or northern boundaries.

Trends Across Regions and Sampling Methods

Nearly 670,000 fishes were captured in the 15 years between 1996 and 2012, including over 36,000 non-native fishes of 14 taxa (Table 1). In addition, two species native to the northern Everglades were first caught in the southern Everglades. Eight to nine non-native fishes accounted for less than 1 % of the relative abundance from throw traps in SRS-N, SRS-S, and TS wet prairies (0.3, 0.5, and 0.7 % respectively), and 1.6 % of the catch in C-111W (Table 1). Electrofishing in the marshes of SRS-N produced a relative abundance of 7.9 % non-natives, with higher relative abundances in SRS-S (26.7 %) and TS (28.7 %). Electrofishing samples in alligator ponds found lower relative abundances of non-native fishes in SRS (2.4 %) than in TS (9.1 %). Non-native fishes composed 8.3 % of the catch in SRS-S mangrove creeks. Relative abundance of non-native fishes was similar in drop-net samples from C-111/TS (5.3–5.5 %) and the SRS-S mangrove fringe (7.4 %). Among projects that sampled over multiple areas of ENP (minnow trap and drift fence), relative abundance of non-native fishes was highest in the RG, TS, and C-111W and generally declined with distance from the eastern boundary of ENP (SRS and WMP), except for mangrove-habitat samples. African jewelfish, Mayan cichlids, and pike killifish were the most widespread and abundant non-natives throughout ENP (Table 1).

The cumulative number of non-native fish species increased over time in the long-term studies. In 1984, after 7 years of sampling, the first non-native fish was collected at the long-term throw-trap sites in SRS-N (Fig. 4). Since then, the relative abundance of non-natives has been less than 2 % of the total catch each year (Fig. 4a), and the richness of non-native taxa has been consistently between one to five non-native species annually (Fig. 4b). The cumulative number of non-native species collected within the long-term throw-trap sites reached four species by 1994 and remained at that number until four additional species were collected from 2003 to 2007 (Fig. 4c). Non-native fish relative abundance peaked in the early 1990s in the drop-net samples (Fig. 4a) with two to six non-native species caught annually (Fig. 4b). The cumulative number of non-native species from drop nets increased from three in 1990 to six in 1997, then increased again between 2005 and 2007 to nine total species (Fig. 4c). In the long-term minnow-trap project in the RG, the relative abundance of non-natives ranged between 9 % in 2001 to 66 % in 2003 (Fig 4a) collecting only four non-native species in 1999 (Fig. 4b & c), but 10 species by 2009 (Fig. 4c).

New Species Accounts

Eight new non-native fish species and three new native species have been observed in ENP since 1999. Both the non-native and native taxa were phylogenetically diverse. The non-native taxa consisted of three cichlids, two loricariids, a callichthyid, a mastacembelid, and a synbranchid. The native taxa consisted of an aphredoderid, an esocid, and a lepisosteid.

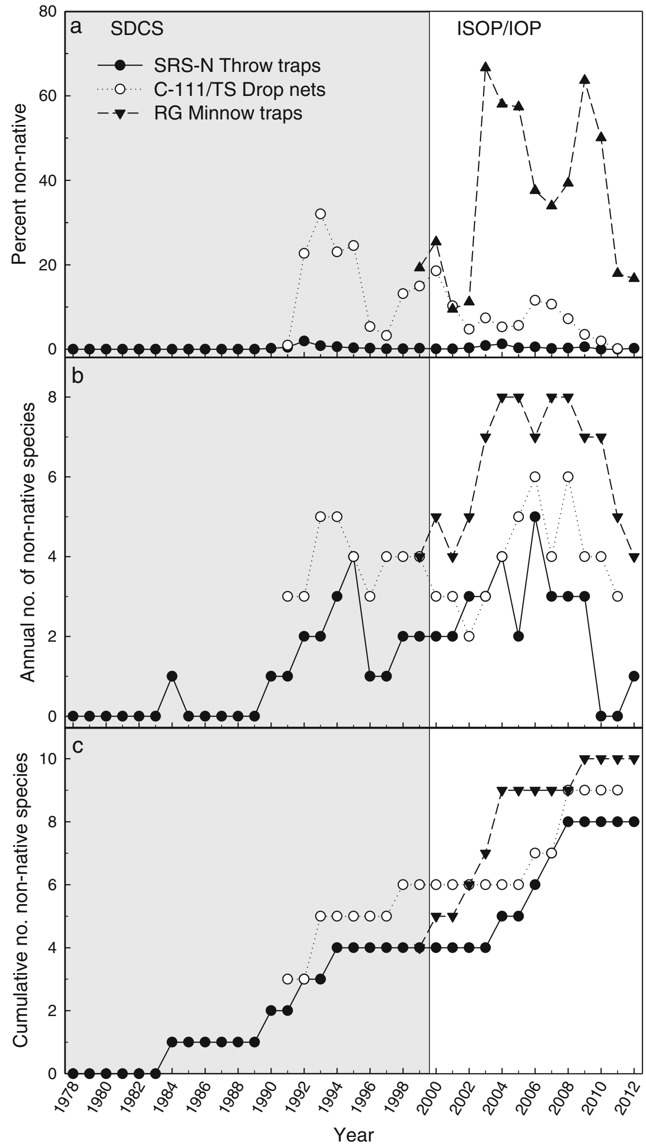

Fig. 4 The **a** relative abundance, **b** annual number of non-native species collected, and **c** cumulative number of non-native species collected with throw traps in SRS-N (1978-May 2012), drop nets in C-111/TS (1990-May 2011) and minnow traps in the RG (1999-May 2012). Water-management periods (SDCS 1978–1999 and ISOP/IOP 1999–2012) are alternatively *shaded*

Jaguar guapote (*Parachromis managuensis*) was first observed in south Florida in 1992 (Shafland 1996, Fig. 2) and quickly moved through the canal system (Gestring and Shafland 1997). It was noted from canals near ENP (Loftus 2000) and observed in L-31W Canal in 1999 (WFL and JLK, pers. obs.). The first ENP specimens were collected about 2.5 km downstream of L-31W Canal in August 2000

(UF 174357, UF 174359, Fig. 5a) at a site sampled monthly after June 1999 (JLK unpub. data). By the end of the 2000 wet season, juveniles had been collected 12 miles west of L-31W Canal in ENP. Although it is most common in the RG, jaguar guapote has been collected near canals along the entire border of ENP (Fig. 5a).

African jewelfish (*Hemichromis letourneuxi*) was first collected in south Florida prior to 1965 in eastern Miami-Dade County (Rivas 1965, as *H. bimaculatus*) and its range in canals expanded in subsequent decades (Loftus and Kushlan 1987; Shafland 1996). The first verified collections in ENP occurred in August 2000 at two sites in the north-eastern RG (UF 174356; Fig. 5b) that were first sampled in 2000, followed by additional specimens in October and December 2000. In 2002, African jewelfish began to spread through eastern ENP and were collected in C-111W about 20 miles south of the original ENP collection site (JLK and O. Beceiro pers. obs.). It is now one of the most abundant (within the RG in particular) and widespread non-native fishes in ENP (Table 1; Fig. 5b), and is implicated in having predatory impacts on native fish populations (Rehage et al. in review).

Presently there appear to be at least two species of sailfin catfishes (*Pterygoplichthys* spp.) in ENP (L. G. Nico, pers comm.), but confusion exists over their identity. Until the taxonomy of *Pterygoplichthys* spp. in Florida is resolved, we have chosen to follow the taxonomy of established species used by Gestring et al. (2010). Sailfin catfishes have been known in Florida since 1981 (Shafland 1996), and prior collections of *Hypostomus* sp. may represent *Pterygoplichthys* (Page 1994; Shafland 1996; Fuller et al. 1999). An adult sailfin catfish, presumably the Orinoco sailfin catfish (*P. multiradiatus*), was observed in SRS-N near a borrow canal in 2001 (J. Taylor, pers. obs.; Fig. 5c), but no voucher was collected. This species was present in the canals bordering ENP prior to 2000 (Loftus 2000). A small *Pterygoplichthys* specimen was collected in ENP along the northern boundary in 2005 (UF 174367). Several specimens assigned to *P. multiradiatus* have been collected since in drift fences on RG marshes near L-31W Canal and as far west as the mangrove creeks of SRS-S (Table 1; Fig. 5c). In the late 1980s, the vermiculated sailfin catfish (*P. disjunctivus*) was collected in Florida (Ludlow and Walsh 1991; Page 1994). In 2010, several probable specimens (identified using Armbruster and Page 2006) were collected downstream of L-29 Canal (JCT, JLK, J. Parkos, and Z. Fratto, pers. obs; Fig. 5d), and they have been collected in L-31W Canal (JLK and J. Parkos, pers. obs.).

The brown hoplo (*Hoplosternum littorale*) has spread rapidly through the canals and waterways of Florida since its first collection in south-central Florida in the early 1990s (Nico et al. 1996; Gestring et al. 2009). In ENP, the first specimen was collected from northwestern TS in 2002 (UF 174393; Fig. 5e). Subsequent collections were made in wetlands near L-31W Canal (UF 174353, UF 174361, UF 174369). Although relatively uncommon in ENP fish samples (Table 1), this species has been found throughout SRS (Fig. 5e).

Butterfly peacock (*Cichla ocellaris*) was stocked successfully into south Florida canals by the Florida Game and Freshwater Fish Commission in 1984 (Shafland 1995). Although first observed in the Shark Valley canal in 1985, the butterfly peacock was neither seen nor collected in ENP afterwards and was not considered established by Loftus (2000). Beginning in 2000, the butterfly peacock was seen in the L-31W and C-111 canals (WFL and JLK, pers. obs.). Four individuals observed in the Royal Palm ponds in November 2002 were the first records for TS (JLK, pers. obs.). Butterfly peacock was frequently observed in the Royal Palm and Earnest Coe Visitor Center ponds in subsequent years but was not collected until 2008, when we found dead specimens at the visitor center pond after a January 2008 cold event (UF 174351). Several individuals have been collected by electrofishing in the C-111W (Table 1). Despite its vulnerability to cold temperatures (Shafland 1995), butterfly peacock, including spawning individuals, have been observed often within the Royal Palm and Earnest Coe Visitor Center ponds and in pools along the northern boundary of ENP. We now consider it established.

Banded cichlid (*Heros severus*) was first collected in Florida from the C-4 canal west of Miami in 1993 (Shafland 1996). Shafland et al. (2008) reported it from L-30 Canal, north of ENP. Both canals join L-31N Canal. A single fish was observed on two occasions in ENP adjacent to L-31W Canal in 2004 (JLK and WFL, pers. obs.; Fig. 5f). There are no other observations or collections within ENP, however several individuals have been collected by electrofishing in L-31N Canal since 2011 (D. Gandy and JSR, unpub. data), suggesting a small population exists in boundary canals.

Peacock eel (*Macrognathus siamensis*) was first collected in Florida in C-111 Canal in 2002 (Shafland et al. 2008). In December 2004, it was collected in the mangrove wetlands south of C-111 Canal (UF 174386; Fig. 5g). Since then, it has been collected north in TS and the RG, along the northern boundary south of L-29 Canal (JCT, JLK, J. Parkos, and Z. Fratto, unpublished data), and west to the SRS-S mangrove creeks (Fig. 5g). Electrofishing produces the most specimens of this burrowing species (Table 1), especially in deeper habitats with soft sediments (e.g., alligator ponds and mangrove creeks).

The Asian swamp eel (*Monopterus albus* complex), first collected in Florida in 1997, was found as a separate introduction in 1999 near the flooded C-113 Canal (Collins et al. 2002). It dispersed rapidly downstream to the lower C-111 in 2000 (Shafland et al. 2010). In December 2007, an eel

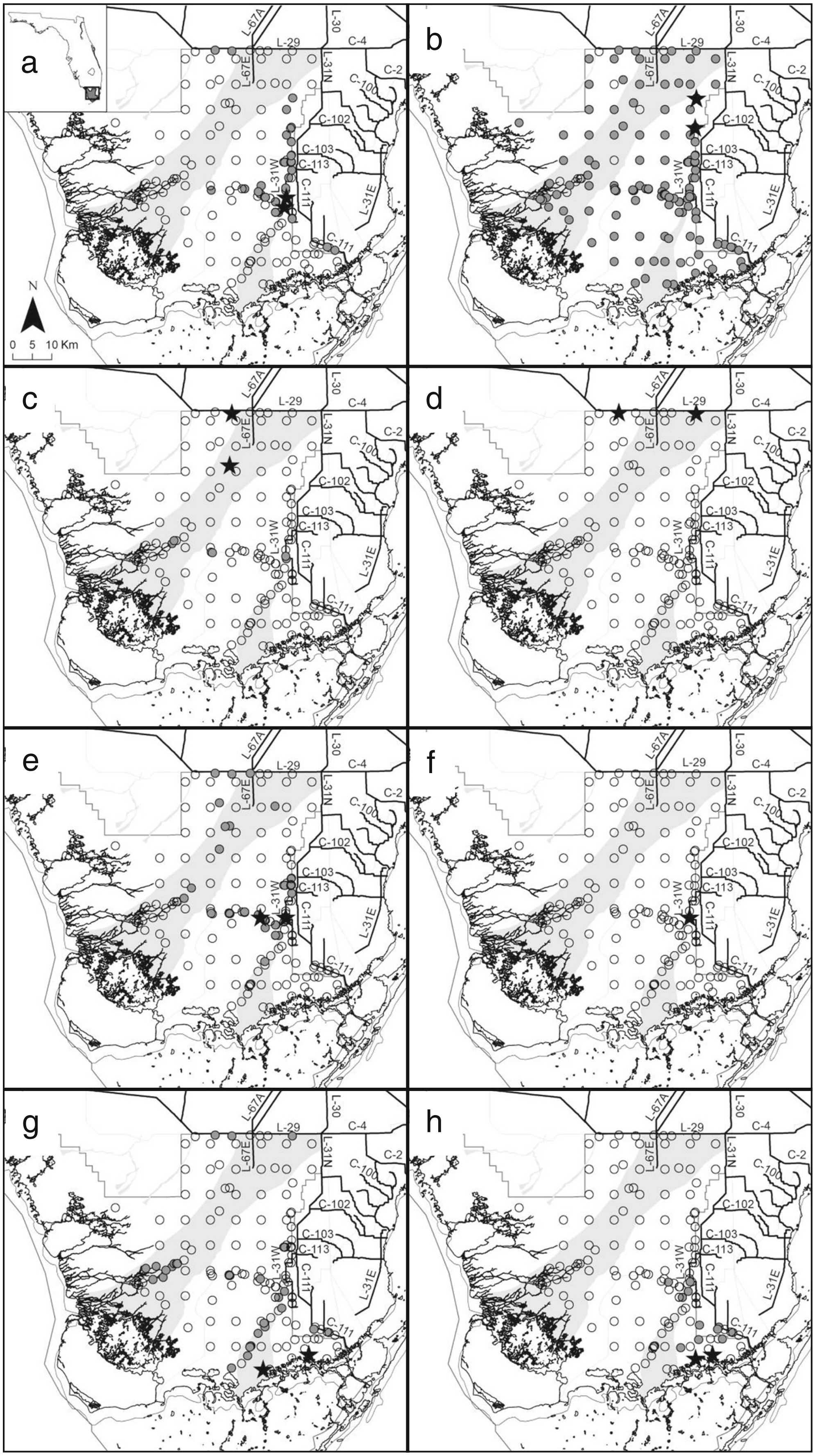

Fig. 5 Map of study area with sample locations. *Solid circles* show where **a** jaguar guapote **b** African jewelfish, **c** Orinoco sailfin catfish, **d** vermiculated sailfin catfish, **e** brown hoplo, **f** banded cichlid, **g** peacock eel, and **h** Asian swamp eel were collected between 2000 and 2012. *Stars* show locations of the two earliest collections of each species. *Open circles* are sample locations where the species was not collected

was collected in the mangroves south of C-111 Canal in ENP (UF 175761; Fig. 5h). It is commonly collected by electrofishing in C-111W (Table 1). A photograph from Royal Palm in 2009 (K. Sunderland, pers. obs, confirmed by JLK) and recent collections from L-31N to L-31W canals (D. Gandy and JSR, unpublished data; JLK, Z. Fratto, and J. Parkos, unpublished data) and in RG since 2011 (Fig. 5h) suggest a northward expansion.

In addition to non-native species, three species native to the northern Everglades but previously unrecorded in ENP have also been collected since 1999. Redfin pickerel (*Esox americanus americanus*) was reported from the northern Everglades (Dineen 1974, JCT and F. Jordan unpub. data) but had not been collected in ENP (Loftus 2000) until November 1999 when a specimen was electrofished in SRS-S. More have been collected since in both SRS-N and the RG (UF 174390, UF 174405; Table 1). Pirate perch (*Aphredoderus sayanus*) was considered a species of doubtful occurrence or persistence in southern Florida (Loftus and Kushlan 1987; Loftus 2000). Apart from a specimen collected in 1930, purportedly near Florida City (UF 541; Briggs 1958), the most recent record from the southern Everglades came from Tamiami Canal in the late 1990s (Leo Nico and WFL, pers. obs.). It was not collected in ENP until 2002 when a specimen was taken in SRS-N. Individuals have been collected since throughout SRS and the RG (UF 174360, UF 174368, UF 175642; Table 1). The third species, longnose gar (*Lepisosteus osseus*), had been collected in Lake Okeechobee and the northern Everglades (Dineen 1974; Kushlan and Lodge 1974) but was listed as a species of doubtful occurrence near ENP (Loftus and Kushlan 1987; Loftus 2000). It was first observed within ENP in L-67E Canal in April 2007 (JLK, pers. obs.). A photo of a longnose gar in a local bait shop, labeled 23 November 2007, was the second observation in the same area (JLK, pers. obs). The only specimen collected in ENP was caught by an angler from L-67E Canal in April 2009 (UF 176786; Gandy et al. 2012). In June 2009, a longnose gar was taken by archery fishing in L-28 Canal north of ENP (G. Zavadzkas, pers. comm.). Gandy et al. (2012) reported other specimens collected south of Lake Okeechobee (including the southernmost record in L-31W Canal).

Discussion

Seventeen species of non-native fishes have been recorded for ENP as of May 2012, 14 of which appear to be established. Three species native to the northern Everglades were also recorded for the first time in ENP. This increase in fish species in ENP parallels the increase in non-natives established in Florida and appears to relate to management activities that increased connectivity of wetlands to the boundary canal system, particularly along the eastern side of ENP. All non-native fish species in ENP (with the exception of Mayan cichlid) established populations in canals outside ENP before detection inside the Park (Loftus 1987; Loftus 1988; Shafland 1996; Shafland et al 2008). Trexler et al. (2000) reported a higher relative abundance of non-native species within RG habitats and the mangroves relative to SRS habitats, and that pattern continues. Besides affecting social values and legal mandates to preserve ENP for native species, these additions represent a significant alteration of the composition of the freshwater fish assemblage, with Cichlidae now the most speciose family (10 taxa) in ENP fresh waters. Several new species have become widespread in ENP, where African jewelfish has become one of the most abundant non-natives.

Changes in water-management operations associated with the ISOP/IOP program enhanced sheetflow into ENP from the canal system and appear to be linked to the introduction of several non-native fishes. Five of eight non-native species collected since 2000 were first observed near eastern boundary canals after the ISOP/IOP management change (L-31W Canal: Jaguar guapote, brown hoplo, and banded cichlid; C-111 Canal: Asian swamp and peacock eels). However, the occurrence of African jewelfish, sailfin catfishes, and the three native species is less easily attributed to ISOP/IOP, although dispersal in canals is implicated. African jewelfish had been dispersing through the canal system for decades (Loftus and Kushlan 1987; Shafland 1996; Shafland et al. 2008) before its collection in ENP in 2000, following implementation of ISOP/IOP. However, it was first collected in the RG approximately 10 km from both the ISOP/IOP-flooded wetlands and northern boundary canals near an area of rural development with ponds, ditches, and an unmanaged canal that floods seasonally. These artificial deep-water habitats likely provided refuge for jewelfish (Schofield et al. 2009), though the exact route of dispersal to or the source of jewelfish in this area is unclear. Sailfin catfishes and the three native species were first observed near canals along the northern boundary in SRS-N. The interconnected canal system was implicated in the southern dispersal of longnose gar (Gandy et al. 2012) as was likely the case with the pirate perch, redfin pickerel, and sailfin catfishes.

The combination of multiple sampling methods and intensive effort may have increased the probability of collecting uncommon species since the 1990s (Jackson and Harvey 1997; Ruetz et al. 2007). After 2000, another method (drift fence) and new sites were added that increased effort in ENP beyond that reported by Trexler et al. (2000). However, projects that maintained consistent annual effort before and after 2000 (SRS throw traps, C-111/TS original drop traps, SRS electrofishing) collected four of the eight new non-native species and two of the three new natives, which suggests range expansions instead of artifacts from increased effort. The minnow-trap project, begun in 1999, collected four non-native species that year (on par with Trexler et al. 2000 and Kobza et al. 2004), and six additional species since 2000. Despite high effort, our studies collected only 14 of the 17 non-native species, and two of the three range-expanding native species. Banded cichlid, Mozambique tilapia, vermiculated sailfin catfish, and longnose gar were not collected in any monitoring project. There is no evidence those four species maintain reproductive populations in ENP, although all are present in the nearby canal system (Shafland et al. 2008; Gestring et al. 2010; Gandy et al. 2012).

As established non-native fishes continue to increase in Florida (Shafland et al. 2008), so does the probability of new introductions to ENP. One hundred ten non-native freshwater fishes have been reported from Florida waters (USGS 2004), demonstrating propagule pressure for future establishment. Species already established in Florida may pose a more immediate risk of introduction to ENP. Thirty-four species maintained reproducing populations in Florida freshwaters as of 2007 (Shafland et al. 2008), twice the number found in ENP. The yellowbelly cichlid (*Cichlasoma salvini*) and the bullseye snakehead (*Channa marulius*) are examples with expanding ranges in canals near the Everglades (Shafland et al. 2008), and both appear adapted to survival in seasonally flooded wetlands with access to canals.

Despite nearly 50 years of concern about non-native fishes (Courtenay et al. 1974; Courtenay and Robins 1975; Shafland 1986), the number of species reproducing in Florida continues to rise (Shafland et al. 2008), as does the number in ENP. Courtenay and Robins (1975) and Loftus (1988) warned that the connectivity of the Florida canal system would enable the spread of non-native species. Elsewhere in the southeastern United States, National Park units play a significant role in protecting the natural biodiversity of freshwater fishes; however, that diversity is affected by disturbances from outside park boundaries that enhance the prevalence of non-native species (Long et al. 2012). Hydrologic restoration of the Everglades is using adaptive management to preserve and protect the ecosystem by improving the quantity, quality, distribution, and timing of water deliveries (CERP 1999). Restoration projects that modify the existing canal system and alter the delivery of water from canals raise the probability of incursions by non-native species into Everglades wetlands. Once non-native fishes become established in open wetlands, control is difficult (Loftus 1988). Therefore, hydrologic restoration projects should be designed to limit the entry of non-native fishes into natural areas. Hydrological, electrical or biological methods designed to control or limit the spread of non-native species (Britton et al. 2010; GLMRIS 2012), or actions that take advantage of the cold intolerance of tropical non-native species (e.g. by partial or complete filling of unnaturally deep habitats to allow winter cooling; Schofield et al. 2009) should be considered for invasive species management in Florida. In doing so, hydrologic restoration may be achieved while minimizing the unintended consequence of aiding the spread of non-native fishes into natural habitats. The Everglades experience should be a lesson for managers of protected wetlands about the need to prevent incursions of non-native fishes through innovative hydrological management.

Acknowledgments We appreciate the assistance of colleagues, technicians, and volunteers who have contributed to this work over many years, especially Z. Fratto and S. Perry. Our work was funded by sources that include: base funding from ENP and USGS, the Critical Ecosystem Science Initiative, Modified Water Deliveries, and CERP Monitoring and Assessment Programs. This publication was produced as part of a special issue devoted to investigating the ecological response of over 20 years of hydrologic restoration and active management in the Taylor Slough drainage of Everglades National Park. Support for this special issue was provided by Everglades National Park, the Southeast Environmental Research Center, the Florida Coastal Everglades Long-Term Ecological Research program (National Science Foundation cooperative agreement #DBI-0620409), the Everglades Foundation, and the South Florida Water Management District.

References

Armbruster JW, Page LM (2006) Redescription of *Pterygoplichthys punctatus* and description of a new species of *Pterygoplichthys* (Siluriformes: Loricariidae). Neotropical Ichthyology 4:401–409

Baker G, Darby N, Williams T, Wullschleger J (2008) Bonneville cutthroat trout restoration project—Great Basin National Park. Natural Resource Report NPS/NRPC/NRR—2008/055. US National Park Service, Fort Collins

Briggs JC (1958) A list of Florida fishes and their distribution. Bulletin of the Florida State Museum, Biological Sciences 2:223–318

Britton JR, Gozlan RE, Copp GH (2010) Managing non-native fish in the environment. Fish and Fisheries. doi:10.111/j.1467-2979.2010.00390.x

Carriger JF, Rand GM, Gardinali PR, Perry WB, Tompkins MS, Fernandez AM (2006) Pesticides of potential ecological concern in sediment from South Florida canals: an ecological risk prioritization for aquatic arthropods. Soil and Sediment Contamination 15:21–45

Chick JH, Ruetz CR III, Trexler JC (2004) Spatial scale and abundance patterns of large fish communities in freshwater marshes of the Florida Everglades. Wetlands 24:652–664

Childers DL, Doren RF, Jones R, Noe GB, Rugge M, Scinto LJ (2003) Decadal changes in vegetation and soil phosphorus pattern across the Everglades landscape. Journal of Environmental Quality 32:344–362

Collins TM, Trexler JC, Nico LG, Rawlings TA (2002) Genetic diversity in a morphologically conservative invasive taxon: multiple introductions of swamp eels in the Southeastern United States. Conservation Biology 16:1024–1035

Comprehensive Everglades Restoration Plan (CERP) (1999) U.S. Army corps of engineers and South Florida water management district. Jacksonville FL. (www.evergladesplan.org/pub/restudy_eis.aspx) Main report accessed 8/12/2012

Courtenay WR Jr, Fuller PL (2004) Underwater and out of sight: invasive fishes in the United States: implications for national parks. Park Science 22:42–45

Courtenay WR Jr, Miley WW II (1975) Range expansion and environmental impress of the introduced walking catfish in the United States. Environmental Conservation 2:145–148

Courtenay WR Jr, Robins CR (1973) Exotic aquatic organisms in Florida with emphasis on fishes: a review and recommendations. Transactions of the American Fisheries Society 102:1–12

Courtenay WR Jr, Robins CR (1975) Exotic organisms: an unsolved complex and problem. Bioscience 25:306–313

Courtenay WR Jr, Sahlman HF, Miley WW II, Herrema DJ (1974) Exotic fishes in fresh and brackish waters of Florida. Biological Conservation 6:292–302

Dineen JW (1974) Fishes of the Everglades. In: Gleason PJ (ed) Environments of south Florida: present and past. Miami Geological Society, Memoir 2, Miami, pp 375–385

Doren RF, Armentano TV, Whiteaker LD, Jones RD (1997) Marsh vegetation patterns and soil phosphorus gradients in the Everglades ecosystem. Aquatic Botany 56:145–163

Drees L (2004) A retrospective on NPS invasive species policy and management. Park Science 22:22–26

Fuller PL, Nico LG, Williams JD (1999) Nonindigenous fishes introduced into inland waters of the United States. American Fisheries Society Special Publication 27, Bethesda, Maryland

Gandy DA, Rehage JS, Munyon JW, Gestring KB, Galvez JI (2012) Canals as vectors for fish movement: potential southward range expansion of *Lepisosteus osseus* L. (longnose gar) in South Florida. Southeastern Naturalist 11:253–262

Gestring KB, Shafland PL (1997) Selected life history attributes of the exotic jaguar guapote (*Cichlasoma managuense*) in Florida. Florida Scientist 60:137–142

Gestring KB, Shafland PL, Stanford MS, Eisenhauer RL (2009) Status and selected life history attributes of the illegally introduced brown hoplo (*Hoplosternum littorale*) in Florida. Florida Scientist 72:37–47

Gestring KB, Shafland PL, Stanford MS (2010) Status of the exotic Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) in Florida. Florida Scientist 72:121–137

Gleason PJ, Stone P (1994) Age, origin, and landscape evolution of the Everglades peatland. In: Davis SM, Ogden JC (eds) Everglades: The ecosystem and its restoration. St. Lucie Press, Delray Beach, pp 149–197

Godfrey MC, Catton T (2011) River of interests: water management in South Florida and the Everglades, 1948-2010. U.S. Government Printing Office. Washington, DC. Available via http://www.evergladesplan.org/about/river_interest_history.aspx Accessed 8/12/2012

Goss CW, Loftus WF, Trexler JC (in press) Fish colonization of ephemeral wetlands in the Florida Everglades. Wetlands

Great Lakes and Mississippi River Interbasin Study (GLMRIS) (2012) Inventory of available controls for aquatic nuisance species of concern: Chicago Area Waterway System. Available via http://glmris.anl.gov/documents/interim/anscontrol/index.cfm. Accessed 8/3/2012

Gunderson LH, Loftus WF (1993) The Everglades. In: Martin WH, Boyce SG, Echternacht AC (eds) Biodiversity of the Southeastern United States: lowland terrestrial communities. Wiley, New York, pp 199–255

Harvey RG, Loftus WF, Rehage JS, Mazzotti FJ (2010) Effects of canals and levees on Everglades ecosystems. UF/IFAS Publication WEC304. Available online at http://edis.ifas.ufl.edu/uw349. Accessed 8/12/2012

Higer AL, Kolipinski MC (1967) Pull-up trap: a quantitative device for sampling shallow-water animals. Ecology 48:1008–1009

Hunt BP (1953) Food relationship between Florida spotted gar and other organisms in the Tamiami Canal, Dade County, Florida. Transactions of the American Fisheries Society 82:14–32

Jackson DA, Harvey HH (1997) Qualitative and quantitative sampling of lake fish communities. Canadian Journal of Fisheries and Aquatic Sciences 54:2807–2813

Jordan F, Coyne S, Trexler JC (1997) Sampling fishes in vegetated habitats: effects of habitat structure on sampling characteristics of the 1-m2 throw trap. Transactions of the American Fisheries Society 126:1012–1020

Kilby JD, Caldwell DK (1955) A list of fishes from the southern tip of the Florida peninsula. Quarterly Journal of the Florida Academy of Sciences 18:195–206

Kobza RM, Trexler JC, Loftus WF, Perry SA (2004) Community structure of fishes inhabiting aquatic refuges in a threatened karst wetland and its implications for ecosystem management. Biological Conservation 116:153–165

Koel TM, Bigelow PE, Doepke PE, Ertel BD, Mahony DL (2006) Conserving Yellowstone cutthroat trout for the future of the GYE Yellowstone's aquatic sciences program. Yellowstone Science 14:20–28

Kolar C, Lodge DM (2000) Freshwater nonindigenous species: interactions with other global changes. In: Mooney HA, Hobbs RJ (eds) Invasive species in a changing world. Island Press, Washington DC, pp 3-30. Am. Fish. Soc. 82:14–32

Kolipinski MC, Higer AL (1969) Some aspects of the effects of the quantity and quality of water on biological communities in Everglades National Park. U.S. Geological Survey Open File Rept. 69007, Tallahassee, Florida

Kotun K, Renshaw A (in review) Taylor Slough hydrology: fifty years of water management 1961–2010. Wetlands

Kushlan JA (1972) The exotic fish, *Aequidens portalegrensis*, in the Big Cypress Swamp. Florida Naturalist 97:102

Kushlan JA (1974) Effects of a natural fish kill on the water quality, plankton, and fish population of a pond in the Big Cypress Swamp, Florida. Transactions of the American Fisheries Society 103:235–243

Kushlan JA (1980) Population fluctuations of Everglades fishes. Copeia 1980:870–874

Kushlan JA, Lodge TE (1974) Ecological and distributional notes on the freshwater fish of Southern Florida. Florida Scientist 37:110–128

Light SS, Dineen JW (1994) Water control in the Everglades: a historical perspective. In: Davis SM, Ogden JC (eds) Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, pp 741–756

Loftus WF (1987) Possible establishment of the Mayan cichlid, *Cichlasoma urophthalmus* (Günther) (Pisces: Cichlidae), in Everglades National Park, Florida. Florida Scientist 50:1–6

Loftus WF (1988) Distribution and ecology of exotic fishes in Everglades National Park. In: Thomas LK (ed) Management of exotic species in natural communities. Proceedings of the George Wright Society Conference on Science in the National Parks, Vol 5. Ft. Collins, Colorado pp 24–34

Loftus WF (2000) Inventory of fishes of Everglades National Park. Florida Scientist 63:27–47

Loftus WF, Kushlan JA (1987) Freshwater fishes of Southern Florida. Bulletin of the Florida State Museum, Biological Sciences 31:147–344

Loftus WF, Johnson RA, Anderson GH (1992) Ecological impacts of the reduction of groundwater levels in short-hydroperiod marshes of the Everglades. In: Stafford JA, Simons JJ (eds) Proceedings of the first international conference on ground water ecology. American Water Resources Association, Bethesda, pp 199–208

Long JM, Nibbelink NP, McAbee KT, Stahli JW (2012) Assessment of freshwater fish assemblages and their habitats in the National Park

Service system of the southeastern United States. Fisheries 37:212–225

Loope L (2004) The challenge of effectively addressing the threat of invasive species to the National Park System. Park Science 22:14–20

Lorenz JJ, McIvor CC, Powell GVN, Frederick PC (1997) A drop net and removable walkway used to quantitatively sample fishes over wetland surfaces in dwarf mangroves of the southern Everglades. Wetlands 17:346–359

Ludlow ME, Walsh SJ (1991) Occurrence of a South American armored catfish in the Hillsborough River, Florida. Florida Scientist 54:48–50

McVoy CW, Said WP, Obeysekera J, VanArman J, Dreschel T (2011) Landscapes and hydrology of the pre-drainage Everglades. University Press of Florida, Gainesville

Merritt ML (1996) Simulation of the water-table altitude in the Biscayne aquifer, southern Dade County, Florida, water years 1945-89. U.S. Geological Survey Water-Supply Paper 2458

Mills EL, Chrisman JR, Holeck DT (1999) The role of canals in the spread of nonindigenous species in North America. In: Claudi R, Leach JH (eds) Nonindigenous freshwater organisms: vectors, biology, and impacts. Lewis Publishers, Boca Raton, pp 347–380

Moore SE, Larson GL (1990) Native brook trout restoration program in Great Smoky Mountains National Park. In: Richardson F, Hamre RH (eds) Wild trout IV: proceedings of the symposium. Yellowstone National Park, Wyoming, pp 62–70

Nico LG (2005) Changes in the fish fauna of the Kissimmee River basin, peninsular Florida: nonnative additions. In: Rinne JN, Hughes RM, Calamusso B (eds) Historical changes in large river fish assemblages of the Americas. American Fisheries Society Symposium 45, Bethesda, Maryland, pp 523–556

Nico LG, Walsh SJ, Robbins RH (1996) An introduced population of the South American callichthyid catfish *Hoplosternum littorale* in the Indian River Lagoon system, Florida. Florida Scientist 3:189–200

Obaza A, DeAngelis DL, Trexler JC (2011) Using data from an encounter sampler to model fish dispersal. Journal of Fish Biology 78:495–513

Odum WE, McIvor CC, Smith TJ III (1982) The ecology of the mangroves of South Florida: a community profile. FWS/OBS-81/24. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC

Page LM (1994) Identification of sailfin catfishes introduced to Florida. Florida Scientist 57:171–172

Parkos JJ, Ruetz CR III, Trexler JC (2011) Disturbance regime and limits on benefits of refuge use for fishes in a fluctuating hydroscape. Oikos 120:1519–1530

Rehage JS, Liston SE, Dunker KJ, Loftus WF (in press) Fish community responses to the combined effects of decreased hydroperiod and nonindigenous fish invasions in a karst wetland: are Everglades solution holes sinks for native fishes? Wetlands

Rehage JS, Loftus WF (2007) Seasonal fish community variation in headwater mangrove creeks in the southwestern Everglades: an examination of their role as dry-down refuges. Bulletin of Marine Science 80:625–645

Rivas LR (1965) Florida freshwater fishes and conservation. Quarterly Journal of the Florida Academy of Sciences 28:255–258

Ruetz CR III, Uzarski DG, Krueger DM, Rutherford ES (2007) Sampling a littoral fish assemblage: comparison of small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 27:825–831

Schofield PJ, Loftus WF, Brown ME (2007) Hypoxia tolerance of two centrarchid sunfishes and an introduced cichlid from karstic Everglades wetlands of southern Florida, U.S.A. Journal of Fish Biology 71(suppl D):87–99

Schofield PJ, Loftus WF, Kobza RM, Cook MI, Slone DDH (2009) Tolerance of nonindigenous cichlid fishes (*Cichlasoma urophthalmus*, *Hemichromis letourneuxi*) to low temperature: laboratory and field experiments in South Florida. Biological Invasions 12:2441–2457

SFNRC (2005) An assessment of the Interim Operation Plan. Project Evaluation Report, South Florida Natural Resources Center, Technical Series 2005:2 Everglades National Park, Homestead, FL

Shafland PL (1986) A review of Florida's efforts to regulate, assess manage exotic fishes. Fisheries 11:20–25

Shafland PL (1995) Introduction and establishment of a successful butterfly peacock fishery in Southeast Florida canals. American Fisheries Society Symposium 15:443–451

Shafland PL (1996) Exotic fishes of Florida-1994. Reviews in Fisheries Science 4:101–122

Shafland PL, Pestrak JM (1982) Lower lethal temperatures for fourteen non-native fishes in Florida. Environmental Biology of Fishes 7:149–156

Shafland PL, Gestring KB, Stanford MS (2008) Florida's exotic freshwater fishes—2007. Florida Scientist 71:220–245

Shafland PL, Gestring KB, Stanford MS (2010) An assessment of the Asian Swamp Eel (*Monopterus albus*) in Florida. Reviews in Fisheries Science 18:25–39

South Florida Water Management District (SFWMD) (2012) DBHYDRO browser. Available via http://www.sfwmd.gov/dbhydro. Accessed 15 Nov 2012

Trexler JC, Loftus WF, Jordan FC, Lorenz JJ, Chick JH, Kobza RM (2000) Empirical assessment of fish introductions in a subtropical wetland ecosystem: an evaluation of contrasting views. Biological Invasions 2:265–277

Tronstad LM, Hall RO Jr, Koel TM, Gerow KG (2010) Introduced lake trout produced a four-level trophic cascade in Yellowstone Lake. Transactions of the American Fisheries Society 139:1536–1550

U.S. Army Corps of Engineers (USACE) (2002) Central and Southern Florida Project: canal-111 South Dade County, Florida S-332D detention area: pre-operations and start-up monitoring data review report. U.S. Army Corps of Engineers, November 2002

U.S. Geological Survey (USGS) (2004) Nonindigenous aquatic species database. Gainesville, Florida. Available via http://nas.er.usgs.gov/. Accessed 28 July 2012

U.S. Geological Survey (USGS) (2012) National water information system: data for the nation. Available via http://waterdata.usgs.gov/nwis/. Accessed 15 Nov 2012

US National Park Service (USNPS) (2007) Management policies 2006. US Government Printing Office, Washington, DC

Warren ML, Burr BM, Walsh SJ, Bart HL, Cashner RC, Etnier DA, Freeman BJ, Kuhajda BR, Mayden RL, Robison HW, Ross ST, Starnes WC (2000) Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25:7–31