

Universidad de Huelva

Departamento de Ciencias Integradas



Distribución de peces continentales en una cuenca mediterránea altamente perturbada: bases ecológicas para la gestión y la conservación

**Memoria para optar al grado de doctor
presentada por:**

Pedro Sáez Gómez

Fecha de lectura: 9 de enero de 2023

Bajo la dirección de doctor:

José Prenda Marín

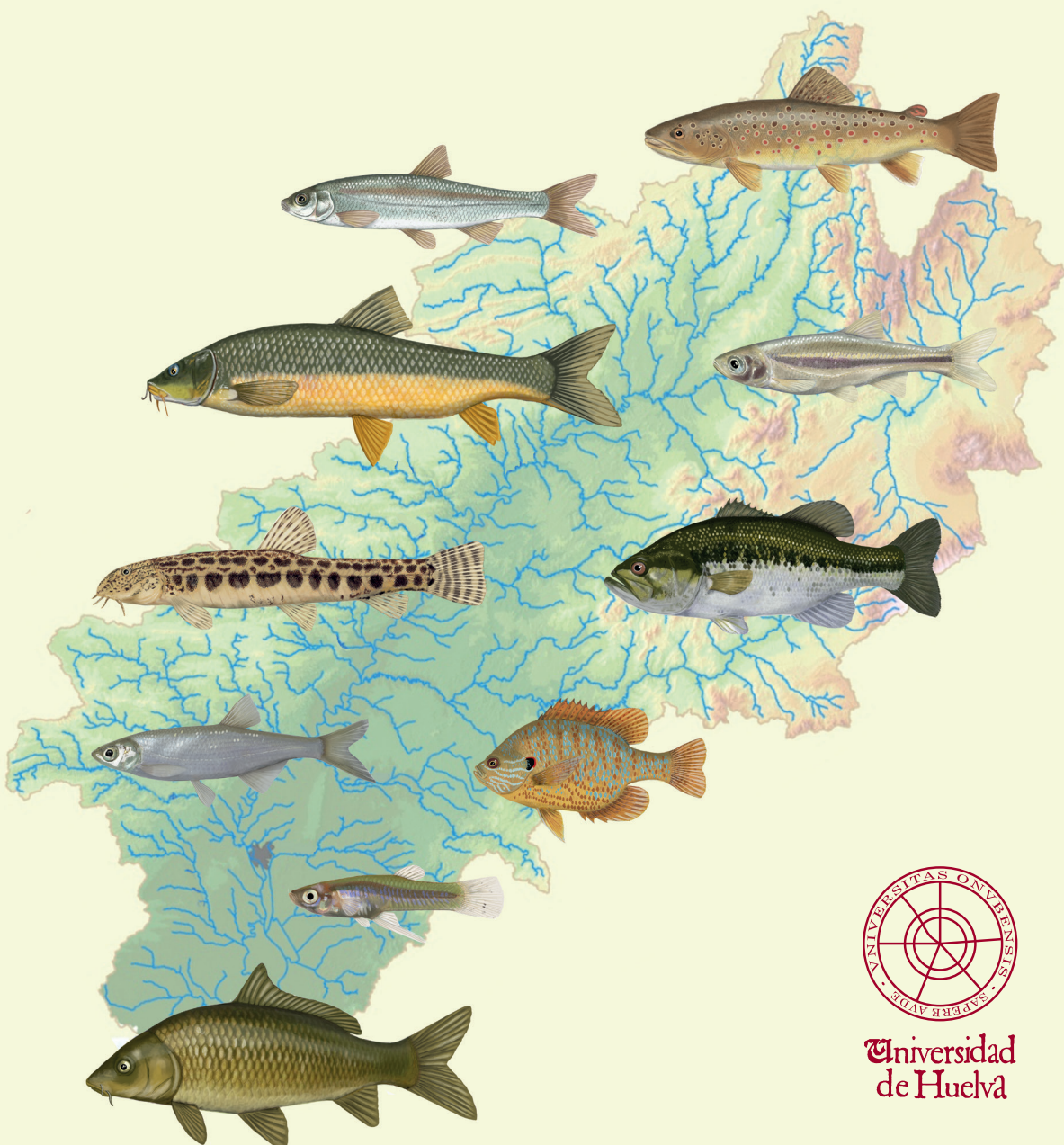
Huelva, 2023



Distribución de **peces continentales** en una **cuenca mediterránea** altamente perturbada:
Bases ecológicas para la gestión y la conservación

Tesis Doctoral · 2022

PEDRO SÁEZ GÓMEZ



**Universidad
de Huelva**

UNIVERSIDAD DE HUELVA
Facultad de Ciencias Experimentales
Departamento de Ciencias Integradas



**DISTRIBUCIÓN DE PECES CONTINENTALES EN UNA
CUENCA MEDITERRÁNEA ALTAMENTE PERTURBADA:
BASES ECOLÓGICAS PARA LA GESTIÓN Y LA
CONSERVACIÓN**

Programa de Doctorado:
Ciencia y Tecnología Industrial y Ambiental

Memoria presentada para optar al grado de doctor presentada por:
Pedro Sáez Gómez

Director
Dr. José Prenda Marín
Catedrático de Universidad

Huelva, 7 de septiembre de 2022

TITLE: FRESHWATER FISH DISTRIBUTION IN A HIGHLY DISTURBED MEDITERRANEAN BASIN: ECOLOGICAL BASIS FOR MANAGEMENT AND CONSERVATION

TÍTULO: DISTRIBUCIÓN DE PECES CONTINENTALES EN UNA CUENCA MEDITERRÁNEA ALTAMENTE PERTURBADA: BASES ECOLÓGICAS PARA LA GESTIÓN Y LA CONSERVACIÓN

Doctorando: Pedro Sáez Gómez

Director: José Prenda Marín

Este estudio ha sido financiado por la Junta de Andalucía, Convocatoria de Proyectos de Excelencia (P07-RNM-03309: “Evaluación del estado ecológico de los medios fluviales de la cuenca del Guadalquivir, según recoge la Directiva Marco de Aguas, a través del uso de bioindicadores basados en peces”)

CITACIÓN RECOMENDADA: Sáez-Gómez, P. 2022. Distribución de peces continentales en una cuenca Mediterránea altamente perturbada: bases ecológicas para la gestión y la conservación. Tesis Doctoral. Universidad de Huelva, España.

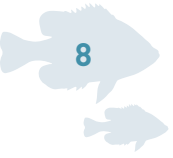
RECOMMENDED CITATION: Sáez-Gómez, P. 2022. Freshwater fish distribution in a highly disturbed Mediterranean basin: ecological basis for management and conservation. Ph.D. Dissertation. Universidad de Huelva, Spain.

Diseño de portada y contraportada: Dhamaberen Studio (www.dharmaberen.com).

Diseño de maquetación: Agustina Gutiérrez (www.tesiteando.es)

Índice general

RESUMEN	9
ABSTRACT	11
CAPÍTULO I.	
INTRODUCCIÓN Y SÍNTESIS GENERAL	15
Introducción	17
Área de estudio	19
La introducción de especies ícticas exóticas en la cuenca del Guadalquivir	22
Fuentes de información histórica como herramienta para el estudio de los cambios en la distribución de los peces	23
Efectos de la escala espacial sobre la distribución de los peces en la cuenca del Guadalquivir: respuestas a nivel de comunidad y de especie	24
Objetivos y metodología	26
CHAPTER II.	
FRESHWATER FISH BIODIVERSITY IN A LARGE MEDITERRANEAN BASIN (GUADALQUIVIR RIVER, S SPAIN): PATTERNS, THREATS, STATUS AND CONSERVATION.	31
CHAPTER III.	
UPDATING THE DISTRIBUTION DATA OF RECENTLY INTRODUCED FRESHWATER FISH IN THE GUADALQUIVIR RIVER BASIN (SPAIN) ..	69
CHAPTER IV.	
MULTISCALE EFFECTS ON FRESHWATER FISH DISTRIBUTION IN A HIGHLY DISTURBED MEDITERRANEAN-TYPE BASIN: COMMUNITY-LEVEL AND SPECIES-LEVEL RESPONSES.	85
CHAPTER V.	
THE ENVIRONMENTAL ASYMMETRY IN A LARGE MEDITERRANEAN BASIN DETERMINES THE SPATIAL PATTERN OF FRESHWATER FISH LOCAL EXTINCTIONS VS. INTRODUCTIONS OF EXOTIC SPECIES	123



DISCUSIÓN GENERAL	153
CONCLUSIONES / CONCLUSIONS	169
Conclusiones	171
Conclusions	173
REFERENCIAS	175
AGRADECIMIENTOS	193
ANEXOS	197

Resumen

La cuenca del río Guadalquivir (S de España) es una de las mayores de la Península Ibérica y cuenta con una notable biodiversidad acuática. Aunque en esta cuenca se han realizado muchos estudios sobre el régimen hidrológico o sobre la calidad del agua, la biodiversidad de los peces continentales, así como su distribución y estado de conservación nunca se han abordado globalmente, como en otras cuencas ibéricas. En esta Tesis se sintetiza la información sobre los peces continentales a través de estudios de campo (285 localidades muestreadas) y otras fuentes de información (revisión bibliográfica, ciencia ciudadana, datos históricos). Examinamos los requisitos locales y regionales para estudiar las asociaciones de especies, así como la presencia de especies individuales a lo largo de toda esta cuenca altamente perturbada por efecto de acciones humanas. Se analizaron los patrones de distribución de los peces a diferentes escalas espaciales y temporales así como las condiciones ambientales generales y su estado de conservación. Documentamos la presencia de 40 especies (20 nativas y 20 exóticas) en la cuenca durante el siglo XX hasta la actualidad. Pero solo capturamos 18 especies durante el trabajo de campo, con una prevalencia de cualquier especie nativa inferior al 23% (excepto *Luciobarbus sclateri*). Destaca la presentación de nuevos datos de distribución de cuatro especies introducidas recientemente en esta cuenca: chanchito (*Australoheros facetus* Jenyns, 1842), pez gato negro (*Ameiurus melas* Rafinesque, 1820), siluro (*Silurus glanis* Linnaeus, 1758) y una especie de piscaro de origen desconocido (*Phoxinus* spp.). Se compilan otros registros para actualizar el rango de distribución de estas especies. La información obtenida refuerza la evidencia sobre el establecimiento y expansión de estas especies no nativas.

La mayor riqueza de especies se encontró en los tramos medios, mientras que los tramos inferiores tuvieron valores de diversidad muy bajos. Alrededor del 50% de las especies están amenazadas, según la UICN, varias especies están disminuyendo a un ritmo alarmante y otras probablemente estén extintas y/o se desconoce su estado actual. Las perturbaciones humanas durante las últimas décadas han provocado cambios importantes en la distribución de los peces y, en consecuencia, en su estado de conservación. Las alteraciones hidrológicas, la agricultura intensiva y las especies introducidas son probablemente las principales amenazas para la ictiofauna del Guadalquivir. Este estudio señala la necesidad urgente y real de identificar áreas

importantes para la conservación de los peces que garanticen una conservación mínima de la biodiversidad íctica a largo plazo, así como de estrategias efectivas para la recuperación de peces donde aún sea posible. También recomendamos nuevos muestreos de campo para identificar las vías de dispersión de las especies exóticas, especialmente de aquellas introducidas recientemente, y para aclarar su estado actual.

Las fuentes históricas de datos se mostraron como una herramienta valiosa para el estudio de los cambios a largo plazo en las comunidades de peces. El análisis comparativo de la ictiofauna del Guadalquivir entre el s.XIX y XXI reveló un proceso asimétrico en la extinción de especies nativas y colonización de exóticas, vinculado principalmente a la historia natural de las especies y a la marcada asimetría ambiental y de perturbaciones existente en la cuenca.

Las relaciones peces-hábitat son un factor clave para el diseño de estrategias de conservación y manejo fecundas, especialmente en áreas altamente perturbadas donde las comunidades de peces están sujetas a muchas presiones humanas. En este sentido, los estudios multi-escala ayudan a mejorar el conocimiento de los componentes espaciales e identifican variables clave locales (p. ej., anchura del cauce) y regionales (p. ej., altitud) en la distribución de las especies. En esta Tesis se consideraron quince variables ambientales a escala local y veinte a nivel regional. Para el análisis espacial se utilizó un total de 18 especies capturadas durante el muestreo de campo. La prevalencia global de especies introducidas fue del 25%, lo que puede considerarse un valor alto. Las especies introducidas más extendidas fueron la gambusia (*Gambusia holbrooki*) y el pez sol (*Lepomis gibbosus*), con una prevalencia en torno al 10%. Las escalas espaciales regional y local mostraron diferente relevancia según el nivel de enfoque del estudio (comunidad o especie). A nivel de comunidad, los componentes locales, regionales y compartidos revelaron una influencia similar sobre el conjunto de los peces, mientras que a nivel de especies individuales, el componente local fue el factor principal que explicó la presencia de la mayoría de las especies. Además, la interacción entre las variables fue escasamente seleccionada y casi ninguna distribución de las especies introducidas se vio afectada por la interacción con variable alguna. Nuestros resultados destacan el mal estado de conservación de la fauna autóctona de peces de la cuenca del río Guadalquivir, así como la importancia de analizar las relaciones peces-hábitat a diferentes escalas y enfoques. Estos resultados proporcionan información útil para evaluar y diseñar estrategias de conservación en cuencas de tipo mediterráneo.

Abstract

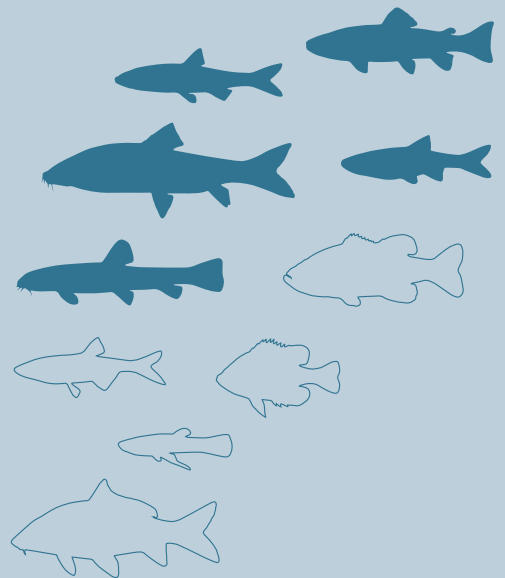
The Guadalquivir River Basin (S Spain) is one of the largest in the Iberian Peninsula and has a remarkable freshwater biodiversity. Although many studies on hydrological regimes or water quality have been conducted in this basin, the biodiversity of freshwater fish as well as their distribution and conservation status have never been globally addressed, as in other Iberian basins. In this context, we synthesized information on freshwater fish using field procedures (285 sampled sites) and other sources of information (bibliographic review, citizen science, historical data). We examined local and regional requirements to study freshwater fish assemblage and occurrence in this highly disturbed basin. Fish distribution patterns at different spatial and temporal scale were analysed, as well as general environmental conditions and the conservation status of the fish community. We documented the presence of 40 species (20 native and 20 exotic) in the basin during the 20th century until today. But we only captured 18 species during the field sampling, with the prevalence for any native species less than 23% (except *Luciobarbus sclateri*). We report new distribution data on four recently introduced species in this basin: chameleon cichlid (*Australoheros facetus* Jenyns, 1842), North American black bullhead (*Ameiurus melas* Rafinesque, 1820), European catfish (*Silurus glanis* Linnaeus, 1758) and a minnow species of unknown origin (*Phoxinus* spp.). A compilation of records is used to update the distribution range of these species. The information collected reinforces the evidence on the establishment and expansion of these non-native species.

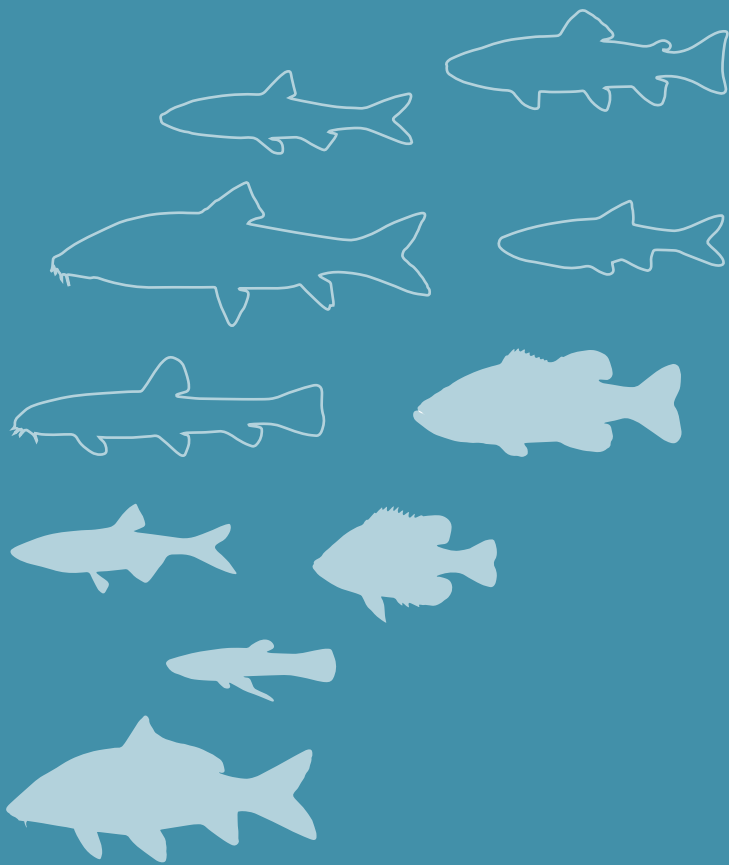
The highest species richness was found in mid reaches, while the lower reaches had very low diversity values. Around 50% of species are threatened, according to the IUCN, several species are declining at an alarming rate and others are probably extinct and/or their current status is unknown. Human disturbances during the last few decades have caused serious changes in fish distribution and consequently in their conservation status. Hydrological alterations, intensive agriculture and introduced species are probably the principal reasons for the Guadalquivir's ichthyofauna imperilment. Our study indicates an urgent and real need to identify important areas for fish conservation to guarantee a minimum fish biodiversity conservation over the long term, as well as effective strategies for fish recovery where it still is possible. We also recommend new

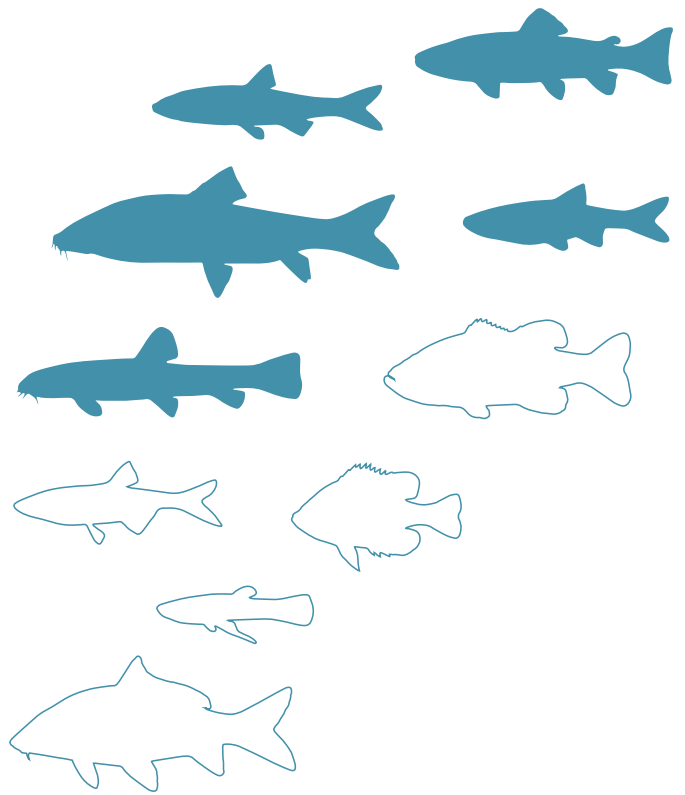
field sampling to identify the dispersal pathways of the exotic species, especially those recently introduced, and to clarify their current statuses.

Historical data sources proved to be a valuable tool for studying long-term changes in fish communities. The comparative analysis of the fish fauna of the Guadalquivir basin between the 19th and 21st centuries revealed an asymmetric process in the extinction of native species and colonization of exotic ones, mainly linked to the natural history of the species and the marked environmental asymmetry and disturbances in the basin.

Fish–habitat relationships are a key element for conservation and management strategies, especially in highly disturbed areas where fish communities are subjected to many human pressures. In this regard, multiscale studies help to improve the knowledge of the spatial components and identify local (e.g. water width) and regional (e.g. elevation) key variables in species distribution. Fifteen environmental variables were considered at local scale and twenty at regional level. A total of 18 species captured during field sampling were used for spatial analysis. The global prevalence for introduced species was 25%, which can be considered a high value. The most extended introduced species were eastern mosquitofish (*Gambusia holbrooki*) and pumpkinseed (*Lepomis gibbosus*), with around 10% prevalence. Regional and local scales showed different relevance according to the level-study approach (community or species). At the community level, the local, regional and shared components revealed similar influence on the fish assemblage, while at individual species level the local component was the main factor to explain most of fish occurrences. Moreover, variables' interaction was scarcely selected and almost no introduced species distribution was affected by the interaction of any variable. Our results highlight the poor conservation status of the native fish fauna of the Guadalquivir River Basin as well as the importance of analyzing fish–habitat relationships at different scales and approaches. These results provide useful information to assess and design conservation strategies in Mediterranean-type basin.







Capítulo I.

Introducción y síntesis general

Introducción y síntesis general

Introducción

Los ecosistemas de acuáticos continentales son los más ricos y diversos de la tierra y también de los más alterados por la acción humana (Loh et al. 1998, Revenga & Mock 2000). Su biodiversidad se está reduciendo a un ritmo alarmante, especialmente en regiones áridas y semiáridas, como la mediterránea, donde la demanda de agua para uso humano está aumentando (Moyle & Yoshiyama 1994, Loh et al. 1998, Cowx & Collares-Pereira 2002, Smith & Darwall 2006). A nivel europeo, el estado de conservación de las especies acuáticas es muy precario, ya que el 44 % de los moluscos de agua dulce, el 37 % de los peces continentales y el 23 % de los anfibios están amenazados (Freyhof & Brooks 2011). Los peces de agua dulce son un elemento básico de esta biodiversidad, representando una cuarta parte de todas las especies vivas de vertebrados. Constituyen el grupo más diverso entre los vertebrados europeos (546 especies de peces) (Bruton 1995, Abell 2002, Kottelat & Freyhof 2007, UICN 2015). Del total de la fauna europea de peces de continentales un 12 % de las especies se encuentra catalogada como en ‘peligro crítico’, un 10 % ‘en peligro’, un 15 % ‘vulnerable’ y un 4 % de especies ‘casi amenazadas’. Esto representa uno de los niveles de amenaza más elevados de entre todos los grupos taxonómicos evaluados en Europa.

En la actualidad todas las grandes cuencas Ibéricas –la mayoría de carácter mediterráneo- se encuentran fuertemente perturbadas como consecuencia de las intensas presiones humanas a las que han estado sometidas, especialmente durante el s. XX. Por lo tanto, los ríos de tipo mediterráneo de la Península Ibérica son un buen modelo ecológico para estudiar cómo los cambios inducidos por los humanos afectan a la distribución y conservación de las comunidades de peces de agua dulce (Aparicio et al. 2000, Clavero et al. 2004, Hermoso et al. 2008, Maceda-Veiga et al. 2010).

En las áreas mediterráneas, donde la biodiversidad de agua dulce es altamente endémica (Cuttelod et al. 2008), la Unión Mundial para la Conservación de la Naturaleza

estima que alrededor del 56 % de las especies endémicas de peces de agua dulce están amenazadas: 18% en ‘peligro crítico’, 18% ‘en peligro’ y 20% ‘vulnerable’ (Smith & Darwall 2006). En este contexto, existe la necesidad urgente de un conocimiento permanentemente actualizado de la estructura, diversidad y distribución de las comunidades de peces de agua dulce del Mediterráneo debido al continuo aumento de las presiones humanas sobre los recursos en el Mediterráneo (p. ej., García-Ruiz et al. 2013, Ruiz et al. 2015).

El estado ecológico de la Cuenca del Guadalquivir es uno de los menos conocidos en la Península Ibérica, a pesar de su relevancia en términos de superficie (alrededor del 10% de la superficie de Iberia), biodiversidad (un tercio de las especies de peces ibéricos habita o habitó recientemente esta cuenca), impactos y el alto número de especies amenazadas que lo habitan (Cuttelod et al. , 2008, Mendiguchía et al. 2007, Hermosín et al. 2013, Vargas & Paneque 2015, Carpintero 2015). La diversidad, el estado de conservación y el patrón de distribución de los peces del Guadalquivir rara vez se han abordado a nivel de cuenca completa. Alrededor del 50% de las especies nativas registradas en la cuenca están amenazadas a nivel internacional (UICN 2015). A nivel nacional, más del 85% de las especies nativas registradas en la Cuenca del Guadalquivir están en peligro (Doadrio 2001). A escala regional la información disponible es muy escasa. El Libro Rojo regional incluye 15 especies amenazadas y una extinta (Franco & Rodríguez 2001). Estos datos muestran la necesidad de una actualización urgente del estado de conservación y amenazas de la ictiofauna del Guadalquivir. Varias especies pueden estar extintas en la actualidad y otras a punto de extinguirse, mientras que la introducción de especies exóticas sigue aumentando. Por lo tanto, urge la necesidad de profundizar en el estudio de la comunidad de peces continentales de la cuenca hidrográfica del Guadalquivir. Identificar las áreas de distribución de las diferentes especies, caracterizar los hábitats, así como cuantificar los posibles impactos en la red de drenaje para conocer la capacidad de respuesta de la comunidad de peces a los diferentes impactos que se están ejerciendo. También es deseable un programa de monitoreo continuo que permita evaluar las tendencias de estas poblaciones y llevar a cabo estrategias reales de manejo y conservación basadas en el estado actual de este componente de la biodiversidad acuática continental (Filipe et al. 2004, Magalhães et al. 2008).

Área de estudio

La cuenca del río Guadalquivir se encuentra al sur de la Península Ibérica y comprende una superficie de 57439 km² (Figura 1). El cauce principal tiene una longitud de 680 km con un caudal medio de 164,3 m³ s⁻¹. La red fluvial, con 80 afluentes principales, se extiende sobre 10578 km de agua dulce de los cuales 238 km pertenecen a aguas de transición. La cuenca tiene un régimen hidrológico típico mediterráneo con una alta variación de caudal intra e interanual (Gasith & Resh 1999, Navarro et al. 2012, Confederación Hidrográfica del Guadalquivir 2015a). El clima mediterráneo se caracteriza por veranos calurosos y secos con temperaturas relativamente suaves en invierno (media anual 16,8 °C) y precipitaciones irregulares y bastante escasas en invierno o primavera (media anual 550 l m⁻²) (Figura 2).



Figura 1. Localización de la cuenca del Guadalquivir en la Península Ibérica.

Las altas temperaturas combinadas con la falta de precipitaciones en verano dan como resultado un profundo déficit hídrico (Robles et al. 2002). Como consecuencia de esta escasez endémica de agua, los patrones naturales de flujo de los ríos se han visto fuertemente modificados desde la antigüedad, especialmente a partir del siglo XVIII. Alrededor del 9,3% de la red está embalsada por grandes presas y casi todo el caudal está regulado en la actualidad. La oferta de agua ha llegado a su máximo, aunque la demanda sigue aumentando (Argüelles et al. 2012). La agricultura representa el 87% de los recursos hídricos dentro del área de captación (Confederación hidrográfica del Guadalquivir 2015a). Más de 9000 hm³ del caudal del río (26% del volumen total de agua dentro de toda la cuenca) se retienen en 29 embalses grandes (> 100 hm³) y más de 140 pequeños de menos de 100 hm³ (Navarro et al. 2007, Confederación hidrográfica del Guadalquivir 2015b). Según la Directiva Europea Marco del Agua (DMA), el 43% de todas las masas de agua continentales del Guadalquivir son de mala o baja calidad (Confederación Hidrográfica del Guadalquivir 2015a).

El área de influencia está rodeada por cadenas montañosas con altitudes que van desde los 1000 m hasta más de 3000 m sobre el nivel del mar, contrastando con la llanura baja del valle del Guadalquivir. La cuenca es muy asimétrica pudiéndose diferenciar cuatro grandes regiones (Figura 2), con geología, fisiografía, clima y presión humana muy dispar. El margen izquierdo del Guadalquivir, altamente perturbado contrasta con el derecho, menos afectado por las actividades humanas. El valle es un terreno llano con una agricultura intensiva muy desarrollada (Rodríguez-Díaz et al., 2007, Hermosín et al., 2013), y una densidad de población humana muy elevada, de unos 70 hab/km² (Confederación Hidrográfica del Guadalquivir 2015a). En consecuencia, la presión humana (desarrollos urbanísticos, industria, infraestructuras, etc.) es muy alta. La agricultura en el sur de España está experimentando grandes cambios desde finales de los años 80, pasando de una agricultura tradicional extensiva de secano de cultivos típicos mediterráneos (trigo, olivo y vino) a un nuevo modelo de regadío intensivo e industrializado, con elevados niveles de erosión del suelo, extracción de agua y/o regulación del flujo, uso de pesticidas y muchos otros efectos secundarios (Carpintero 2015).

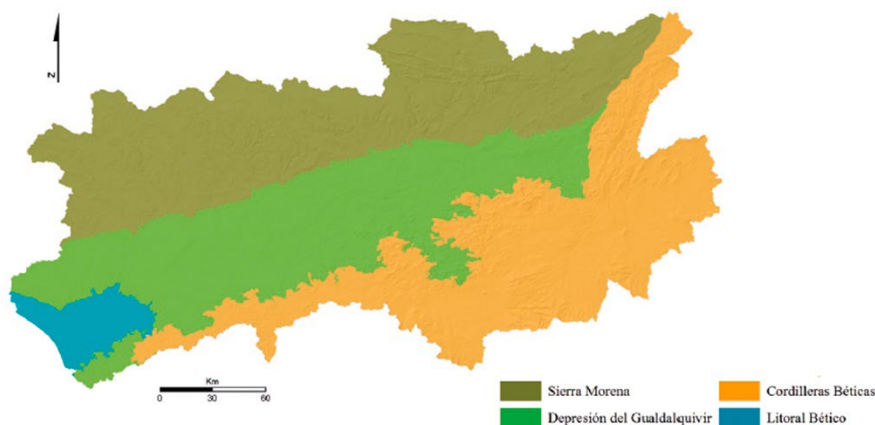


Figura 2. Delimitación de las principales regiones del Guadalquivir de acuerdo con la configuración paisajística, climática, litológica, régimen hídrico y calidad de las aguas. Fuente: Fernández-Delgado et al. 2014.

Una consecuencia directa de estos cambios agrícolas recientes, típicamente asociados con un aumento de los olivares de regadío, ha sido la introducción de una cantidad extraordinaria de sólidos en suspensión en la red de drenaje, causando una turbidez extrema del agua. Los valores de concentración de sedimentos en suspensión (600 mg l^{-1}) registrados por Ruiz et al. (2010) en el cauce principal del río se encuentran entre los más altos conocidos en el mundo, dos y tres veces mayores que el del Danubio (326 mg l^{-1}) y el Amazonas (200 mg l^{-1}) respectivamente (Carpintero 2015). Este hecho está afectando gravemente a la comunidad de peces que habita el bajo Guadalquivir (González-Ortegón et al. 2010). Otras dos fuentes significativas de impacto humano en la cuenca provienen de la introducción de especies foráneas (Clavero et al. 2004, Ramos-Merchante & Prenda 2018) y la eliminación de aguas residuales (Bhat & Blomquist 2004). En conjunto, estas perturbaciones han provocado cambios importantes en la fauna de peces de agua dulce del Guadalquivir durante los dos últimos siglos (Ramos-Merchante & Prenda 2018, Ramos-Merchante et al. 2021).

La introducción de especies ícticas exóticas en la cuenca del Guadalquivir

La introducción de especies foráneas es una de las principales amenazas a la integridad de los ecosistemas en todo el mundo, especialmente para los medios acuáticos continentales (Gozlan et al. 2010, Hermoso et al. 2011, Clavero & Hermoso 2011). Los impactos causados por la introducción de especies son muy diversos y dependen principalmente de las características de las especies introducidas y del hábitat (Ribeiro & Leunda 2012). En las regiones áridas y semiáridas, como las mediterráneas, donde la demanda de agua para uso humano es muy alta (Cowx & Collares-Pereira 2002), se ha generalizado la creación de embalses. Se ha comprobado que estas infraestructuras son un factor decisivo para la penetración de especies exóticas e invasoras (Clavero & Hermoso 2011). En las cuencas mediterráneas la capacidad de embalse ha alcanzado el máximo, en consecuencia, la presencia de especies de peces no autóctonas es muy elevada y su rango de distribución es cada vez mayor (Clavero & García-Berthou 2006). Los medios continentales ibéricos se encuentran entre los ecosistemas más invadidos dentro de la región mediterránea y las introducciones de peces se consideran una gran amenaza para la ictiofauna nativa que se caracteriza por una alta proporción de especies endémicas (Clavero & García-Berthou 2006, Ribeiro & Leunda 2012).

Los trabajos realizados por Fernández-Delgado et al. (2014) detectaron en la cuenca hidrográfica del Guadalquivir hasta 14 especies no autóctonas, una más que las autóctonas detectadas (13 especies). Otro estudio reciente obtuvo resultados similares determinando una elevada proporción de especies no nativas (10 nativas vs. 9 introducidas) (Ramos-Merchante & Prenda 2018). Estos y otros estudios (ver por ejemplo García de Lomas et al. 2009, Moreno-Valcárcel et al. 2013) ponen de relieve el establecimiento reciente en la cuenca de varias especies con alto potencial invasor como son el chanchito (*Australoheros facetus* Jenyns, 1842), el pez gato (*Ameiurus melas* Rafinesque, 1820) y el siluro (*Silurus glanis* Linnaeus, 1758). Todas estas especies están incluidas en las listas de las especies exóticas más invasoras (EEI) debido a su potencial amenaza para la biodiversidad nativa (Clavero 2011, van der Veer & Nentwig 2015, Carboneras et al. 2018). Por ello, el conocimiento actualizado sobre nuevas introducciones y su amplitud de distribución es esencial para detectar qué amenazas se ciernen sobre los ecosistemas acuáticos mediterráneos ibéricos que permitan implementar estrategias de conservación apropiadas.

En esta Tesis Doctoral nos proponemos abordar de manera general el estudio de la diversidad, distribución y estado de conservación de la ictiofauna nativa y exótica de la cuenca del río Guadalquivir. Para ello realizamos una revisión general de la fauna peces del Guadalquivir registrada desde el siglo XIX hasta la actualidad (1); el análisis de los patrones actuales de distribución, riqueza y diversidad de los peces en esta cuenca (2); la evaluación el estado de conservación de la fauna piscícola del Guadalquivir. Utilizamos el uso combinado de datos procedentes de ciencia ciudadana y muestreos de campo para actualizar la distribución de tres especies con alto potencial invasor recientemente introducidas (*Australoheros facetus*, *Ameirus melas* y *Silurus glanis*) en la cuenca del Guadalquivir. Asimismo, se muestra el primer registro de una especie invasora perteneciente al género *Phoxinus* spp. en esta cuenca.

Fuentes de información histórica como herramienta para el estudio de los cambios en la distribución de los peces

La evaluación precisa del estado de conservación de las especies, así como el estudio de los cambios en la distribución de las mismas idealmente debería basarse en información obtenida a largo plazo. Esta información es básica para comprender los factores relacionados con la disminución de especies nativas, la introducción de especies invasoras y su dinámica poblacional (Swetnam et al. 1999, Willis & Birks 2006). Sin embargo, los datos utilizados en los estudios para evaluar estos cambios se han obtenido por lo general durante las últimas décadas (rara vez más de 50 años), mientras que los efectos de las actividades humanas se vienen produciendo desde hace siglos (Clavero & Villero 2014, Clavero & Hermoso 2015). Como consecuencia la información sobre la distribución histórica de las especies evaluadas es ignorada en la mayoría de las estrategias de conservación (Szabo & Hedl 2011, Clavero & Villero 2014, Clavero & Revilla 2014). Los procesos de declive y extinciones locales, así como la expansión de especies invasoras, pueden ser solo representaciones en miniatura (un subconjunto de la tendencia real) de sus distribuciones históricas (Yackulic et al. 2011, Kwok 2017, Clavero et al. 2022). Por lo tanto, ampliar la escala temporal proporciona un análisis más amplio y completo para comprender los patrones y tendencias de las poblaciones (Clavero & Villero 2014, Kwok 2017, Clavero et al. 2022).

Los ecólogos han sido tradicionalmente reacios a utilizar fuentes de datos históricas, considerándolas imprecisas y anecdóticas (Scharf 2014, Clavero & Hermoso 2015). Sin embargo, existen fuentes históricas de alta calidad con un conjunto de datos estandarizados obtenidos en un tiempo limitado que representan una importante fuente de información (Clavero & Revilla 2014, Clavero & Villero 2014, Kwok 2017). Este tipo de datos permiten reconstruir e identificar cambios en la distribución de especies, así como conocer las distribuciones antes de la aparición de muchos cambios ambientales actuales a gran escala (p.ej., cambios en los usos del suelo, industrialización y construcción de barreras transversales; Habit et al. 2010, Haidvogel et al. 2015, Pont et al. 2015). Diversos estudios previos han utilizado información de los últimos siglos para identificar comunidades menos perturbadas, estimar Condiciones de Referencia o desarrollar programas de conservación (Aparicio et al. 2000, Filipe et al. 2009, Habit et al. 2010, Viana et al. 2022). Por lo tanto, la ecología histórica aplicada proporciona una línea de base o una “imagen” de la salud de los ecosistemas (Stoddard et al. 2006, Clavero & Villero 2014, Haidvogel et al. 2015, Viana et al. 2022) de gran utilidad para la gestión y conservación (Swetnam et al. 1999, Clavero & Hermoso 2015, Clavero et al. 2022).

En la presente Tesis Doctoral se empleó la información recopilada en *El Diccionario geográfico-estadístico-histórico de España y sus posesiones de Ultramar* de Pascual Madoz (Madoz 1845-1850) para examinar los procesos asimétricos (márgenes y sectores de la cuenca) en la extinción de especies nativas y la invasión de no nativas en la cuenca del Guadalquivir entre el s. XIX y XXI.

Efectos de la escala espacial sobre la distribución de los peces en la cuenca del Guadalquivir: respuestas a nivel de comunidad y de especie

La intensificación humana de los usos del suelo a lo largo del siglo pasado ha tenido importantes repercusiones sobre los ecosistemas acuáticos continentales en todo el planeta. Específicamente, en la cuenca mediterránea, un conjunto de impactos antrópicos muy diverso y desigualmente distribuido, como son la fragmentación y la pérdida de hábitat, la sobreexplotación de especies y recursos hídricos, alteraciones hidrológicas, la agricultura intensiva o la introducción de especies exóticas están amenazando seriamente estos ecosistemas (Prenda et al. 2006, Hermoso & Clavero 2011).

En este contexto, el estudio de las relaciones entre hábitat y especies representan un elemento clave para las estrategias de conservación y manejo, especialmente en estas áreas altamente perturbadas donde las comunidades de peces están sujetas a muchas presiones humanas. Los estudios multi-escala ayudan a profundizar en el conocimiento de los componentes espaciales implicados e identifican variables clave locales (p.ej., ancho del cauce) y regionales (p. ej., superficie agrícola) en la distribución de especies. Tradicionalmente, los estudios ecológicos se han centrado en los efectos de los factores proximales en las comunidades de peces, y rara vez han tenido en cuenta las consecuencias de los procesos a mayor escala y sus interacciones (Wang et al. 2006). Hoy en día, se sabe que la ocurrencia de especies no solo está restringida por factores locales tales como aquellos relacionados con las características inmediatas del hábitat (calidad del agua, corriente de agua, forma del canal, pendiente, etc.), sino que otros factores distantes que operan a mayor escala espacial o temporal (p.ej., clima, aislamiento del hábitat) también pueden jugar un papel importante (Hawkes 1975, Huston 1999, Arunachalam 2000). La hipótesis más ampliamente aceptada sugiere que factores a gran escala determinan el conjunto de especies potenciales que pueden ocurrir localmente. Mientras tanto, los factores de pequeña escala a menudo reducen la biodiversidad potencial de las especies que realmente se encuentran en un sitio específico (p. ej., Tonn et al. 1990, Poff 1997, Houston 1999). Sobre esta base, los modelos de ocurrencia de especies en conjuntos locales deben incluir no solo factores locales, sino también regionales para determinar sus efectos relativos en un sitio determinado. Este conocimiento es fundamental en cualquier esfuerzo por gestionar y restaurar ecosistemas fluviales deteriorados (Wang et al. 2006).

Existen varios modelos conceptuales para explicar los principales patrones espaciales en los ecosistemas fluviales. La zonificación longitudinal según el Concepto de Continuidad del Río “River Continuum” es el patrón de distribución más comúnmente estudiado en la ecología de los peces de río. Este patrón relaciona los cambios en la composición de la comunidad con los gradientes ambientales desde la cabecera hasta la desembocadura del río (Vila-Gispert et al. 2002, Morán-López et al. 2006). Por lo general, este gradiente se asocia no solo con la zonificación biótica, sino también con el aumento de la riqueza de especies aguas abajo debido a un aumento en el tamaño del río y en la heterogeneidad ambiental (Schlosser 1982). A escala local, los factores relacionados con la morfología hidráulica (p. ej., la heterogeneidad del sustrato, la profundidad del canal y la velocidad del agua) junto

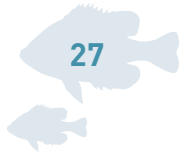
con las características adicionales del hábitat (p.ej., la temperatura del agua, la vegetación) se han descrito como las características (o factores de estrés) más importantes para la distribución de los peces (Matthews 1998, Lamouroux et al. 1999). Más recientemente, las asociaciones entre factores locales y regionales también han dado lugar al desarrollo de modelos jerárquicos que describen las relaciones espaciales dentro de un sistema fluvial como una serie anidada desde el hábitat local hasta la cuenca (Poff 1997,).

Sin embargo, el papel de los factores ambientales a diferentes escalas y su influencia en la presencia de especies se ha abordado menos en la ecología de peces (pero ver Wang et al. 2006, Kennard et al. 2007, Troia & Gido 2015) a pesar de la relevancia de la fauna de peces para la biodiversidad de agua dulce. Estudios anteriores han considerado esta perspectiva principalmente a nivel comunitario (Tonn et al. 1990, Angermeier & Winston 1998). Sin embargo, el enfoque a nivel de especie puede proporcionar información importante para comprender los mecanismos subyacentes a los patrones de distribución de estas y los impactos humanos. Analizar el papel de los factores locales y regionales en la ocurrencia de cada especie puede ayudar a comprender las respuestas a nivel de la comunidad e implementar una buena planificación de la conservación (Angermeier & Winston 1999).

En esta Tesis Doctoral se estudia la fauna de peces continentales de la cuenca del río Guadalquivir con el fin de identificar cómo los efectos ambientales locales y regionales y sus interacciones influyen en la distribución de las especies. Usando datos de 285 localidades de muestreo, examinamos a dos escalas diferentes (local y regional), los principales gradientes en las comunidades de peces y los factores más decisivos a la hora de explicar la presencia de las especies.

Objetivos y metodología

El objetivo principal de esta tesis es evaluar el estado de conservación de la ictiofauna de la cuenca del Guadalquivir, así como identificar los factores y procesos que determinan la distribución actual de la comunidad de peces.



Las **hipótesis** previamente establecidas para el desarrollo de esta tesis son:

1. La comunidad de peces nativos de la cuenca ha sufrido un acusado declive en el último siglo.
2. Las fuertes perturbaciones de origen antrópico existentes en la red de drenaje han alterado los patrones naturales de distribución de la riqueza y biodiversidad de peces continentales.
3. La fuerte asimetría ambiental existente entre ambos márgenes de la cuenca provoca del mismo modo una fuerte asimetría en la distribución de la fauna de peces.
4. Los efectos a escala local y regional que determinan la distribución de especies afectan de forma desigual a las especies

Los **objetivos generales de la tesis** son:

1. Proporcionar una revisión completa de la fauna de peces del Guadalquivir registrada desde el siglo XX hasta el presente.
2. Determinar los patrones actuales de distribución general de peces, riqueza y diversidad.
3. Determinar el estado de conservación de la comunidad de peces de la cuenca.
4. Identificar los factores, naturales o antrópicos, que determinan la distribución de las especies.
5. Proporcionar las bases ecológicas para el correcto diseño de estrategias de conservación y manejo.

Para abordar estos objetivos se empleó una aproximación multidisciplinar en la obtención de la información que comprendió revisión bibliográfica, ciencia ciudadana, fuentes históricas y muestreos de campo.

Revisión bibliográfica: Se realizó una intensiva búsqueda en documentos científico-técnicos publicados en el último siglo que proporcionaran información fiable sobre la presencia y distribución de peces en la cuenca del Guadalquivir.

Ciencia ciudadana: Para actualizar la información sobre especies invasoras recientes en la cuenca del Guadalquivir realizamos exhaustivas búsquedas en diferentes sitios

web, como redes sociales (p.ej., YouTube, Facebook), foros de pesca recreativa, blogs y buscadores (p.ej., Google). Además, enviamos una solicitud de información sobre los registros de las especies en estudio a los sitios web de pesca deportiva. Realizamos una búsqueda booleana utilizando una combinación de diferentes palabras clave, incluidos nombres científicos y comunes en español de las especies objeto y el nombre del río (Guadalquivir). Los registros de las especies se aceptaron solo cuando incluían la localidad, el año y estaban acompañados de foto o video (ver Gago et al. 2016 para más detalles). Entrevistamos, siempre que fue posible, al pescador que proporcionó la información para confirmar los datos y evitar duplicidades en los registros.

Fuentes históricas: Se extrajeron los registros históricos de peces de agua dulce existentes en *El Diccionario geográfico-estadístico-histórico de España y sus posesiones de Ultramar* de Pascual Madoz (Madoz 1845-1850). Para ello realizamos una búsqueda en las copias digitalizadas del diccionario Madoz disponible en www.bibliotecavirtualdeandalucia.es utilizando la herramienta de búsqueda en el lector de documentos pdf y los nombres comunes (y topónimos) de todos los peces ibéricos. La información recopilada en Madoz comprendía 229 nombres de lugares (es decir, ubicaciones) en la cuenca del río Guadalquivir, con 472 registros de peces de agua dulce, 82 de los cuales se referían simplemente a “peces” y 42 a “pesca”.

Muestreos de campo: Se emplearán los datos recopilados por el grupo de investigación ‘Biología de las aguas epicontinentales (RNM 324)’ en las campañas de muestreo realizadas en el marco del proyecto ‘Evaluación ecológica de los medios fluviales de la cuenca del Guadalquivir según recoge la directiva marco de agua a través del uso de bioindicadores basados en peces (P07-RNM-03309)’. En dichas campañas un total de 285 localidades distribuidas por toda la cuenca fueron muestreadas. Por un lado, se caracterizó la comunidad de peces utilizando dos métodos y por otro lado se caracterizaron los hábitats a través de variables bióticas y abióticas tomadas *in situ*. Según el ancho y la profundidad de la ubicación, se utilizaron dos métodos de muestreo de peces alternativos. Una combinación de diferentes métodos de pesca es una opción apropiada para muestrear una amplia gama de hábitats, especies y tamaños de peces (Heggenes et al. 1990, Reynolds 1996, Bunt et al. 1998, Clavero et al. 2006; Figura 3). Los sitios con corrientes, baja salinidad ($<1,5 \text{ mS cm}^{-1}$) y poca profundidad ($<1,2 \text{ m}$) fueron muestreados mediante pesca eléctrica vadeando aguas arriba a lo largo de una longitud de 100 m del cauce durante aproximadamente una hora. El equipo incluía una caja de control que suministra una corriente continua pulsada, 300 / 600V, 4-6A sin

redes de bloqueo (Electracatch International, motor Honda EU 20i con un rectificador WF6 y una red con un diámetro de 30 cm y un tamaño de malla de 4 mm). Cuando las condiciones de salinidad y profundidad no permitían la pesca eléctrica, principalmente en ríos y embalses de gran tamaño, utilizamos cuatro tipos de trampas pasivas: redes de trasmallo, nasas, trampas “minnow” metálicas y de plástico. Dos redes de trasmallo (10 mx 2 m, 175 mm x 25 mm y tamaño de malla 200 mm x 20 mm), tres pares de nasas (tamaño de malla de 12 mm y 3 mm), quince trampas de metal “minnow” (tamaño de malla de 6 mm) y diez pares de trampas “minnow” de plástico para peces pequeños (entrada de 25 mm) durante un mínimo de 8 horas (ver Clavero et al. 2006 para más detalles) (Figura 3).

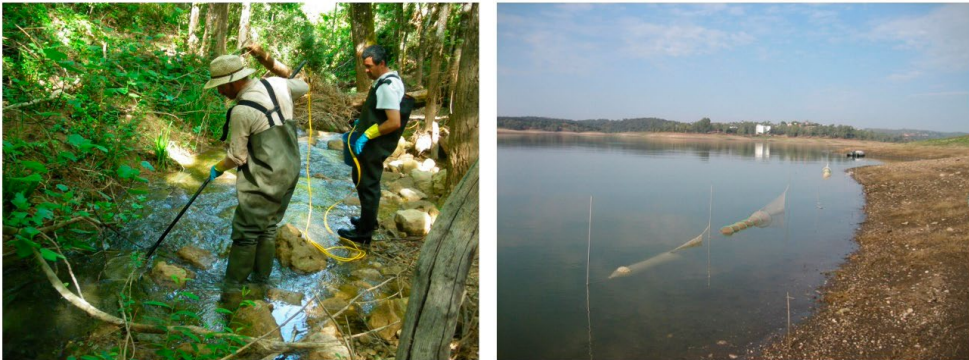
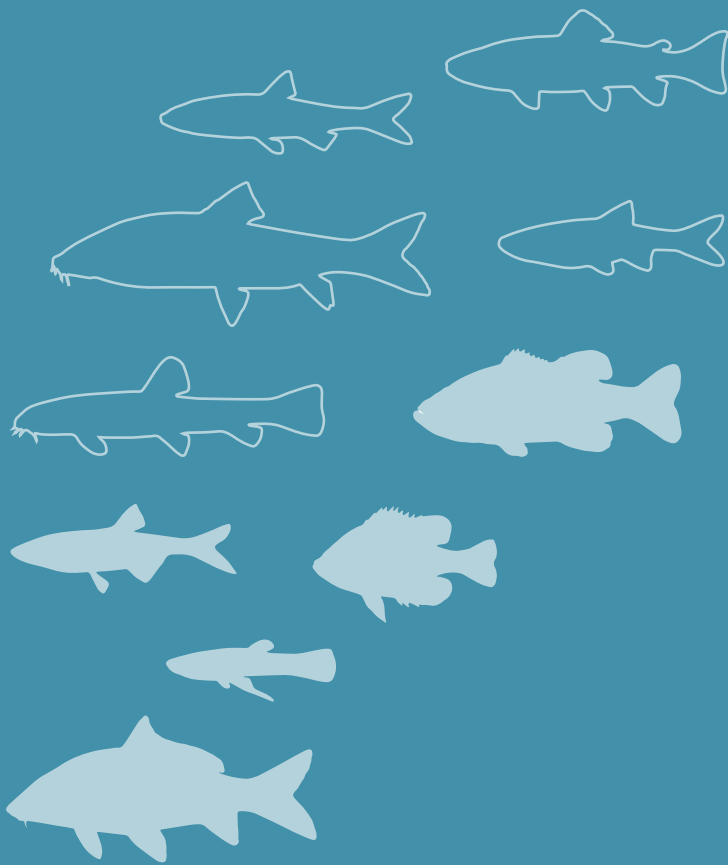
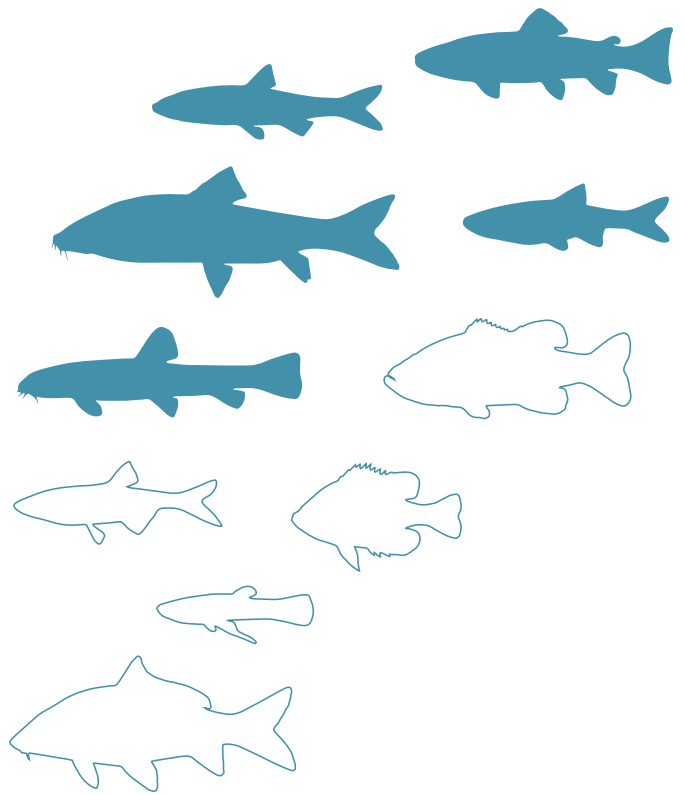


Figura 3. Muestreo con pesca eléctrica vadeando aguas arriba a lo largo de 100 m de cauce (imagen izquierda) y muestreo mediante el uso de trampas pasivas (nasas) (imagen derecha) durante un tiempo mínimo de 8 horas.

Hábitat se caracterizó a través de 31 variables ambientales para cada localidad utilizando un enfoque a dos escalas: local y regional. Las variables locales se definieron como aquellas relacionadas con el punto de muestreo, mientras que las variables regionales se refieren al área de drenaje. En consecuencia, las variables locales se obtuvieron *in situ* durante el trabajo de campo y las variables regionales se calcularán durante los trabajos de gabinete utilizando Sistemas de Información Geográfica (SIG) y datos de cobertura proporcionados por las administraciones.





Chapter II.

**Freshwater fish biodiversity
in a large mediterranean basin
(Guadalquivir river, s Spain):
Patterns, threats, status and
conservation**

Citation:

Sáez-Gómez P, Prenda J (2019) Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain).

BioInvasions Records 8(4): 924–932,

https://www.reabic.net/journals/bir/2019/4/BIR_2019_Saez-Gomez_Prenda.pdf

Received: 13 March 2019

Accepted: 4 July 2019

Published: 15 October 2019

Copyright: © Sáez-Gómez and Prenda

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS.

Freshwater Fish Biodiversity in a Large Mediterranean Basin (Guadalquivir River, S Spain): Patterns, Threats, Status and Conservation

Pedro Sáez-Gómez and José Prenda *

Department of Integrative Sciences, University of Huelva, 21071 Huelva, Spain;
pedro.saez@ciecema.uhu.es

*Correspondence: jprenda@uhu.es

Abstract: The Guadalquivir River Basin is one of the largest in the Iberian Peninsula and has a remarkable freshwater biodiversity. Although many studies on hydrological regimes or water quality have been conducted in this basin the biodiversity of freshwater fish, as well as their distribution and conservation status, has never been globally addressed as in other Iberian basins. In this context, we synthesized information on freshwater fish using field procedures and a bibliographic search. Fish distribution patterns at different spatial scales and general environmental conditions were analyzed as well as the conservation status of the fish community. We documented the presence of 40 species (20 native and 20 exotic) in the basin during the 20th century until today. However, we only captured 18 species during the field sampling, with a prevalence for any native species of less than 23% (except *Luciobarbus sclateri*). The highest species richness was found in mid reaches, while the lower reaches had very low diversity values. Around 50% of species are threatened; according to the IUCN, several species are declining at an alarming rate and others are probably extinct and/or their current status is unknown. Human disturbances during the last few decades have caused serious changes in fish distribution and consequently to their conservation status. Hydrological alterations, intensive agriculture and introduced species are probably the principal reasons for Guadalquivir's ichthyofauna imperilment. Our study indicates an urgent and real need to identify important areas for fish conservation to guarantee a minimum fish biodiversity conservation over the long term, as well as effective strategies for fish recovery where it still is possible.

Keywords: fish fauna; Guadalquivir; distribution; ichthyofauna; Iberian Peninsula

Introduction

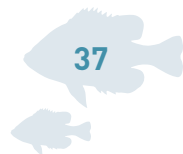
Freshwater ecosystems are the richest and most diverse ecosystems on earth and also one of the most threatened (Loh et al.1998, Revenga and Mock 2000). Their biodiversity is being reduced at an alarming rate, especially in arid and semi-arid regions where water demand for human uses is increasing (e.g., Mediterranean areas) (Moyle and Yoshiyama 1994, Loh et al.1998, Cowx and Collares-Pereira 2002, Smith and Darwall 2006). At a European level, the conservation status of aquatic species is very poor, as 44% of freshwater mollusks, 37% of freshwater fishes and 23% of amphibians are threatened (Freyhof and Brooks 2011). Freshwater fish are a basic element of this biodiversity, representing one-fourth of all living vertebrate species, the world's most endangered vertebrate group after amphibians and the most species-rich group among European vertebrates (546 fish species) (Bruton 1995, Abell 2002, Kottelat and Freyhof 2007, IUCN 2022). European freshwater fish fauna consists of 12% critically endangered species, 10% endangered, 15% vulnerable and 4% species near-threatened. This is one of the highest levels of threat of any important taxonomic group ever evaluated in Europe (Kottelat and Freyhof 2007, Freyhof and Brooks 2011, IUCN 2022).

In Mediterranean areas, where freshwater biodiversity is highly endemic (Cuttelod et al. 2008), the World Conservation Union estimates that around 56% of endemic freshwater fish species are threatened: 18% critically endangered, 18% endangered and 20% vulnerable (Smith and Darwall 2006). In this context, there is an urgent need for a permanently updated knowledge of the structure, diversity and distribution of Mediterranean freshwater fish communities due to the continual increase in human pressures on lands and resources in the Mediterranean (e.g., (García-Ruiz et al. 2013, Ruiz et al. 2015).

The ecological status of the Guadalquivir River Basin is one of the least known in the Iberian Peninsula, despite its significant relevance in terms of area (around 10% of the Iberian land surface), biodiversity (one-third of Iberian fish species inhabit or have recently inhabited this basin; see results), impacts (Mendiguchía et al. 2007, Hermosín et al. 2013, Vargas et al. 2015, Carpintero 2015) and the high number of threatened species that inhabit it (Cuttelod et al. 2008). Before the 20th century, the fish fauna of the Guadalquivir was characterized, compared to other

Iberian basins, by a diverse community of migratory species (catadromous and anadromous). These species constituted an important economic resource for many nearby towns (Granado-Lorencio 1991). However, the construction of reservoirs in the canal, as well as in the tributaries, was the main factor in the decline/extinction of these species (Granado-Lorencio 1991). Since the beginning of the 20th century, more than 150 reservoirs have been built in the basin, eleven of them in the main course of the river, which have isolated large sectors of the basin and blocked the migratory movements of many species (Granado-Lorencio 1991). One of the first inventories of species in the basin was carried out in 1989, which included a list of 19 native and introduced species with places and dates of capture in the basin (Doadrio 1989). However, the diversity, conservation status and distribution pattern of Guadalquivir's fish have rarely been addressed at a whole-basin level. Around 50% of native species recorded in the basin are threatened (UICN 2022). At a national scale, more than 85% of native species recorded in the Guadalquivir Basin are endangered (Doadrio 2001). At a regional scale, the information available is very scarce. The regional Red Data Book includes 15 endangered species and one that is extinct (Franco-Ruíz 2001). These data show the need for an urgent updating of the conservation status and threats to Guadalquivir's ichthyofauna; several species may be extinct nowadays and others are about to be so, while the introduction of exotic species continues to increase. A continuous monitoring program would also be necessary to assess population trends and to carry out real management and conservation strategies based on the actual status of this freshwater biodiversity component (Filipe et al. 2004, Magalhães et al. 2008).

In this study, we examined the diversity, distribution and conservation status of the Guadalquivir River Basin's freshwater fish fauna. The specific objectives were: (1) to provide a complete list of the Guadalquivir fish fauna recorded from the 20th century to the present, (2) to determine current patterns of general fish distribution, richness and diversity, (3) to determine the conservation status of fish fauna in the basin and (4) to make recommendations for fish biodiversity conservation in the Guadalquivir River Basin.



Materials and Methods

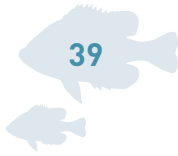
Study Area

The Guadalquivir River is located in the south of the Iberian Peninsula, flowing west to the Atlantic Ocean. The main channel is 680 km in length, the fifth longest river in the Iberian Peninsula. The basin presents 80 main tributaries (basin areas between 12.6 km² and 8255.6 km²) with a total drainage area of 57,439 km² and an average human population density of 69.6 hab/km² (Confederación Hidrográfica del Guadalquivir 2015a). The basin has a typical Mediterranean hydrological regime with high intra- and inter-annual discharge variation (Gasith and Resh 1999, Navarro et al. 2012, Confederación Hidrográfica del Guadalquivir 2015a)

The basin faces intense direct and indirect human pressures, mostly from agriculture (Rodríguez Díaz et al. 2007, Hermosín et al. 2013), flow regulation (often related to agriculture), species introductions (Clavero et al. 2004) and wastewater disposal (Bhat and Blomquist 2004; see Table 1). Agriculture has been undergoing major changes in Southern Spain since the end of the 1980s. A sharp change is taking place: from traditional non-irrigated extensive agriculture of typical Mediterranean crops (wheat, olives and wine) to a new, intensive, industrial and irrigated agricultural model, with high soil erosion levels, water abstraction and/or flow regulation, pesticide disposal and many other side effects (Table 1). A main consequence of these recent agricultural changes, usually associated with an increase in irrigated olive groves, is the introduction of an extraordinary suspended solid-loading into the drainage network that causes extreme levels in water turbidity (Carpintero 2015). The values of suspended sediment concentration (600 mg L⁻¹) registered by Ruiz et al. (Ruiz et al. 2010) in the main river channel are among the highest known in the world, two and three times greater than that of the Danube (326 mg L⁻¹) and Amazon (200 mg L⁻¹), respectively (Carpintero 2015). These values are mainly located in the lower Guadalquivir reaches. This is seriously affecting the fish community and its nursery function, a well-known phenomenon in the Guadalquivir estuary (González-Ortegón et al. 2010).

Table 1. Guadalquivir River Basin environmental characteristics (data source: Confederación Hidrográfica del Guadalquivir: <http://www.chguadalquivir.es/demarcacion-hidrografica-guadalquivir#PlanHidrológicodelGuadalquivir2009-2015> (accessed on 23 July 2021). * 'Dehesa' is a particular Mediterranean ecosystem where man has removed bushes to improve the farm (Díaz et al. 1997).

	Count	hm ³ /year	km ²	%
Environmental information				
Human population (n° inhabitants)	4,141,635			
Municipality (n°)	429			
Annual average rainfall (mm) (1942–2005)	561			
Annual average contribution		7043		
Average net provision (m ³ /ha/year)	2906			
Olive water demand (m ³ /ha/year)	1500			
Environmental quality (n° water mass)				
Good or moderate ecological status	252			56.9
Poor or bad ecological status	191			43.1
Chemical status (n° water mass)				
Good chemical status				46.1
Bad chemical status				53.9
N° pollution discharges	1719			
Water use				
Supply		436.41		10.9
Industry		36.26		0.9
Agriculture		3504.06		87.4
Energy		31		0.8
Land use				
Irrigated crops			8460	14.7
Rainfed cultivation			24,000	41.8
Forests			7140	12.4
Scrublands			10,000	17.4
Dehesas *			4000	7.0
Grasslands			1400	2.4
Bare or sparsely vegetated land			829	1.4
Water (lagoons, marshes, reservoirs, etc.)			880	1.5
Unproductive soil (urban áreas, roads, etc.)			730	1.3



The flow of the Guadalquivir Basin is fully regulated. Thus, the water supply cannot be increased, but demand continues to rise more or less uncontrollably (Argüelles et al. 2012). The number of reservoirs has reached a maximum. About 9193 hm³ of river flow is nowadays retained in 29 large reservoirs (>100 hm³) and more than 140 smaller ones (<100 hm³) (Confederación Hidrográfica del Guadalquivir 2015b). There are also numerous cut-offs, channeling and dredging works to promote river traffic, especially in the lower reaches of the river (Cruz Villalón 1988, Granado-Lorencio 1991). As a consequence, the natural flow pattern of the main channel has been strongly modified. With respect to ecological status, according to the European Water Framework Directive (WFD; 2000/60/EC), 43% of all inland water bodies have poor or low level quality (Confederación Hidrográfica del Guadalquivir 2015a; Table 1).

The Guadalquivir Basin displays a strong environmental asymmetry with respect to both left and right margins. Geology, physiography, climate and human pressure all vary. The right margin is located within the Iberian Massif, a low relief mountain range covered with oak forests and dehesas and characterized by a very low human population density, mostly devoted to marginal mountain agriculture and especially extensive farming and cattle raising. This area has a high conservation value and most of it is protected as several natural parks. The left margin corresponds to Cenozoic basins and the Betic Mountain chain. This is a highly developed flat land covered by intensive agriculture (irrigated and non-irrigated). Human population density is very high, and human pressures, in general, are correspondingly high.

Data Collection

We obtained fish data via field sampling and a bibliographic search. Sampling was conducted at 285 locations over the entire basin (216 in rivers and 69 in reservoirs) between June–September 2007 (reservoirs) and March–July 2008 (rivers) (Figure 1). The 285 sampling locations were distributed at random within 46 different sub-basins (including the main channel) that represented 56.3% of the total number of sub-basins and 96.1% of the total basin area, respectively (Figure 1).

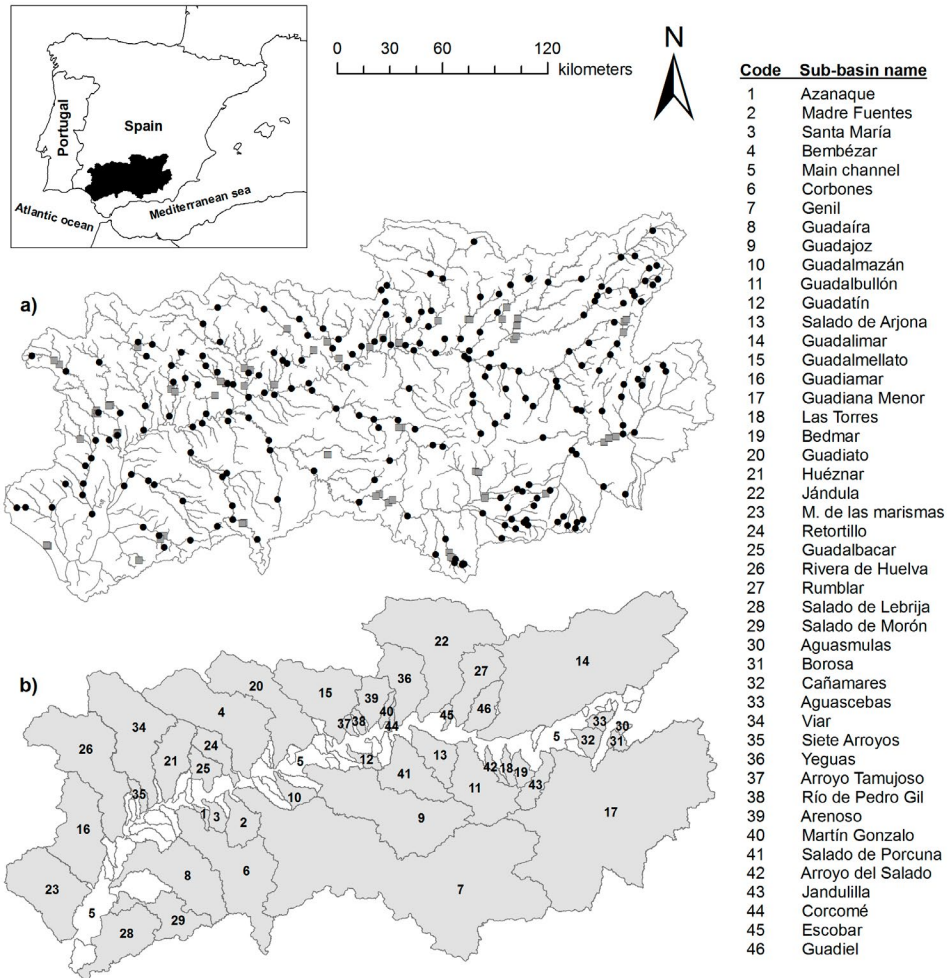


Figure 1. Map of the Guadalquivir River Basin. (a) Fish sampling sites: filled circles indicate rivers ($n = 216$) and grey squares denote reservoirs ($n = 69$). (b) Map of sub-basins sampled (gray color) and main channel (code-number 5) in the Guadalquivir River Basin. The code-number indicates the name for each sub-basin.

Depending on location width and depth, two alternative sampling methods were used. A combination of different fishing methods is an appropriate option for sampling a wide range of habitats, species and fish sizes (Heggenes et al. 1990, Reynolds 1996, Bunt et al. 1998, Clavero et al. 2006). Typical stream sites with low salinity ($<1.5 \text{ mS cm}^{-1}$) and shallow depth ($<1.2 \text{ m}$) were electrofished by wading upstream along a

channel length of 100 m during approximately one hour. The equipment comprised a control box delivering a pulsed direct current, 300/600 V, 4–6 A without block nets (Electracatch International, Honda EU 20i motor with a WF6 rectifier and a landing net with a 30 cm diameter and a 4 mm mesh size). The relative density was calculated for all captured species at all sampling points as catches per unit effort (hereafter, CPUE). The CPUE was defined as the number of individuals captured per 100 m stream length per hour sampling.

When the salinity and depth conditions did not allow electrofishing, mainly in large rivers and reservoirs, we used four types of passive traps: trammel nets, fyke nets, minnow traps and plastic bottle minnow traps. Two trammel nets (10 m × 2 m, 175 mm × 25 mm and 200 mm × 20 mm mesh size), three pairs of fyke nets (12 mm and 3 mm mesh size), fifteen metal minnow traps (6 mm mesh size) and ten pairs of plastic minnow traps (25 mm inlet) were set for a minimum of 8 h (see Bunt et al. 1998 for more details). After capture, fish were identified to species level, counted, measured and returned live to the river. The CPUE was defined here as individuals captured in the aforementioned trap combination (2 trammel nets + 3 pairs of fyke nets + 15 metallic mesh minnow traps + 10 pairs of plastic bottle minnow traps) per 12 h sampling.

A bibliographic search was performed for all fish species recorded in the Guadalquivir River Basin throughout the 20th century to develop a second presence/absence historical data set. This search covered scientific journals, technical reports, books and daily press with potential information on freshwater fish distribution. The Carta Piscícola Española (<http://www.cartapiscicola.es> (accessed on 27 September 2022)), and the International Standardization of Common Names for Iberian Endemic Freshwater Fishes (Leunda et al. 2009) was used for scientific and common fish nomenclature, respectively.

Data Analysis

Shannon (H') alpha diversity index (see Moreno 2001) and species richness values were compared at different scales and habitats using Kruskal–Wallis tests and Dunn's post test. All analyses were performed in SPSS Statistics[®] v. 21 (IBM Corp 2012). The Shannon (H') index was calculated with PAST[®] (v.2.14) (Hammer et al. 2001).

Results

Faunal Composition

In an Iberian context, the Guadalquivir's ichthyofauna has great relevance as 31.1% of all native Iberian species live or have recently inhabited the Guadalquivir River Basin (Table 2), although it merely encompasses 9.8% of the total surface area of the Iberian Peninsula and only three families of native fish are not found in the basin. In particular, migratory species are very well represented, accounting for 54.5% of all Iberian species (Table 2). Cyprinidae is the richest family (both for native and exotic species) in the basin constituting 21.6% of Iberian species (Table 2) and 55.4% of the sampled species (Figure 2). Also, introduced species are widely represented in the Guadalquivir Basin with 48.4% of the total species recorded in Iberia (Table 2).

Table 2. Families and number (%) of Iberian freshwater fish species recorded in the Guadalquivir River Basin. Sources: Carta Piscícola Española for Spanish data (<http://www.cartapiscicola.es>, accessed on 27 September 2022) and Fishbase for Portuguese data (http://www.fishbase.org/Country/CountryChecklist.php?showAll=yes&c_code=620&vhabitat=fresh, accessed on 15 July 2022). * *Tinca tinca* is considered introduced according to Clavero and Villero 2013.

	Family	Iberian Peninsula	Guadalquivir
Native	Petromyzontidae	6	1 (16.7)
	Acipenseridae	1	1 (100)
	Clupeidae	2	2 (100)
	Anguillidae	1	1 (100)
	Salmonidae	2	1 (50)
	Cyprinidae	37	8 (21.6)
	Cobitidae	3	1 (33.3)
	Nemacheilidae	1	0 (0)
	Cyprinodontidae	2	1 (50)
	Valenciidae	1	0 (0)
	Atherinidae	1	1 (100)
	Gasterosteidae	1	1 (100)
	Cottidae	2	0 (0)
	Blenniidae	1	1 (100)
	TOTAL	61	19 (31.1)
Introduced	Salmonidae	4	1 (25.0)
	Esocidae	1	1 (100)
	Cyprinidae	11 *	6 (54.5)
	Cobitidae	1	0 (0)
	Nemacheilidae	1	0 (0)
	Ictaluridae	2	1 (50)
	Siluridae	1	1 (100)
	Cyprinodontidae	1	0 (0)
	Fundulidae	1	1 (100)
	Poeciliidae	3	1 (33.3)
	Cichlidae	1	1 (100)
	Centrarchidae	2	2 (100)
	Percidae	2	0 (0)
	TOTAL	31	15 (48.4)

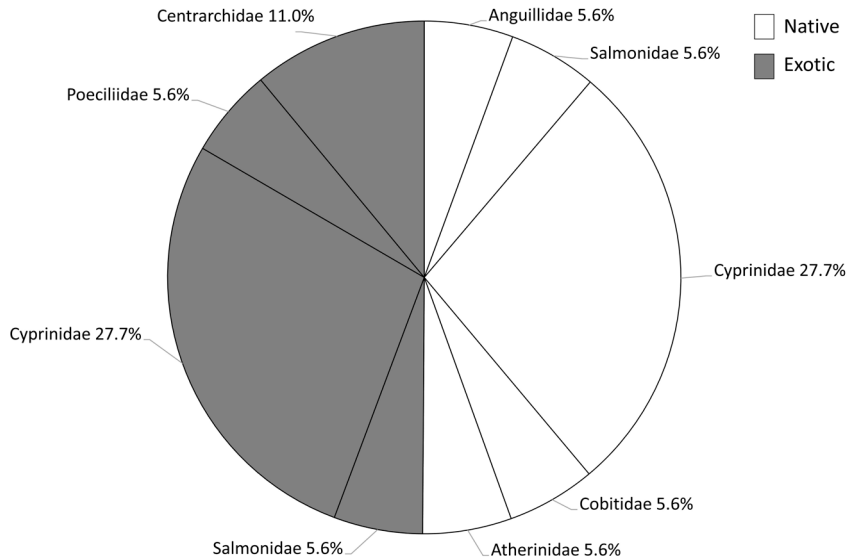


Figure 2. Percent of species number of the total families found in the Guadalquivir River Basin during the sampling sessions.

During fieldwork a total of 18 fish species (9 native, 7 introduced and 2 translocated) were captured in the Guadalquivir River Basin (see Table S1 for sub-basin details). In addition, the bibliographic search revealed the presence of at least 22 additional species (11 native and 11 exotic) during the 20th century. Just over 18% of the sampled locations were apparently fishless (after 197.7 h spent electric fishing and 3578.7 m traversed at these points), all of them located in rivers (24% of all river locations). Cyprinidae was clearly the family with the greatest number of native and exotic sampled species, accounting in total for more than 50% of species richness (Figure 2). Species undetected during field sessions either have very low densities or they are extinct (see below).

Sampled Species

Seven native primary freshwater fish species were captured (Table 3): brown trout (*Salmo trutta* Linnaeus, 1758), southern Iberian barbel (*Luciobarbus sclateri* (Günther, 1868)), Iberian arched-mouth nase (*Iberochondrostoma lemmingii* (Steindachner, 1866)), southern straight-mouth nase (*Pseudochondrostoma willkommii* (Steindachner,

1866)), calandino (*Squalius alburnoides* (Steindachner, 1866)), southern Iberian chub (*Squalius pyrenaicus* (Günther, 1868)), southern Iberian spined-loach (*Cobitis paludica* (de Buen, 1930)), and big-scale sand smelt (*Atherina boyeri* Risso, 1810), as well as one migratory species, European eel (*Anguilla anguilla* (Linnaeus, 1758)). The introduced exotic species captured included: rainbow trout (*Oncorhynchus mykiss* (Walbaum, 1792)), bleak (*Alburnus alburnus* (Linnaeus, 1758)), goldfish (*Carassius auratus* (Linnaeus, 1758)), common carp (*Cyprinus carpio* Linnaeus, 1758), eastern mosquitofish (*Gambusia holbrooki* Girard, 1859), pumpkinseed (*Lepomis gibbosus* (Linnaeus, 1758)) and largemouth bass (*Micropterus salmoides* (Lacépède, 1802)). The introduced translocated species (presumably from other Iberian river basins) were Pyrenean gudgeon (*Gobio lozanoi* Doadrio and Madeira, 2004) and a minnow species of unknown origin (*Phoxinus* spp.), probably the Pyrenean minnow (*Phoxinus bigerri* Kottelat, 2007) (Table 3). All native species had a very restricted distribution (prevalence less than 23%), except the southern Iberian barbel, which is the most widespread (a prevalence of 58.6%; see Table 3) and abundant species (more than 50% of the total captured fish) throughout the basin. Four species had prevalence values between 10% and 23%, and the four remaining species were present at less than 9% of the sampled sites. Excluding the southern Iberian barbel, the average prevalence of native fish was 9.8%. Among the locations with fishes, 42.1% presented at least one introduced species. *Atherina boyeri* is not a primary freshwater species; however, in the Guadalquivir basin there is an exclusively freshwater population (Zóñar pond) (Doadrio 2001) and far from any contact with the coast (>100 km), so we decided to include it in this study.

Largemouth bass and common carp were the most common exotic species (23.5% and 22.1% of the sampled sites, respectively,) followed by pumpkinseed (18.6%) and eastern mosquitofish (16.1%). The other species had prevalence values below 10% (Table 3). There are marked differences between native vs. introduced species prevalence in lotic environments, where the first are largely distributed (71.8% and 25.0%, respectively). Lentic environments, on the contrary, do not differ greatly, showing a prevalence of 91.3% for native species and 95.7% for introduced ones.

Table 3. List of native and exotic freshwater fishes detected during the field sampling. Threat categories are referred to IUCN Red List (UICN 2022) and Red book of Spanish freshwater fish, RBSF (Doadrio 2001). CR: Critically endangered; EN: endangered; VU: vulnerable; LC: least concern.

	Family	Species	IUCN (2022)	RBSF (2001)	Prevalence (%) (n = 285)
Native	Anguillidae	<i>Anguilla anguilla</i>	CR	VU	0.7
	Salmonidae	<i>Salmo trutta</i>	LC	VU	11.9
		<i>Luciobarbus sclateri</i>	LC	LC	58.6
	Cyprinidae	<i>Iberochondrostoma lemmingii</i>	VU	VU	2.1
		<i>Pseudochondrostoma willkommii</i>	VU	VU	22.8
		<i>Squalius alburnoides</i>	VU	VU	15.8
		<i>Squalius pyrenaicus</i>	-	VU	8.1
	Cobitidae	<i>Cobitis paludica</i>	VU	VU	15.4
	Atherinidae	<i>Atherina boyeri</i>	LC	VU	1.8
	TOTAL				
Introduced	Salmonidae	<i>Oncorhynchus mykiss</i>			1.8
		<i>Alburnus alburnus</i>			8.1
		<i>Carassius auratus</i>			3.5
	Cyprinidae	<i>Cyprinus carpio</i>			22.1
		<i>Gobio lozanoi</i>			0,4
		<i>Phoxinus</i> spp.			0,4
	Poeciliidae	<i>Gambusia holbrooki</i>			16.1
	Centrarchidae	<i>Lepomis gibbosus</i>			18.6
<i>Micropterus salmoides</i>				23.5	
TOTAL					42.1

Bibliographic-Recorded Species

A total of 11 native species had been previously recorded in the Guadalquivir River Basin but were not captured in this study (Table 4), including 7 sedentary species: Oretanian arched-mouth nase (*Iberochondrostoma oretanum* (Doadrio and Carmona, 2003)), jarabugo (*Anaocypris hispanica* (Steindachner, 1866)), Iberian long-snout barbel (*Luciobarbus comizo* (Steindachner, 1864)), bogardilla (*Squalius palaciosi* Doadrio, 1980), three-spined

stickleback (*Gasterosteus aculeatus* Linnaeus, 1758), freshwater blenny (*Salaria fluviatilis* Asso y del Rio, 1801), and baetican toothcarp (*Aphanius baeticus* (Doadrio, Carmona and Fernández-Delgado, 2002)); and 4 migratory species: Atlantic sturgeon (*Acipenser sturio* Linnaeus, 1758), sea lamprey (*Petromyzon marinus* Linnaeus, 1758), allis shad (*Alosa alosa* (Linnaeus, 1758)) and twaite shad (*Alosa fallax* (Lacépède, 1803)).

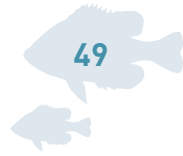
Some of these species may have gone extinct locally (e.g., Atlantic sturgeon, allis shad, three-spined stickleback and bogardilla) (Granado-Lorencio 1991, Doadrio 2001, Granado-Lorencio and Hernando 2001). Others have been recently described (e.g., baetican toothcarp, Oretanian arched-mouth nase) (Doadrio et al. 2002, Doadrio and Carmona 2003) or have a very small distribution range (e.g., jarabugo) (De Miguel et al. 2010). Iberian long-snout barbel and freshwater blenny records, according to Doadrio (2001), have to be considered with caution and need to be checked (Doadrio 2001).

Other records for 11 additional exotic species were obtained in the bibliographic search: tench (*Tinca tinca* (Linnaeus, 1758)), mummichog (*Fundulus heteroclitus* (Linnaeus, 1766)), black bullhead (*Ameiurus melas* (Rafinesque, 1820)), European catfish (*Silurus glanis* Linnaeus, 1758), Siberian sturgeon (*Acipenser baerii* Brandt, 1869), Adriatic sturgeon (*Acipenser naccarii* Bonaparte, 1836), northern pike (*Esox lucius* Linnaeus, 1758), oscar (*Astronotus ocellatus* (Agassiz, 1831)), chameleon cichlid (*Australoheros facetus* (Jenyns, 1842)), pirapitinga (*Piaractus brachypomus* (Cuvier, 1818)) and *Hypostomus* sp. (Table 4). Some of these species have been well established in the basin and surrounding areas for many years (e.g., mummichog, tench) (Clavero and Villero 2013, Gutiérrez-Estrada et al. 1998), whereas others were recently introduced (e.g., black bullhead, European catfish) (García de Lomas et al. 2009, Moreno-Valcárcel et al. 2013). The probable historical presence of the Adriatic sturgeon has been a matter of debate, leading to several studies to either confirm or reject its occurrence (Garrido-Ramos et al. 1997, Doukakis et al. 2000, De la Herrán et al. 2004), but there is still no consensus within the scientific community. However, some Adriatic sturgeon (>25 kg weight) that escaped from fish farms have been captured by anglers (authors' unpublished data). The status of this, and the rest of the introduced species that have been cited in the literature, is currently unknown.

Table 4. List of native and exotic freshwater fishes detected during the bibliographic search. Threat categories are referred to IUCN Red List (IUCN 2022) and Red book of Spanish freshwater fish, RBSF (Doadrio 2001). CR: critically endangered; EN: endangered; VU: vulnerable; LC: least concern. References for each data source ('Ref') are included in the reference list at the end of the article. (*) indicates the species that are still present in the Guadalquivir River Basin. (?) indicates species without data on their current status. *Iberochondrostoma oretanum* is not included in RBSF (2001).

	Family	Species	IUCN (2022)	RBSF (2001)	Ref.	Current presence	Locally extinct
Native	Petromyzontidae	<i>Petromyzon marinus</i>	LC	EN	[6,11,21]	*	
	Acipenseridae	<i>Acipenser sturio</i>	CR	CR	[6,8,9,10,11,14]		*
	Clupeidae	<i>Alosa alosa</i>	LC	VU	[1,6]		*
		<i>Alosa fallax</i>	LC	VU	[6,11,19]	*	
		<i>Iberochondrostoma oretanum</i>	CR	-	[13]	*	
	Cyprinidae	<i>Anaocypris hispanica</i>	EN	EN	[20]	*	
		<i>Luciobarbus comizo</i>	VU	VU	[11]		*
		<i>Squalius palaciosi</i>	CR	EN	[3,11]		?
	Cyprinodontidae	<i>Aphanius baeticus</i>	EN	EN	[1,11,12]	*	
	Gasterosteidae	<i>Gasterosteus aculeatus</i>	LC	EN	[2]		*
Blenniidae	<i>Salaria fluviatilis</i>	LC	EN	[11]		?	
Introduced	Acipenseridae	<i>Acipenser baerii</i>			[9]	?	
		<i>Acipenser naccarii</i>			[8,14]	*	
	Esocidae	<i>Esox lucius</i>			[5]	*	
	Cyprinidae	<i>Tinca tinca</i>			[11,23]	*	
	Ictaluridae	<i>Ameiurus melas</i>			[18,19]	*	
	Siluridae	<i>Silurus glanis</i>			[22]	*	
	Fundulidae	<i>Fundulus heteroclitus</i>			[4,11,19]	*	
	Cichlidae	<i>Astronotus ocellatus</i>			[7,15]	?	
		<i>Australoheros facetus</i>			[18]	*	
	Characidae	<i>Piaractus brachipomus</i>			[16,17]	?	
Loricariidae	<i>Hypostomus sp.</i>			[6]	?		

(1) Lozano Rey (1935), (2) Hernando (1975), (3) Doadrio (1980), (4) Fernández-Delgado et al. (1986), (5) Fernández-Delgado et al. (2014), (6) Granado-Lorencio (1991), (7) Puentes (1996), (8) Garrido-Ramos et al. (1997) (9) Elvira & Almodóvar (1999), (10) Alმაça & Elvira (2000), (11) Doadrio (2001), (12) Doadrio et al. (2002), (13) Doadrio & Carmona (2003), (14) De la Herrán et al. (2004), (15) Elvira (2004), (16) Flórez (2007), (17) García Novo et al. (2007), (18) García de Lomas et al. (2009), (19) Arias García (2010), (20) De Miguel et al. (2010), (21) Mateus et al. (2012), (22) Moreno-Valcárcel et al. (2013), (23) Clavero & Villero (2013).



Patterns of Species Richness and Diversity

The total fish species richness (both native and exotic) for a given location ranged between 0 and 6 while the Shannon diversity index (H') ranged from 0–1.54 to 0–1.35 for native and exotic species, respectively, (see Table S2 for sub-basin details). A positive correlation was found between native and exotic richness and H' ($r_s = 0.178$, $p < 0.01$ and $r = 0.150$, $p < 0.05$, respectively). In addition, Wilcoxon signed-rank test showed no difference between native and exotic species in Shannon diversity ($Z = -1.36$, $N = 285$, $p > 0.05$), contrary to species richness ($Z = -3.90$, $N = 285$, $p < 0.001$). Therefore, sites with high values of native biodiversity tended to show similar values for exotic biodiversity due to the high penetration of exotic species (overall prevalence of 42.1%; 95.7% for reservoirs and 25% for rivers).

Mean native biodiversity was independent of the type of water body, whether main channel, tributary or reservoir (Figure 3). However, mean exotic biodiversity was clearly overrepresented in reservoirs, which also acted as reservoirs for non-native fish, while they had a minor importance compared to native fauna in tributaries or the main channel (Figure 3). The right margin had higher biodiversity values than the left margin. Finally, with respect to Strahler's order, two different patterns emerged, one for native species and another for exotics. Native biodiversity peaked at order 2 and progressively was reduced until a minimum at locations higher than order 4, while exotics peaked at order 4 following a progressive increase from order 1 (Figure 3) (for all comparisons, Kruskal–Wallis, $p < 0.05$, Dunn's post test).

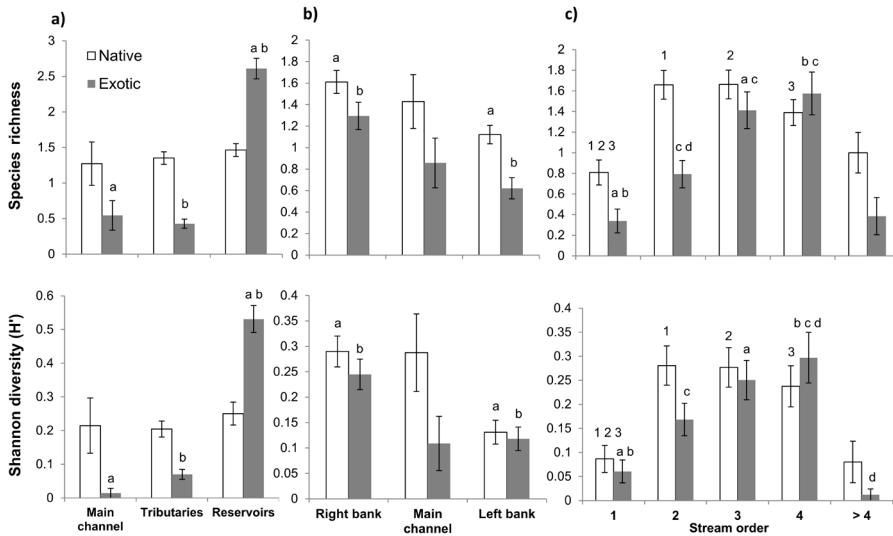


Figure 3. Main fish biodiversity descriptors (average species richness and Shannon H' diversity index) for native and exotic species at different aquatic habitat typologies in the Guadalquivir Basin. Mainstream, tributaries and reservoirs (a); mainstream, left and right bank tributaries (b) and stream order (c), according to Strahler (1964). Error bars indicate standard error (SE). The same letter above bars shows that values are statistically different (Dunn's post test; $\alpha = 0.05$) when Kruskal–Wallis $p < 0.05$.

Conservation Status

To check the fish conservation status of the Guadalquivir River Basin, for each of 46 sub-basins the frequency of species included in any IUCN categories (Least Concern, Vulnerable, Critically Endangered) (IUCN 2022) was calculated (Figure 4). Among the total sub-basins sampled, 13% ($n = 6$) had no fish fauna and another one contained only exotic species (approximately 3% of total area). The rest of the sub-basins had a quite variable, but generally poor, conservation status (Figure 4). More than half of the sampled species were included in some of the most threatened IUCN categories (Tables 3 and 4). Similarly, 55% of species found in the bibliographical search were also included in some of these IUCN categories (Tables 3 and 4). The left margin presented a higher proportion for Least Concern and Vulnerable categories than the right one, but the right margin had more Critically Endangered species (Figure 4). Despite the existence of critically endangered species in the left bank (according to bibliographic search) they were not detected in the field study.

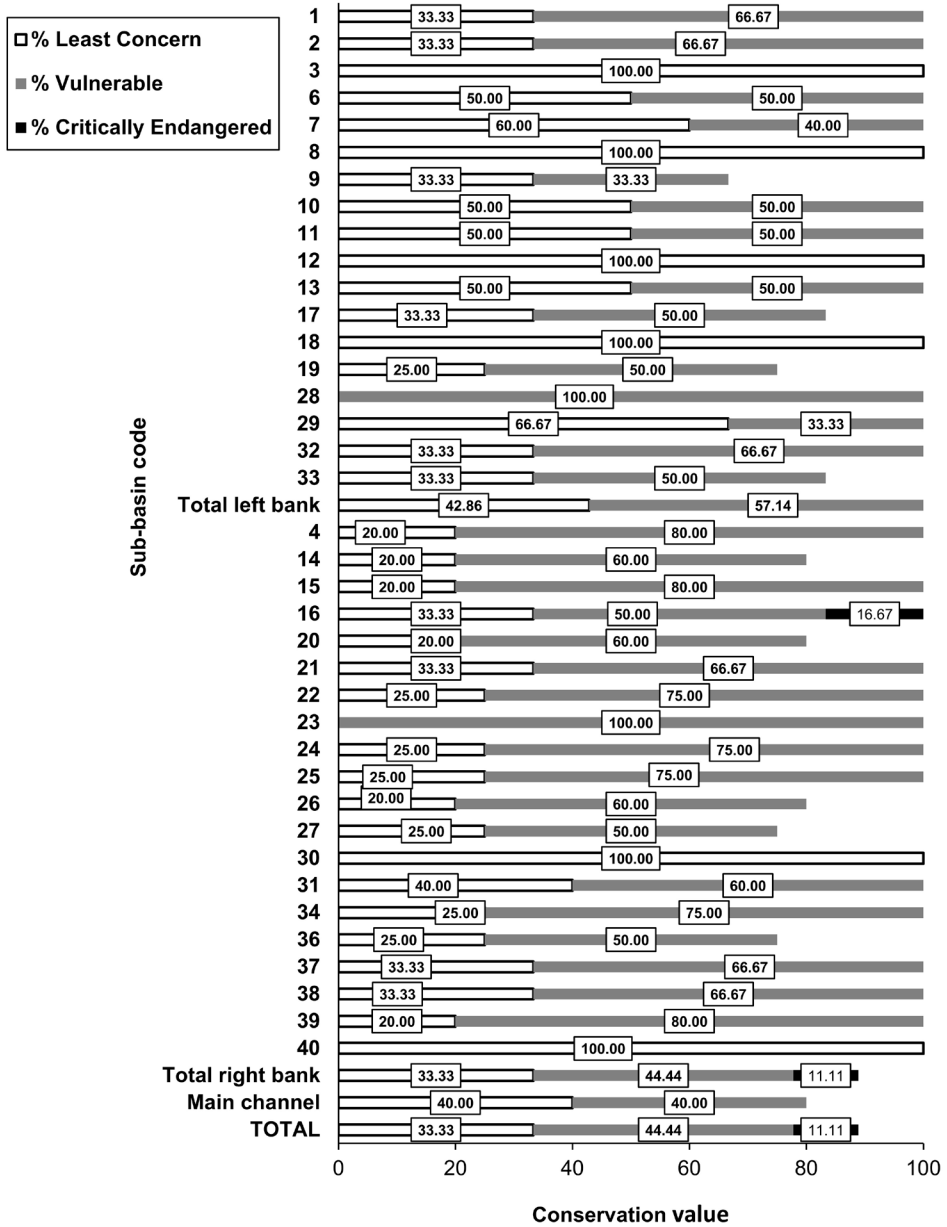


Figure 4. Conservation status (%) of sampled threatened fish species (IUCN red list criteria, version 15.1, July 2022) in different Guadalquivir River sub-basins.

Discussion

The Guadalquivir River Basin has a remarkable importance in the context of Mediterranean freshwater fish biodiversity and conservation (Smith and Darwall 2006). Despite not being one of the most diverse basins in the region, it contains a high number of species, many of them endemic (Smith and Darwall 2006). Around one-third of the native species registered in the Iberian Peninsula are nowadays present or have recently inhabited this basin and the species richness found within it is similar to other large Iberian basins (Figure 5).

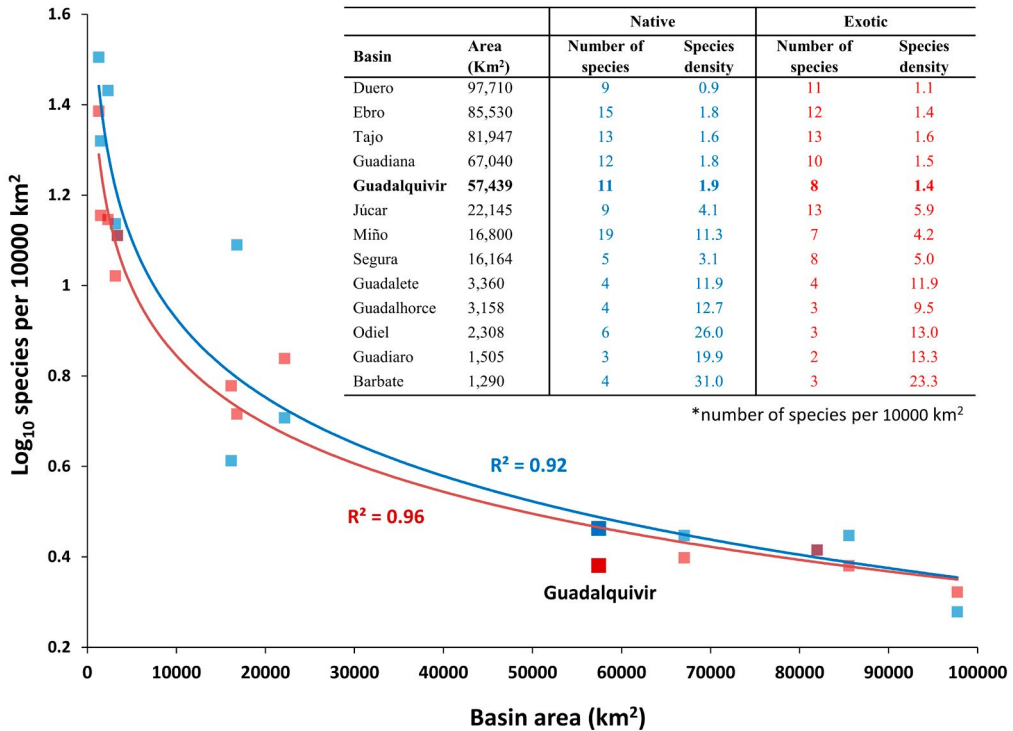


Figure 5. Species density–basin area relationship for the main Iberian basins. Drainage area, freshwater fish number and species density are shown. Raw data from: Hernando and Soriguer 1992, Elvira 1995, Clavero et al. 2004). The blue color refers to the native species and the red to the exotic ones.

Changes in the Guadalquivir Basin due to human activities during the last century have greatly modified the ecological characteristics of the water bodies and, subsequently, their fish communities (Granado-Lorencio 1991, González-Ortegón et al. 2010, Hermosín et al. 2013). During the 20th century, around 30 large dams were built and largely as a consequence of this the irrigated land increased by approximately 7000 km², 83% of the current total irrigated area (Confederación Hidrográfica del Guadalquivir 2015a). This habitat transformation, especially reservoir building, has promoted the spread of exotic species (Clavero et al. 2004) and has numerically reduced or driven to extinction a large proportion of native species, particularly migratory ones (Granado-Lorencio 1991, Nicola et al. 1996, Clavero and Hermoso 2011). At the same time, agricultural intensification has markedly increased the discharge of agrochemicals (fertilizers and pesticides) as huge loads of suspended solids, which have greatly increased water turbidity, especially at the lower basin reaches (González-Ortegón et al. 2010, Hermosín et al. 2013). Here, navigation has provoked strong changes in the main channel to reduce the distance from Seville harbour to the sea by more than 70 km (Menanteau 1982, 1984). This has isolated the main channel from surrounding areas and has allowed the penetration of seawater further upstream, along with different marine species (e.g., *Dicentrarchus labrax*) (Granado-Lorencio 1991, Arias García et al. 2010).

Guadalquivir Fish Biodiversity

Iberian freshwater fish are characterized by a small number of families but a high degree of endemism (Doadrio 2001). This may be a consequence of both geographic isolation and stressful ecological conditions derived from the extreme Mediterranean hydrologic regime (Almança 1976, Doadrio 2001). This is characterized by autumn–winter catastrophic floods and summer droughts that leave many river sections dry during the summer and early autumn (Gasith and Resh 1999). The native ichthyofauna of the Guadalquivir Basin is dominated, as in most Iberian basins, by the Cyprinidae family (Hernando and Soriguer 1992), which is well adapted to the extreme environmental conditions of the Mediterranean climate.

Stream fish community richness tends to increase from headwaters to lower sections of river basins (Sheldon 1968, Horwitz 1978, Reeves et al. 1988). However, this general biodiversity pattern is altered in the Guadalquivir Basin most likely as a

response to poor habitat quality in the lower river sections, as has been observed in many highly populated basins in temperate areas (Aparicio et al. 2000, Corbacho and Sánchez 2001). Downstream reaches (usually >4 order) have high contamination levels, high prevalence of exotic species and physical habitat disturbances, among other things, that prevent a large number of species from establishing there (Hughes and Gammon 1987, Corbacho and Sánchez 2001).

The positive correlation observed between native and exotic fish richness may indicate that the dominant factors determining native diversity (e.g., competition, disturbance, availability of resources, etc.) are the same as those influencing invasions (Huston 1994, Levine and D'Antonio 1999). Here, sites with high values of native richness (a high habitat quality for a large number of species) are more vulnerable to invasion than those places with low diversity. This sharply contrasts with classical ecological theories that contend that diverse communities better resist exotic species invasion (McArthur 1970, McArthur 1972, Case 1991). It may also be the case that the rivers draining the right margin of the Guadalquivir had higher richness (and a fewer number of sites without fish) for both native and exotic fish than the rivers along the left margin. These latter rivers drain mostly flat, highly productive agricultural land occupied by intensive farming, industrial areas and densely populated human settlements, while those draining the right margin run through mountainous areas covered by natural forests, with low human disturbance and extensive agriculture and cattle raising (Rodríguez Díaz, et al. 2007, Confederación Hidrográfica del Guadalquivir 2015a).

Introduced Species

The introduction of exotic species in the Guadalquivir Basin is a general and widespread problem that is heavily threatening the native fauna. It is also causing the homogenization of freshwater biodiversity, a problem largely extending to all Iberian river basins (Rahel 2002, Clavero et al. 2004, Hermoso et al. 2008)

Our results point out that most exotic biodiversity is a direct consequence of reservoirs. These human constructions provide the stable lentic habitats to which native fauna is not well adapted, but where, on the contrary, introduced species can thrive, thus acting as exotic species reservoirs, allowing them to disperse from here and to colonize

other more or less nearby areas (Martínez et al. 1994, Clavero et al. 2004, Corbacho and Sánchez 2001). Without reservoirs, many of these exotic fish species would not survive in Mediterranean rivers or would do so in very low abundance (Martínez et al. 1994, Corbacho and Sánchez 2001). The altitudinal segregation between native and exotic species is mainly caused by two factors. On the one hand, headwaters are usually isolated areas with low habitat transformation, in many cases included within protected areas (Saunders et al. 2002). On the other hand, many authors suggest that middle and lower river reaches have better conditions for the settlement of exotic species (slower water and a large cumulative number of reservoirs for downstream exotic fish dispersion) (Corbacho and Sánchez 2001, Clavero et al. 2004).

Many exotic species have been introduced and have subsequently proliferated in the Guadalquivir Basin during recent decades. Around 54% of these species have been introduced into Spain during the last century (Elvira and Almodóvar 2001). Fourteen of the detected introduced species (70% of the total) are now well established in the basin and/or are in the process of expansion. Four of these have colonized the basin within the last ten years: (1) bleak (Vinyoles et al. 2007) and (2) black bullhead (García de Lomas et al. 2009) are common in the middle and lower stretch of the basin, and finally (3) European catfish, the latest species detected in the basin (Moreno-Valcárcel et al. 2013), which involves a serious threat to regional wildlife (Copp et al. 2009). The latter's preference for slow waters may favor its proliferation in the lowest sections of the basin, including the nature sanctuary of Doñana National Park and surrounding areas, with serious threats to this unique ecosystem.

Conservation Status

The conservation status of the Guadalquivir fish fauna is nowadays very poor, as more than half of the recorded native species in the basin are classified in a threat category, either nationally or internationally (see Tables 3 and 4).

The high degree of fish endemism in Mediterranean river basins, such as the Guadalquivir, demonstrates that this fauna, on average, displays rare and isolated populations naturally (e.g., oretanian arched-mouth nase, jarabugo, bogardilla and baetican toothcarp) (Almança 1976, Doadrio 2001). Furthermore, some of these species

have a low tolerance to disturbance, so that their extinction risk increases considerably (Hermoso et al. 2008, Blanco-Garrido et al. 2009). Several formerly common species are now disappearing; for example, the Southern Iberian chub, the Iberian arched-mouth, the calandino and the European eel have considerably reduced distributions with respect to those observed in recent studies (Doadrio 2001).

Two freshwater species are considered officially extinct in the Guadalquivir Basin: the three-spined stickleback and the Iberian long-snout barbel (Granado-Lorencio 1991, Granado-Lorencio 2009, Arias García 2010). The first represented the southernmost population in Europe (Hernando 1975). The direct causes of its extinction will never be known, but some speculate about habitat transformation, pollution and fish trading for aquarists (Granado-Lorencio and Hernando 2001). The causes of Iberian long-snout barbel extinction are also unknown; however, the very small number of records and their antiquity (Lozano Rey 1935) suggests that the historical presence of this species in the basin should be viewed with caution (Granado-Lorencio 2001).

Migratory species are the worst preserved fish species. Only one of the five species (European eel, prevalence <1%) with historical presence in the basin was captured, whereas two others are very scarce (i.e., sea lamprey and twaite shad) and the remaining two are regionally extinct (Atlantic sturgeon and allis shad (Arias García 2010, UICN 2022)). The last published records for the sea lamprey come from 1992 and 1999, and in some studies it is considered extinct (Arias García 2010); however, we are aware of sporadic, but periodic captures of this species in the estuary (authors' unpublished data). There are very few individual twaite shad dispersed in the lowest sections of the basin during early autumn and spring.

The relationship between the conservation of migratory fish fauna and the impact of dams is a widespread and well-known problem around the world (Stanley and Doyle 2003, Limburg and Waldman 2009). Dams without adequate fish passage systems hinder access to upstream areas, which may include breeding grounds, this being one of the main challenges to their conservation (Stanley and Doyle 2003, Limburg and Waldman 2009). Spain is one of the most dammed countries in the world, which represents an important environmental problem (Nicola et al. 1996, Clavero et al. 2004) because, among other reasons, most dams are impassable, i.e., it is not possible to install

feasible fishways due to their height. In the Guadalquivir River, the Alcalá del Rio dam, built in 1931, is a major obstacle for upstream fish migration, especially for sturgeon (Granado-Lorencio 1991). Later on, in 1956, another dam (Cantillana dam) was built approximately 22 km upstream of Alcalá del Rio precipitating the total fragmentation of the lower section of the river from the middle one. Other specific causes involved in the regression of these species include: flow reduction (due to dams and irrigated crops), gravel extractions (damaging spawning grounds), pollution from urban and industry activities and overfishing, e.g., caviar industry, elver fishing (Granado-Lorencio 1991, Doadrio 2001, Ramos-Merchante and Prenda 2018).

Conservation and Management Recommendations

A regional strategy for freshwater fish conservation was approved in 2012 (see <http://www.juntadeandalucia.es/boja/2012/60/boletin.60.pdf> for more details, accessed on 26 September 2022) and its first actions, mainly species detection, range distribution estimates and ex situ programs, have recently been initiated. This strategy aims to act on species included in the regional Red Book: four critically endangered, five endangered and seven vulnerable (Franco-Ruíz 2001). However, three endangered species (*Salmo trutta*, *Alosa alosa* and *Alosa fallax*) are not included in the strategy. However, up to now, the current management and conservation measures taken have not seemed to alter the trend of the most endangered species due to the continuous degradation of the aquatic ecosystems of the basin (González-Ortegón et al. 2010, Hermosín et al. 2013, Ramos-Merchante and Prenda 2018) as well as the absence of large-scale actions that can interfere with human activities (e.g., agriculture) (González-Ortegón et al. 2010, Hermosín et al. 2013). Only baetican toothcarp and brown trout, which have specific conservation plans for eight and six years, respectively, seem to have stabilized their populations (Pérez Pavón et al. 2012, Larios-López et al. 2015)

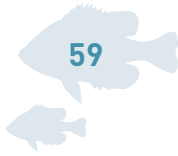
The current conservation status (according to IUCN criteria) of all threatened fish species in the Guadalquivir Basin as well as introduced species should be revised and updated, placing each species in their appropriate global and regional coherent category, including possible extinctions. For example, the Andalusian regional Red Book includes the European eel in the 'Least Concern' category while in the IUCN Red list it appears as 'Critically Endangered'. As another example, the possible hybrid origin of bogardilla

(Doadrio 2001) should be clarified. This taxon is included in the regional conservation strategy and considerable funds could be invested for its conservation and protection, without even knowing its true taxonomic status. In addition, this “species” has not been collected in the last ten years (UICN 2022).

The definition and detection of priority sites for freshwater fish conservation is necessary to determine the appropriate measures of restoration in the most valuable areas for fish. These should be areas with high native species richness or inhabited by endangered species. The legal declaration of protected natural areas would be useful to preserve them. Removing obsolete dams will increase connectivity among populations, thus avoiding their isolation (Stanley and Doyle 2003) and promoting their recovery, especially among migratory species. This measure is being carried out in several countries in Europe and America (Stanley and Doyle 2003). The ex situ programs could, in the future, provide individuals for repopulations, introductions and/or reintroductions for genetic improvement. In this regard, the development of live gene banks could help avoid the biodiversity loss of depauperated populations (Cowx and Collares-Pereira 2000, Doadrio 2001, Doadrio and Carmona 2014). Finally, invasive species should be eliminated, if possible, especially from fish priority sites.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Species richness (S), number of families (F), Shannon (H') diversity indices and species density ($D = n^{\circ}$ species per 1000 km²) for each sampled sub-basin (45 and the main channel). Table S2: List of freshwater fish species sampled in each sub-basin. Species name are codified using the first letter of the genus and the two first letters of the species.

Author Contributions: “Conceptualization, P.SG. and J.P.; methodology, .P.SG.; software, P.SG.; validation, P.SG. and J.P.; formal analysis, P.SG.; investigation, P.SG and J.P.; resources, P.SG and J.P.; data curation, P.SG.; writing—original draft preparation, P.SG.; writing—review and editing, P.SG and J.P.; visualization, P.SG and J.P.; supervision, J.P.; project administration, J.P.; funding acquisition, J.P. All authors have read and agreed to the published version of the manuscript.”



Funding: This research was funded by the Junta de Andalucía, Convocatoria de Proyectos de Excelencia (P07-RNM-03309), and was carried out at the Centro Internacional de Estudios y Convenciones Ecológicas y Medioambientales (CIECEM) of the University of Huelva.

Institutional Review Board Statement: The authors declare that all procedures have been approved by the Andalusian Authority for Wildlife Protection. This study was carried out in accordance with national and international guidelines for care and use of animals.

Data Availability Statement: Data can be found within the paper and Supplementary Materials.

Acknowledgments: We wish to thank everyone from the CIECEM for their invaluable help and logistic support.

Conflicts of Interest: The authors declare no competing interests of financial or non-financial nature.

SUPPLEMENTARY MATERIAL

Table S1. List of freshwater fish species sampled in each sub-basin. Species name are codified using the first letter of the genus and the two first letters of the species (see Table 3 and 4). Abbreviation for each species: AAN (*Anguilla Anguilla*), STR (*Salmo trutta*), LSC (*Luciobarbus sclateri*), ILE (*Iberochondrostoma lemmingii*), PWI (*Pseudochondrostoma willkommii*), SAL (*Squalius alburnoides*), SPY (*Squalius pyrenaicus*), CPA (*Cobitis paludica*), ABO (*Atherina boyeri*), OMY (*Oncorhynchus mykiss*), AAL (*Alburnus alburnus*), CAU (*Carassius auratus*), CCA (*Cyprinus carpio*), GLO (*Gobio lozanoi*), PHO (*Phoxinus spp.*), GHO (*Gambusia holbrooki*), LGI (*Lepomis gibbosus*), MSA (*Micropterus salmoides*). The symbol (+) indicates the presence of the species in the sub-basin.

	Sub-Basin Code	AAN	STR	LSC	ILE	PWI	SAL	SPY	CPA
	1			+		+			+
	2			+					
	3			+		+	+		
	6			+		+			
	7		+	+		+			+
	8			+					
	9			+				+	+
	10			+		+			
	11			+					+
	12			+					
Left bank	13			+			+		
	17		+	+		+	+	+	+
	18			+					
	19			+			+	+	+
	28					+			
	29			+		+			
	32			+		+			+
	33		+	+		+	+	+	+
	41								
	42								
	43								
TOTAL LEFT			+	+		+	+	+	+

	Sub-Basin Code	AAN	STR	LSC	ILE	PWI	SAL	SPY	CPA
	4			+	+	+	+		+
	14			+		+	+	+	+
	15			+	+	+	+		+
	16	+		+		+	+		+
	20			+		+	+	+	+
	21		+	+	+	+	+		+
	22			+		+	+		+
	23								+
	24			+		+	+		+
	25			+		+	+		+
	26			+		+	+	+	+
Right bank	27			+		+	+	+	
	30		+						
	31		+	+		+	+		+
	34			+		+	+		+
	35								
	36			+		+	+	+	
	37			+			+		+
	38			+		+	+		
	39			+	+	+	+		+
	40			+					
	44								
	45								
	46								
TOTAL RIGHT		+	+	+	+	+	+	+	+
MAIN CHANNEL 5			+	+		+	+	+	

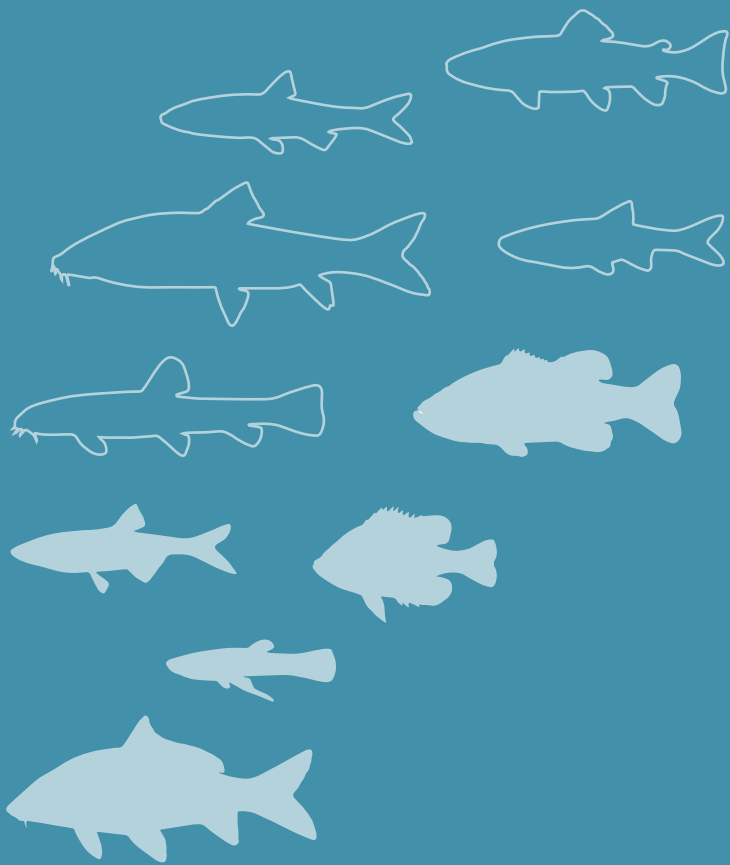
Table S2. Species richness (S), number of families (F), Shannon (H') diversity indices and species density ($D = n^\circ$ species per 1000 km²) for each sampled sub-basin (45 and the main channel).

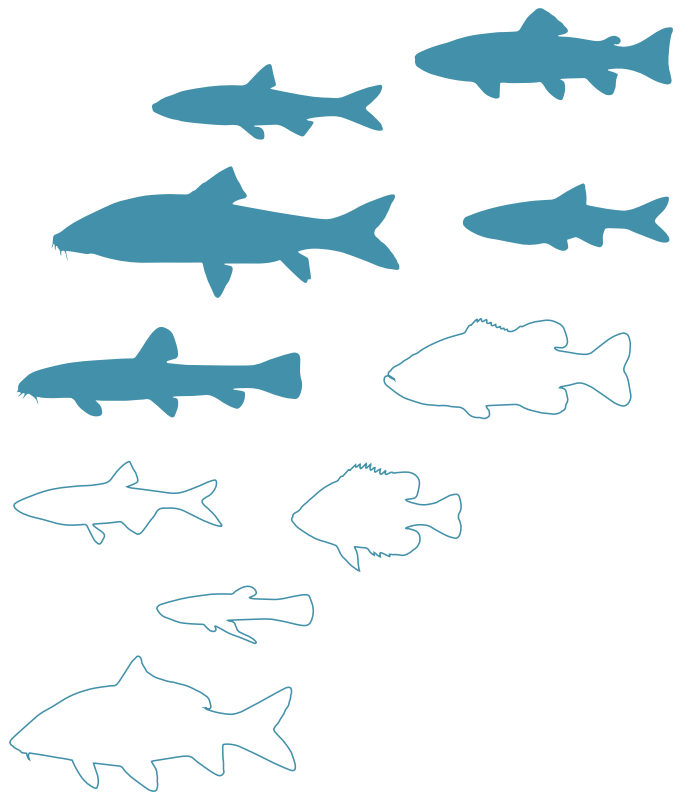
Sub-Basin Name	Code	Surface (km ²)	River	Reservoir
			N	N
Azanaque	1	56	1	0
Madre Fuentes	2	412	1	0
Santa María	3	151	1	0
Corbones	6	1963	6	2
Genil	7	8460	27	13
Guadaíra	8	1626	6	0
Guadajoz	9	2579	10	2
Guadalmazán	10	217	1	0
Guadalbullón	11	1207	6	0
Guadatín	12	119	1	0
Salado de Arjona	13	521	1	0
Guadiana Menor	17	7494	31	5
Las Torres	18	103	2	0
Bedmar	19	161	2	0
Salado de Lebrija	28	978	0	2
Salado de Morón	29	786	4	2
Cañamares	32	192	2	0
Aguascebas	33	111	1	0
Salado de Porcuna	41	859	1	0
Arroyo del Salado	42	85	1	0
Jandulilla	43	312	1	0
Total left bank		27259	106	26
Bembézar	4	2093	6	3
Guadalimar	14	5441	23	6
Guadalmellato	15	1388	5	2
Guadamar	16	1425	7	1

Native Species				Exotic Species			
S	F	H'	D	S	F	H'	D
3	2	0.24	53,57	0	0	0.00	0,00
3	1	0.92	7,28	1	1	0.00	2,43
1	1	0.00	6,62	0	0	0.00	0,00
2	1	0.10	1,02	4	3	0.17	2,04
5	3	0.12	0,59	6	4	0.16	0,71
1	1	0.00	0,62	3	2	0.14	1,85
3	2	0.17	1,16	3	2	0.10	1,16
2	1	0.67	9,22	0	0	0.00	0,00
2	2	0.02	1,66	1	1	0.00	0,83
1	1	0.00	8,40	0	0	0.00	0,00
2	1	0.30	3,84	0	0	0.00	0,00
6	3	0.11	0,80	4	3	0.08	0,53
1	1	0.00	9,71	0	0	0.00	0,00
4	2	0.16	24,84	0	0	0.00	0,00
1	1	0.00	1,02	2	2	0.53	2,04
3	2	0.21	3,82	4	3	0.29	5,09
3	2	0.19	15,63	0	0	0.00	0,00
6	3	1.54	54,05	0	0	0.00	0,00
0	0	0.00	0,00	0	0	0.00	0,00
0	0	0.00	0,00	0	0	0.00	0,00
0	0	0.00	0,00	0	0	0.00	0,00
7	4	0.13	0,26	9	5	0.12	0,33
5	2	0.47	2,39	5	3	0.44	2,39
5	2	0.24	0,92	6	4	0.12	1,10
5	1	0.33	3,60	7	3	0.52	5,04
6	4	0.30	4,21	5	3	0.49	3,51

Sub-Basin Name	Code	Surface (km ²)	River	Reservoir
			N	N
Guadiato	20	1591	6	3
Huéznar	21	733	5	2
Jándula	22	2720	6	1
M. de las marismas	23	1469	3	3
Retortillo	24	358	4	2
Guadalbacar	25	274	2	1
Rivera de Huelva	26	2079	7	9
Rumblar	27	740	3	2
Aguasmulas	30	33	1	0
Borosa	31	96	1	0
Viar	34	1884	4	1
Siete Arroyos	35	107	1	0
Yeguas	36	857	4	2
Arroyo Tamujoso	37	63	1	0
Río de Pedro Gil	38	65	1	0
Arenoso	39	433	3	1
Martín Gonzalo	40	82	1	1
Corcomé	44	46	1	0
Escobar	45	62	1	0
Guadiel	46	364	3	0
Total right bank		23247	99	40
Main channel	5	4644	11	3
TOTAL BASIN		57439	216	69

Native Species				Exotic Species			
S	F	H'	D	S	F	H'	D
5	2	0.09	3,14	5	3	0.45	3,14
6	3	0.44	8,19	5	3	0.27	6,82
4	2	0.15	1,47	6	3	0.17	2,21
1	1	0.00	0,68	3	3	0.11	2,04
4	2	0.33	11,17	4	3	0.18	11,17
4	2	0.37	14,60	5	3	0.45	18,25
5	2	0.40	2,41	5	3	0.31	2,41
4	1	0.39	5,41	2	2	0.08	2,70
1	1	0.00	30,30	0	0	0.00	0,00
5	3	1.19	52,08	1	1	0.00	10,42
4	2	0.28	2,12	4	3	0.33	2,12
0	0	0.00	0,00	1	1	0.00	9,35
4	1	0.39	4,67	4	2	0.22	4,67
3	2	0.82	47,62	0	0	0.00	0,00
3	1	0.84	46,15	0	0	0.00	0,00
5	2	0.35	11,55	2	2	0.15	4,62
1	1	0.00	12,20	1	1	0.00	12,20
0	0	0.00	0,00	0	0	0.00	0,00
0	0	0.00	0,00	0	0	0.00	0,00
0	0	0.00	0,00	0	0	0.00	0,00
9	5	0.29	0,39	9	5	0.24	0,39
5	2	0.29	1,08	6	4	0.11	1,29
9	5	0.22	0,16	10	5	0.18	0,17





Chapter III.

**Updating the distribution data of
recently introduced freshwater fish in
the Guadalquivir River Basin (Spain)**

Citation:

Sáez-Gómez P, Prenda J (2019) Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain).

BioInvasions Records 8(4): 924–932,

https://www.reabic.net/journals/bir/2019/4/BIR_2019_Saez-Gomez_Prenda.pdf

Received: 13 March 2019

Accepted: 4 July 2019

Published: 15 October 2019

Copyright: © Sáez-Gómez and Prenda

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS.

Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain)

Pedro Sáez-Gómez and José Prenda*

Department of Integrative Sciences, University of Huelva. Campus universitario de El Carmen, Avda. Andalucía s/n, 21071 Huelva, Spain

Author e-mails: pedro.saez@ciecema.uhu.es (PSG), jprenda@uhu.es (JP)

*Corresponding author

Abstract: We report new distribution data on four recently introduced species in the Guadalquivir River basin: chameleon cichlid (*Australoheros facetus* Jenyns, 1842), North American black bullhead (*Ameiurus melas* Rafinesque, 1820), European catfish (*Silurus glanis* Linnaeus, 1758) and a minnow species of unknown origin (*Phoxinus* spp.). A compilation of records is used to update the distribution range of these species. The information collected reinforces the evidence on the establishment and expansion of these non-native species. We recommend new field sampling to identify the dispersal pathways and to clarify their current statuses.

Key words: exotic species, Mediterranean rivers, invasive, *Australoheros facetus*, *Ameiurus melas*, *Phoxinus* ssp., *Silurus glanis*

Introduction

Introductions of non-native species are recognized as one of the main threats for freshwater biodiversity worldwide (Gozlan et al. 2010). The impacts caused by the arrival of new species are highly diverse and depend primarily on the introduced species and habitat features (Ribeiro and Leunda 2012). In arid and semi-arid regions (e.g. Mediterranean basin) where water demand for human uses is high (Cowx and Collares-Pereira 2002), the number of reservoirs has reached almost a maximum, and consequently, the number of non-native species and their distribution range is increasing. Thus, Iberian inland waters are among the most invaded ecosystems within the Mediterranean region and fish introductions are considered a major threat to native ichthyofauna which comprise a high proportion of endemic species (Ribeiro and Leunda 2012).

Guadalquivir River basin is highly important in terms of biodiversity and number of threatened taxa (Doadrio 2001), as around 50% of the native species recorded in the basin are included in an IUCN-2015 category. Yet, the current ichthyofauna of the basin contains large proportion of introduced species. Fernández-Delgado et al. (2014) detected up to 14 non-native species showing a higher richness than natives ones (13 species). A recent study also determined high non-native species richness (10 vs. 9 for native and introduced species respectively; see Ramos-Merchante and Prenda 2018). These and other studies (García de Lomas et al. 2009; Moreno-Valcárcel et al. 2013) revealed the recent detection of several species with high invasive potential such as chameleon fish (*Australoheros facetus* Jenyns, 1842), North American black bullhead (*Ameirus melas* Rafinesque, 1820) and European catfish (*Silurus glanis* Linnaeus, 1758). These species are included in the rank lists of the most invasive alien species (IAS) because their potential threat to biodiversity (Clavero 2011; van der Veer and Nentwig 2015; Carboneras et al. 2018). Therefore, updated knowledge about new introductions and their distribution ranges is essential to detect new threats and implement appropriate conservation strategies.

Here we provide new distribution data on the three recently introduced species: *Australoheros facetus*, *Ameirus melas* and *Silurus glanis* in the Guadalquivir River basin (South Spain) and also report the first record of an invasive species belonging to the genus *Phoxinus* in this basin.

Materials and methods

The Guadalquivir is the fifth longest river in the Iberian Peninsula, situated in the south of Spain, running in a dominant east-west direction to the Atlantic Ocean. The main channel is 680 km long, with a drainage area of 57439 km². Based on non-native species distribution data from other studies (García de Lomas et al. 2009; Moreno-Valcárcel et al. 2013; Fernández-Delgado et al. 2014) we compiled information from two data sources (field sampling and anglers' records) in order to update the current distribution of *Australoheros facetus*, *Ameirus melas*, *Silurus glanis* and *Phoxinus* spp. in the basin.

Firstly, during the course of a research project on fish fauna distribution in Guadalquivir River basin (see acknowledgements for details) we conducted a field sampling at 285 locations over the entire basin (216 in rivers and 69 in reservoirs) between June 2007 and July 2008 (Figure 1A). Depending on location width and depth, two alternative sampling methods were used. Typical stream sites with low salinity ($< 1.5 \text{ mS cm}^{-1}$) and shallow depth ($< 1.2 \text{ m}$) were electrofished by wading upstream along a channel length of 100 m during approximately one hour. The equipment comprised a control box delivering a pulsed direct current, 300/600 V, 4–6 A without block nets (Electracatch International, Honda EU 20i motor with a WF6 rectifier and a landing net with a 30 cm diameter and a 4 mm mesh size). When the salinity and depth conditions did not allow electrofishing, mainly in large rivers and reservoirs, we used four types of passive traps: trammel nets, fyke nets, minnow traps and plastic bottle minnow traps. Two trammel nets (10 m \times 2 m, 175 mm \times 25 mm and 200 mm \times 20 mm mesh size), three pairs of fyke nets (12 mm and 3 mm mesh size), fifteen metal minnow traps (6 mm mesh size) and ten pairs of plastic minnow traps (25 mm inlet) were set for a minimum of 8 h (see Clavero et al. 2006 for more details). After capture, fish were identified to species level, counted, measured and returned live to the river.

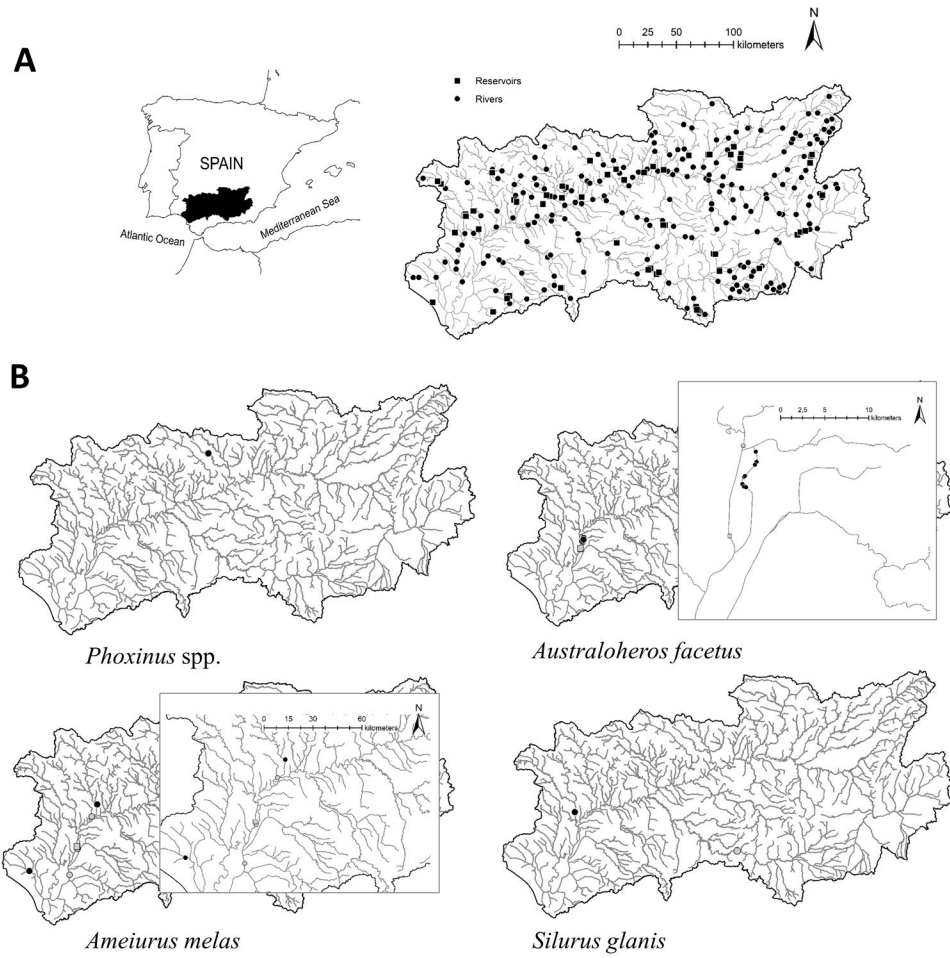


Figure 1. Map of the Guadalquivir River Basin and geographical locations of the records for each species. Dark circles represent the new records described in this study. Grey circles and squares correspond to the previous records reported by FernándezDelgado et al. 2014 and García de Lomas et al. 2009 respectively. Fine-scale is shown for *Australoheros facetus* and *Ameiurus melas*. For details see Supplementary material Table S1.

Secondly, we completed the information obtained in the field samplings with extensive searches on different social media websites (e.g. YouTube, Facebook), recreational fisheries forums, blogs and search engines (i.e. Google) to obtain records of the studied species. In addition, we sent a request for information on records of the species under study to fisheries websites. Following the Gago et al. (2016) criteria, we performed a Boolean search between July 2010 and October 2015 using a combination of different keywords, including scientific and common names in Spanish (i.e. chanchito, pez gato, siluro, piscardo) and river name (Guadalquivir). Species records were accepted only when it included the locality, year and accompanying media (picture or video) (see Gago et al. 2016 for details). We interviewed, whenever possible, the angler who reported the information to confirm this and avoid double counting. The geographical coordinates were extracted from Google Earth Pro. Finally, we added to the database a remarkable sighting of North American black bullhead that we made in the Doñana National Park, a highly protected area in the lower section of the basin.

Results and discussion

A total of 18 records were obtained in the Guadalquivir River basin (Supplementary material Table S1), with fishing forum websites representing the main source of information with 46.2% of the total records. A single record was never detected in more than one data source (i.e. duplicate records). Chameleon cichlid was the species with the highest number of records (69%) and the species with the highest number of specimens registered was the North American black bullhead (> 2000) (Table S1). During the fish sampling, other 8 non-native species well known in previous studies were also collected (Doadrio 2001; Vinyoles et al. 2007): *Oncorhynchus mykiss* (Walbaum, 1972), *Alburnus alburnus* (Linnaeus, 1758), *Carassius auratus* (Bloch, 1782), *Cyprinus carpio* (Linnaeus, 1758), *Gobio lozanoi* (Doadrio and Madeira, 2004), *Gambusia holbrooki* (Girard, 1859), *Lepomis gibbosus* (Linnaeus, 1758) and *Micropterus salmoides* (Lacépède, 1802).

Phoxinus spp.

Traditionally, minnow populations from the Iberian Peninsula have been identified as *Phoxinus phoxinus* (Linnaeus, 1758) (Doadrio 2001). However, Kottelat (2007) reclassified these populations as *P. bigerri*. Since the author did not analyse samples from Iberia he suggests caution identifying these populations. The Iberian distribution includes some rivers in the Cantabrian Mountains and the Ebro River basin (Kottelat and Freyhof 2007). However, the origin (native or introduced) of Atlantic populations is unknown due to continuous introductions carried out by anglers (e.g. Cantabrian Rivers and Douro basin) who use the species as live bait or as food for trout (Doadrio and Garzón 1986; Doadrio 2001; SIBIC 2014). Moreover, species from *Phoxinus* genus can reproduce and generate hybrids, even intergeneric hybrids (Eisenhour and Piller 1997). For this reason, identifications based on morphometric characteristics can be misleading and genetic analysis represent the most reliable tool. Three individuals from *Phoxinus* genus were collected on May 1st 2008 (Table S1) in a right bank tributary of the Guadalquivir (Guadalbarbo River; Figure 1). Morphological measures taken from the sampled specimens (e. g. distance between the end of the first and last ray branched of the anal fin, see Kottelat 2007) did not allow unambiguous identification of the species since they could correspond to both *P. phoxinus* and *P. bigerri* as well as commercial hybrids. On this basis, we consider this population as *Phoxinus* spp. until additional studies based on genetic analysis can clarify this issue. The fish exhibited bright colours and emerging spawning characteristics, such as a reddish abdomen and base of fins, a darker band on the flank, yellow spots on the operculum with intensive colour and head tubercles (Figure 2), and thus reproduction is highly likely. After the capture, individuals were measured to the nearest 1 mm and weighed to the nearest 0.01 g. Length and weight measurements were: 44, 56 and 55 mm and 0.83, 1.70 and 1.60 g, respectively. Three native species: Iberian arched-mouth nase (*Iberochondrostoma lemmingii* – Steindachner, 1866), southern Iberian barbel (*Luciobarbus sclateri* – Günther, 1868), and calandino (*Iberocypris alburnoides* – Steindachner, 1866) and one non-native species, bleak (*Alburnus alburnus* – Linnaeus, 1758), were also captured in the same locality. Subsequent sampling has confirmed the establishment of a minnow population in this location (referred to as *P. phoxinus*, see Fernández-Delgado et al. 2014). The specimens were preserved in the ichthyological collection of the Department of Integrative Sciences (University of Huelva, Spain).



Figure 2. Minnow (*Phoxinus* spp.) specimens captured in the Guadalquivir basin (only two are shown) during the field session with emerging spawning characteristics: bright colours, reddish base of fins, darker band on the flanks, and yellow spots on the operculum.

Chameleon cichlid – Australoheros facetus (Jenyns, 1842)

Chameleon cichlid was identified in the Guadalquivir River for the first time in 2007 during the implementation of control measures on non-native Chinese mitten crab (*Eriocheir sinensis*) (see García de Lomas et al. 2009). Between 7 Oct. 2010 and 10 Mar. 2015, we have compiled in the same river section 9 new records, via angler captures, corresponding to 12 individuals (Table S1). These new records provide evidence on the survival and establishment of an emerging population in this locality (Seville city, Guadalquivir dock; Figure 1). Specimens of *A. facetus* captured coincide with identification characters reported by Doadrio (2001) and FernándezDelgado et al. (2014); the dorsal fin is composed by 15–17 hard and 9–11 soft rays, the anal fin shows 5–6 hard rays and the caudal fin is rounded with a dark spot at the base. Some of these

captures corresponded to reproductive individuals (> 20 cm) building nests in shallow areas (PS, *pers. obs.*). The chameleon cichlid is a highly valued species by aquarist, lacking any sporting value.

North American black bullhead – Ameiurus melas (Rafinesque, 1820)

The species was first detected in the lower part of the Guadalquivir River basin in 2007 (García de Lomas et al. 2009) and subsequently it has dispersed both upstream and downstream from this location (FernándezDelgado et al. 2014). We report data from two new localities (Table S1). The first locality corresponds to the Viar River, a right bank tributary of the Guadalquivir (Figure 1) where the species first appeared in the spring of 2009 via angler captures. This species is currently reproducing in this location and has been observed performing parental care behaviours (*i.e.* guarding; PS, *pers. obs.*).

The second sub-basin corresponds to the Doñana National Park. On the 26th of July 2016 we observed a large shoal of bullhead individuals in the “La Rocina”, a shallow freshwater inland marsh (Figures 1, 3). During the sighting we were able to capture by hand some specimens for identification purposes and we estimate, based on field observation, abundance around several thousands of individuals (Figure 3).

Specimens of *A. melas* collected in the Guadalquivir basin coincide with identification reported by Elvira (1984) and Cucherousset et al. (2006): D I/6, P I/7, V 8, A 19–21 and C 19–20. Its presence in Doñana has been known since 2010 (MA Bravo, *pers. comm.*), however, during the last few years the species is spreading throughout the lower sections of the basin (FernándezDelgado et al. 2014), where environmental conditions are most appropriate for the species (*i.e.* lentic or low-flow habitats with a mud substrate).

European catfish – Silurus glanis (Linnaeus, 1758)

This species, the largest European freshwater fish, reaches sizes up to 5 meters in length and more than 100 kilograms in weight. In the Iberian Peninsula this species was detected for the first time in 1974 in the Ebro River (Doadrio 2001). It is considered a serious threat to aquatic ecosystems (Copp et al. 2009). The first record of this species

in the Guadalquivir was in 2011 in Iznájar reservoir, the largest in the basin (Moreno-Valcárcel et al. 2013). We report a new locality located 250 km downstream from Iznájar reservoir, in a lower stretch of a Guadalquivir right bank tributary (Rivera de Huelva; Figure 1). This new record, via angler captures in February 2015, corresponds to 3 adult individuals. Specimens were identified following Kobayakawa (1989) and Kottelat and Freyhof (2007). The weights of these specimens ranged from 3 to 8 kg. Until now, there was no evidence of the European catfish presence outside the Iznájar reservoir.

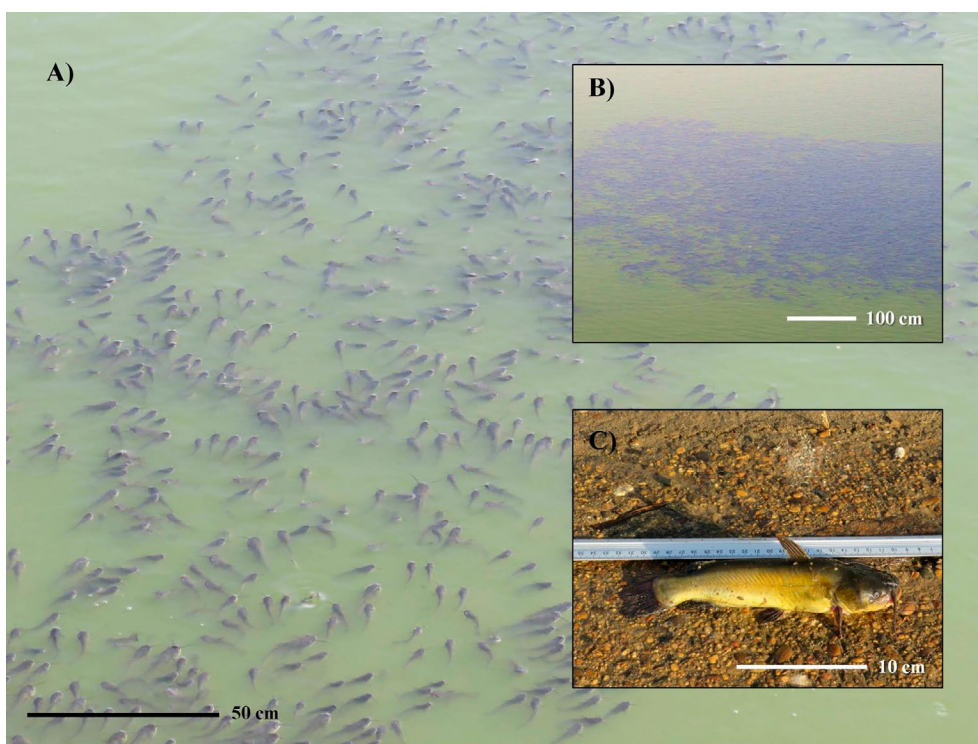
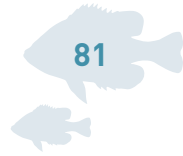


Figure 3. Near (a) and distant (b) views of a large group (> 2000) of young North American black bullheads in Doñana National Park (SW Spain). Many adults (> 20 cm length) were also found in the group (c).



Concluding remarks

The information collected in this study provides evidence on the reproduction of three non-native species in the Guadalquivir River basin (*Phoxinus* spp., Chameleon cichlid and North American black bullhead). Therefore, the establishment of these species in different sections of the basin is highly likely. The presence of these invasive species (Leunda 2010) in different sections of the basin can be confirmed and their distribution ranges will probably increase in the next few years. Regardless of the taxonomy of *Phoxinus* specimens collected in this study, this genus has a high invasive potential in the Iberian Peninsula (see Clavero 2011). For this reason, the knowledge of this population by researchers and wildlife managers can help to avoid its expansion because there is currently only one population located in a small tributary. At the same time, genetic analyses and new samplings of this population are necessary to set the taxonomy of this species. European catfish have been detected many kilometres downstream from the first recorded site, and there are no records between the two areas, so their presence there is likely to be due to new introductions. This species constitute a great threat to native fish fauna due to its voracity and wide dietary range, comprising up to 53 freshwater fish species reported by Copp et al. 2009. It is therefore critical to increase sampling effort, to improve our knowledge about the invasion degree by this species of the Guadalquivir basin.

Acknowledgements

This study was supported by the Junta de Andalucía, Convocatoria de Proyectos de Excelencia (P07-RNM-03309) and was carried out at the Centro Internacional de Estudios y Convenciones Ecológicas y Medioambientales (CIECEM) of the University of Huelva. We are grateful to two anonymous reviewers who made constructive comments improving this work.

Supplementary material

Table S1. Record list collected for each species including latitude and longitude in decimal degrees (coordinates), number of specimens (N), river name and data source.

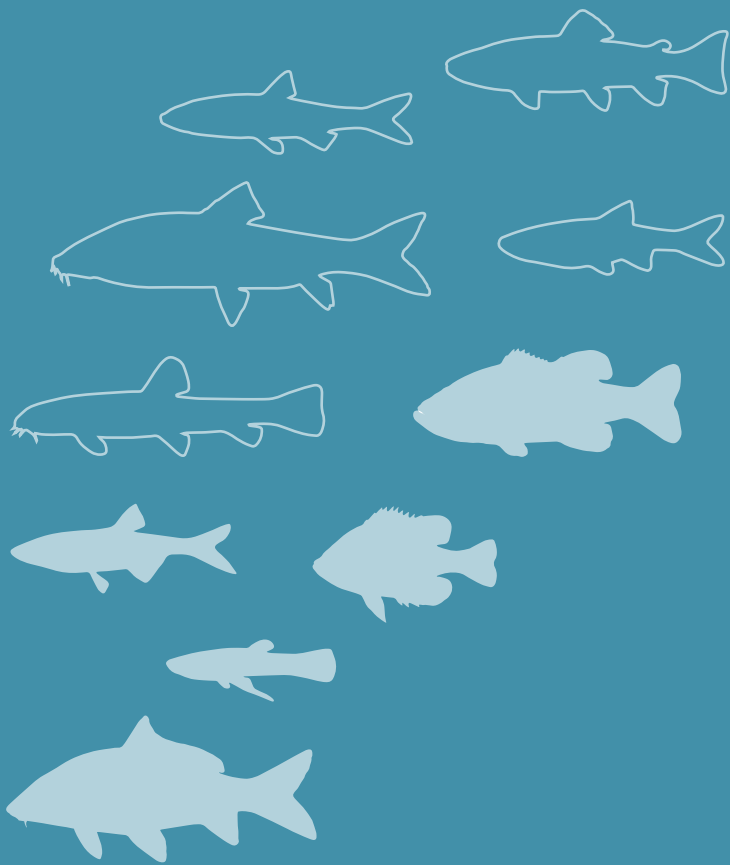
This material is available as part of online article from:

http://www.reabic.net/journals/bir/2019/Supplements/BIR_2019_Saez-Gomez_Prenda_Table_S1.xlsx

Table S1. Record list collected for each species including latitude and longitude in decimal degrees (coordinates), number of specimens (N), river name and data source.

Species	Date	Location name	Latitude	Longitude	Survey date
<i>Phoxinus sp.</i>	05/01/2008	Guadalbarbo	38.180037°	-4,888,418	05/01/2008
	07/10/2010	Guadalquivir	37.398269°	-6.003951°	07/10/2010
	08/17/2010	Guadalquivir	37.413106°	-5.989803°	08/17/2010
	07/20/2011	Guadalquivir	37.423448°	-5.991000°	07/20/2011
	04/16/2012	Guadalquivir	37.410142°	-5.991528°	4/16/2012
<i>Australoheros facetus</i>	05/12/2012	Guadalquivir	37.397349°	-6.004918°	05/12/2012
	06/22/2013	Guadalquivir	37.387417°	-6.004745°	06/22/2013
	05/28/2015	Guadalquivir	37.389957°	-6.006921°	05/28/2015
	09/16/2015	Guadalquivir	37.386798°	-6.002287°	09/16/2015
	10/03/2015	Guadalquivir	37.387646°	-6.003338°	10/03/2015
<i>Ameiurus melas</i>	06/14/2009	Viar	37.683727°	-5.826569°	06/14/2009
	07/26/2016	Rocina	37.125855°	-6.493750°	07/26/2016
<i>Silurus glanis</i>	February 2015	Rivera de Huelva	37.559697°	-6.050213°	February 2015

<i>Phoxinus spp.</i>	<i>Australoheros facetus</i>	<i>Ameiurus melas</i>	<i>Silurus glanis</i>	Source
3	0	0	0	Field sampling
0	4	0	0	Fishing forum website
0	1	0	0	Fishing forum website
0	1	0	0	Fishing forum website
0	1	0	0	YouTube
0	1	0	0	Facebook
0	1	0	0	Fishing forum website
0	1	0	0	Facebook
0	1	0	0	Facebook
0	1	0	0	Facebook
0	0	>20	0	Fishing forum website
0	0	>2000	0	Author's sighting
0	0	0	3	Fishing forum website



CHAPTERS IV AND V: ARTICLES

Los artículos que forman parte de los capítulos IV y V, debido a restricciones relativas a derechos de autor, han sido retirados de la tesis. En sustitución de éstos, ofrecemos la siguiente información: referencia bibliográfica, enlace al artículo si estuviera publicado y resumen.

- Sáez-Gómez, P., Ramos-Merchante, A., & Prenda, J. (2020). Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses. In *Aquatic Ecology* (Vol. 54, Issue 3, pp. 869–887). Springer Science and Business Media LLC. <https://doi.org/10.1007/s10452-020-09783-9>

Enlace al texto completo: <https://doi.org/10.1007/s10452-020-09783-9>

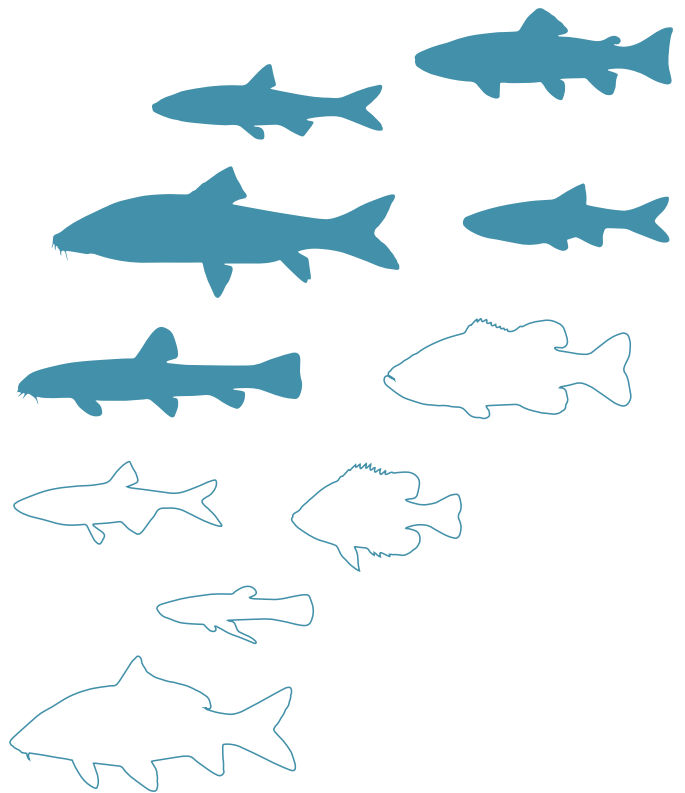
Resumen:

Fish–habitat relationships are a key element for conservation and management strategies, especially in highly disturbed areas where fish communities are subjected to many human pressures. In this regard, multiscale studies help to improve the knowledge of the spatial components and identify local (e.g. water width) and regional (e.g. elevation) key variables in species distribution. We examined local and regional requirements to study freshwater fish assemblage and occurrence at 216 locations in a highly disturbed basin, the Guadalquivir River Basin (S Spain). Fifteen environmental variables were considered at local scale and twenty at regional level. A total of eighteen species were captured during field sampling. The global prevalence for introduced species was 25%, which can be considered a high value. The most extended introduced species were eastern mosquitofish (*Gambusia holbrooki*) and pumpkinseed (*Lepomis gibbosus*), with around 10% prevalence. Regional and local scales showed different relevance according to the level-study approach (community or species). At the community level, the local, regional and shared components revealed similar influence on the fish assemblage, while at individual species level the local component was the main factor to explain most of fish occurrences. Moreover, variables' interaction was scarcely selected and almost no introduced species distribution was affected by the interaction of any variable. Our results highlight the poor conservation status of the native fish fauna of the Guadalquivir River Basin as well as the importance of analyzing fish–habitat relationships at different scales and approach. These results provide useful information to assess and design conservation strategies in Mediterranean-type basin.

- Sáez-Gómez P, Ramos-Merchante A, Prenda J. The environmental asymmetry in a large Mediterranean basin determines the spatial pattern of freshwater fish local extinctions vs. introductions of exotic species. Submitted to *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Resumen:

Long-term data provide an excellent tool to assess changes in species distribution. Historical data sources are an important source of data prior to most current impacts, yet they have rarely been used in ecology. We use historical sources and field sampling to analyze the patterns extinctions of native species as well as the establishment of invasive species in a highly disturbed Mediterranean basin (Guadalquivir, Spain). We compiled 472 historical freshwater fish records and data from 285 sampling points to characterize historical and current native and non-native species distribution. Through the combined analysis of species records and 19 environmental variables, we explore the proximal causes of these extinction/colonization processes. The number of extinct species showed an asymmetric (inverse) pattern with respect to the basin margins, mainly caused by the historical distribution of native species and their life history. The invasion of non-native species showed a downstream-upstream pattern on both margins related with the presence of reservoirs and human activities (disturbance). The high number of reservoirs in the right margin promoted the establishment of non-native species in this area. Sites with the lowest level of disturbance (located in right margin) were those that presented a higher range of current distribution of both exotic and native species, indicating that the poor environmental quality of the left margin hinders the establishment of invasive species. The marked differences in human pressures between the margins and sectors of the basin (longitudinal gradient) suggest that they are cause for the asymmetry found in the loss/gain of species. This work highlights the importance of historical ecology to understand the processes that have produced current changes in fish communities in Mediterranean environments, as well as, provide relevant information for conservation strategies.



Chapter IV.

Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses

Citation:

Sález-Gómez P, Ramos-Merchante A, Prenda J. (2020). Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses. *Aquatic Ecology*, 54(3): 869-887.

<https://link.springer.com/article/10.1007/s10452-020-09783-9>

Received: 30 November 2019

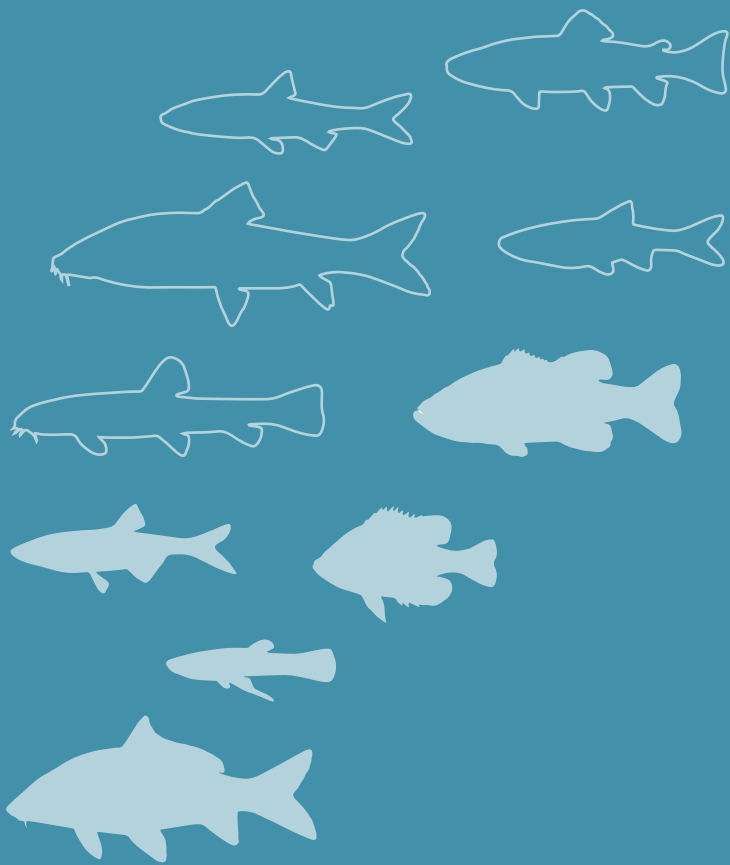
Accepted: 3 July 2020

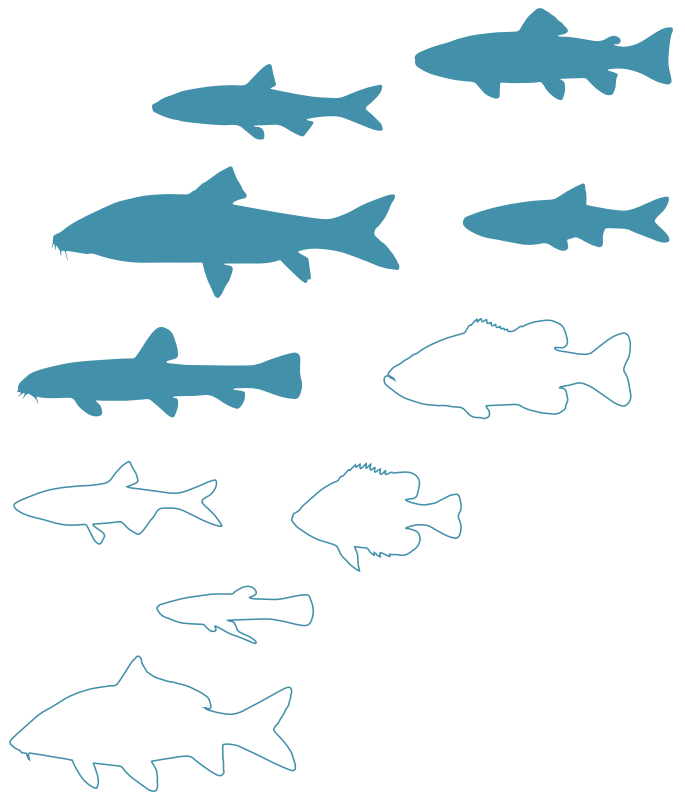
Published online: 16 July 2020

Copyright: © Sález-Gómez and Prenda

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS.



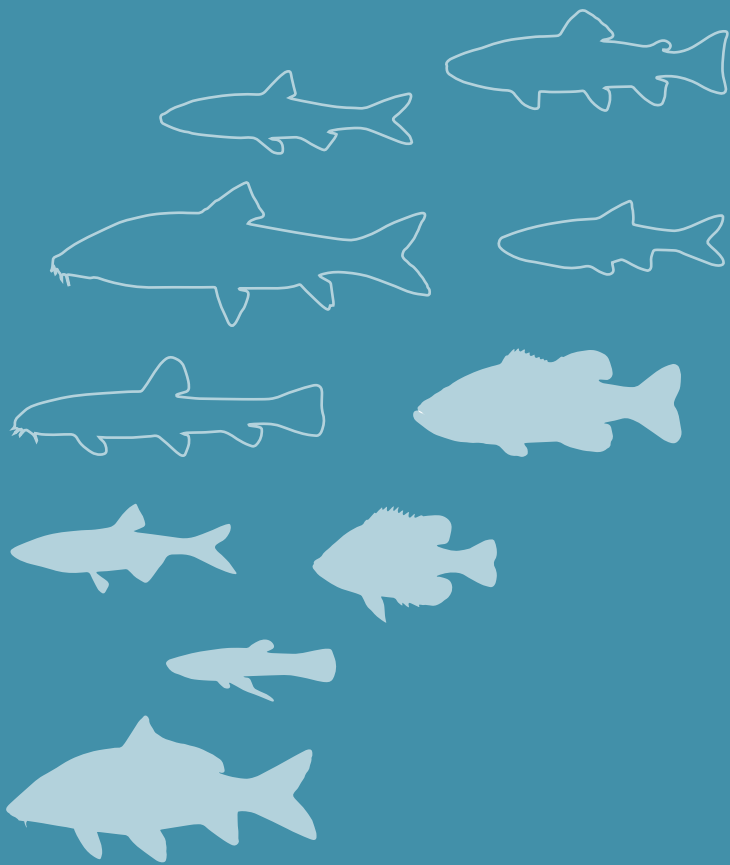


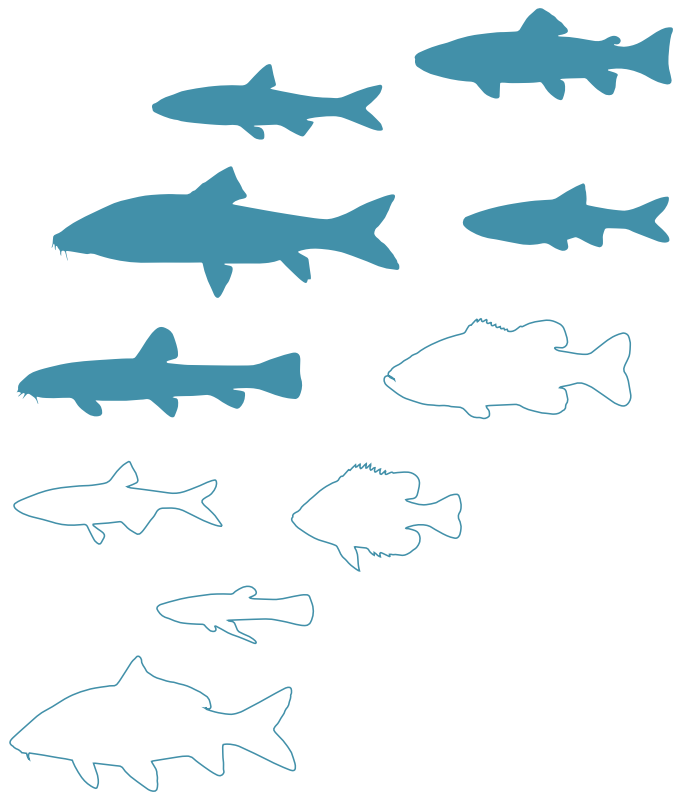
Chapter V.

**The environmental asymmetry
in a large mediterranean basin
determines the spatial pattern of
freshwater fish local extinctions vs.
introductions of exotic species**

Citation:

Sález-Gómez P, Ramos-Merchante A, Prenda J. The environmental asymmetry in a large Mediterranean basin determines the spatial pattern of freshwater fish local extinctions vs. introductions of exotic species. Submitted to *Aquatic Conservation: Marine and Freshwater Ecosystems*.





Discusión general

Discusión general

Los documentos que integran esta Tesis Doctoral abordan, utilizando la cuenca del Guadalquivir como sistema de estudio, la problemática de conservación en la que se encuentran los ríos Mediterráneos. En la actual situación de crisis ambiental, con una incesante demanda de recursos naturales, los medios acuáticos son uno de los ecosistemas que más rápidamente están sufriendo estos efectos. La incesante demanda de agua para usos agrícolas o ganaderos está limitando la cantidad y calidad de las mismas, poniendo en serio peligro las comunidades de peces que albergan. Por otro lado, la globalización está fomentando una rápida homogenización de los ecosistemas facilitando el establecimiento y expansión de especies exóticas. Los peces continentales han constituido tradicionalmente uno de los grupos de vertebrados que menos atención ha suscitado entre la comunidad científica. Por estos motivos es indispensable conocer los impactos y los mecanismos de respuesta a los que están sometidos los peces continentales Mediterráneos.

Los cambios en la cuenca del Guadalquivir debidos a las actividades humanas durante el último siglo han modificado en gran medida las características ecológicas de las masas de agua y, consecuentemente, de sus comunidades de peces (Granado-Lorencio 1991, González-Ortegón et al. 2010, Hermosín et al. 2013). Durante el siglo XX se construyeron alrededor de 30 grandes presas y en gran medida como consecuencia de ello la superficie de regadío se incrementó en aproximadamente 7000 km², el 83% de la superficie regada total actual (Confederación Hidrográfica del Guadalquivir 2015a). Estas transformaciones del hábitat fluvial, han promovido la propagación de especies exóticas (Clavero et al. 2004) y el declive de una gran proporción de especies nativas, particularmente las migradoras (Granado-Lorencio 1991, Nicola et al. 1996, Clavero & Hermoso 2011). Al mismo tiempo, la intensificación de la agricultura ha incrementado notablemente el vertido de agroquímicos (fertilizantes y pesticidas), así como de grandes cantidades de sólidos en suspensión, que han incrementado considerablemente la turbiedad del agua, especialmente en los tramos bajos de la cuenca (González-Ortegón et al. 2010, Hermosín et al. 2013).

En esta porción terminal del río la navegación ha provocado fuertes cambios en el cauce principal para reducir la distancia del puerto de Sevilla al mar en más de 70 km (Menanteau 1982, 1984). Esto ha aislado el cauce principal de las áreas circundantes y ha permitido la penetración del agua de mar aguas arriba, junto con diferentes especies marinas (Granado-Lorencio 1991, Arias-García 2010).

Biodiversidad de los peces del Guadalquivir

Los peces ibéricos de agua dulce se caracterizan taxonómicamente por pertenecer a un número reducido de familias, pero con un alto grado de endemismo (Doadrio 2001). Esto debe ser consecuencia tanto del aislamiento geográfico, como de las estresantes condiciones ecológicas derivadas del régimen hidrológico del clima mediterráneo (Almaça 1976, Doadrio 2001). Este se caracteriza por inundaciones, eventualmente catastróficas, en otoño-invierno y por sequías de verano que dejan sin agua muchos tramos de la red de drenaje durante parte de la primavera, el verano y principios de otoño (Gasith & Resh 1999). La ictiofauna autóctona de la cuenca del Guadalquivir está dominada, como en la mayoría de las cuencas ibéricas, por la familia Cyprinidae, bien adaptada a las condiciones ambientales extremas del clima mediterráneo.

La cuenca del Guadalquivir presenta (o ha presentado) una de las comunidades de peces más ricas del Mediterráneo considerándose un 'hotspot' de biodiversidad en el Mediterráneo (Smith & Darwall 2006). El 31,1% de todas las especies ibéricas nativas habitan o han habitado recientemente en la cuenca del río Guadalquivir y la riqueza de especies por unidad de superficie encontrada es similar a otras grandes cuencas ibéricas. Sin embargo, pocas estrategias de conservación se han llevado a cabo para intentar poner freno al declive que sufre su ictiofauna. Los resultados de esta tesis revelan que en la actualidad la riqueza de especies exóticas iguala a la de nativas.

La riqueza de la comunidad de peces de los ríos tiende a aumentar desde las cabeceras hasta las secciones más bajas de las cuencas fluviales (Sheldon 1968, Horwitz 1978, Reeves et al. 1998). Pero este patrón general de biodiversidad se encuentra distorsionado en la cuenca del Guadalquivir, muy probablemente en respuesta a la mala calidad del hábitat en las secciones bajas del río, como se ha observado en otras cuencas con alta densidad de población humana (Aparicio et al. 2000, Corbacho & Sánchez

2001). Los tramos aguas abajo (generalmente de orden 4 y superiores) soportan un alto nivel de contaminación, una alta prevalencia de especies exóticas, importantes perturbaciones físicas del hábitat, entre otros impactos, que impiden que una fracción significativa de su fauna potencial se establezca en ellos (Hughes & Gammon 1987, Corbacho & Sánchez 2001).

La correlación positiva observada en la cuenca del Guadalquivir entre la riqueza de peces nativos y la de exóticos señala que los factores dominantes que determinan la diversidad nativa (p. ej., competencia, régimen de perturbaciones, disponibilidad de recursos, etc.) son los mismos y actúan en el mismo sentido que los que influyen en las exóticas (Huston 1994, Levine & D'Antonio 1999). Es decir, las zonas con altos valores de riqueza nativa, con una alta calidad del hábitat para un gran número de especies, son más vulnerables a las invasiones que aquellos lugares con baja diversidad. Esto contrasta marcadamente con las teorías ecológicas clásicas que sostienen que las comunidades diversas resisten las invasiones de especies exóticas mejor que las más pobres (ver McArthur 1970, 1972, Case 1991).

La diversidad de peces (nativos y exóticos) está en su mayoría restringida a determinados cauces de la margen derecha de la cuenca (Sierra Morena). Las especies nativas mostraron una distribución muy restringida (prevalencia inferior al 23% de los puntos muestreados), con la excepción del barbo (*Luciobarbus sclateri*) que es la especie más extendida (prevalencia del 58,6%) y abundante ya que representó más del 50% del total de peces capturados durante los muestreos de campo. Los ríos que drenan la margen derecha de la cuenca del Guadalquivir contienen mayor riqueza y menor número de localidades sin peces, tanto de especies autóctonas como exóticas que los ríos de la margen izquierda. Estos últimos drenan tierras agrícolas en su mayoría llanas y altamente productivas ocupadas por cultivos intensivos, áreas industriales y asentamientos humanos densamente poblados, mientras que los que drenan la margen derecha discurren por zonas montañosas cubiertas por bosques, con pocas perturbaciones humanas y agricultura y ganadería extensivas (Rodríguez Díaz et al. 2007, Confederación Hidrográfica del Guadalquivir 2015a).

Especies introducidas

La introducción de especies exóticas es un problema general que amenaza gravemente a la fauna autóctona a nivel mundial. También está provocando la homogeneización de la biodiversidad acuática continental, un problema que se extiende en gran medida a todas las cuencas hidrográficas ibéricas (Clavero et al. 2004, Hermoso et al. 2008, Rahel 2002).

Los resultados obtenidos en esta tesis muestran que la biodiversidad exótica está relacionada con los embalses. Estas construcciones humanas proporcionan hábitats lénticos estables, pero impredecibles, donde las especies introducidas pueden prosperar; actuando como centros de dispersión o hábitats fuente *sensu* Pulliam (1988). Una vez establecidos en el nuevo ecosistema, los peces exóticos eliminan eficientemente a los nativos, desplazándolos competitivamente o depredando sobre ellos.

Sin embalses, muchas especies de peces exóticos no sobrevivirían en los ríos mediterráneos o lo harían en condiciones muy precarias de abundancia y amplitud de distribución (Martínez et al. 2004). Las diferencias en el orden de los cursos de agua usados por especies nativas y exóticas se deben principalmente a dos factores. Por un lado, los cursos de agua de bajo orden suelen estar aislados, en áreas de mayor altitud con escasa transformación del hábitat, en muchos casos incluidos dentro de áreas protegidas (Saunders 2002). Por otro lado, los tramos medios y bajos de los ríos tienen mejores condiciones para el asentamiento de especies exóticas, la mayoría de ecosistemas lénticos (aguas más lentas y un número acumulado de embalses mayor, lo que facilita la dispersión de los peces exóticos río abajo) (Clavero et al. 2004).

Muchas especies exóticas se han introducido y han proliferado en la cuenca del Guadalquivir durante las últimas décadas: 14 (70% del total) y están bien implantadas en la cuenca y/o en proceso de expansión; 4 han colonizado la cuenca en los últimos diez años: 1) el alburno (*Alburnus alburnus*) (Vinyoles et al. 2007) y 2) el pez gato (*Ameiurus melas*) (García de Lomas et al. 2009) son frecuentes en los tramos medio y bajo, 3) el piscardo (*Phoxinus spp.*) se encuentra en un solo río, el chanchito (*Cichlasoma facetum*) se encuentra en los cursos de agua cercanos a la ciudad de Sevilla y (4) el siluro (*Silurus glanis*), la última especie detectada en la cuenca (Moreno-Valcárcel et al. 2013), lo que supone una grave amenaza para la fauna regional (Copp et al. 2009). La preferencia de este último por aguas lentas puede favorecer su proliferación en los tramos más bajos de

la cuenca, incluido el Parque Nacional de Doñana y zonas aledañas con graves amenazas para este singular ecosistema.

La información recogida en esta tesis aporta evidencias sobre la reproducción en la cuenca del Guadalquivir de tres especies alóctonas con elevado potencial invasor e (*Phoxinus* spp., *Australoheros facetum* y *Ameiurus melas*). Por lo tanto, es muy probable que se encuentren establecidas en el Guadalquivir y es muy probable que sus rangos de distribución aumenten en los próximos años. Independientemente de la taxonomía de los ejemplares de *Phoxinus* recogidos en este estudio, este género tiene un alto potencial invasor en la Península Ibérica (ver Clavero 2011). Por esta razón, el conocimiento de esta población por parte de investigadores y gestores ambientales puede ayudar a evitar su expansión debido a que actualmente solo se conoce una población ubicada en un pequeño afluente de la margen derecha del Guadalquivir. Al mismo tiempo, son necesarios análisis genéticos y nuevos muestreos de esta población para establecer definitivamente la taxonomía de esta especie. *Silurus glanis* se ha detectado muchos kilómetros río abajo del primer sitio en que fue observada y no hay registros entre las dos áreas, por lo que es probable que su presencia se deba a nuevas introducciones. Por otro lado la ausencia de muestreos realizados por la administración en la zona de expansión cercana al lugar donde fue detectada por primera vez limita el conocimiento sobre su grado de expansión. Esta especie constituye una gran amenaza para la ictiofauna nativa de esta cuenca mediterránea debido a su voracidad y amplio espectro trófico, que comprende hasta 53 especies de peces de agua dulce (Copp et al. 2009). Por tanto, es fundamental aumentar el esfuerzo de muestreo, para mejorar nuestro conocimiento sobre el grado de invasión de esta especie en la cuenca del Guadalquivir.

Modelos de distribución de las comunidades de peces de la cuenca del Guadalquivir

Determinar cómo los factores bióticos y abióticos condicionan la presencia de cada especie así como la estructura de las comunidades es una información básica para implementar estrategias efectivas de conservación. Esta tesis contribuye a una mejor comprensión de cómo las variables ambientales locales y regionales, así como el enfoque del estudio (comunidad o especie) pueden afectar de diferente manera a la distribución de los peces de una cuenca sometida a fuertes presiones antrópicas.

Los factores regionales y locales revelaron una marcada zonación longitudinal donde las asociaciones de especies de peces estaban fuertemente vinculadas a un gradiente longitudinal de perturbación. Esto determinó una fuerte segregación entre localidades más perturbadas y menos perturbadas y, en consecuencia, altas correlaciones con variables antropogénicas y naturales. Por un lado, los sitios de cabecera generalmente ubicados en áreas protegidas y por lo tanto con menos presión humana estaban dominados por especies nativas. En los sitios más perturbados de los tramos inferiores, con alta densidad de población humana y actividad humana intensa, urbana/industrial, agrícola, las especies más prevalentes fueron las no nativas. Las características biológicas de estas especies, típicamente de ambientes lénticos (Corbacho & Sánchez 2001, Carol et al. 2006), generalmente han limitado su rango de distribución a los tramos inferiores de la cuenca. En general, la composición de la comunidad de peces nativos fluctuó desde una sola especie con altos requerimientos de hábitat (*S. trutta*), seguida por conjuntos de especies dominados por pequeños cipriniformes, como *S. alburnoides*, *C. paludica* e *I. lemmingii*, hasta asociaciones que incluyen grandes ciprínidos, generalmente más resistentes a las perturbaciones (Ferreira et al. 2007) como *L. sclateri* y *P. willkommii*. Por otro lado, la comunidad de especies introducidas, por lo general con mayor rango de tolerancia a las perturbaciones (p.ej, *C. carpio*, *M. salmoides*, *L. gibbosus*, *G. holbrooki*) se ubicó casi exclusivamente en los tramos bajos de la cuenca.

Las características del hábitat a escala local también definieron un gradiente longitudinal. En este sentido, las características físico-químicas del agua jugaron un papel importante en la distribución de las especies. Las especies con altos requerimientos de hábitat (p.ej, *S. trutta*, *S. pyrenaicus*) (Corbacho & Sánchez 2001, Ferreira et al. 2007) habitaron tramos con alta velocidad de la corriente y alta concentración de oxígeno disuelto y bajos valores de conductividad, turbidez (es decir, baja carga de sólidos suspendidos) y de concentración de fósforo reactivo soluble (Oliveira et al. 2012, Ramos-Merchante & Prenda 2018). Por lo tanto, este patrón estuvo estrechamente relacionado con los efectos regionales, ya que las cabeceras se caracterizan, en general, por una alta calidad del agua (Vila-Gispert 2002, Oliveira et al. 2012, Ramos-Merchante & Prenda 2018). Estos resultados están en concordancia con el patrón representado por el análisis de partición de la varianza, ya que no se encontraron grandes diferencias entre las contribuciones regionales, locales y compartidas y son consistentes con lo observado en otras cuencas perturbadas ibéricas (fuertes interacciones entre

contribuciones locales y regionales) (Magalhães et al. 2002, Ferreira et al. 2007). La baja prevalencia de especies nativas en los tramos inferiores de la cuenca revela una fuerte alteración en la composición de la asociación de especies de peces a lo largo de los gradientes longitudinales (Vila-Gispert et al. 2002, Ramos-Merchante & Prenda 2018). Nuestros resultados, de acuerdo con nuestra hipótesis inicial, también concuerdan con los obtenidos en varias cuencas mediterráneas igualmente perturbadas, como la del Guadiana u otras pequeñas cuencas del norte y sur ibéricos (Corbacho & Sánchez 2001, Magalhães et al. 2002, Vila-Gispert 2002).

Modelos de especies individuales

La alta precisión de la mayoría de los modelos de regresión logística ($AUC \geq 0,8$) se debió al uso de un buen conjunto de variables para explicar la presencia de especies. Sin embargo, la precisión varió entre especies. En general, los modelos para especies no nativas obtuvieron una mejor explicación sobre su distribución que los autóctonos. La desequilibrada proporción entre presencia y ausencia (21,4% de sitios sin peces) puede afectar a la precisión y el poder predictivo de los modelos de varias especies. Los modelos logísticos para *I. lemmingii* y *M. salmoides* carecieron de poder predictivo debido al pequeño número de localidades donde estuvieron presentes (6 y 8 respectivamente). Además, algunas medidas específicas del hábitat (p.ej., sustrato, macrófitos) pueden mejorar, casi parcialmente, los modelos para estas especies (Levin 1994, Bond & Lake 2003). Finalmente, las interacciones entre especies (Guisan & Zimmermann 2000, Clavero et al. 2013) y factores históricos como el aislamiento producido por la formación y evolución de las cuencas (Carmona et al. 1999, Williams et al. 2003) también pueden condicionar los resultados.

En promedio, el número de factores seleccionados para cada especie varió entre escalas (un promedio de 3,1 vs. 1,6 para las variables regionales y locales respectivamente), por lo que las variables regionales mostraron una mayor relevancia que las locales. El área de drenaje fue el factor regional más influyente con correlaciones positivas con especies nativas y no nativas. Por tanto, un gran tamaño del área de drenaje favorece la presencia de muchas de las especies que habitan en la cuenca del Guadalquivir. Las variables antrópicas, como la densidad de población humana, mostraron efectos negativos en la ocurrencia de la mayoría de las especies nativas, pero no se observó ningún efecto

en el caso de las no nativas. De la misma manera la agricultura intensiva se relacionó negativamente con *S. alburnoides*, *M. salmoides*, *L. gibbosus* y *A. alburnus*. El área aguas arriba de los embalses favoreció la presencia de algunas especies no nativas como *L. gibbosus* y *G. holbrooki* y la ausencia de algunas nativas (*L. sclateri*, *S. alburnoides*), como lo describen otros autores (Clavero et al. 2004, Carol et al. 2006, Clavero et al. 2013). En cuanto a los factores locales, la mayoría de las especies no nativas habitaron ríos anchos, mientras que la mayoría de las especies nativas evitaron sitios con baja concentración de oxígeno disuelto. Las características fisicoquímicas y la morfología del cauce también juegan un papel importante en la presencia de especies. La anchura del cauce estuvo relacionada positivamente con la presencia de algunas especies lénticas introducidas (*L. gibbosus*, *C. carpio* y *A. alburnus*). Las concentraciones de oxígeno disuelto y fósforo y la temperatura del agua también se correlacionaron significativamente con la presencia de algunas especies de peces, de acuerdo con sus estrategias de vida y requisitos de hábitat.

Las especies cuya distribución está determinada principalmente por factores locales (p. ej., *I. lemmingii*) pueden tener una distribución irregular en la cuenca y, por lo tanto, ser más vulnerables a los impactos locales; sin embargo, las medidas de conservación suelen ser más eficaces que las que se rigen por factores regionales (p. ej. *S. pyrenaicus*) afectadas principalmente por perturbaciones a gran escala como el cambio climático o la fragmentación del hábitat. Las fuertes transformaciones en la cuenca debidas a los grandes cambios en las prácticas agrícolas y las infraestructuras hidráulicas durante las últimas décadas (Rodríguez Díaz et al. 2007, Hermosin et al. 2013) probablemente hayan determinado la extinción de algunas especies (p.ej., especies migradoras y *Gasterosteus aculeatus*) (Hernando 1975, Granado-Lorencio & Hernando 2001, Arias-García 2010) y la marcada reducción en el rango de distribución de otras especies hasta hace poco abundantes (*A. anguilla*, *I. lemmingii*).

Efectos regionales y locales en la presencia de especies

Los factores regionales, locales y los compartidos mostraron efectos significativos en la distribución de los peces en la cuenca del río Guadalquivir, aunque hubo una fuerte interacción entre escalas y la variación total explicada por estos componentes varió ampliamente entre especies. El componente compartido fue el que más influyó en la presencia de peces. Además, no se explicó la distribución de especies basándose

principalmente en atributos locales, por lo que algunas de estas variables pueden estar estructuradas regionalmente. Esta superposición puede deberse a las implicaciones regionales de algunos de los descriptores locales. Los estudios futuros deberían considerar otros factores ambientales, así como las variaciones ambientales interanuales para mejorar el conocimiento de las relaciones peces-hábitat (Lohr & Fausch 1997, Magalhães et al. 2002, Yoon et al. 2011). Los resultados son consistentes con nuestro enfoque inicial donde planteamos la hipótesis de que las variables locales y regionales afectan a las especies de manera diferente.

Patrones espaciales de extinción e invasión de la ictiofauna

La homogeneización biótica es un patrón ecológico no aleatorio en el que las invasiones de especies exóticas y extinciones de nativas tienen un papel determinante (Clavero & García-Berthou 2006, Leprieur et al. 2009, Leprieur et al. 2008). Tanto los procesos de colonización como las extinciones dependen de las características del hábitat y de los niveles de perturbación (Leprieur et al. 2009, Villéger et al. 2011). En el suroeste de Europa, las especies de peces no nativas reducen las diferencias en la composición de la comunidad de peces entre cuencas, promoviendo una elevada homogeneización (Leprieur et al. 2008, Villéger et al. 2011). Desde mediados del siglo XIX hasta el siglo XXI, la comunidad de peces de agua dulce del Guadalquivir ha sufrido fuertes cambios en su distribución y abundancia. Los resultados obtenidos en esta tesis revelan patrones específicos de extinción de especies nativas e invasión de especies no nativas. El número de especies perdidas mostró un patrón inverso entre los sectores de ambas márgenes. Los sectores del margen izquierdo indicaron un proceso de extinción muy pronunciado desde los sectores de cabecera hacia los de las partes bajas de la cuenca. Sin embargo, las diferencias en las especies perdidas de la margen derecha fueron muy leves, independientemente del gradiente altitudinal. Los procesos de invasión de especies no nativas mostraron un patrón similar (aguas abajo - aguas arriba) entre márgenes, aunque el número de especies no nativas ganadas (es decir, establecidas) difirió significativamente entre márgenes (mayor en el margen derecho), por lo que se observaron dos patrones diferentes (longitudinal y entre márgenes). Probablemente el patrón de extinción de especies nativas responda a las extinciones de las poblaciones de *S. trutta* y *A. anguilla* muy condicionados por su historia natural (Clavero & Hermoso 2015, Clavero et al. 2017)

y con una distribución histórica desigual a lo largo de la cuenca (Ramos-Merchante et al. 2021). La asimetría existente en la distribución de los embalses y la calidad de las aguas puede ser la principal causa a las diferencias encontradas en los procesos de colonización de especies no nativas (mayor en la margen derecha).

Numerosos estudios han puesto de manifiesto el papel clave que juegan los embalses en el establecimiento de estas especies (Corbacho & Sánchez 2001, Clavero et al. 2004, Clavero & García-Berthou 2006, Clavero & Hermoso 2011, Hermoso et al. 2011). Además, el elevado número de embalses favorece el aislamiento de muchos tramos del río, limitando los procesos de recolonización por parte de especies autóctonas (Clavero et al. 2004, Hermoso et al. 2011). La mayoría de las especies no nativas son típicamente de ambientes lénticos, por lo que los tramos bajos de la cuenca tienen un hábitat más adecuado para ellas (Clavero et al. 2004, Corbacho & Sánchez 2001). Por otro lado, el margen derecho tiene menos presión antrópica que el izquierdo (Ramos-Merchante & Prenda 2018). Los resultados de esta tesis muestran que los ríos que drenan la margen derecha del Guadalquivir tienen una mayor presencia de peces tanto autóctonos como exóticos que los ríos de la margen izquierda. Además, se detectó una fuerte distribución asimétrica de patrones naturales y presiones humanas analizadas. Los ríos del margen izquierdo drenan tierras agrícolas en gran parte planas y altamente productivas ocupadas por cultivos intensivos, zonas industriales y asentamientos humanos densamente poblados (es decir, perturbaciones humanas), mientras que los que drenan el margen derecho discurren por áreas montañosas cubiertas por bosques naturales, con poca actividad humana (Gasith & Resh 1999, Confederación Hidrográfica del Guadalquivir 2015). Estos datos indican que el estado ecológico de las masas de agua del margen izquierdo podría ser tan pobre que dificulta el establecimiento de especies no nativas, como sugieren estudios previos sobre la calidad del hábitat (Ramos-Merchante & Prenda 2018).

Estado de conservación

El estado de conservación de la ictiofauna de la cuenca del Guadalquivir es actualmente muy pobre. Más de la mitad de las especies autóctonas registradas en la cuenca están catalogadas en alguna categoría de amenaza, tanto a nivel nacional como internacional.

El alto grado de endemidad de los peces de las cuencas de los ríos mediterráneos, como el Guadalquivir, demuestra que esta fauna, por término medio, presenta poblaciones raras y aisladas (p. ej., *Iberochondrostoma oretanum*, *Anaecypris hispanica*, *Squalius palaciosi* y *Aphanius baeticus*) (Almança 1976, Doadrio 2001). Además, algunas de estas especies muestran una baja tolerancia a las perturbaciones antrópicas, por lo que su riesgo de extinción aumenta considerablemente por efecto de las presiones humanas (Hermoso et al. 2008b, Blanco-Garrido et al. 2009). Varias especies que antes eran comunes en la cuenca ahora están desapareciendo; por ejemplo, *Squalius pyrenaicus*, *Iberochondrostoma lemmingii*, *Squalius alburnoides* y *Anguilla anguilla* tienen distribuciones considerablemente reducidas con respecto a las observadas en estudios recientes (Doadrio 2001).

Dos especies de agua dulce se consideran oficialmente extintas en la cuenca del Guadalquivir: *Gasterosteus aculeatus* y *Barbus comizo* (Granado-Lorencio 2001, Granado-Lorencio & Hernando 2001, Arias-García 2010). El primero presentaba la población más meridional de Europa (Hernando 1975). Las causas directas de su extinción nunca se conocerán, pero algunos especulan sobre la transformación del hábitat, la contaminación y el comercio de peces para los acuaristas (Granado-Lorencio & Hernando 2001). También se desconocen las causas de la extinción del *B. comiza*; sin embargo, el escaso número de registros y su antigüedad (Lozano Rey 1935) sugieren que la presencia histórica de esta especie en la cuenca debe tomarse con cautela (Granado-Lorencio 2001).

Las especies migradoras son las especies de peces con peor estado de conservación. En esta Tesis solo se capturó una de las cinco especies con presencia histórica en la cuenca (anguila, prevalencia <1%), mientras que otras dos son muy escasas (*Petromyzon marinus* y *Alosa fallax*) y las dos restantes están extintas regionalmente (*Acipenser sturio* y *Alosa alosa*) (Arias-García 2010, UICN 2015). Los últimos registros publicados para *P. marinus* son de 1992 y 1999, respectivamente, y en algunos estudios se considera extinta (Arias-García 2010). Sin embargo, se conocen casos esporádicos, pero periódicos de capturas de esta especie en la ría del Guadalquivir (datos no publicados de los autores). Son muy pocos los ejemplares de *A. fallax* registrados en los tramos más bajos de la cuenca a principios de otoño y primavera.

La relación entre la conservación de la fauna de peces migratorios y el impacto de las presas es un problema generalizado y bien conocido en todo el mundo (Limburg & Waldman 2009, Stanley & Doyle 2003). Las presas sin sistemas adecuados de paso de peces normalmente impiden el acceso a las áreas aguas arriba, que pueden incluir áreas de reproducción, siendo este uno de los principales desafíos para su conservación (Limburg & Waldman 2009, Stanley & Doyle 2003). España es uno de los países del mundo con más embalses, lo que representa un importante problema medioambiental (Nicola et al. 1996, Clavero et al. 2004) porque, entre otras razones, la mayoría de las presas son barreras infranqueables para los peces. Esto implica que no es posible instalar escalas viables para peces debido a su altura. En el río Guadalquivir, la presa de Alcalá del Río -construida en 1931- es un obstáculo insalvable para la migración de los peces río arriba, especialmente para el esturión (Granado-Lorencio 1991). Posteriormente, en 1956 se construyó la presa de Cantillana, aproximadamente 22 km aguas arriba de Alcalá del Río, produciendo la fragmentación total del tramo bajo del río y su completo aislamiento con el tramo medio. Otras causas específicas implicadas en la regresión de estas especies incluyen: reducciones de caudal (debido a embalses y extracciones para riego), extracciones de áridos (daño a las zonas de desove), contaminación por vertidos urbanos e industriales y sobrepesca (p.ej. industria del caviar, pesca de angulas) (Granado-Lorencio 1991, Fernández-Pasquier 1999, Doadrio 2001).

Conocer las relaciones peces-hábitat en múltiples escalas es una herramienta útil para investigadores, gestores ambientales y para diseñar estrategias de restauración y conservación (Godinho & Ferreira 2000, Filipe et al. 2004, Hermoso et al. 2009, Clavero et al. 2010) especialmente en cuencas altamente perturbadas donde los patrones naturales pueden estar distorsionados (Magalhães et al. 2002, Morán-López et al. 2006, Hermoso et al. 2009). Los estudios centrados en la identificación de áreas importantes para la fauna de peces se basan en estos estudios previos sobre preferencias de hábitat y por lo tanto tienen una gran relevancia para futuras investigaciones (Filipe et al. 2004, Hermoso et al. 2009).

Recomendaciones para la gestión y conservación de los peces del Guadalquivir

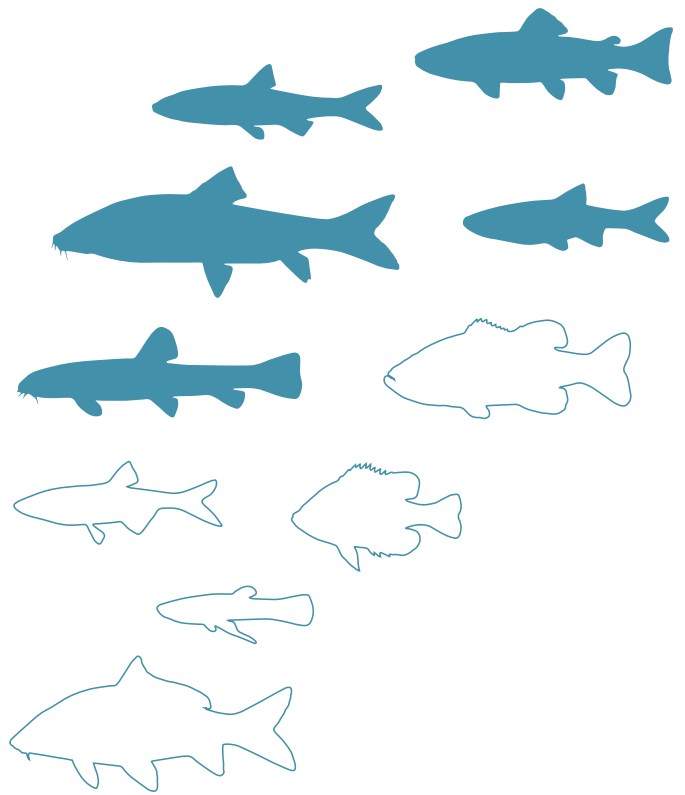
En 2012 se aprobó una estrategia regional para la conservación de peces continentales (ver <http://www.juntadeandalucia.es/boja/2012/60/boletin.60.pdf> para más detalles) y sus primeras acciones, principalmente detección de especies foráneas, análisis del ámbito de distribución y programas de cría *ex-situ*, se han iniciado recientemente. Esta estrategia pretende actuar sobre especies incluidas en el Libro Rojo regional: 4 en peligro crítico, 5 en peligro y 7 vulnerables (Franco & Rodríguez 2001). Sin embargo, tres de las especies en peligro de extinción (*A. alosa*, *A. fallax* y *Salmo trutta*) no están incluidas en la estrategia. Hasta el momento, las actuales medidas de gestión y conservación adoptadas no parecen modificar la tendencia regresiva de las especies más amenazadas. Solo *A. baeticus* y *S. trutta*, que cuentan con planes de conservación específicos, parecen haber estabilizado sus poblaciones (Pérez Pavón et al. 2012, Larios-López et al. 2015).

El estado de conservación actual según los criterios de la UICN de todas las especies de peces amenazadas en la cuenca del Guadalquivir, así como de las especies introducidas, debe revisarse y actualizarse, situando a cada especie en su categoría global y regional apropiada, incluidas las posibles extinciones. Por ejemplo, el Libro Rojo autonómico de Andalucía incluye a la anguila europea en la categoría de ‘Preocupación Menor’ mientras que en la lista roja de la UICN aparece como ‘En Peligro Crítico’. Otro ejemplo de discrepancia se refiere al posible origen híbrido de la bogardilla (Doadrio 2001), que conviene aclarar. Este taxón está incluido en la estrategia de conservación regional y se podrían invertir considerables fondos para su conservación y protección, sin siquiera conocer su verdadero estado taxonómico. Además, esta “especie” no ha sido colectada en los últimos diez años (IUCN 2015).

La definición y detección de sitios prioritarios para la conservación de los peces continentales es necesaria para determinar las medidas apropiadas de restauración en las áreas más valiosas para esta fauna imprescindible. Estas deben ser áreas con alta riqueza de especies nativas o habitadas por especies en peligro de extinción. La declaración de espacios naturales protegidos sería una herramienta útil para preservarlos. La eliminación de presas obsoletas aumentará la conectividad entre poblaciones, evitando así su aislamiento (Stanley & Doyle 2003) y favoreciendo su recuperación, especialmente

entre las especies migradoras. Esta medida se está llevando a cabo en varios países de Europa y América (Stanley & Doyle 2003). Los programas *ex-situ* podrían, en el futuro, proporcionar stocks para repoblaciones, introducciones y/o reintroducciones para mejora poblacional y genética. En este sentido, el desarrollo de bancos de genes vivos podría ayudar a evitar la pérdida de biodiversidad de poblaciones empobrecidas (Cowx & Collares-Pereira 2000, Doadrio 2001, Doadrio & Carmona 2014). Finalmente, las especies invasoras deben eliminarse, si es posible, especialmente de los sitios prioritarios para peces.

Las especies asociadas principalmente a factores locales (p. ej., *I. lemmingii*) pueden ser más vulnerables a las perturbaciones locales y, en consecuencia, a las extinciones locales (Clavero et al. 2004). Sin embargo, en la cuenca del río Guadalquivir, la mayoría de las especies se distribuyen en función de factores regionales (o compartidos) y sus principales amenazas son a gran escala, como las discontinuidades de los ríos (Branco et al. 2012). Estos resultados, de acuerdo con otros de un estudio reciente, resaltan el mal estado de conservación de la cuenca (ver Ramos-Merchante & Prenda 2018). Es necesaria una gestión global e integrada de los recursos hídricos y la fauna piscícola para evitar el actual deterioro del hábitat en esta cuenca. En este sentido, esta tesis brinda información sobre cómo las especies responden a la heterogeneidad del paisaje y muestra el estado actual de conservación deficiente de la comunidad de peces nativos, en particular *A. Anguilla* e *I. lemmingii*, así como el aumento del número de especies no introducidas. Nuestros modelos destacan la importancia de analizar las correlaciones peces-hábitat a diferentes escalas y pueden usarse para evaluar y rediseñar estrategias de conservación donde también deben considerarse procesos ecológicos como la capacidad reproductiva o de dispersión (Magalhães et al. 2002, Ferreira et al. 2007, Oliveira et al. 2012).



Conclusiones / Conclusions

Conclusiones

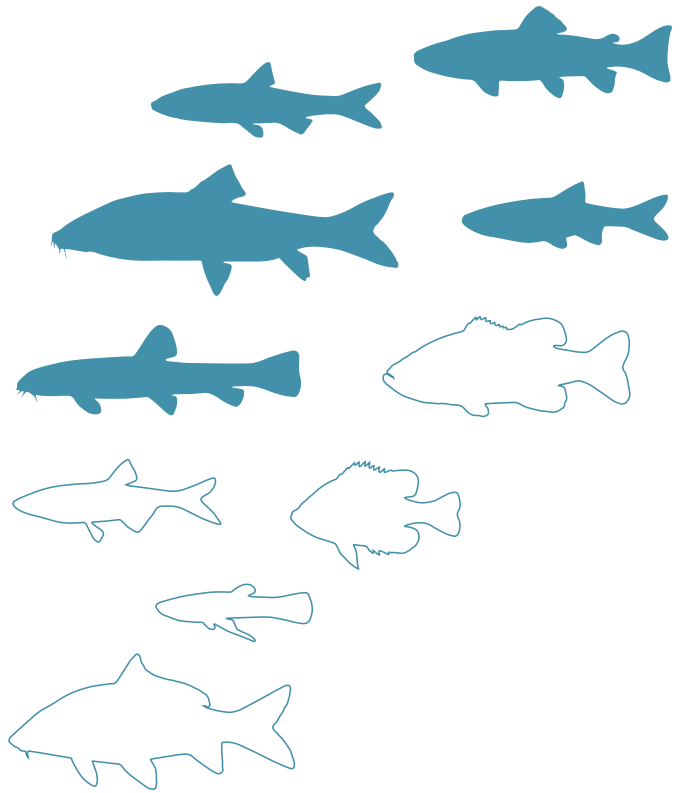
1. Se capturaron un total de 18 especies de peces (9 autóctonas, 7 introducidas y 2 translocadas) en la cuenca del río Guadalquivir en 285 puntos de muestreo. Una búsqueda bibliográfica reveló la presencia de al menos 22 especies adicionales (11 nativas y 11 exóticas) presentes en algún momento a lo largo del siglo XX. Algo más del 18% de los lugares muestreados no tenían peces, todos ellos ubicados en ríos.
2. Todas las especies autóctonas mostraron una distribución muy restringida (prevalencia inferior al 23%), excepto el barbo ibérico meridional (*Luciobarbus sclateri*) que fue la especie más ampliamente distribuida (prevalencia del 58,6%) y abundante (más del 50% del total de peces capturados) en toda la cuenca.
3. El patrón general de biodiversidad (desde cabeceras hasta tramos inferiores) se altera en la cuenca del Guadalquivir. La biodiversidad nativa de peces de agua dulce alcanzó su punto máximo en cursos de agua de orden 2 y se redujo progresivamente hasta un mínimo en lugares superiores al orden 4, mientras que los exóticos alcanzaron su punto máximo en el orden 4 del río.
4. Tres especies de reciente introducción (*Phoxinus* spp, *Ameiurus melas*, *Australoheros facetus*), con alto potencial invasor, se establecen en la cuenca del río Guadalquivir. Además, se han detectado siluros (*Silurus glanis*) muchos kilómetros río abajo del primer sitio en que fue registrada esta especie, lo que indica procesos de expansión o nuevas introducciones.
5. A nivel de la comunidad, los factores regionales y locales revelaron una zonificación longitudinal marcada donde las asociaciones de especies de peces estaban fuertemente vinculadas a un gradiente longitudinal de perturbación, desde las cabeceras hasta la desembocadura del río.
6. Para los modelos de especies individuales, las variables locales y regionales y sus interacciones, revelaron asociaciones significativas con la presencia de especies, lo que sugiere una fuerte interacción entre las escalas.

7. Los procesos de extinción de especies nativas y colonización de especies exóticas entre el s. XIX y XXI mostraron una marcada asimetría entre las márgenes de la cuenca y la zonificación longitudinal. Estos procesos se encuentran íntimamente relacionados con la historia natural de las especies extinguidas, así como la asimetría ambiental y de perturbación existente en la cuenca.
8. La conservación eficiente de la ictiofauna del Guadalquivir, según estos resultados, pasa por la definición de tramos de alta riqueza y diversidad de especies y por la aplicación de medidas de gestión a escala local. La creación específica de espacios naturales protegidos en los que los peces sean primordiales facilitaría la conservación de este segmento fundamental de la biodiversidad hoy gravemente amenazado.

Conclusions

1. A total of 18 fish species (9 native, 7 introduced and 2 translocated) were captured in the Guadalquivir River Basin throughout 285 sampling points. The bibliographic search revealed the presence of at least 22 additional species (11 native and 11 exotic) during the 20th century. Just over eighteen percent of the sampled locations were fishless, all of them located in rivers.
2. All native species had a very restricted distribution (prevalence less than 23%), excepting the southern Iberian barbel (*Luciobarbus sclateri*) which is the most widespread (a prevalence of 58.6%) and abundant species (more than 50% of the total captured fish) throughout the basin.
3. The general biodiversity pattern (from headwaters to lower sections) is altered in the Guadalquivir Basin. Freshwater fish native biodiversity peaked at river order 2 and progressively was reduced until a minimum at locations higher than order 4, while exotics peaked at river order 4.
4. Three recently introduced species (*Phoxinus* spp, *Ameiurus melas*, *Australoheros facetus*), with high invasive potential, are established in the Guadalquivir River Basin. In addition, European catfish (*Silurus glanis*) have been detected many kilometers downstream from the first recorded site, indicating expansion processes or new introductions.
5. At the fish community level, regional and local factors revealed a marked longitudinal zonation where fish assemblage was strongly associated with a longitudinal gradient of perturbation (i.e. from headwaters to river mouth).
6. For individual species models, local and regional variables, and their interactions, revealed significant associations with the presence of species, suggesting a strong interaction between the scales.

7. The processes of extinction of native species and colonization of exotic ones between the s. XIX and XXI showed a marked asymmetry between the margins and the longitudinal zonation of the basin. These processes are closely related to the natural history of the extinct species as well as the environmental and disturbance asymmetry in the basin.
8. The efficient conservation of the fish fauna of the Guadalquivir river basin, according to the results presented here, needs a selection of stream reaches of high species richness and diversity and the application of direct management measures at a local scale. The creation of protected areas in which fish are essential will be essential to conserve this fundamental segment of biodiversity, seriously threatened nowadays.



Referencias

Referencias

- Abell R. (2002) Conservation biology for the biodiversity crisis: a freshwater follow-up. *Conservation Biology* 16:1435-1437.
- Abell R, Allan JD, Lehner B. (2007) Unlocking the potential of protected areas for freshwaters. *Biological Conservation* 134(1): 48–63. <https://doi.org/10.1016/j.biocon.2006.08.017>
- Almaça EC (1976) La speciation chez les Cyprinidae de la Péninsule ibérique. *Revue des Travaux de l'Institut des Pêches Maritimes* 40:399-411.
- Almaça C, Elvira B (2000) Past and present distribution of *Acipenser sturio* L., 1758 on the Iberian Peninsula. *Boletín del Instituto Español de Oceanografía* 16: 11-16.
- Anderson MJ. (2005) PERMANOVA Permutational multivariate analysis of variance. *Austral Ecology*, 1–24.
- Allan D, Erickson D, Fay J (1997) The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 37:149–161
- Angermeier PL, Winston MR (1998) Local vs. Regional influences on local diversity in stream fish communities of Virginia. *Ecology* 79:911–927
- Angermeier PL, Winston MR (1999) Characterizing fish community diversity across Virginia landscapes: prerequisite for conservation. *Ecological Applications* 9:335–349
- Aparicio E, Vargas MJ, Olmo JM, de Sostoa A (2000) Decline of native freshwater fishes in a Mediterranean watershed on the Iberian peninsula: a quantitative assessment. *Environmental Biology of Fishes* 59(1):11-19
- Argüelles A, Berbel J, Gutiérrez C (2012) La evolución de la Cuenca del Guadalquivir (España). *Revista de Obras Públicas* 3.537:1-13.
- Arias García AM. (2010) Macrofauna acuática. In: Ruiz J, Losada MA, Polo MJ, García J (2010) Propuesta metodológica para diagnosticar y pronosticar las consecuencias de las actuaciones humanas en el estuario del Guadalquivir. Informe técnico. Instituto de Ciencias Marinas de Andalucía (CSIC), Grupo de Dinámica de Flujos Ambientales (Centro Andaluz de Medio Ambiente – Universidad de Granada), Grupo de Dinámica Fluvial e Hidrología (Universidad de Córdoba), Grupo Albiotox (Universidad Complutense). Puerto de Sevilla. Sevilla.
- Arunachalam M (2000) Assemblage structure of stream fishes in the Western Ghats (India). *Hydrobiologia* 430:1–31
- Barton K (2016) MuMIn: Multi-Model Inference. R package version 1.15.6. <https://CRAN.R-project.org/package=MuMIn>.
- Beaujean AA (2012) BaylorEdPsych: R package for Baylor University Educational Psychology quantitative courses (Version 0.5) [Computer software]. Waco, TX: Baylor University.

- Beaumont WRC, Taylor AAL, Lee MJ, Welton JS (2002) Guidelines for electric fishing best practice. Environment Agency R&D Technical Report W2-054/TR.
- Berbel J, Pedraza V, Giannoccaro G (2013) The trajectory towards basin closure of a European river: Guadalquivir. *International Journal of River Basin Management* 11:111-119
- Bhat A, Blomquist W (2004) 'Policy, politics, and water management in the Guadalquivir River Basin, Spain.' *Water Resources Research* 40(8). doi:10.1029/2003WR002726.
- Blanco-Garrido F, Clavero M, Prenda J (2009) Jarabugo (*Anaecypris hispanica*) and freshwater blenny (*Salaria fluviatilis*): habitat preferences and relationship with exotic fish species in the middle Guadiana basin. *Limnetica* 28(1):139-148.
- Bond NR, Lake PS (2003) Characterizing fish-habitat associations in streams as the first step in ecological restoration. *Austral Ecology* 28:611-621
- Borcard D, Legendre P, Drapeau P (1992) Partialling out the spatial component of ecological variation. *Ecology* 73:1045-1055
- Branco P, Segurado P, Santos JM, Pinheiro P, Ferreira MT (2012) Does longitudinal connectivity loss affect the distribution of freshwater fish? *Ecological Engineering* 48:70-78.
- Bray JR, Curtis JT (1957) An Ordination of the Upland Forest Communities of Southern Wisconsin. *Ecological Monographs* 27: 325-349.
- Bruton MN (1995) Have fishes had their chips? The dilemma of threatened fishes. *Environmental Biology of Fishes* 43:1-27.
- Bunt C, Cooke SJ, McKinley RS. (1998) Creation and maintenance of habitat downstream from a weir for the greenside darter (*Etheostoma blenniodes*) a rare fish in Canada. *Environmental Biology of Fishes* 51:297-308.
- Carboneras C, Genovesi P, Vilà M, Blackburn TM, Carrete M, Clavero M, et al (2018) A prioritised list of invasive alien species to assist the effective implementation of EU legislation. *Journal of Applied Ecology* 55: 539-547, DOI: 10.1111/1365-2664.12997
- Carmona JA, Doadrio I, Márquez AL, Real R, Hugueny B, Vargas JM (1999) Distribution patterns of indigenous freshwater fishes in the Tagus River basin, Spain. *Environmental Biology of Fishes* 54:371-387
- Carol J, Benejam L, Alcaraz C, Vila-Gispert A, Zamora L, Navarro E, Armengol J, García-Berthou E (2006) The effects of limnological features on fish assemblages of 14 Spanish reservoirs. *Ecology of Freshwater Fish* 15:66-77
- Carpintero M (2015) Characterization of suspended sediments in the Guadalquivir estuary at modeled scale. Dissertation, Universidad de Córdoba.
- Carta Piscícola Española (2014). SIBIC. www.cartapiscicola.es (accessed 13 March 2019)

- Case TJ (1991) Invasion resistance, species build-up and community collapse in metapopulation models with inter-species competition. *Biological Journal of the Linnean Society* 42:239-266.
- Cheng ST, Herricks EE, Tsai WP, Chang FJ (2016) Assessing the natural and anthropogenic influences on basin-wide fish species richness. *Science of the Total Environment* 572:825-836
- Clarke KR. (1993) Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18: 117-143.
- Clarke KR, Warwick RM, Somerfield PJ, Gorley RN. (2005) Change in marine communities: an approach to statistical analysis and interpretation, 3rd edn. PRIMER-E Ltd, Plymouth, UK.
- Clavero M., Blanco-Garrido F, Prenda J (2004) Fish fauna in Iberian Mediterranean river basins: biodiversity, introduced species and damming impacts. *Aquatic Conservation: Marine and Freshwater Ecosystems* 14:575-585.
- Clavero M, Blanco-Garrido F, Prenda J (2006) Monitoring small fish populations in streams: a comparison of four passive methods. *Fisheries Research* 78(2):243-251.
- Clavero M, Garcia-Berthou E (2006) Homogenization dynamics and introduction routes of invasive freshwater fish in the Iberian Peninsula. *Ecological Applications* 16:2313-2324
- Clavero M, Hermoso V, Levin N, Kark S (2010) Geographical linkages between threats and imperilment in freshwater fish in the Mediterranean Basin. *Diversity and Distributions* 16:744-754
- Clavero M (2011) Assessing the risk of freshwater fish introductions into the Iberian Peninsula. *Freshwater Biology* 56: 2145-2155, <https://doi.org/10.1111/j.1365-2427.2011.02642.x>
- Clavero, M., Hermoso, V (2011) Reservoirs promote the taxonomic homogenization of fish communities within river basins. *Biodiversity and Conservation* 20:41-57.
- Clavero M, Hermoso V, Aparicio E, Godinho FN (2013) Biodiversity in heavily modified waterbodies: native and introduced fish in Iberian reservoirs. *Freshwater Biology* 58:1190-1201
- Clavero M, Villero D (2013) Historical ecology and invasion biology: Long-term distribution changes of introduced freshwater species. *BioScience* 64(2):145-153.
- Clavero M, Revilla E. (2014). Mine centuries-old citizen science. *Nature* 510(7503): 35-35.
- Clavero M, Hermoso V. (2015). Historical data to plan the recovery of the European eel. *Journal of Applied Ecology* 52(4): 960-968.
- Clavero M, Ninyerola M, Hermoso V, Filipe AF, Pla M, Villero D, Brotons L, Delibes M. (2017). Historical citizen science to understand and predict climate-driven trout decline. *Proceedings of the Royal Society B: Biological Sciences* 284(1846), <https://doi.org/10.1098/rspb.2016.1979>

- Clavero M, García-Reyes A, Fernández-Gil A, Revilla E, Fernández N. (2022). Where wolves were: setting historical baselines for wolf recovery in Spain. *Animal Conservation*. <https://doi.org/10.1111/acv.12814>
- Closs GP, Krkosek M, Olden JD. (2016). *Conservation of freshwater fishes*. Cambridge University Press.
- Confederación Hidrográfica del Guadalquivir (2015a) Plan Hidrológico de la Demarcación Hidrográfica del Guadalquivir. <http://www.chguadalquivir.es>. Accessed 15 June 2015.
- Confederación hidrográfica del Guadalquivir (2015b) Geoportál/Descargas/Embalses. <http://idechg.chguadalquivir.es/geoportál/es/servicios/descargas.html?selectorFromDBProduct=Embalses>. Accessed 15 June 2015.
- Copp GH, Britton R, Cucherousset J, García-Berthou E, Kirk R, Peeler E, Stakènas S (2009) Voracious invader or benign feline? A review of the environmental biology of European catfish *Silurus glanis* in its native and introduced ranges. *Fish and Fisheries* 10:252-282.
- Corbacho C, Sanchez JM (2001) Patterns of species richness and introduced species in native freshwater fish faunas of a Mediterranean-type basin: The Guadiana river (Southwest Iberian Peninsula). *Regul River* 17:699-707.
- Cowx IG, Collares-Pereira MJ (2000) Conservation of endangered fish species in the face of water resource development schemes in the Guadiana river, Portugal: harmony of the incompatible. In: Cowx IG (ed) *Management and Ecology of River Fisheries*. Fishing News Books, Blackwell Science, Oxford, pp 428-438.
- Cowx IG, Collares-Pereira ML (2002) Freshwater fish conservation: options for the future. In: Collares-Pereira MJ, Cowx IG, Coelho MM (ed). *Conservation of freshwater fishes: options for the future*. Fishing News Books, Blackwell Science, Oxford, pp 443-452.
- Cruz Villalón J (1988) La intervención del hombre en la ría y marismas del Guadalquivir. *Eria: Revista cuatrimestral del geografía* 16:109-123. ISSN 0211-0563.
- Cucherousset J, Paillisson JM, Carpentier A, Eybert MC, Olden JD (2006) Habitat use of an artificial wetland by the invasive catfish *Ameiurus melas*. *Ecology of Freshwater Fish* 15: 589-596, <https://doi.org/10.1111/j.1600-0633.2006.00199.x>
- Cuttelod A, García N, Abdul Malak D, Temple H, Katariya V (2008) The Mediterranean: a biodiversity hotspot under threat. In: Vié JC, Hilton-Taylor C, Stuart SN (ed). *The 2008 Review of The IUCN Red List of Threatened Species*. IUCN Gland, Switzerland.
- De la Herrán R, Robles F, Martínez-Espín E, Lorente JA, Ruiz Rejón C, Garrido-Ramos MA, Ruiz Rejón M (2004) Genetic identification of western sturgeons and its implication for conservation. *Conservation Genetics* 5:545-551.
- De Miguel R, Pino E, Ramiro A, Aranda F, De la Peña JP, Doadrio I, Fernández-Delgado C (2010) On the occurrence of

- Anaocypris hispanica*, an extremely endangered Iberian endemism, in the Guadalquivir River basin. *Journal of Fish Biology* 76:1454-1465.
- Díaz M, Campos P, Pulido FJ (1997) The Spanish dehesas: a diversity of land use and wildlife. In: Pain D, Pienkowski M (ed). *Farming and birds in Europe: The Common Agricultural Policy and its implications for bird conservation*. Academic Press, London, pp 178-209.
- Doadrio I (1980) Descripción de un nuevo género y de una nueva especie *Iberocypris palaciosi* n. gen. n. sp. (Pisces, Cyprinidae). *Doñana Acta Vertebrata* 7: 5-16.
- Doadrio I, Garzón P (1986) Nuevas localidades de *Phoxinus phoxinus* (L., 1758) (Ostariophysi, Cyprinidae) en la Península Ibérica. *Miscellània Zoològica* 10: 389-390
- Doadrio I (1989) Catálogo de los peces de agua dulce del Museo Nacional de Ciencias Naturales. Museo Nacional de Ciencias Naturales, Madrid, CSIC, Spain, 61 pp.
- Doadrio I (2001) Atlas y libro rojo de los peces continentales de España. Dirección General de Conservación de la Naturaleza-Museo Nacional de Ciencias Naturales, Madrid, 374 pp.
- Doadrio I, Carmona JA, Fernández-Delgado C (2002) Morphometric study of the Iberian *Aphanius* (Actinopterygii, Cyprinodontiformes), with description of a new species. *Folia Zoológica* 51(1):67-79.
- Doadrio I, Carmona JA (2003) A new species of the genus *Chondrostoma* Agassiz, 1832 (Actinopterygii, Cyprinidae) from the Iberian Peninsula. *Graellsia* 59(1):29-36.
- Doadrio I., Carmona J. A. (2014). *Pardilla oretana* – *Iberochondrostoma oretanum*. In: Salvador A, Elvira B (ed) *Enciclopedia Virtual de los Vertebrados Españoles*. Museo Nacional de Ciencias Naturales, Madrid. <http://www.vertebradosibericos.org/>
- Doukakis P, Birstein VJ, DeSalle R, Ludwig AN, Ludwig A, Machordom A, Almodóvar A, Elvira B (2000) Failure to confirm previous identification of two putative museum specimens of the Atlantic sturgeon, *Acipenser sturio*, as the Adriatic sturgeon, *A. naccarii*. *Marine Biology* 136:373-377.
- Dumont A, Salmoral G, Llamas MR. (2013). The water footprint of a river basin with a special focus on groundwater: The case of Guadalquivir basin (Spain). *Water Resources and Industry* 1-2: 70-76. <https://doi.org/10.1016/j.wri.2013.04.001>
- Eisenhour DJ, Piller KR (1997) Two new intergeneric hybrids involving *Semotilus atromaculatus* and the genus *Phoxinus* with analysis of additional *Semotilus atromaculatus*: *Phoxinus* hybrids. *Copeia* 1997: 204-209, DOI: 10.2307/1447860
- Elvira B (1984) First records of the North American catfish *Ictalurus melas* (Rafinesque, 1820) (Pisces, Ictaluridae) in Spanish waters. *Cybio* 8(1): 96-98
- Elvira B (1995) Native and exotic freshwater fishes in Spanish river basins. *Freshwater Biology* 33:103-108.

- Elvira B, Almodóvar E (1999) A morphological study of native sturgeon *Acipenser sturio* in Spain, and recent records of exotic Siberian sturgeon *A. baerii*. *Journal of Applied Ichthyology* 15: 278-279.
- Elvira B, Almodóvar A (2001) Freshwater fish introductions in Spain: facts and figures at the beginning of the 21st century. *Journal of Fish Biology* 59(Supplement A), 323-331.
- Elvira B (2004) Pirañas en nuestras aguas. *Trofeo pesca* 134: 182-183.
- Feld CK, Segurado P, Gutiérrez-Cánovas C (2016) Analysing the impact of multiple stressors in aquatic biomonitoring data: A 'cookbook' with applications in R. *Science of the Total Environment* 573:1320-1339
- Fernandez-Delgado C, Hernando JA, Herrera M, Bellido M (1986) Sobre el status taxonómico del genero Valencia Myers, 1928 en el suroeste de Iberia. *Donana, Acta Vertebrata* 13: 161-163.
- Fernández-Delgado C, Rincón PA, Gálvez-Bravo L, De Miguel RJ, Oliva-Paterna FJ, Moreno-Valcárcel R, Pino E, Ramiro A, Peña JP (2014) Distribución y estado de conservación de los peces dulceacuícolas del río Guadalquivir. Principales áreas fluviales para su conservación. Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid, 275 pp
- Fernández-Pasquier V (1999) *Acipenser sturio* L. in the Guadalquivir river, Spain. Water regulation and fishery as factors in stock decline from 1932 to 1967. *Journal of Applied Ichthyology* 15(4-5):133-135.
- Ferreira MT, Sousa L, Santos JM, Reino L, Oliveira J, Almeida PR, Cortes RV (2007) Regional and local environmental correlates of native Iberian fish fauna. *Ecology of Freshwater Fish* 16:504-514
- Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental Conservation* 24:38-49
- Filipe AF, Marques TA, Seabra S, Tiago P, Ribeiro F, Costa LMD, Cowx IG, Collares-Pereira MJ (2004) Selection of priority areas for fish conservation in Guadiana river basin, Iberian Peninsula. *Conservation Biology* 18:189-200.
- Filipe A.F, Araújo MB, Doadrio I, Angermeier PL, Collares-Pereira MJ. (2009) Biogeography of Iberian freshwater fishes revisited: The roles of historical versus contemporary constraints. *Journal of Biogeography* 36: 2096-2110.
- Fischer JR, Quist MC (2014) Characterizing lentic freshwater fish assemblages using multiple sampling methods. *Environmental Monitoring and Assessment* 186:4461-4474
- Flórez A (2007) "La piraña era Pacus". ABC [Sevilla], 22 de Julio de 2007, p.38.
- Franco-Ruiz A, Rodríguez de los Santos M (2001) Libro Rojo de los Vertebrados Amenazados de Andalucía. Consejería de Medio Ambiente. Junta de Andalucía.
- Freyhof J, Brooks E (2011) European Red List of Freshwater Fishes. Luxembourg: Publications Office of the European Union.

- http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_freshwater_fishes.pdf
- Gago J, Anastácio P, Gkenas C, Banha F, Ribeiro F (2016) Spatial distribution patterns of the non-native European catfish, *Silurus glanis*, from multiple online sources—a case study for the River Tagus (Iberian Peninsula). *Fisheries Management and Ecology* 23: 503-509, <https://doi.org/10.1111/fme.12189>
- García-Alix A, Jiménez-Espejo FJ, Lozano JA, Jiménez-Moreno G, Martínez-Ruiz F, Sanjuán LG et al (2013) Anthropogenic impact and lead pollution throughout the Holocene in Southern Iberia. *Science of the Total Environment* 449:451–460
- García de Lomas J, Dana ED, López Santiago J, González R, Ceballos G, Ortega F (2009) First record of the North American black bullhead *Ameiurus melas* (Rafinesque, 1820) in the Guadalquivir Estuary (Southern Spain). *Aquatic Invasions* 4(4):719-723.
- García-Novo F, Martín-Vicente A, Toja-Santillana J (2007) *La frontera de Doñana*. Universidad de Sevilla. España.
- García-Ruiz, JM, Nadal-Romero E, Lana-Renault N, Beguería S (2013) Erosion in Mediterranean landscapes: changes and future challenges. *Geomorphology* 198: 20-36.
- Garrido-Ramos M.A, Soriguer MC, de la Herrán R, Jamilena M, Ruíz Tejón C, Domezain A, Hernando JA, Ruíz Rejón M (1997) Morphometric and genetic analysis as proof of the existence of two sturgeon species in the Guadalquivir river. *Marine Biology* 129:33-39.
- Gasith A, Resh VH (1999) Streams in Mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics* 30:51-81.
- Gauch HG (1982) *Multivariate analysis in community ecology*. Cambridge University Press, New York
- Godinho FN, Ferreira MT (2000) Composition of endemic fish assemblages in relation to exotic species and river regulation in a temperate stream. *Biological Invasions* 2:231–244
- González-Ortegón E, Subida MD, Cuesta JA, Arias AM, Fernández-Delgado C, Drake P (2010) The impact of extreme turbidity events on the nursery function of a temperate European estuary with regulated freshwater inflow. *Estuarine, Coastal and Shelf Science* 87:311-324.
- Gozlan RE, Britton JR, Cowx I, Copp GH (2010) Current knowledge on non-native freshwater fish introductions. *Journal of Fish Biology* 76: 751-786, <https://doi.org/10.1111/j.1095-8649.2010.02566.x>
- Granado-Lorencio C (1991) The effect of man on the fish fauna of the River Guadalquivir, Spain. *Fisheries Research*, 12:91-100.
- Granado-Lorencio C, Hernando JA (2001) Espinoso - *Gasterosteus gymnurus*. In: Franco A, Rodríguez M (Coord) *Libro rojo de los vertebrados de Andalucía*. Consejería de Medio Ambiente. Junta de Andalucía.

- Granado-Lorencio C (2001) Barbo comizo - *Barbus comiza*. In: Franco A, Rodríguez M (Coord) Libro rojo de los vertebrados de Andalucía. Consejería de Medio Ambiente. Junta de Andalucía.
- Grenouillet G, Pont D, Hérisse C (2004) Within-basin fish assemblage structure: the relative influence of habitat versus stream spatial position on local species richness. *Canadian Journal of Fisheries and Aquatic Sciences* 61:93–102
- Growns IO, Pollard DA, Harris JH (1996) A comparison of electric fishing and gillnetting to examine the effects of anthropogenic disturbance on riverine fish communities. *Fisheries Management and Ecology* 3:13–24
- Guisan A, Zimmermann NE (2000) Predictive habitat distribution models in ecology. *Ecological Modelling* 135:147–186
- Gutiérrez-Estrada JC, Prenda J, Oliva F, Fernández-Delgado C (1998) Distribution and hábitat Preferences of the Introduced Mummichog *Fundulus heteroclitus* (Linnaeus) in South-western Spain. *Estuarine, Coastal and Shelf Science* 46:827–835.
- Habit E, Piedra P, Ruzzante DE, Walde SJ, Belk MC, Cussac VE, Gonzalez J, Colin N. (2010) Changes in the distribution of native fishes in response to introduced species and other anthropogenic effects. *Global Ecology and Biogeography* 19: 697–710.
- Haidvogel G, Pont D, Dolak H, Hohensinner S. (2015) Long-term evolution of fish communities in European mountainous rivers: past log driving effects, river management and species introduction (Salzach River, Danube). *Aquatic Sciences* 77: 395–410.
- Hammer O, Harper DAT, Ryan PD (2001) PAST: paleontological Statistics software package for education and data analysis. *Palaentologica Electronica* 4:1–9.
- Hawkes H (1975) River zonation and classification. In: Whitton BA (ed) *River ecology*. University of California Press, Berkeley
- Heggenes J, Brabrand C, Saltveit SJ (1990) Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. *Transactions of the American Fisheries Society* 119:101–111.
- Hermosín MC, Calderon MJ, Real M, Cornejo J (2013) Impact of herbicides used in olive groves on waters of the Guadalquivir river basin (southern Spain). *Agriculture Ecosystems and Environment* 164:229–243.
- Hermoso V, Blanco-Garrido F, Prenda J (2008a) Spatial distribution of exotic fish species in the Guadiana river basin, with two new records. *Limnetica* 27:189–194.
- Hermoso V, Clavero M, Blanco-Garrido F, Prenda, J (2008b) Assessing freshwater fish sensitivity to different sources of perturbation in a Mediterranean basin. *Ecology of Freshwater Fish* 18:269–281.
- Hermoso V, Linke S, Prenda J (2009) Identifying priority sites for the conservation of freshwater fish biodiversity in a Mediterranean basin with a high degree of

- threatened endemics. *Hydrobiologia* 623:127–140
- Hermoso V, Clavero M (2011) Threatening processes and conservation management of endemic freshwater fish in the Mediterranean basin: a review. *Marine and Freshwater Research* 62:244–254
- Hermoso V, Clavero M, Blanco-Garrido F, Prenda J. (2011). Invasive species and habitat degradation in Iberian streams: an analysis of their role in freshwater fish diversity loss. *Ecological Applications* 21(1): 175–188.
- Hermoso V, Cattarino L, Kennard MJ, Watts M, Linke S. (2015). Catchment zoning for freshwater conservation: Refining plans to enhance action on the ground. *Journal of Applied Ecology* 52(4): 940–949. <https://doi.org/10.1111/1365-2664.12454>
- Hernando JA (1975) Notas sobre la distribución de los peces fluviales en el suroeste de España. *Doñana Acta Vertebrata* 2(2):263–264.
- Hernando JA, Soriguer MC (1992) Biogeography of the freshwater fish of the Iberian Peninsula. *Limnetica* 8:243–253.
- Holmlund CM, Hammer M. (1996). Functional effects of methylazoxymethanol-induced cerebellar hypoplasia in rats. *Neurotoxicology and Teratology*, 18(5): 529–537. [https://doi.org/10.1016/0892-0362\(96\)00083-9](https://doi.org/10.1016/0892-0362(96)00083-9)
- Hornung M, Reynolds B (1995) The effect of natural and anthropogenic environmental changes on ecosystem processes at the basin scale. *Trends in Ecology and Evolution* 10:443–449
- Horwitz RJ (1978) Temporal variability patterns and the distribution patterns of stream fishes. *Ecological Monographs* 48:307–321.
- Hosmer DW Jr, Lemeshow S (1989) *Applied logistic regression*. Wiley, New York
- Hughes M, Gammon JR (1987) Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Transactions of the American Fisheries Society* 116(2):196–209.
- Huston MA (1994) *Biological diversity: the coexistence of species on changing landscapes*. Cambridge Univ. Press, Cambridge.
- Huston MA (1999) Local processes and regional patterns: appropriate scales for understanding variation in the diversity of plants and animals. *Oikos* 86:393–401
- IBM Corp. Released (2012) *IBM SPSS Statistics for Windows, Version 21.0*. Armonk, NY: IBM Corp.
- Ishwaran H, Kogalur UB, Gorodeski EZ, Minn AJ, Lauer MS (2010) High-dimensional variable selection for survival data. *Journal of the American Statistical Association* 105:205–217
- IUCN Red List of Threatened Species. Version 15.1 (July 2022 <www.iucnredlist.org>. Accessed 07 September 2022.
- Kennard MJ, Olden JD, Arthington AH, Pusey BJ, Poff NL (2007) Multiscale effects of flow regime and habitat and their interaction on fish assemblage structure in eastern Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 64:1346–1359

- Kennedy, GJA, Strange, CD (1981) Efficiency of electric fishing for salmonids in relation to river width. *Aquaculture Research* 12(2):55-60.
- Kobayakawa M (1989) Systematic revision of the catfish genus *Silurus*, with description of a new species from Thailand and Burma. *Japanese Journal of Ichthyology* 36(2): 155-170
- Kottelat M (2007) Three new species of *Phoxinus* from Greece and southern France (Teleostei: Cyprinidae). *Ichthyological Exploration of Freshwaters* 18: 145-162
- Kottelat M, Freyhof J (2007) *Handbook of European Freshwater Fishes*. Kottelat, Cornol, Switzerland and Freyhof, Berlin.
- Kwok R. (2017). Historical data: Hidden in the past. *Nature* 549(7672): 419-421.
- Lamouroux N, Capra H, Pouilly M, Souchon Y (1999) Fish habitat preferences in large streams of southern France. *Freshwater Biology* 42:673-687
- Larios-López JE, Tierno de Figueroa JM, Alonso-González C, Nebot Sanz B (2015) Distribution of brown trout (*Salmo trutta* Linnaeus, 1758) (Teleostei: Salmonidae) in its southwesternmost European limit: possible causes. *Italian Journal of Zoology* 82:404-415. <https://doi.org/10.1080/11250003.2015.1018351>
- Lepart J, Debussche M (1992) *In Landscape boundaries.*, Springer, New York, NY
- Leprieur F, Beauchard O, Hugueny B, Grenouillet G, Brosse S. (2008). Null model of biotic homogenization: a test with the European freshwater fish fauna. *Diversity and Distributions* 14(2): 291-300.
- Leprieur F, Olden JD, Lek S, Brosse S. (2009). Contrasting patterns and mechanisms of spatial turnover for native and exotic freshwater fish in Europe. *Journal of Biogeography* 36(10): 1899-1912.
- Legendre P, Legendre L. (1998) *Numerical Ecology - Second English Edition*, Elsevier Scientific, Amsterdam.
- Leunda PM, Elvira B, Ribeiro F, Miranda R, Oscoz J, Alves M.J, Collares-Pereira MJ (2009) International standardization of common names for Iberian endemic freshwater fishes. *Limnetica*, 28(2):189-202.
- Leunda PM (2010) Impacts of non-native fishes on Iberian freshwater ichthyofauna: current knowledge and gaps. *Aquatic Invasions* 5(3): 239-262
- Levine JM, D'Antonio CM (1999) Elton revised: A review of evidence linking diversity and invasibility. *Oikos* 87:15-26.
- Limburg KE, Waldman JR (2009) Dramatic declines in north Atlantic diadromous fishes. *Bioscience*. 59(11):955-965.
- Loh J, Randers J, MacGillivray A, Kapos V, Jenkins M, Groombridge B, Cox N (1998) *Living planet report*. World Wide Fund for Nature, Gland, Switzerland.
- Lozano Rey L (1935) *Los peces fluviales de España*. Academia de Ciencias Exactas, Físicas y Naturales, Madrid.
- McArthur RH (1970) Species-packing and competitive equilibrium for many species. *Theoretical Population Biology* 1:1-11.
- McArthur R. H (1972) *Geographical ecology: patterns in the distribution of species*. Harper and Row, New York.

- Maceda-Veiga A. (2013). Towards the conservation of freshwater fish: Iberian Rivers as an example of threats and management practices. *Reviews in Fish Biology and Fisheries* 23(1) 1–22. <https://doi.org/10.1007/s11160-012-9275-5>
- Maceda-Veiga A, López R, Green AJ. (2017). Dramatic impact of alien carp *Cyprinus carpio* on globally threatened diving ducks and other waterbirds in Mediterranean shallow lakes. *Biological Conservation* 212: 74-85.
- Magalhães MF, Batalha DC, Collares-Pereira MJ (2002) Gradients in stream fish assemblages across a Mediterranean landscape: contributions of environmental factors and spatial structure. *Freshwater Biology* 47:1015–1031
- Magalhães MF, Ramalho CE, Collares-Pereira MJ (2008) Assessing biotic integrity in a Mediterranean watershed: development and evaluation of a fishbased index. *Fisheries Management and Ecology* 15:273-289.
- McGarigal K, Cushman S, Stafford S (2000) *Multivariate statistics for wildlife and ecology research*. Springer, New York
- Madoz P. 1845–1850. *Diccionario Geográfico, Estadístico y Histórico de España, y sus Posesiones de Ultramar*, Vol. 16. Madrid, Spain; P. Madoz.
- Maidment DR. (2002). *ArcHydro: GIS for water resources*. Redlands, CA: ESRI Press.
- Martín-Ortega J, Gutiérrez Martín C, Berbel, J. (2008). Caracterización de los usos del agua en la demarcación del Guadalquivir en aplicación de la Directiva Marco de Aguas. *Revista de Estudios Regionales*: 81: 45–76.
- Martínez PJ, Chart TE, Trammel MA, Wullschlegel JG, Bergersen EP (1994) Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. *Environmental Biology of Fishes* 40:227-239.
- Mateus CS, Rodríguez-Muñoz R, Quintella BR, Alves MJ, Almeida PR (2012) Lampreys of the Iberian Peninsula: distribution, population status and conservation. *Endangered Species Research* 16: 183-198.
- Matthews WJ (1998) *Patterns in freshwater fish ecology*. Chapman and Hall, New York
- Menanteau L (1982) *Les marismas du Guadalquivir; exemple de transformation d'un paysage alluvial au cours du Quaternaire récent*. Dissertation, University of Paris-Sorbone.
- Menanteau L (1984) *Evolución histórica y consecuencias morfológicas de la intervención humana en las zonas húmedas: El caso de las marismas del Guadalquivir*. In: *Las zonas húmedas en Andalucía*. Monografías de la Dirección General del Medio Ambiente. Ministerio de Obras Públicas y Urbanismo.
- Mendiguchía C, Moreno C, García-Vargas M (2007) Evaluation of natural and anthropogenic influences on the Guadalquivir River (Spain) by dissolved heavy metals and nutrients. *Chemosphere* 69(10):1509-1517.

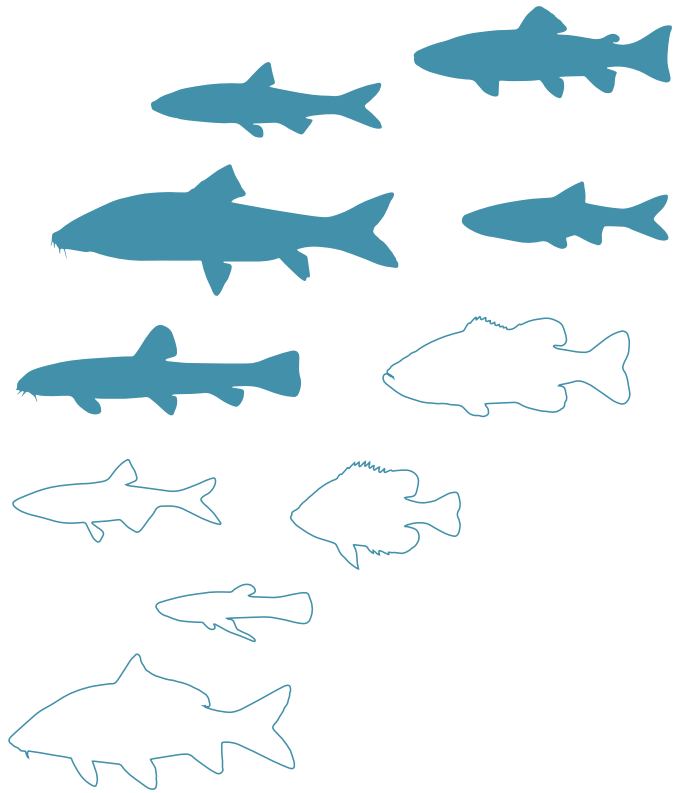
- Molle F, Wester P, Hirsch P (2010) River basin closure: processes, implications and responses. *Agricultural Water Management* 97:569–577
- Montgomery DR (1999) Process domains and the River Continuum 1. *Journal of the American Water Resources Association* 35:397–410
- Morán-López R, da Silva RE, Pérez-Bote JL, Corbacho Amado C (2006) Associations between fish assemblages and environmental factors for Mediterranean-type rivers during summer. *Journal of Fish Biology* 69:1552–1569
- Moreno CE (2001) Methods to Measure Biodiversity. M&T – Manuales y Tesis SEA, vol. 1. Zaragoza, 84pp. <http://entomologia.rediris.es/sea/manytes/metodos.pdf>
- Moreno-Valcárcel R, De Miguel RJ, Fernández-Delgado C (2013) The first record of the European catfish *Silurus glanis* Linnaeus, 1758 in the Guadalquivir River basin. *Limnetica* 32(1):23–26.
- Moyle PB, Yoshiyama RM (1994) Protection of aquatic biodiversity in California: a five-tiered approach. *Fisheries*. 19(2):6–18.
- Navarro G, Huertas IE, Costas E, Flecha S, Díez-Minguito M, Caballero I, López-Rodas V, Prieto L, Ruiz J (2012) Use of a real-time remote monitoring network (RTRM) to characterize the Guadalquivir estuary (Spain). *Sensors* 12(2):1398–1421.
- Nicola GG, Elvira B, Almodóvar A (1996) Dams and fish passage facilities in the large rivers of Spain: effects on migratory species. *Archiv für Hydrobiologie* 10 (Suppl. 113), 375–379.
- Oliveira JM, Segurado P, Santos JM, Teixeira A, Ferreira MT et al (2012) Modelling stream-fish functional traits in reference conditions: regional and local environmental correlates. *PLoS ONE* 7:e45787.
- Ogle DH, Doll JC, Wheeler P, Dinno A (2022). FSA: Fisheries Stock Analysis. R package version 0.9.
- Oksanen J, Blanchet F, Kindt R, Legendre P, O'Hara R. (2016) Vegan: community ecology package. R package 2.3-3, Available at: <https://cran.r-project.org/web/packa>.
- Pearce J, Ferrier S (2000) Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological Modelling* 133:225–245.
- Peoples BK, Davis AJ, Midway SR, Olden JD, Stoczynski L. (2020). Landscape-scale drivers of fish faunal homogenization and differentiation in the eastern United States. *Hydrobiologia*, 847(18): 3727–3741.
- Pérez Pavón MJ, Paracuellos M, López Santiago J, Sigilló N, Garrido JR, Martos MJ, Nevado JC (2012) Salinete y fartet emblemas de la ictiofauna ibérica. *Quercus*, 316:28–36.
- Poff NL (1997) Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. *Journal of the North American Benthological Society* 16:391–409.
- Pont D, Logez M, Carrel G, Rogers C, Haidvogel G. (2015) Historical change in fish

- species distribution: shifting reference conditions and global warming effects. *Aquatic Sciences* 77: 441–453.
- Potyó I, Guti G (2012) Requirements for representative sampling for fluvial fish assemblages—literary review. *Opuscula Zool* 43:203–209
- Prenda J, Clavero M, Blanco-Garrido F, Menor A, Hermoso V (2006) Threats to the conservation of biotic integrity in Iberian fluvial ecosystems. *Limnetica* 25:377–388.
- Puentes PS (1996) Peces de acuario en el Guadalquivir. El óscar tigre, nuevo en estas aguas. *Trofeo Pesca* 46: 96.
- R Core Team (2015) *R A Language and Environment for Statistical Computing*. R Found. Stat. Comput, Vienna Austria ISBN 3–900051–07–0 <https://r-project.org/>
- Rahel FJ (2002) Homogenization of freshwater faunas. *Annual Review of Ecology and Systematics*. 33:291–315.
- Ramos-Merchant A, Prenda J (2018) The ecological and conservation status of the Guadalquivir River Basin (s Spain) through the application of a fish-based multimetric index. *Ecological Indicators* 84:45–59.
- Ramos-Merchant, A, Sáez-Gómez P, Prenda J. (2021). Historical distribution of freshwater fishes and the reference conditions concept in a large Mediterranean basin. *Aquatic Conservation: Marine and Freshwater Ecosystems* 31(4): 888–902.
- Reeves GH, Bisson PA, Dambacher JM (1998) Fish communities. In: Naiman RJ, Bilby RE (ed) *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*. Springer, New York.
- Reventa C, Mock G (2000) Freshwater biodiversity in crisis. *Earth Trends World Resources Institute*: 1–4. (<http://earth-trends.wri.org>).
- Reventa C, Kura Y (2003) Status and trends of biodiversity of inland water ecosystems. Technical series number 11. Montreal, QC: Secretariat of the Convention on Biological Diversity
- Reynolds, JB (1996) Electrofishing. In: Murphy BR, Willis DW (ed) *Fisheries Techniques*, second ed. American Fisheries Society, Bethesda, pp. 221–253.
- Ribeiro F, Leunda PM (2012) Non-native fish impacts on Mediterranean freshwater ecosystems: current knowledge and research needs. *Fisheries Management and Ecology* 19: 142–156, <https://doi.org/10.1111/j.1365-2400.2011.00842.x>
- Rodríguez Díaz JA, Weatherhead EK, Knox JW, Camacho E (2007) Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain. *Regional Environmental Change* 7:149–159
- Ruiz J, Losada MA, Polo MJ, García J (2010) Propuesta metodológica para diagnosticar y pronosticar las consecuencias de las actuaciones humanas en el estuario del Guadalquivir. Informe técnico. Instituto de Ciencias Marinas de Andalucía, Consejo Superior de Investigaciones Científicas; Grupo de Dinámica de Flujos Ambientales, Centro Andaluz de Medio

- Ambiente – Universidad de Granada; Grupo de Dinámica Fluvial e Hidrología, Universidad de Córdoba; Grupo Albiotox, Universidad Complutense. Complutense. Puerto de Sevilla. Sevilla.
- Ruiz J, Polo MJ, Díez-Minguito M, Navarro G, Morris EP, Huertas E, Caballero I, Contreras E, Losada MA (2015) The Guadalquivir estuary: a hot spot for environmental and human conflicts. Chapter 8. p. 199- 232. In: Environmental Management and Governance. Advances in Coastal and Marine Resources. Finkl, C.W., Makowski, C. (Eds). Springer, London.
- Sáez-Gómez P, Prenda J (2019) Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain). *BioInvasions Records* 8:924–932
- Sáez-Gómez P, Ramos-Merchante A, Prenda, J. (2020). Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses. *Aquatic Ecology* 54(3): 869-887.
- Sáez-Gómez P, Prenda J. (2022). Freshwater Fish Biodiversity in a Large Mediterranean Basin (Guadalquivir River, S Spain): Patterns, Threats, Status and Conservation. *Diversity* 14(10): 831. <https://doi.org/10.3390/d14100831>.
- Saunders DL, Meeuwing JJ, Vincent CJ (2002) Freshwater protected areas: strategies for conservation. *Conservation Biology* 16:30-41.
- Scharf EA. (2014) Deep time: the emerging role of archaeology in land-scape ecology. *Landscape Ecology* 29: 563–569.
- Schlosser IJ (1982) Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs* 52:395–414
- Sheldon AL (1968) Species diversity and longitudinal succession in stream fishes. *Ecology* 49:193-198.
- Sing T, Sander O, Beerenwinkel N, Lengauer T (2005) ROCr: visualizing classifier performance in R. *Bioinformatics* 21(20):7881
- Smith KG, Darwall WRT (ed) (2006). *The Status and Distribution of Freshwater Fish Endemic to the Mediterranean Basin*. IUCN, Gland, Switzerland and Cambridge.
- Stanley EH, Doyle MW (2003) Trading off: the ecological effects of dam removal. *Frontiers in Ecology and Environment* 1(1):15-22.
- Stoddard JL, Larsen DP, Hawkins CP, Johnson RK, Norris RH. (2006). Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological Applications* 16(4): 1267-1276.
- Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) *Handbook of applied hydrology*. New York, McGraw-Hill.
- Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. *Journal of*

- the North American Benthological Society 29:344–358
- Su G, Logez M, Xu J, Tao S, Villéger S, Brosse, S. (2021). Human impacts on global freshwater fish biodiversity. *Science* 371(6531): 835–838. <https://doi.org/10.1126/science.abd3369>
- Swetnam TW, Allen CD, Betancourt JL. (1999) Applied historical ecology: using the past to manage for the future. *Ecological Applications* 9: 1189–1206.
- Szabo P, Hedl R. (2011) Advancing the integration of history and ecology for conservation. *Conservation Biology* 25: 680–687.
- ter Braak CJF (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67:1167–1179
- ter Braak CJF (1987) CANOCO-A fortran program for canonical community ordination by [partial][detrended][canonical] correspondence analysis (version 2.1.). ITI-TNO Institut of Applied Computer Sciences, Wageningen, The Netherlands
- ter Braak CJ (1990) Update notes: CANOCO, version 3.10, p 35
- ter Braak CJ, Verdonschot PF (1995) Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquat Sci* 57:255–289
- ter Braak CJ, Smilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). www.canoco.com.
- Tonn WM, Magnuson JJ, Rask M, Toivonen J (1990) Intercontinental comparison of small-lake fish assemblages: the balance between local and regional processes. *The American Naturalist* 136:345–375
- Troia MJ, Gido KB (2015) Functional strategies drive community assembly of stream fishes along environmental gradients and across spatial scales. *Oecologia* 177:545–559
- van der Veer G, Nentwig W (2015) Environmental and economic impact assessment of alien and invasive fish species in Europe using the generic impact scoring system. *Ecology of Freshwater Fish* 24: 646–656, <https://doi.org/10.1111/eff.12181>
- Vargas J, Paneque P (2015) Major Hydraulic Projects, Coalitions and Conflict. Seville's Harbour and the Dredging of the Guadalquivir (Spain). *Water* 7(12):6736–6749.
- Viana DS, Blanco-Garrido F, Delibes M, Clavero M. (2022). A 16th century biodiversity and crop inventory. *Ecology*: e3783.
- Vinyoles D, Robalo JI, de Sostoa A, Almodovar A, Elvira B, Nicola GG, Fernández-Delgado C, Santos CS, Doadrio I, Sarda-Palomer F, Almada VC (2007). Spread of the alien bleak *Alburnus alburnus* (Linnaeus, 1758) (Actinopterygii, Cyprinidae) in the Iberian Peninsula: the role of reservoirs. *Graellsia* 61(1):101–110.
- Vila-Gispert A, García-Berthou E, Moreno-Amich R (2002) Fish zonation in a Mediterranean stream: Effects of human disturbances. *Aquat Sci Res Across Bound* 64:163–170

- Villéger S, Blanchet S, Beauchard O, Oberdorff T, Brosse S. (2011). Homogenization patterns of the world's freshwater fish faunas. *Proceedings of the National Academy of Sciences* 108(44): 18003-18008.
- Walsh C, Mac Nally R (2008) hier.part: hierarchical partitioning. R package version 1.0.3. Vienna, Austria: R Foundation for Statistical Computing.
- Wang L, Lyons J, Kanehl P, Bannerman R (2001) Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* 28:255-266
- Wang L, Lyons J, Rasmussen P, Seelbach P, Simon T, Wiley M, Kanehl P, Baker E, Niemela S, Stewart PM (2003) Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 60:491-505
- Wang L, Seelbach PW, Lyons J (2006) Effects of levels of human disturbance on the influence of catchment, riparian, and reach-scale factors on fish assemblages. *American Fisheries Society Symposium* 48(48):641-664.
- Willis KJ, Birks HJB. (2006) What is natural? The need for a long-term perspective in biodiversity conservation. *Science* 314: 1261-1265.
- Yackulic CB, Sanderson EW, Uriarte M. (2011). Anthropogenic and environmental drivers of modern range loss in large mammals. *Proceedings of the National Academy of Sciences* 108(10): 4024-4029.
- Yoon JD, Kim JH, Byeon MS, Yang HJ, Park JY, Shim JH, Song HB, Yang H, Jang MH (2011) Distribution patterns of fish communities with respect to environmental gradients in Korean streams. *Annales de Limnologie-International Journal of Limnology* 47:S63-S71



Agradecimientos

Agradecimientos

No sabría concretar el número de veces que me he imaginado escribiendo estas líneas, como síntoma inequívoco de que el final de este largo camino estaría cerca. No creo que encuentre mejor momento ni sitio que el actual, con vistas al Canal Beagle, para echar la vista atrás e intentar agradecer toda la ayuda y apoyo que he recibido en estos años.

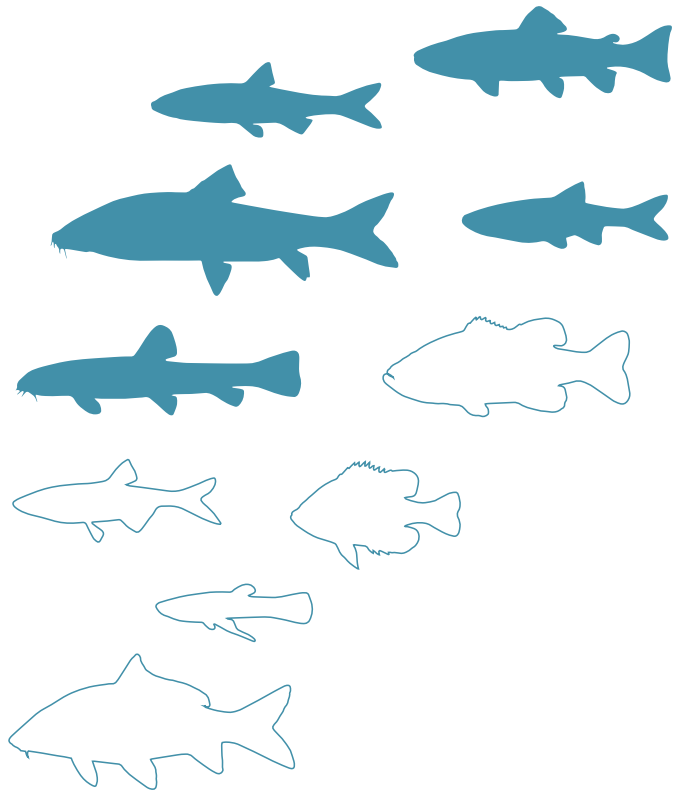
A mi familia (biológica), sin la que nada hubiese sido posible, ni esta tesis ni casi nada. Mi madre es tan autora (o más) de este trabajo ya que creyó en mí incluso cuando ni yo mismo lo hacía. A ella le debo, además de la vida, tantas cosas que necesitaría otra tesis para poder detallarlas. Gracias a mi padre me acerqué desde muy pequeño al campo y me enseñó a observarlo y respetarlo. A ambos les debo mi pasión por la naturaleza y la curiosidad por estudiarla y comprenderla. Aquellos lejanos e interminables veranos explorando las dunas y las marismas del Guadiana y el Carreras han llegado a proyectarse de alguna manera en esta Tesis Doctoral. Mi adorada ‘hermanísima’ María, mi hermano Manolo y mis ‘hijos’ Isabel y Manuel han sido pilares fundamentales para que esta tesis haya tenido lugar. Vuestra ayuda ha sido crucial, aunque a veces no fuerais conscientes de ello. A mi familia de ‘gamberros’ de ‘Saber Vivir’ (David, Marcelo, Luises, Pablo, Alberto, José Enrique, Ale y Estepa) y a todos los buenos amigos que de algún modo han estado ayudándome en este tiempo (p. ej. primo Carlos, Juan Rivero, toda la familia *Nightjaring*, etc, etc, etc), aunque fuera ‘solo’ aguantándome, cerveza en mano, mis frustraciones y torpezas. Enrique, ya no solo vamos a pescar con caña sino que intentamos conservar esos peces que tanto nos entusiasman.

Un agradecimiento especial requiere mi director de tesis, José Prenda. Gracias Pepe por confiar en mí para realizar esta tesis y ofrecerme la posibilidad de trabajar haciendo Ciencia, algo de lo que siempre te estaré agradecido. Gracias también a mi compañero Adrián Ramos de la UHU que siempre estuvo dispuesto a ayudar y echar una mano cuando hizo falta.

Mis compañeros 'pajareros' han significado mucho para mí en estos años, aunque a más de uno le sorprenderá no encontrar ninguna pluma de chotacabras o ricotí en estas páginas. Gracias Germán y Cristian por estos años trabajando juntos (y los que nos quedan). Habéis sido para mí un gran descubrimiento personal y profesional. Camacho! No digo *ná* y te lo digo *tó*! Gracias por estar. Seguiremos caminando juntos y levantándonos con los ojos humeantes.

Estoy convencido de que me dejo a mucha gente sin mencionar, no me lo tengáis en cuenta ;) Gracias!

Puerto Williams, 11 de julio de 2022



Anexos

ANEXOS

El artículo “Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses” ha sido retirado del apartado Anexos debido a restricciones relativas a derechos de autor. En sustitución de éste, ofrecemos la siguiente información: referencia bibliográfica, enlace al artículo y resumen.

- Sáez-Gómez, P., Ramos-Merchante, A., & Prenda, J. (2020). Multiscale effects on freshwater fish distribution in a highly disturbed Mediterranean-type basin: community-level and species-level responses. In *Aquatic Ecology* (Vol. 54, Issue 3, pp. 869–887). Springer Science and Business Media LLC. <https://doi.org/10.1007/s10452-020-09783-9>

Enlace al texto completo: <https://doi.org/10.1007/s10452-020-09783-9>

Resumen:

Fish–habitat relationships are a key element for conservation and management strategies, especially in highly disturbed areas where fish communities are subjected to many human pressures. In this regard, multiscale studies help to improve the knowledge of the spatial components and identify local (e.g. water width) and regional (e.g. elevation) key variables in species distribution. We examined local and regional requirements to study freshwater fish assemblage and occurrence at 216 locations in a highly disturbed basin, the Guadalquivir River Basin (S Spain). Fifteen environmental variables were considered at local scale and twenty at regional level. A total of eighteen species were captured during field sampling. The global prevalence for introduced species was 25%, which can be considered a high value. The most extended introduced species were eastern mosquitofish (*Gambusia holbrooki*) and pumpkinseed (*Lepomis gibbosus*), with around 10% prevalence. Regional and local scales showed different relevance according to the level-study approach (community or species). At the community level, the local, regional and shared components revealed similar influence on the fish assemblage, while at individual species level the local component was the main factor to explain most of fish occurrences. Moreover, variables’ interaction was scarcely selected and almost no introduced species distribution was affected by the interaction of any variable. Our results highlight the poor conservation status of the native fish fauna of the Guadalquivir River Basin as well as the importance of analyzing fish–habitat relationships at different scales and approach. These results provide useful information to assess and design conservation strategies in Mediterranean-type basin.



Article

Freshwater Fish Biodiversity in a Large Mediterranean Basin (Guadalquivir River, S Spain): Patterns, Threats, Status and Conservation

Pedro Sáez-Gómez and José Prenda *

Department of Integrative Sciences, University of Huelva, 21071 Huelva, Spain

* Correspondence: jprenda@uhu.es

Abstract: The Guadalquivir River Basin is one of the largest in the Iberian Peninsula and has a remarkable freshwater biodiversity. Although many studies on hydrological regimes or water quality have been conducted in this basin the biodiversity of freshwater fish, as well as their distribution and conservation status, has never been globally addressed as in other Iberian basins. In this context, we synthesized information on freshwater fish using field procedures and a bibliographic search. Fish distribution patterns at different spatial scales and general environmental conditions were analyzed as well as the conservation status of the fish community. We documented the presence of 40 species (20 native and 20 exotic) in the basin during the 20th century until today. However, we only captured 18 species during the field sampling, with a prevalence for any native species of less than 23% (except *Luciobarbus sclateri*). The highest species richness was found in mid reaches, while the lower reaches had very low diversity values. Around 50% of species are threatened; according to the IUCN, several species are declining at an alarming rate and others are probably extinct and/or their current status is unknown. Human disturbances during the last few decades have caused serious changes in fish distribution and consequently to their conservation status. Hydrological alterations, intensive agriculture and introduced species are probably the principal reasons for Guadalquivir's ichthyofauna imperilment. Our study indicates an urgent and real need to identify important areas for fish conservation to guarantee a minimum fish biodiversity conservation over the long term, as well as effective strategies for fish recovery where it still is possible.

Keywords: fish fauna; Guadalquivir; distribution; ichthyofauna; Iberian Peninsula

Citation: Sáez-Gómez, P.; Prenda, J. Freshwater Fish Biodiversity in a Large Mediterranean Basin (Guadalquivir River, S Spain): Patterns, Threats, Status and Conservation. *Diversity* **2022**, *14*, 831. <https://doi.org/10.3390/d14100831>

Academic Editor:
Moreira da Costa Luis

Received: 12 September 2022
Accepted: 30 September 2022
Published: 3 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Freshwater ecosystems are the richest and most diverse ecosystems on earth and also one of the most threatened [1,2]. Their biodiversity is being reduced at an alarming rate, especially in arid and semi-arid regions where water demand for human uses is increasing (e.g., Mediterranean areas) [1,3–5]. At a European level, the conservation status of aquatic species is very poor, as 44% of freshwater mollusks, 37% of freshwater fishes and 23% of amphibians are threatened [6]. Freshwater fish are a basic element of this biodiversity, representing one-fourth of all living vertebrate species, the world's most endangered vertebrate group after amphibians and the most species-rich group among European vertebrates (546 fish species) [7–10]. European freshwater fish fauna consists of 12% critically endangered species, 10% endangered, 15% vulnerable and 4% species near-threatened. This is one of the highest levels of threat of any important taxonomic group ever evaluated in Europe [6,9,10].

In Mediterranean areas, where freshwater biodiversity is highly endemic [11], the World Conservation Union estimates that around 56% of endemic freshwater fish species are threatened: 18% critically endangered, 18% endangered and 20% vulnerable [5]. In

this context, there is an urgent need for a permanently updated knowledge of the structure, diversity and distribution of Mediterranean freshwater fish communities due to the continual increase in human pressures on lands and resources in the Mediterranean (e.g., [12,13]).

The ecological status of the Guadalquivir River Basin is one of the least known in the Iberian Peninsula, despite its significant relevance in terms of area (around 10% of the Iberian land surface), biodiversity (one-third of Iberian fish species inhabit or have recently inhabited this basin; see results), impacts [14–17] and the high number of threatened species that inhabit it [11]. Before the 20th century, the fish fauna of the Guadalquivir was characterized, compared to other Iberian basins, by a diverse community of migratory species (catadromous and anadromous). These species constituted an important economic resource for many nearby towns [18]. However, the construction of reservoirs in the canal, as well as in the tributaries, was the main factor in the decline/extinction of these species [18]. Since the beginning of the 20th century, more than 150 reservoirs have been built in the basin, eleven of them in the main course of the river, which have isolated large sectors of the basin and blocked the migratory movements of many species [18]. One of the first inventories of species in the basin was carried out in 1989, which included a list of 19 native and introduced species with places and dates of capture in the basin [19]. However, the diversity, conservation status and distribution pattern of Guadalquivir's fish have rarely been addressed at a whole-basin level. Around 50% of native species recorded in the basin are threatened [10]. At a national scale, more than 85% of native species recorded in the Guadalquivir Basin are endangered [20]. At a regional scale, the information available is very scarce. The regional Red Data Book includes 15 endangered species and one that is extinct [21]. These data show the need for an urgent updating of the conservation status and threats to Guadalquivir's ichthyofauna; several species may be extinct nowadays and others are about to be so, while the introduction of exotic species continues to increase. A continuous monitoring program would also be necessary to assess population trends and to carry out real management and conservation strategies based on the actual status of this freshwater biodiversity component [22,23].

In this study, we examined the diversity, distribution and conservation status of the Guadalquivir River Basin's freshwater fish fauna. The specific objectives were: (1) to provide a complete list of the Guadalquivir fish fauna recorded from the 20th century to the present, (2) to determine current patterns of general fish distribution, richness and diversity, (3) to determine the conservation status of fish fauna in the basin and (4) to make recommendations for fish biodiversity conservation in the Guadalquivir River Basin.

2. Materials and Methods

2.1. Study Area

The Guadalquivir River is located in the south of the Iberian Peninsula, flowing west to the Atlantic Ocean. The main channel is 680 km in length, the fifth longest river in the Iberian Peninsula. The basin presents 80 main tributaries (basin areas between 12.6 km² and 8255.6 km²) with a total drainage area of 57,439 km² and an average human population density of 69.6 hab/km² [24]. The basin has a typical Mediterranean hydrological regime with high intra- and inter-annual discharge variation [24–26].

The basin faces intense direct and indirect human pressures, mostly from agriculture [15,27], flow regulation (often related to agriculture), species introductions [28] and wastewater disposal ([29]; see Table 1). Agriculture has been undergoing major changes in Southern Spain since the end of the 1980s. A sharp change is taking place: from traditional non-irrigated extensive agriculture of typical Mediterranean crops (wheat, olives and wine) to a new, intensive, industrial and irrigated agricultural model, with high soil erosion levels, water abstraction and/or flow regulation, pesticide disposal and many other side effects (Table 1). A main consequence of these recent agricultural changes, usu-

ally associated with an increase in irrigated olive groves, is the introduction of an extraordinary suspended solid-loading into the drainage network that causes extreme levels in water turbidity [17]. The values of suspended sediment concentration (600 mg L^{-1}) registered by Ruiz et al. [30] in the main river channel are among the highest known in the world, two and three times greater than that of the Danube (326 mg L^{-1}) and Amazon (200 mg L^{-1}), respectively [17]. These values are mainly located in the lower Guadalquivir reaches. This is seriously affecting the fish community and its nursery function, a well-known phenomenon in the Guadalquivir estuary [31].

Table 1. Guadalquivir River Basin environmental characteristics (data source: Confederación Hidrográfica del Guadalquivir: <http://www.chguadalquivir.es/demarcacion-hidrografica-guadalquivir#PlanHidrológicodelGuadalquivir2009-2015> (accessed on 23 July 2021). * ‘Dehesa’ is a particular Mediterranean ecosystem where man has removed bushes to improve the farm [32].

	Count	hm ³ /year	km ²	%
Environmental information				
Human population (n° inhabitants)	4,141,635			
Municipality (n°)	429			
Annual average rainfall (mm) (1942–2005)	561			
Annual average contribution		7043		
Average net provision (m ³ /ha/year)	2906			
Olive water demand (m ³ /ha/year)	1500			
Environmental quality (n° water mass)				
Good or moderate ecological status	252			56.9
Poor or bad ecological status	191			43.1
Chemical status (n° water mass)				
Good chemical status				46.1
Bad chemical status				53.9
N° pollution discharges	1719			
Water use				
Supply		436.41		10.9
Industry		36.26		0.9
Agriculture		3504.06		87.4
Energy		31		0.8
Land use				
Irrigated crops			8460	14.7
Rainfed cultivation			24,000	41.8
Forests			7140	12.4
Scrublands			10,000	17.4
Dehesas *			4000	7.0
Grasslands			1400	2.4
Bare or sparsely vegetated land			829	1.4
Water (lagoons, marshes, reservoirs, etc.)			880	1.5
Unproductive soil (urban áreas, roads, etc.)			730	1.3

The flow of the Guadalquivir Basin is fully regulated. Thus, the water supply cannot be increased, but demand continues to rise more or less uncontrollably [33]. The number of reservoirs has reached a maximum. About 9193 hm³ of river flow is nowadays retained in 29 large reservoirs (>100 hm³) and more than 140 smaller ones (<100 hm³) [34]. There

are also numerous cut-offs, channeling and dredging works to promote river traffic, especially in the lower reaches of the river [18,35]. As a consequence, the natural flow pattern of the main channel has been strongly modified. With respect to ecological status, according to the European Water Framework Directive (WFD; 2000/60/EC), 43% of all inland water bodies have poor or low level quality ([24], Table 1).

The Guadalquivir Basin displays a strong environmental asymmetry with respect to both left and right margins. Geology, physiography, climate and human pressure all vary. The right margin is located within the Iberian Massif, a low relief mountain range covered with oak forests and dehesas and characterized by a very low human population density, mostly devoted to marginal mountain agriculture and especially extensive farming and cattle raising. This area has a high conservation value and most of it is protected as several natural parks. The left margin corresponds to Cenozoic basins and the Betic Mountain chain. This is a highly developed flat land covered by intensive agriculture (irrigated and non-irrigated). Human population density is very high, and human pressures, in general, are correspondingly high.

2.2. Data Collection

We obtained fish data via field sampling and a bibliographic search. Sampling was conducted at 285 locations over the entire basin (216 in rivers and 69 in reservoirs) between June–September 2007 (reservoirs) and March–July 2008 (rivers) (Figure 1). The 285 sampling locations were distributed at random within 46 different sub-basins (including the main channel) that represented 56.3% of the total number of sub-basins and 96.1% of the total basin area, respectively (Figure 1).

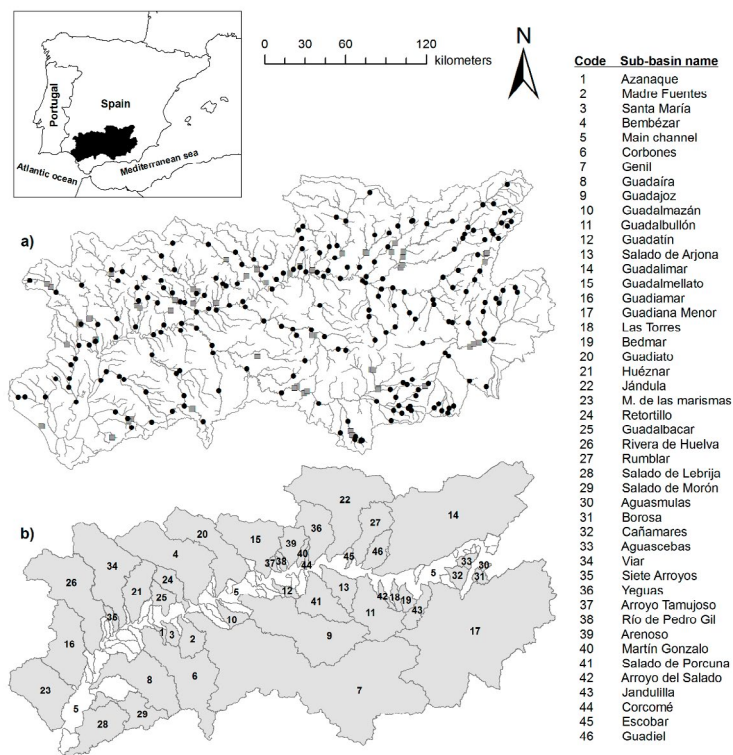


Figure 1. Map of the Guadalquivir River Basin. (a) Fish sampling sites: filled circles indicate rivers ($n = 216$) and grey squares denote reservoirs ($n = 69$). (b) Map of sub-basins sampled (gray color) and main channel (code-number 5) in the Guadalquivir River Basin. The code-number indicates the name for each sub-basin.

Depending on location width and depth, two alternative sampling methods were used. A combination of different fishing methods is an appropriate option for sampling a wide range of habitats, species and fish sizes [36–39]. Typical stream sites with low salinity ($<1.5 \text{ mS cm}^{-1}$) and shallow depth ($<1.2 \text{ m}$) were electrofished by wading upstream along a channel length of 100 m during approximately one hour. The equipment comprised a control box delivering a pulsed direct current, 300/600 V, 4–6 A without block nets (Electracatch International, Honda EU 20i motor with a WF6 rectifier and a landing net with a 30 cm diameter and a 4 mm mesh size). The relative density was calculated for all captured species at all sampling points as catches per unit effort (hereafter, CPUE). The CPUE was defined as the number of individuals captured per 100 m stream length per hour sampling.

When the salinity and depth conditions did not allow electrofishing, mainly in large rivers and reservoirs, we used four types of passive traps: trammel nets, fyke nets, minnow traps and plastic bottle minnow traps. Two trammel nets ($10 \text{ m} \times 2 \text{ m}$, $175 \text{ mm} \times 25 \text{ mm}$ and $200 \text{ mm} \times 20 \text{ mm}$ mesh size), three pairs of fyke nets (12 mm and 3 mm mesh size), fifteen metal minnow traps (6 mm mesh size) and ten pairs of plastic minnow traps (25 mm inlet) were set for a minimum of 8 h (see [38] for more details). After capture, fish

were identified to species level, counted, measured and returned live to the river. The CPUE was defined here as individuals captured in the aforementioned trap combination (2 trammel nets + 3 pairs of fyke nets + 15 metallic mesh minnow traps + 10 pairs of plastic bottle minnow traps) per 12 h sampling.

A bibliographic search was performed for all fish species recorded in the Guadalquivir River Basin throughout the 20th century to develop a second presence/absence historical data set. This search covered scientific journals, technical reports, books and daily press with potential information on freshwater fish distribution. The Carta Piscícola Española (<http://www.cartapiscicola.es> accessed on 27 September 2022), and the International Standardization of Common Names for Iberian Endemic Freshwater Fishes [40] was used for scientific and common fish nomenclature, respectively.

2.3. Data Analysis

Shannon (H') alpha diversity index (see [41]) and species richness values were compared at different scales and habitats using Kruskal–Wallis tests and Dunn’s post test. All analyses were performed in SPSS Statistics® v. 21 [42]. The Shannon (H') index was calculated with PAST® (v.2.14) [43].

3. Results

3.1. Faunal Composition

In an Iberian context, the Guadalquivir’s ichthyofauna has great relevance as 31.1% of all native Iberian species live or have recently inhabited the Guadalquivir River Basin (Table 2), although it merely encompasses 9.8% of the total surface area of the Iberian Peninsula and only three families of native fish are not found in the basin. In particular, migratory species are very well represented, accounting for 54.5% of all Iberian species (Table 2). Cyprinidae is the richest family (both for native and exotic species) in the basin constituting 21.6% of Iberian species (Table 2) and 55.4% of the sampled species (Figure 2). Also, introduced species are widely represented in the Guadalquivir Basin with 48.4% of the total species recorded in Iberia (Table 2).

Table 2. Families and number (%) of Iberian freshwater fish species recorded in the Guadalquivir River Basin. Sources: Carta Piscícola Española for Spanish data (<http://www.cartapiscicola.es>, accessed on 27 September 2022) and Fishbase for Portuguese data (http://www.fishbase.org/Country/CountryChecklist.php?showAll=yes&c_code=620&vhabitat=fresh, accessed on 15 July 2022). * *Tinca tinca* is considered introduced according [44].

	Family	Iberian Peninsula	Guadalquivir
Native	Petromyzontidae	6	1 (16.7)
	Acipenseridae	1	1 (100)
	Clupeidae	2	2 (100)
	Anguillidae	1	1 (100)
	Salmonidae	2	1 (50)
	Cyprinidae	37	8 (21.6)
	Cobitidae	3	1 (33.3)
	Nemacheilidae	1	0 (0)
	Cyprinodontidae	2	1 (50)
	Valenciidae	1	0 (0)
	Atherinidae	1	1 (100)
	Gasterosteidae	1	1 (100)
	Cottidae	2	0 (0)
	Blenniidae	1	1 (100)
	TOTAL	61	19 (31.1)
Introduced	Salmonidae	4	1 (25.0)
	Esocidae	1	1 (100)
	Cyprinidae	11 *	6 (54.5)

Cobitidae	1	0 (0)
Nemacheilidae	1	0 (0)
Ictaluridae	2	1 (50)
Siluridae	1	1 (100)
Cyprinodontidae	1	0 (0)
Fundulidae	1	1 (100)
Poeciliidae	3	1 (33.3)
Cichlidae	1	1 (100)
Centrarchidae	2	2 (100)
Percidae	2	0 (0)
TOTAL	31	15 (48.4)

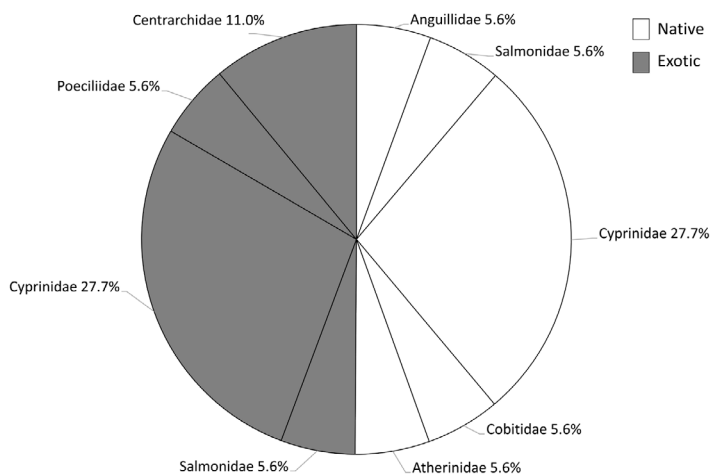


Figure 2. Percent of species number of the total families found in the Guadalquivir River Basin during the sampling sessions.

During fieldwork a total of 18 fish species (9 native, 7 introduced and 2 translocated) were captured in the Guadalquivir River Basin (see Table S1 for sub-basin details). In addition, the bibliographic search revealed the presence of at least 22 additional species (11 native and 11 exotic) during the 20th century. Just over 18% of the sampled locations were apparently fishless (after 197.7 h spent electric fishing and 3578.7 m traversed at these points), all of them located in rivers (24% of all river locations). Cyprinidae was clearly the family with the greatest number of native and exotic sampled species, accounting in total for more than 50% of species richness (Figure 2). Species undetected during field sessions either have very low densities or they are extinct (see below).

3.1.1. Sampled Species

Seven native primary freshwater fish species were captured (Table 3): brown trout (*Salmo trutta* Linnaeus, 1758), southern Iberian barbel (*Luciobarbus sclateri* (Günther, 1868)), Iberian arched-mouth nase (*Iberochondrostoma lemmingii* (Steindachner, 1866)), southern straight-mouth nase (*Pseudochondrostoma willkommii* (Steindachner, 1866)), calandino (*Squalius alburnoides* (Steindachner, 1866)), southern Iberian chub (*Squalius pyrenaicus* (Günther, 1868)), southern Iberian spined-loach (*Cobitis paludica* (de Buen, 1930)), and big-scale sand smelt (*Atherina boyeri* Risso, 1810), as well as one migratory species, European eel (*Anguilla anguilla* (Linnaeus, 1758)). The introduced exotic species captured included:

rainbow trout (*Oncorhynchus mykiss* (Walbaum, 1792)), bleak (*Alburnus alburnus* (Linnaeus, 1758)), goldfish (*Carassius auratus* (Linnaeus, 1758)), common carp (*Cyprinus carpio* Linnaeus, 1758), eastern mosquitofish (*Gambusia holbrooki* Girard, 1859), pumpkinseed [*Lepomis gibbosus* (Linnaeus, 1758)] and largemouth bass (*Micropterus salmoides* (Lacépède, 1802)). The introduced translocated species (presumably from other Iberian river basins) were Pyrenean gudgeon (*Gobio lozanoi* Doadrio and Madeira, 2004) and a minnow species of unknown origin (*Phoxinus* spp.), probably the Pyrenean minnow (*Phoxinus bigerri* Kottelat, 2007) (Table 3). All native species had a very restricted distribution (prevalence less than 23%), except the southern Iberian barbel, which is the most widespread (a prevalence of 58.6%; see Table 3) and abundant species (more than 50% of the total captured fish) throughout the basin. Four species had prevalence values between 10% and 23%, and the four remaining species were present at less than 9% of the sampled sites. Excluding the southern Iberian barbel, the average prevalence of native fish was 9.8%. Among the locations with fishes, 42.1% presented at least one introduced species. *Atherina boyeri* is not a primary freshwater species; however, in the Guadalquivir basin there is an exclusively freshwater population (Zóñar pond) [20] and far from any contact with the coast (>100 km), so we decided to include it in this study.

Largemouth bass and common carp were the most common exotic species (23.5% and 22.1% of the sampled sites, respectively), followed by pumpkinseed (18.6%) and eastern mosquitofish (16.1%). The other species had prevalence values below 10% (Table 3). There are marked differences between native vs. introduced species prevalence in lotic environments, where the first are largely distributed (71.8% and 25.0%, respectively). Lentic environments, on the contrary, do not differ greatly, showing a prevalence of 91.3% for native species and 95.7% for introduced ones.

Table 3. List of native and exotic freshwater fishes detected during the field sampling. Threat categories are referred to IUCN Red List [10] and Red book of Spanish freshwater fish, RBSF [20]. CR: Critically endangered; EN: endangered; VU: vulnerable; LC: least concern.

	Family	Species	IUCN (2022)	RBSF (2001)	Prevalence (%) (n = 285)
Native	Anguillidae	<i>Anguilla anguilla</i>	CR	VU	0.7
	Salmonidae	<i>Salmo trutta</i>	LC	VU	11.9
	Cyprinidae	<i>Luciobarbus sclateri</i>	LC	LC	58.6
		<i>Iberochondrostoma lemmingii</i>	VU	VU	2.1
		<i>Pseudochondrostoma willkommii</i>	VU	VU	22.8
		<i>Squalius alburnoides</i>	VU	VU	15.8
		<i>Squalius pyrenaicus</i>	-	VU	8.1
	Cobitidae	<i>Cobitis paludica</i>	VU	VU	15.4
	Atherinidae	<i>Atherina boyeri</i>	LC	VU	1.8
	TOTAL				76.5
Introduced	Salmonidae	<i>Oncorhynchus mykiss</i>			1.8
	Cyprinidae	<i>Alburnus alburnus</i>			8.1
		<i>Carassius auratus</i>			3.5
		<i>Cyprinus carpio</i>			22.1
		<i>Gobio lozanoi</i>			0.4
		<i>Phoxinus</i> spp.			0.4
	Poeciliidae	<i>Gambusia holbrooki</i>			16.1
	Centrarchidae	<i>Lepomis gibbosus</i>			18.6
		<i>Micropterus salmoides</i>			23.5
TOTAL				42.1	

3.1.2. Bibliographic-Recorded Species

A total of 11 native species had been previously recorded in the Guadalquivir River Basin but were not captured in this study (Table 4), including 7 sedentary species: Oretanian arched-mouth nase (*Iberochondrostoma oretanum* (Doadrio and Carmona, 2003)), jarabugo (*Anaocypris hispanica* (Steindachner, 1866)), Iberian long-snout barbel (*Luciobarbus comizo* (Steindachner, 1864)), bogardilla (*Squalius palaciosi* Doadrio, 1980), three-spined stickleback (*Gasterosteus aculeatus* Linnaeus, 1758), freshwater blenny (*Salaria fluviatilis* Asso y del Rio, 1801), and baetican toothcarp (*Aphanius baeticus* (Doadrio, Carmona and Fernández-Delgado, 2002)); and 4 migratory species: Atlantic sturgeon (*Acipenser sturio* Linnaeus, 1758), sea lamprey (*Petromyzon marinus* Linnaeus, 1758), allis shad [*Alosa alosa* (Linnaeus, 1758)] and twaite shad [*Alosa fallax* (Lacépède, 1803)].

Some of these species may have gone extinct locally (e.g., Atlantic sturgeon, allis shad, three-spined stickleback and bogardilla) [18,20,45]. Others have been recently described (e.g., baetican toothcarp, Oretanian arched-mouth nase) [46,47] or have a very small distribution range (e.g., jarabugo) [48]. Iberian long-snout barbel and freshwater blenny records, according to Doadrio [20], have to be considered with caution and need to be checked [see 20].

Other records for 11 additional exotic species were obtained in the bibliographic search: tench (*Tinca tinca* (Linnaeus, 1758)), mummichog (*Fundulus heteroclitus* (Linnaeus, 1766)), black bullhead (*Ameiurus melas* (Rafinesque, 1820)), European catfish (*Silurus glanis* Linnaeus, 1758), Siberian sturgeon (*Acipenser baerii* Brandt, 1869), Adriatic sturgeon (*Acipenser naccarii* Bonaparte, 1836), northern pike (*Esox lucius* Linnaeus, 1758), oscar (*Astronotus ocellatus* (Agassiz, 1831)), chameleon cichlid (*Australoheros facetus* (Jenyns, 1842)), pirapitinga (*Piaractus brachypomus* (Cuvier, 1818)) and *Hypostomus* sp. (Table 4). Some of these species have been well established in the basin and surrounding areas for many years (e.g., mummichog, tench) [44,49], whereas others were recently introduced (e.g., black bullhead, European catfish) [50,51]. The probable historical presence of the Adriatic sturgeon has been a matter of debate, leading to several studies to either confirm or reject its occurrence [52–54], but there is still no consensus within the scientific community. However, some Adriatic sturgeon (>25 kg weight) that escaped from fish farms have been captured by anglers (authors' unpublished data). The status of this, and the rest of the introduced species that have been cited in the literature, is currently unknown.

Table 4. List of native and exotic freshwater fishes detected during the bibliographic search. Threat categories are referred to IUCN Red List [10] and Red book of Spanish freshwater fish, RBSF [20]. CR: critically endangered; EN: endangered; VU: vulnerable; LC: least concern. References for each data source ('Ref') are included in the reference list at the end of the article. (*) indicates the species that are still present in the Guadalquivir River Basin. (?) indicates species without data on their current status. *Iberochondrostoma oretanum* is not included in RBSF (2001).

	Family	Species	IUCN (2022)	RBSF (2001)	Ref.	Current Presence	Locally Extinct
Native	Petromyzontidae	<i>Petromyzon marinus</i>	LC	EN	[18,20,55]	*	
	Acipenseridae	<i>Acipenser sturio</i>	CR	CR	[18,20,52,54,56,57]		*
	Clupeidae	<i>Alosa alosa</i>	LC	VU	[18,58]		*
		<i>Alosa fallax</i>	LC	VU	[18,20,59]	*	
	Cyprinidae	<i>Iberochondrostoma oretanum</i>	CR	-	[47]	*	
		<i>Anaocypris hispanica</i>	EN	EN	[48]	*	
		<i>Luciobarbus comizo</i>	VU	VU	[20]		*
		<i>Squalius palaciosi</i>	CR	EN	[20,60]		?
	Cyprinodontidae	<i>Aphanius baeticus</i>	EN	EN	[20,46,58]	*	
	Gasterosteidae	<i>Gasterosteus aculeatus</i>	LC	EN	[45,61]		*
	Blenniidae	<i>Salaria fluviatilis</i>	LC	EN	[20]		?

Introduced	Acipenseridae	<i>Acipenser baerii</i>	[56]	?
		<i>Acipenser naccarii</i>	[52,54]	*
	Esocidae	<i>Esox lucius</i>	[62]	*
	Cyprinidae	<i>Tinca tinca</i>	[20,44]	*
	Ictaluridae	<i>Ameiurus melas</i>	[50,59]	*
	Siluridae	<i>Silurus glanis</i>	[51]	*
	Fundulidae	<i>Fundulus heteroclitus</i>	[20,59,63]	*
	Cichlidae	<i>Astronotus ocellatus</i>	[64,65]	?
		<i>Australoheros facetus</i>	[50]	*
	Characidae	<i>Piaractus brachyomus</i>	[66,67]	?
Loricariidae	<i>Hypostomus</i> sp.	[18]	?	

3.2. Patterns of Species Richness and Diversity

The total fish species richness (both native and exotic) for a given location ranged between 0 and 6 while the Shannon diversity index (H') ranged from 0–1.54 to 0–1.35 for native and exotic species, respectively, (see Table S2 for sub-basin details). A positive correlation was found between native and exotic richness and H' ($r_s = 0.178$, $p < 0.01$ and $r = 0.150$, $p < 0.05$, respectively). In addition, Wilcoxon signed-rank test showed no difference between native and exotic species in Shannon diversity ($Z = -1.36$, $N = 285$, $p > 0.05$), contrary to species richness ($Z = -3.90$, $N = 285$, $p < 0.001$). Therefore, sites with high values of native biodiversity tended to show similar values for exotic biodiversity due to the high penetration of exotic species (overall prevalence of 42.1%; 95.7% for reservoirs and 25% for rivers).

Mean native biodiversity was independent of the type of water body, whether main channel, tributary or reservoir (Figure 3). However, mean exotic biodiversity was clearly overrepresented in reservoirs, which also acted as reservoirs for non-native fish, while they had a minor importance compared to native fauna in tributaries or the main channel (Figure 3). The right margin had higher biodiversity values than the left margin. Finally, with respect to Strahler's order, two different patterns emerged, one for native species and another for exotics. Native biodiversity peaked at order 2 and progressively was reduced until a minimum at locations higher than order 4, while exotics peaked at order 4 following a progressive increase from order 1 (Figure 3) (for all comparisons, Kruskal–Wallis, $p < 0.05$, Dunn's post test).

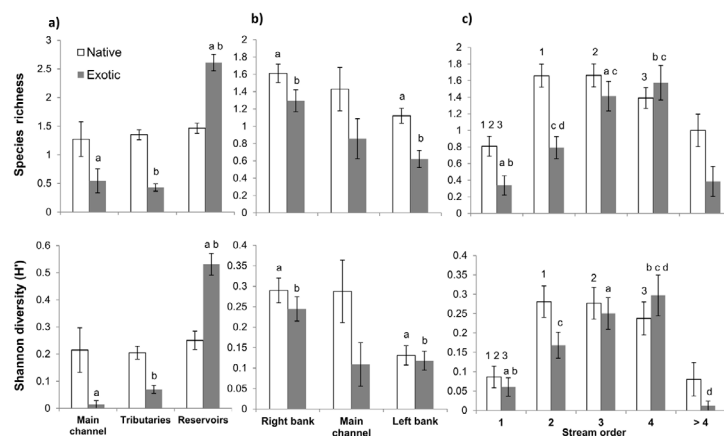


Figure 3. Main fish biodiversity descriptors (average species richness and Shannon H' diversity index) for native and exotic species at different aquatic habitat typologies in the Guadalquivir Basin.

Mainstream, tributaries and reservoirs (a); mainstream, left and right bank tributaries (b) and stream order (c), according to Strahler (1964). Error bars indicate standard error (SE). The same letter above bars shows that values are statistically different (Dunn’s post test; $\alpha = 0.05$) when Kruskal–Wallis $p < 0.05$.

3.3. Conservation Status

To check the fish conservation status of the Guadalquivir River Basin, for each of 46 sub-basins the frequency of species included in any IUCN categories (Least Concern, Vulnerable, Critically Endangered) [10] was calculated (Figure 4). Among the total sub-basins sampled, 13% (n = 6) had no fish fauna and another one contained only exotic species (approximately 3% of total area). The rest of the sub-basins had a quite variable, but generally poor, conservation status (Figure 4). More than half of the sampled species were included in some of the most threatened IUCN categories (Tables 3 and 4). Similarly, 55% of species found in the bibliographical search were also included in some of these IUCN categories (Tables 3 and 4). The left margin presented a higher proportion for Least Concern and Vulnerable categories than the right one, but the right margin had more Critically Endangered species (Figure 4). Despite the existence of critically endangered species in the left bank (according to bibliographic search) they were not detected in the field study.

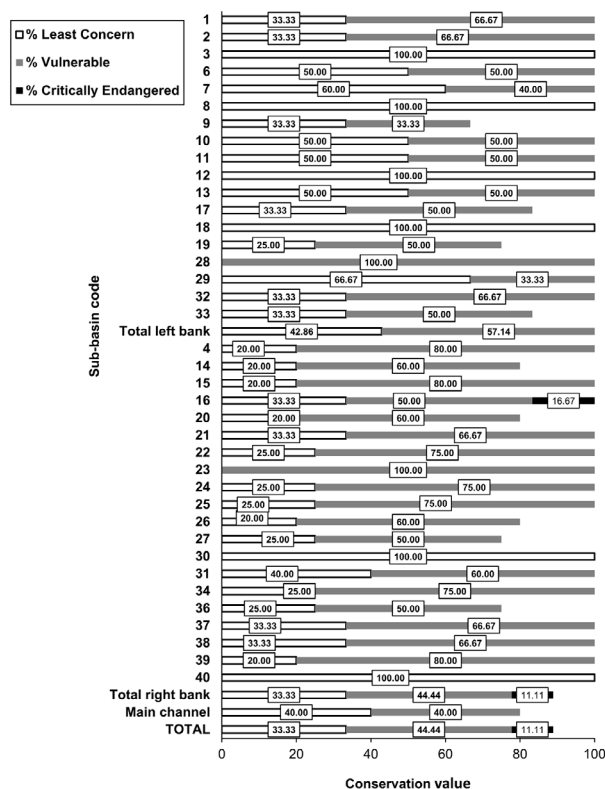


Figure 4. Conservation status (%) of sampled threatened fish species (IUCN red list criteria, version 15.1. July 2022) in different Guadalquivir River sub-basins.

4. Discussion

The Guadalquivir River Basin has a remarkable importance in the context of Mediterranean freshwater fish biodiversity and conservation [5]. Despite not being one of the most diverse basins in the region, it contains a high number of species, many of them endemic [5]. Around one-third of the native species registered in the Iberian Peninsula are nowadays present or have recently inhabited this basin and the species richness found within it is similar to other large Iberian basins (Figure 5).

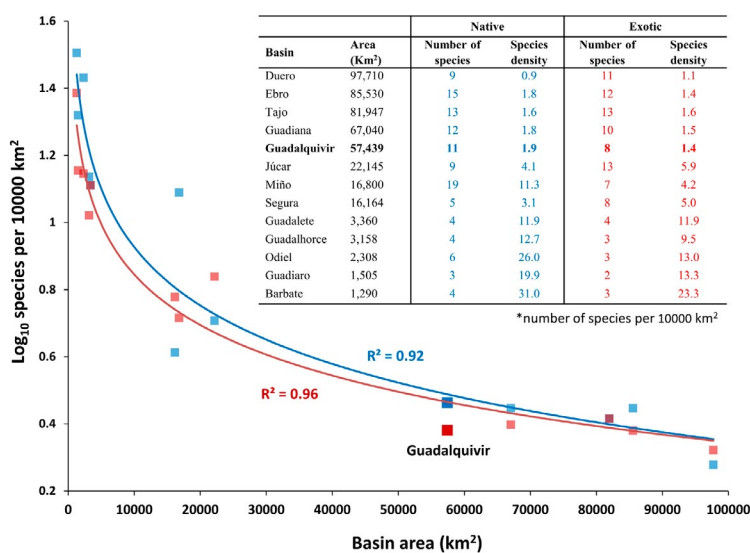


Figure 5. Species density–basin area relationship for the main Iberian basins. Drainage area, freshwater fish number and species density are shown. Raw data from: [28,68,69]. The blue color refers to the native species and the red to the exotic ones.

Changes in the Guadalquivir Basin due to human activities during the last century have greatly modified the ecological characteristics of the water bodies and, subsequently, their fish communities [15,18,31]. During the 20th century, around 30 large dams were built and largely as a consequence of this the irrigated land increased by approximately 7000 km², 83% of the current total irrigated area [24]. This habitat transformation, especially reservoir building, has promoted the spread of exotic species [28] and has numerically reduced or driven to extinction a large proportion of native species, particularly migratory ones [18,70,71]. At the same time, agricultural intensification has markedly increased the discharge of agrochemicals (fertilizers and pesticides) as huge loads of suspended solids, which have greatly increased water turbidity, especially at the lower basin reaches [15,31]. Here, navigation has provoked strong changes in the main channel to reduce the distance from Seville harbour to the sea by more than 70 km [72,73]. This has isolated the main channel from surrounding areas and has allowed the penetration of seawater further upstream, along with different marine species (e.g., *Dicentrarchus labrax*) [18,59].

4.1. Guadalquivir Fish Biodiversity

Iberian freshwater fish are characterized by a small number of families but a high degree of endemism [20]. This may be a consequence of both geographic isolation and stressful ecological conditions derived from the extreme Mediterranean hydrologic regime [20,74]. This is characterized by autumn–winter catastrophic floods and summer droughts that leave many river sections dry during the summer and early autumn [25]. The native ichthyofauna of the Guadalquivir Basin is dominated, as in most Iberian basins, by the Cyprinidae family [69], which is well adapted to the extreme environmental conditions of the Mediterranean climate.

Stream fish community richness tends to increase from headwaters to lower sections of river basins [75–77]. However, this general biodiversity pattern is altered in the Guadalquivir Basin most likely as a response to poor habitat quality in the lower river sections, as has been observed in many highly populated basins in temperate areas [78,79]. Downstream reaches (usually >4 order) have high contamination levels, high prevalence of exotic species and physical habitat disturbances, among other things, that prevent a large number of species from establishing there [79,80].

The positive correlation observed between native and exotic fish richness may indicate that the dominant factors determining native diversity (e.g., competition, disturbance, availability of resources, etc.) are the same as those influencing invasions [81,82]. Here, sites with high values of native richness (a high habitat quality for a large number of species) are more vulnerable to invasion than those places with low diversity. This sharply contrasts with classical ecological theories that contend that diverse communities better resist exotic species invasion [83–85]. It may also be the case that the rivers draining the right margin of the Guadalquivir had higher richness (and a fewer number of sites without fish) for both native and exotic fish than the rivers along the left margin. These latter rivers drain mostly flat, highly productive agricultural land occupied by intensive farming, industrial areas and densely populated human settlements, while those draining the right margin run through mountainous areas covered by natural forests, with low human disturbance and extensive agriculture and cattle raising [24,27].

4.2. Introduced Species

The introduction of exotic species in the Guadalquivir Basin is a general and widespread problem that is heavily threatening the native fauna. It is also causing the homogenization of freshwater biodiversity, a problem largely extending to all Iberian river basins [28,86,87].

Our results point out that most exotic biodiversity is a direct consequence of reservoirs. These human constructions provide the stable lentic habitats to which native fauna is not well adapted, but where, on the contrary, introduced species can thrive, thus acting as exotic species reservoirs, allowing them to disperse from here and to colonize other more or less nearby areas [28,79,88]. Without reservoirs, many of these exotic fish species would not survive in Mediterranean rivers or would do so in very low abundance [79,88]. The altitudinal segregation between native and exotic species is mainly caused by two factors. On the one hand, headwaters are usually isolated areas with low habitat transformation, in many cases included within protected areas [89]. On the other hand, many authors suggest that middle and lower river reaches have better conditions for the settlement of exotic species (slower water and a large cumulative number of reservoirs for downstream exotic fish dispersion) [28,79].

Many exotic species have been introduced and have subsequently proliferated in the Guadalquivir Basin during recent decades. Around 54% of these species have been introduced into Spain during the last century [90]. Fourteen of the detected introduced species (70% of the total) are now well established in the basin and/or are in the process of expansion. Four of these have colonized the basin within the last ten years: (1) bleak [91] and (2) black bullhead [50] are common in the middle and lower stretch of the basin, and finally

(3) European catfish, the latest species detected in the basin [51], which involves a serious threat to regional wildlife [92]. The latter's preference for slow waters may favor its proliferation in the lowest sections of the basin, including the nature sanctuary of Doñana National Park and surrounding areas, with serious threats to this unique ecosystem.

4.3. Conservation Status

The conservation status of the Guadalquivir fish fauna is nowadays very poor, as more than half of the recorded native species in the basin are classified in a threat category, either nationally or internationally (see Tables 3 and 4).

The high degree of fish endemism in Mediterranean river basins, such as the Guadalquivir, demonstrates that this fauna, on average, displays rare and isolated populations naturally (e.g., oretanian arched-mouth nase, jarabugo, bogardilla and baetican toothcarp) [20,74]. Furthermore, some of these species have a low tolerance to disturbance, so that their extinction risk increases considerably [93,94]. Several formerly common species are now disappearing; for example, the Southern Iberian chub, the Iberian arched-mouth, the calandino and the European eel have considerably reduced distributions with respect to those observed in recent studies [20].

Two freshwater species are considered officially extinct in the Guadalquivir Basin: the three-spined stickleback and the Iberian long-snout barbel [18,59,95]. The first represented the southernmost population in Europe [61]. The direct causes of its extinction will never be known, but some speculate about habitat transformation, pollution and fish trading for aquarists [45]. The causes of Iberian long-snout barbel extinction are also unknown; however, the very small number of records and their antiquity [58] suggests that the historical presence of this species in the basin should be viewed with caution [95].

Migratory species are the worst preserved fish species. Only one of the five species (European eel, prevalence <1%) with historical presence in the basin was captured, whereas two others are very scarce (i.e., sea lamprey and twaite shad) and the remaining two are regionally extinct (Atlantic sturgeon and allis shad [10,59]). The last published records for the sea lamprey come from 1992 and 1999, and in some studies it is considered extinct [59]; however, we are aware of sporadic, but periodic captures of this species in the estuary (authors' unpublished data). There are very few individual twaite shad dispersed in the lowest sections of the basin during early autumn and spring.

The relationship between the conservation of migratory fish fauna and the impact of dams is a widespread and well-known problem around the world [96,97]. Dams without adequate fish passage systems hinder access to upstream areas, which may include breeding grounds, this being one of the main challenges to their conservation [96,97]. Spain is one of the most dammed countries in the world, which represents an important environmental problem [28,70] because, among other reasons, most dams are impassable, i.e., it is not possible to install feasible fishways due to their height. In the Guadalquivir River, the Alcalá del Río dam, built in 1931, is a major obstacle for upstream fish migration, especially for sturgeon [18]. Later on, in 1956, another dam (Cantillana dam) was built approximately 22 km upstream of Alcalá del Río precipitating the total fragmentation of the lower section of the river from the middle one. Other specific causes involved in the regression of these species include: flow reduction (due to dams and irrigated crops), gravel extractions (damaging spawning grounds), pollution from urban and industry activities and overfishing, e.g., caviar industry, elver fishing [18,20,98].

4.4. Conservation and Management Recommendations

A regional strategy for freshwater fish conservation was approved in 2012 (see <http://www.juntadeandalucia.es/boja/2012/60/boletin.60.pdf> for more details, accessed on 26 September 2022) and its first actions, mainly species detection, range distribution estimates and ex situ programs, have recently been initiated. This strategy aims to act on species included in the regional Red Book: four critically endangered, five endangered and seven vulnerable [21]. However, three endangered species (*Salmo trutta*, *Alosa alosa* and

Alosa fallax) are not included in the strategy. However, up to now, the current management and conservation measures taken have not seemed to alter the trend of the most endangered species due to the continuous degradation of the aquatic ecosystems of the basin [15,31,99] as well as the absence of large-scale actions that can interfere with human activities (e.g., agriculture) [15,31]. Only baetican toothcarp and brown trout, which have specific conservation plans for eight and six years, respectively, seem to have stabilized their populations [100,101].

The current conservation status (according to IUCN criteria) of all threatened fish species in the Guadalquivir Basin as well as introduced species should be revised and updated, placing each species in their appropriate global and regional coherent category, including possible extinctions. For example, the Andalusian regional Red Book includes the European eel in the 'Least Concern' category while in the IUCN Red list it appears as 'Critically Endangered'. As another example, the possible hybrid origin of bogardilla [20] should be clarified. This taxon is included in the regional conservation strategy and considerable funds could be invested for its conservation and protection, without even knowing its true taxonomic status. In addition, this "species" has not been collected in the last ten years [10].

The definition and detection of priority sites for freshwater fish conservation is necessary to determine the appropriate measures of restoration in the most valuable areas for fish. These should be areas with high native species richness or inhabited by endangered species. The legal declaration of protected natural areas would be useful to preserve them. Removing obsolete dams will increase connectivity among populations, thus avoiding their isolation [97] and promoting their recovery, especially among migratory species. This measure is being carried out in several countries in Europe and America [97]. The ex situ programs could, in the future, provide individuals for repopulations, introductions and/or reintroductions for genetic improvement. In this regard, the development of live gene banks could help avoid the biodiversity loss of depauperated populations [20,102,103]. Finally, invasive species should be eliminated, if possible, especially from fish priority sites.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d14100831/s1>, Table S1: Species richness (S), number of families (F), Shannon (H') diversity indices and species density ($D = n^{\circ}$ species per 1000 km²) for each sampled sub-basin (45 and the main channel). Table S2: List of freshwater fish species sampled in each sub-basin. Species name are codified using the first letter of the genus and the two first letters of the species.

Author Contributions: "Conceptualization, P.S.-G. and J.P.; methodology, P.S.-G.; software, P.S.-G.; validation, P.S.-G. and J.P.; formal analysis, P.S.-G.; investigation, P.S.-G. and J.P.; resources, P.S.-G. and J.P.; data curation, P.S.-G.; writing—original draft preparation, P.S.-G.; writing—review and editing, P.S.-G. and J.P.; visualization, P.S.-G. and J.P.; supervision, J.P.; project administration, J.P.; funding acquisition, J.P. All authors have read and agreed to the published version of the manuscript."

Funding: This research was funded by the Junta de Andalucía, Convocatoria de Proyectos de Excelencia (P07-RNM-03309), and was carried out at the Centro Internacional de Estudios y Convenciones Ecológicas y Medioambientales (CIECEM) of the University of Huelva.

Institutional Review Board Statement: The authors declare that all procedures have been approved by the Andalusian Authority for Wildlife Protection. This study was carried out in accordance with national and international guidelines for care and use of animals.

Data Availability Statement: Data can be found within the paper and Supplementary Materials.

Acknowledgments: We wish to thank everyone from the CIECEM for their invaluable help and logistic support.

Conflicts of Interest: The authors declare no competing interests of financial or non-financial nature.

References

- Loh, J.; Randers, J.; MacGillivray, A.; Kapos, V.; Jenkins, M.; Groombridge, B.; Cox, N. *Living Planet Report*; World Wide Fund for Nature: Gland, Switzerland, 1998.
- Revenge, C.; Mock, G. *Freshwater Biodiversity in Crisis*; Earth Trends World Resources Institute: 2000; pp. 1–4. Available online: <http://earthtrends.wri.org> (<https://netedu.xauat.edu.cn/jpkc/netedu/jpkc2009/szylyybh/content/wlzy/4/Freshwater%20Biodiversity%20in%20Crisis.pdf>).
- Moyle, P.B.; Yoshiyama, R.M. Protection of aquatic biodiversity in California: A five-tiered approach. *Fisheries* **1994**, *19*, 6–18.
- Cowx, I.G.; Collares-Pereira, M.L. Freshwater fish conservation: Options for the future. In *Conservation of Freshwater Fishes: OP-TIONS for the Future*; Collares-Pereira, M.J., Cowx, I.G., Coelho, M.M., Eds.; Fishind News Books, Blackwell Science, Oxford: London, UK, 2002; pp 443–452.
- Smith, K.G.; Darwall, W.R.T. (Eds.) *The Status and Distribution of Freshwater Fish Endemic to the Mediterranean Basin*; IUCN: Gland, Switzerland, 2006.
- Freyhof, J.; Brooks, E. *European Red List of Freshwater Fishes*; Publications Office of the European Union: Luxembourg, 2011. Available online: http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_freshwater_fishes.pdf.
- Bruton, M.N. Have fishes had their chips? The dilemma of threatened fishes. *Environ. Biol. Fishes* **1995**, *43*, 1–27.
- Abell, R. Conservation biology for the biodiversity crisis: A freshwater follow-up. *Conserv. Biol.* **2002**, *16*, 1435–1437.
- Kottelat, M.; Freyhof, J. *Handbook of European Freshwater Fishes*; Kottelat: Cornol, Switzerland, 2007.
- IUCN Red List of Threatened Species. Version 15.1. July 2022. Available online: www.iucnredlist.org (accessed on 7 September 2022).
- Cuttelod, A.; Garcia, N.; Abdul, M.D.; Temple, H.; Kataraya, V. The Mediterranean: A biodiversity hotspot under threat. In *The 2008 Review of The IUCN Red List of Threatened Species*; Vié, J.C., Hilton-Taylor, C., Stuart, S.N., Eds.; IUCN: Gland, Switzerland, 2008.
- García-Ruiz, J.M.; Nadal-Romero, E.; Lana-Renault, N.; Beguería, S. Erosion in Mediterranean landscapes: Changes and future challenges. *Geomorphology* **2013**, *198*, 20–36.
- Ruiz, J.; Polo, M.J.; Díez-Minguito, M.; Navarro, G.; Morris, E.P.; Huertas, E.; Caballero, I.; Contreras, E.; Losada, M.A. The Guadalquivir estuary: A hot spot for environmental and human conflicts. In *Environmental Management and Governance*; Finkl, C.W., Makowski, C., Eds.; Advances in Coastal and Marine Resources; Springer: London, UK, 2015; Chapter 8, pp. 199–232.
- Mendiguchía, C.; Moreno, C.; García-Vargas, M. Evaluation of natural and anthropogenic influences on the Guadalquivir River (Spain) by dissolved heavy metals and nutrients. *Chemosphere* **2007**, *69*, 1509–1517.
- Hermosin, M.C.; Calderon, M.J.; Real, M.; Cornejo, J. Impact of herbicides used in olive groves on waters of the Guadalquivir river basin (southern Spain). *Agri. Ecosyst. Environ.* **2013**, *164*, 229–243.
- Vargas, J.; Paneque, P. Major Hydraulic Projects, Coalitions and Conflict. Seville's Harbour and the Dredging of the Guadalquivir (Spain). *Water* **2015**, *7*, 6736–6749.
- Carpintero, M. Characterization of Suspended Sediments in the Guadalquivir Estuary al Modeled Scale. Ph.D. Thesis, Universidad de Córdoba, Córdoba (Spain), 2015.
- Granado-Lorenzo, C. The effect of man on the fish fauna of the River Guadalquivir, Spain. *Fish. Res.* **1991**, *12*, 91–100.
- Doadrio, I. Catálogo de los peces de agua dulce del Museo Nacional de Ciencias Naturales. *Museo Nacional de Ciencias Naturales*; CSIC: Madrid, Spain, 1989; p. 61.
- Doadrio, I. *Atlas y Libro Rojo de los Peces Continentales de España*; Dirección General de Conservación de la Naturaleza-Museo Nacional de Ciencias Naturales: Madrid, Spain, 2001; 374p.
- Franco-Ruiz, A.; Rodríguez de los Santos, M. *Libro Rojo de los Vertebrados Amenazados de Andalucía*; Consejería de Medio Ambiente. Junta de Andalucía: Spain, 2001.
- Filipe, A.F.; Marques, T.A.; Seabra, S.; Tiago, P.; Ribeiro, F.; Costa, L.M.D.; Cowx, I.G.; Collares-Pereira, M.J. Selection of priority areas for fish conservation in Guadiana river basin, Iberian Peninsula. *Conserv. Biol.* **2004**, *18*, 189–200.
- Magalhães, M.F.; Ramalho, C.E.; Collares-Pereira, M.J. Assessing biotic integrity in a Mediterranean watershed: Development and evaluation of a fishbased index. *Fish. Manag. Ecol.* **2008**, *15*, 273–289.
- Confederación Hidrográfica del Guadalquivir. *Plan Hidrológico de la Demarcación Hidrográfica del Guadalquivir*. Available online: <http://www.chguadalquivir.es> (accessed on 15 June 2015).
- Gasith, A.; Resh, V.H. Streams in Mediterranean climate regions: Abiotic influences and biotic responses to predictable seasonal events. *Annu. Rev. Ecol. Syst.* **1999**, *30*, 51–81.
- Navarro, G.; Huertas, I.E.; Costas, E.; Flecha, S.; Díez-Minguito, M.; Caballero, I.; López-Rodas, V.; Prieto, L.; Ruiz, J. Use of a real-time remote monitoring network (RTRM) to characterize the Guadalquivir estuary (Spain). *Sensors* **2012**, *12*, 1398–1421.
- Rodríguez Díaz, J.A.; Weatherhead, E.K.; Knox, J.W.; Camacho, E. Climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain. *Reg. Environ. Chang.* **2007**, *7*, 149–159.
- Clavero, M.; Blanco-Garrido, F.; Prenda, J. Fish fauna in Iberian Mediterranean river basins: Biodiversity, introduced species and damming impacts. *Aquat. Conserv.* **2004**, *14*, 575–585.

29. Bhat, A.; Blomquist, W. 'Policy, politics, and water management in the Guadalquivir River Basin, Spain.' *Water Resour. Res.* **2004**, *40*, 22. <https://doi.org/10.1029/2003WR002726>.
30. Ruiz, J.; Losada, M.A.; Polo, M.J.; García, J. *Propuesta Metodológica Para Diagnosticar y Pronosticar las Consecuencias de las Actuaciones Humanas en el Estuario del Guadalquivir*; Informe técnico; Instituto de Ciencias Marinas de Andalucía, Consejo Superior de Investigaciones Científicas; Grupo de Dinámica de Flujos Ambientales, Centro Andaluz de Medio Ambiente—Universidad de Granada; Grupo de Dinámica Fluvial e Hidrología, Universidad de Córdoba; Grupo Albiotox, Universidad Complutense. Complutense: Puerto de Sevilla, Sevilla, 2010.
31. González-Ortegón, E.; Subida, M.D.; Cuesta, J.A.; Arias, A.M.; Fernández-Delgado, C.; Drake, P. The impact of extreme turbidity events on the nursery function of a temperate European estuary with regulated freshwater inflow. *Estuar. Coast. Shelf Sci.* **2010**, *87*, 311–324.
32. Díaz, M.; Campos, P.; Pulido, F.J. *The Spanish dehesas: A diversity of land use and wildlife*. In *Farming and Birds in Europe: The Common Agricultural Policy and Its Implications for Bird Conservation*; Pain, D., Pienkowski, M., Eds.; Academic Press: London, UK, 1997; pp 178–209.
33. Argüelles, A.; Berbel, J.; Gutiérrez, C. La evolución de la Cuenca del Guadalquivir (España). *Rev. De Obras Públicas* **2012**, *3537*, 51–64.
34. Confederación Hidrográfica del Guadalquivir. 2015b: Geoportal/Descargas/Embalses. Available online: <http://fidechg.chguadalquivir.es/geoportal/es/servicios/descargas.html?selectorFromDBProduct=Embalses> (accessed on 15 June 2015).
35. Cruz Villalón, J. La intervención del hombre en la ría y marismas del Guadalquivir. *Eria Rev. Cuatrimest. Del Geogr.* **1988**, *16*, 109–123. ISSN 0211-0563.
36. Heggenes, J.; Brabrand, C.; Saltveit, S.J. Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. *Trans. Am. Fish. Soc.* **1990**, *119*, 101–111.
37. Reynolds, J.B. Electrofishing. In *Fisheries Techniques*, 2nd ed.; Murphy, B.R., Willis, D.W., Eds.; American Fisheries Society: Bethesda, MD, USA, 1996; pp. 221–253.
38. Bunt, C.; Cooke, S.J.; McKinley, R.S. Creation and maintenance of habitat downstream from a weir for the greenside darter (*Etheostoma blenniodes*) a rare fish in Canada. *Environ. Biol. Fishes* **1998**, *51*, 297–308.
39. Clavero, M.; Blanco-Garrido, F.; Prenda, J. Monitoring small fish populations in streams: A comparison of four passive methods. *Fish. Res.* **2006**, *78*, 243–251.
40. Leunda, P.M.; Elvira, B.; Ribeiro, F.; Miranda, R.; Oscoz, J.; Alves, M.J.; Collares-Pereira, M.J. International standardization of common names for Iberian endemic freshwater fishes. *Limnetica* **2009**, *28*, 189–202.
41. Moreno, C.E. *Methods to Measure Biodiversity*; M&T—Manuales y Tesis SEA; Zaragoza, Spain, 2001; Volume 1, 84p. Available online: <http://entomologia.rediris.es/sea/manytes/metodos.pdf> (accessed on).
42. IBM Corp. Released. *IBM SPSS Statistics for Windows, Version 21.0*; IBM Corp: Armonk, NY, USA, 2012.
43. Hammer, O.; Harper, D.A.T.; Ryan, P.D. PAST: Paleontological Statistics software package for education and data analysis. *Palaentologica Electron.* **2001**, *4*, 9.
44. Clavero, M.; Villero, D. Historical ecology and invasion biology: Long-term distribution changes of introduced freshwater species. *BioScience* **2013**, *64*, 145–153.
45. Granado-Lorencio, C.; Hernando, J.A. Espinoso—*Gasterosteus gymnurus*; In *Libro rojo de los Vertebrados de Andalucía*; Franco, A., Rodríguez, M., Eds.; Consejería de Medio Ambiente. Junta de Andalucía: Spain, 2001.
46. Doadrio, I.; Carmona, J.A.; Fernández-Delgado, C. Morphometric study of the Iberian Aphanius (*Actinopterygii*, *Cyprinodontiformes*), with description of a new species. *Folia Zool. -Praha* **2002**, *51*, 67–79.
47. Doadrio, I.; Carmona, J.A. A new species of the genus *Chondrostoma* Agassiz, 1832 (*Actinopterygii*, *Cyprinidae*) from the Iberian Peninsula. *Graellsia* **2003**, *59*, 29–36.
48. De Miguel, R.; Pino, E.; Ramiro, A.; Aranda, F.; De la Peña, J.P.; Doadrio, I.; Fernández-Delgado, C. On the occurrence of *Anaocypris hispanica*, an extremely endangered Iberian endemism, in the Guadalquivir River basin. *J. Fish. Biol.* **2010**, *76*, 1454–1465.
49. Gutiérrez-Estrada, J.C.; Prenda, J.; Oliva, F.; Fernández-Delgado, C. Distribution and hábitat Preferences of the Introduced Mummichog *Fundulus heteroclitus* (Linnaeus) in South-western Spain. *Estuar. Coast. Shelf Sci.* **1998**, *46*, 827–835.
50. García de Lomas, J.; Dana, E.D.; López Santiago, J.; González, R.; Ceballos, G.; Ortega, F. First record of the North American black bullhead *Ameiurus melas* (Rafinesque, 1820) in the Guadalquivir Estuary (Southern Spain). *Aquat. Invasions* **2009**, *4*, 719–723.
51. Moreno-Valcárcel, R.; De Miguel, R.J.; Fernández-Delgado, C. The first record of the European catfish *Silurus glanis* Linnaeus, 1758 in the Guadalquivir River basin. *Limnetica* **2013**, *32*, 23–26.
52. Garrido-Ramos, M.A.; Soriguier, M.C.; de la Herrán, R.; Jamilena, M.; Ruíz Tejón, C.; Domezain, A.; Hernando, J.A.; Ruíz Rejón, M. Morphometric and genetic analysis as proof of the existence of two sturgeon species in the Guadalquivir river. *Mar. Biol.* **1997**, *129*, 33–39.
53. Doukakis, P.; Birstein, V.J.; DeSalle, R.; Ludwig, A.N.; Ludwig, A.; Machordom, A.; Almodóvar, A.; Elvira, B. Failure to confirm previous identification of two putative museum specimens of the Atlantic sturgeon, *Acipenser sturio*, as the Adriatic sturgeon, *A. naccarii*. *Mar. Biol.* **2000**, *136*, 373–377.

54. De la Herrán, R.; Robles, F.; Martínez-Espín, E.; Lorente, J.A.; Ruiz Rejón, C.; Garrido-Ramos, M.A.; Ruiz Rejón, M. Genetic identification of western sturgeons and its implication for conservation. *Conserv. Genet.* **2004**, *5*, 545–551.
55. Mateus, C.S.; Rodríguez-Muñoz, R.; Quintella, B.R.; Alves, M.J.; Almeida, P.R. Lampreys of the Iberian Peninsula: Distribution, population status and conservation. *Endanger. Species Res.* **2012**, *16*, 183–198.
56. Elvira, B.; Almodóvar, E. A morphological study of native sturgeon *Acipenser sturio* in Spain, and recent records of exotic Siberian sturgeon *A. baerii*. *J. Appl. Ichthyol.* **1999**, *15*, 278–279.
57. Almaça, C.; Elvira, B. Past and present distribution of *Acipenser sturio* L., 1758 on the Iberian Peninsula. *Bol. Inst. Esp. Oceanogr.* **2000**, *16*, 11–16.
58. Lozano Rey, L. *Los Peces Fluviales de España*; Academia de Ciencias Exactas, Físicas y Naturales: Madrid, Spain, 1935.
59. Arias García, A.M. *Macrofauna acuática*. In *Propuesta Metodológica Para Diagnosticar y Pronosticar las Consecuencias de las Actuaciones Humanas en el Estuario del Guadalquivir*; Ruiz, J., Losada, M.A., Polo, M.J., García, J., Eds.; Informe técnico; Instituto de Ciencias Marinas de Andalucía (CSIC), Grupo de Dinámica de Flujos Ambientales (Centro Andaluz de Medio Ambiente—Universidad de Granada), Grupo de Dinámica Fluvial e Hidrología (Universidad de Córdoba), Grupo Albiotox (Universidad Complutense): Puerto de Sevilla, Sevilla, 2010.
60. Doadrio, I. Descripción de un nuevo género y de una nueva especie *Iberocypris palaciosi* n. gen. n. sp. (Pisces, Cyprinidae). *Doñana Acta Vertebr.* **1980**, *7*, 5–16.
61. Hernando, J.A. Notas sobre la distribución de los peces fluviales en el suroeste de España. *Doñana Acta Vertebr.* **1975**, *2*, 263–264.
62. Fernández-Delgado, C.; Rincón, P.A.; Gálvez-Bravo, L.; De Miguel, R.J.; Oliva-Paterna, F.J.; Moreno-Valcárcel, R.; Pino, E.; Ramiro, A.; Peña, J.P. *Distribución y Estado de Conservación de los Peces Dulceacuícolas del río Guadalquivir. Principales Áreas Fluviales para su Conservación*; Ministerio de Agricultura, Alimentación y Medio Ambiente: Madrid, Spain, 2014; 275p.
63. Fernandez-Delgado, C.; Hernando, J.A.; Herrera, M.; Bellido, M. Sobre el status taxonómico del genero Valencia Myers, 1928 en el suroeste de Iberia. *Donana Acta Vertebr.* **1986**, *13*, 161–163.
64. Puentes, P.S. Peces de acuario en el Guadalquivir. El óscar tigre, nuevo en estas aguas. *Trofeo Pesca* **1996**, *46*, 96.
65. Elvira, B. Pirañas en nuestras aguas. *Trofeo Pesca* **2004**, *134*, 182–183.
66. Flórez, A. 2007. La piraña era Pacus. *ABC Sevilla*, 22 July 2007, p. 38..
67. García-Novo, F.; Martín-Vicente, A.; Toja-Santillana, J. *La Frontera de Doñana*; Universidad de Sevilla: Sevilla, España, 2007.
68. Elvira, B. Native and exotic freshwater fishes in Spanish river basins. *Freshw. Biol.* **1995**, *33*, 103–108.
69. Hernando, J.A.; Soriguer, M.C. Biogeography of the freshwater fish of the Iberian Peninsula. *Limnetica* **1992**, *8*, 243–253.
70. Nicola, G.G.; Elvira, B.; Almodóvar, A. Dams and fish passage facilities in the large rivers of Spain: Effects on migratory species. *Arch. Hydrobiol.* **1996**, *113*, 375–379.
71. Clavero, M.; Hermoso, V. Reservoirs promote the taxonomic homogenization of fish communities within river basins. *Biodivers Conserv.* **2011**, *20*, 41–57.
72. Menanteau, L. Les Marismas du Guadalquivir: Exemple de Transformation d'un Paysage Alluvial au Cours du Quaternaire récent. PhD dissertation, University of Paris-Sorbone, Paris, France, 1982.
73. Menanteau, L. Evolución histórica y consecuencias morfológicas de la intervención humana en las zonas húmedas: El caso de las marismas del Guadalquivir. In *Monografías de la Dirección General del Medio Ambiente*; Las zonas húmedas en Andalucía; Ministerio de Obras Públicas y Urbanismo: Madrid, Spain, 1984.
74. Almança, E.C. La speciation chez les Cyprinidae de la Péninsule ibérique. *Rev. Des Trav. De L'institut Des Pêches Marit.* **1976**, *40*, 399–411.
75. Sheldon, A.L. Species diversity and longitudinal succession in stream fishes. *Ecology* **1968**, *49*, 193–198.
76. Horwitz, R.J. Temporal variability patterns and the distribution patterns of stream fishes. *Ecol. Monogr.* **1978**, *48*, 307–321.
77. Reeves, G.H.; Bisson, P.A.; Dambacher, J.M. Fish communities. In *River Ecology and Management: Lessons from the Pacific Coastal Ecoregion*; Naiman, R.J., Bilby, R.E., Eds.; Springer: New York, NY, USA, 1988.
78. Aparicio, E.; Vargas, M.J.; Olmo, J.M.; de Sostoa, A. Decline of native freshwater fishes in a Mediterranean watershed on the Iberian peninsula: A quantitative assessment. *Environ. Biol. Fishes* **2000**, *59*, 11–19.
79. Corbacho, C.; Sanchez, J.M. Patterns of species richness and introduced species in native freshwater fish faunas of a Mediterranean-type basin: The Guadiana river (Southwest Iberian Peninsula). *Regul. River* **2001**, *17*, 699–707.
80. Hughes, M.; Gammon, J.R. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Trans. Am. Fish. Soc.* **1987**, *116*, 196–209.
81. Huston, M.A. *Biological Diversity: The Coexistence of Species on Changing Landscapes*; Cambridge Univ. Press: Cambridge, UK, 1994.
82. Levine, J.M.; D'Antonio, C.M. Elton revised: A review of evidence linking diversity and invasibility. *Oikos* **1999**, *87*, 15–26.
83. McArthur, R.H. Species-packing and competitive equilibrium for many species. *Theor. Popul. Biol.* **1970**, *1*, 1–11.
84. McArthur, R.H. *Geographical Ecology: Patterns in the Distribution of Species*; Harper and Row: New York, NY, USA, 1972.
85. Case, T.J. Invasion resistance, species build-up and community collapse in metapopulation models with inter-species competition. *Biol. J. Linn. Soc.* **1991**, *42*, 239–266.

86. Hermoso, V.; Blanco-Garrido, F.; Prenda, J. Spatial distribution of exotic fish species in the Guadiana river basin, with two new records. *Limnetica* **2008**, *27*, 189–194.
87. Rahel, F.J. Homogenization of freshwater faunas. *Annual. Rev. Ecol. Syst.* **2002**, *33*, 291–315.
88. Martínez, P.J.; Chart, T.E.; Trammel, M.A.; Wullschlegel, J.G.; Bergersen, E.P. Fish species composition before and after construction of a main stem reservoir on the White River, Colorado. *Environ. Biol. Fishes* **1994**, *40*, 227–239.
89. Saunders, D.L.; Meeuwing, J.J.; Vincent, C.J. Freshwater protected areas: Strategies for conservation. *Conserv. Biol.* **2002**, *16*, 30–41.
90. Elvira, B.; Almodóvar, A. Freshwater fish introductions in Spain: Facts and figures at the beginning of the 21st century. *J. Fish Biol.* **2001**, *59*, 323–331.
91. Vinyoles, D.; Robalo, J.I.; de Sostoa, A.; Almodovar, A.; Elvira, B.; Nicola, G.G.; Fernández-Delgado, C.; Santos, C.S.; Doadrio, I.; Sarda-Palomer, F.; et al. Spread of the alien bleak *Alburnus alburnus* (Linnaeus, 1758) (Actinopterygii, Cyprinidae) in the Iberian Peninsula: The role of reservoirs. *Graellsia* **2007**, *61*, 101–110.
92. Copp, G.H.; Britton, R.; Cucherousset, J.; García-Berthou, E.; Kirk, R.; Peeler, E.; Stakénas, S. Voracious invader or benign feline? A review of the environmental biology of European catfish *Silurus glanis* in its native and introduced ranges. *Fish Fish.* **2009**, *10*, 252–282.
93. Hermoso, V.; Clavero, M.; Blanco-Garrido, F.; Prenda, J. Assessing freshwater fish sensitivity to different sources of perturbation in a Mediterranean basin. *Ecol. Freshw. Fish* **2008**, *18*, 269–281.
94. Blanco-Garrido, F.; Clavero, M.; Prenda, J. Jarabugo (*Anaocypris hispanica*) and freshwater blenny (*Salaria fluviatilis*): Habitat preferences and relationship with exotic fish species in the middle Guadiana basin. *Limnetica* **2009**, *28*, 139–148.
95. Granado-Lorencio, C. Barbo comizo—Barbus comiza. In *Libro Rojo de los Vertebrados de Andalucía*; Franco, A., Rodríguez, M., Eds.; Consejería de Medio Ambiente. Junta de Andalucía: Spain, 2001.
96. Limburg, K.E.; Waldman, J.R. Dramatic declines in north Atlantic diadromous fishes. *Bioscience* **2009**, *59*, 955–965.
97. Stanley, E.H.; Doyle, M.W. Trading off: The ecological effects of dam removal. *Front. Ecol. Environ.* **2003**, *1*, 15–22.
98. Fernández-Pasquier, V. Acipenser sturio L. in the Guadalquivir river, Spain. Water regulation and fishery as factors in stock decline from 1932 to 1967. *J. Appl. Ichthyol.* **1999**, *15*, 133–135.
99. Ramos-Merchante, A.; Prenda, J. The ecological and conservation status of the Guadalquivir River Basin (s Spain) through the application of a fish-based multimetric index. *Ecol. Indic.* **2018**, *84*, 45–59.
100. Pérez Pavón, M.J.; Paracuellos, M.; López Santiago, J.; Sigilló, N.; Garrido, J.R.; Martos, M.J.; Nevado, J.C. Salinete y fartet emblemáticas de la ictiofauna ibérica. *Quercus* **2012**, *316*, 28–36.
101. Larios-López, J.E.; Tierno de Figueroa, J.M.; Alonso-González, C.; Nebot Sanz, B. Distribution of brown trout (*Salmo trutta* Linnaeus, 1758) (Teleostei: Salmonidae) in its southwesternmost European limit: Possible causes. *Ital. J. Zool.* **2015**, *82*, 404–415. <https://doi.org/10.1080/11250003.2015.1018351>.
102. Cowx, I.G.; Collares-Pereira, M.J. Conservation of endangered fish species in the face of water resource development schemes in the Guadiana river, Portugal: Harmony of the incompatible. In *Management and Ecology of River Fisheries*; Cowx, I.G., Ed.; Fishing News Books, Blackwell Science, Oxford: London, UK, 2000; pp. 428–438.
103. Doadrio, I.; Carmona, J.A. Pardilla oretana—*Iberochondrostoma oretanum*. In *Enciclopedia Virtual de los Vertebrados Españoles*; Salvador, A., Elvira, B., Eds.; Museo Nacional de Ciencias Naturales: Madrid, Spain, 2014. Available online: <http://www.vertebradosibericos.org/> (accessed on 15 August 2022).



Rapid Communication

Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain)

Pedro Sáez-Gómez and José Prenda*

Department of Integrative Sciences, University of Huelva. Campus universitario de El Carmen, Avda. Andalucía s/n, 21071 Huelva, Spain

Author e-mails: pedro.saez@ciecema.uhu.es (PSG), jprenda@uhu.es (JP)

*Corresponding author

Citation: Sáez-Gómez P, Prenda J (2019) Updating the distribution data of recently introduced freshwater fish in the Guadalquivir River Basin (Spain). *BioInvasions Records* 8(4): 924–932, <https://doi.org/10.3391/bir.2019.8.4.21>

Received: 13 March 2019

Accepted: 4 July 2019

Published: 15 October 2019

Thematic editor: Michal Janáč

Copyright: © Sáez-Gómez and Prenda

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS

Abstract

We report new distribution data on four recently introduced species in the Guadalquivir River basin: chameleon cichlid (*Australoheros facetus* Jenyns, 1842), North American black bullhead (*Ameiurus melas* Rafinesque, 1820), European catfish (*Silurus glanis* Linnaeus, 1758) and a minnow species of unknown origin (*Phoxinus* spp.). A compilation of records is used to update the distribution range of these species. The information collected reinforces the evidence on the establishment and expansion of these non-native species. We recommend new field sampling to identify the dispersal pathways and to clarify their current statuses.

Key words: exotic species, Mediterranean rivers, invasive, *Australoheros facetus*, *Ameiurus melas*, *Phoxinus* spp., *Silurus glanis*

Introduction

Introductions of non-native species are recognized as one of the main threats for freshwater biodiversity worldwide (Gozlan et al. 2010). The impacts caused by the arrival of new species are highly diverse and depend primarily on the introduced species and habitat features (Ribeiro and Leunda 2012). In arid and semi-arid regions (e.g. Mediterranean basin) where water demand for human uses is high (Cowx and Collares-Pereira 2002), the number of reservoirs has reached almost a maximum, and consequently, the number of non-native species and their distribution range is increasing. Thus, Iberian inland waters are among the most invaded ecosystems within the Mediterranean region and fish introductions are considered a major threat to native ichthyofauna which comprise a high proportion of endemic species (Ribeiro and Leunda 2012).

Guadalquivir River basin is highly important in terms of biodiversity and number of threatened taxa (Doadrio 2001), as around 50% of the native species recorded in the basin are included in an IUCN-2015 category. Yet, the current ichthyofauna of the basin contains large proportion of introduced species. Fernández-Delgado et al. (2014) detected up to 14 non-native species showing a higher richness than natives ones



(13 species). A recent study also determined high non-native species richness (10 vs. 9 for native and introduced species respectively; see Ramos-Merchante and Prenda 2018). These and other studies (García de Lomas et al. 2009; Moreno-Valcárcel et al. 2013) revealed the recent detection of several species with high invasive potential such as chameleon fish (*Australoheros facetus* Jenyns, 1842), North American black bullhead (*Ameirus melas* Rafinesque, 1820) and European catfish (*Silurus glanis* Linnaeus, 1758). These species are included in the rank lists of the most invasive alien species (IAS) because their potential threat to biodiversity (Clavero 2011; van der Veer and Nentwig 2015; Carboneras et al. 2018). Therefore, updated knowledge about new introductions and their distribution ranges is essential to detect new threats and implement appropriate conservation strategies.

Here we provide new distribution data on the three recently introduced species: *Australoheros facetus*, *Ameirus melas* and *Silurus glanis* in the Guadalquivir River basin (South Spain) and also report the first record of an invasive species belonging to the genus *Phoxinus* in this basin.

Materials and methods

The Guadalquivir is the fifth longest river in the Iberian Peninsula, situated in the south of Spain, running in a dominant east-west direction to the Atlantic Ocean. The main channel is 680 km long, with a drainage area of 57439 km². Based on non-native species distribution data from other studies (García de Lomas et al. 2009; Moreno-Valcárcel et al. 2013; Fernández-Delgado et al. 2014) we compiled information from two data sources (field sampling and anglers' records) in order to update the current distribution of *Australoheros facetus*, *Ameirus melas*, *Silurus glanis* and *Phoxinus* spp. in the basin.

Firstly, during the course of a research project on fish fauna distribution in Guadalquivir River basin (see acknowledgements for details) we conducted a field sampling at 285 locations over the entire basin (216 in rivers and 69 in reservoirs) between June 2007 and July 2008 (Figure 1A). Depending on location width and depth, two alternative sampling methods were used. Typical stream sites with low salinity (< 1.5 mS cm⁻¹) and shallow depth (< 1.2 m) were electrofished by wading upstream along a channel length of 100 m during approximately one hour. The equipment comprised a control box delivering a pulsed direct current, 300/600 V, 4–6 A without block nets (Electracatch International, Honda EU 20i motor with a WF6 rectifier and a landing net with a 30 cm diameter and a 4 mm mesh size). When the salinity and depth conditions did not allow electrofishing, mainly in large rivers and reservoirs, we used four types of passive traps: trammel nets, fyke nets, minnow traps and plastic bottle minnow traps. Two trammel nets (10 m × 2 m, 175 mm × 25 mm and 200 mm × 20 mm

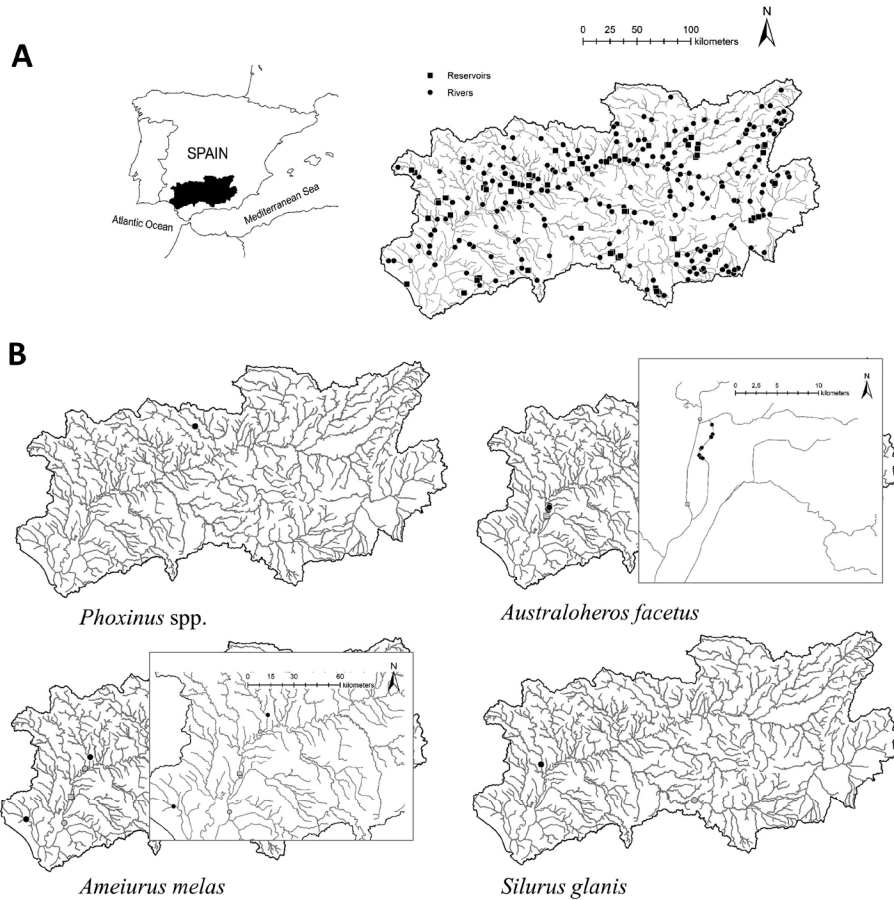


Figure 1. Map of the Guadalquivir River Basin and geographical locations of the records for each species. Dark circles represent the new records described in this study. Grey circles and squares correspond to the previous records reported by Fernández-Delgado et al. 2014 and García de Lomas et al. 2009 respectively. Fine-scale is shown for *Australoheros facetus* and *Ameiurus melas*. For details see Supplementary material Table S1.

mesh size), three pairs of fyke nets (12 mm and 3 mm mesh size), fifteen metal minnow traps (6 mm mesh size) and ten pairs of plastic minnow traps (25 mm inlet) were set for a minimum of 8 h (see Clavero et al. 2006 for more details). After capture, fish were identified to species level, counted, measured and returned live to the river.

Secondly, we completed the information obtained in the field samplings with extensive searches on different social media websites (e.g. YouTube, Facebook), recreational fisheries forums, blogs and search engines (i.e. Google) to obtain records of the studied species. In addition, we sent a request for information on records of the species under study to fisheries



websites. Following the Gago et al. (2016) criteria, we performed a Boolean search between July 2010 and October 2015 using a combination of different keywords, including scientific and common names in Spanish (i.e. chanchito, pez gato, siluro, piscardo) and river name (Guadalquivir). Species records were accepted only when it included the locality, year and accompanying media (picture or video) (see Gago et al. 2016 for details). We interviewed, whenever possible, the angler who reported the information to confirm this and avoid double counting. The geographical coordinates were extracted from Google Earth Pro. Finally, we added to the database a remarkable sighting of North American black bullhead that we made in the Doñana National Park, a highly protected area in the lower section of the basin.

Results and discussion

A total of 18 records were obtained in the Guadalquivir River basin (Supplementary material Table S1), with fishing forum websites representing the main source of information with 46.2% of the total records. A single record was never detected in more than one data source (i.e. duplicate records). Chameleon cichlid was the species with the highest number of records (69%) and the species with the highest number of specimens registered was the North American black bullhead (> 2000) (Table S1). During the fish sampling, other 8 non-native species well known in previous studies were also collected (Doadrio 2001; Vinyoles et al. 2007): *Oncorhynchus mykiss* (Walbaum, 1972), *Alburnus alburnus* (Linnaeus, 1758), *Carassius auratus* (Bloch, 1782), *Cyprinus carpio* (Linnaeus, 1758), *Gobio lozanoi* (Doadrio and Madeira, 2004), *Gambusia holbrooki* (Girard, 1859), *Lepomis gibbosus* (Linnaeus, 1758) and *Micropterus salmoides* (Lacépède, 1802).

Phoxinus spp.

Traditionally, minnow populations from the Iberian Peninsula have been identified as *Phoxinus phoxinus* (Linnaeus, 1758) (Doadrio 2001). However, Kottelat (2007) reclassified these populations as *P. bigerri*. Since the author did not analyse samples from Iberia he suggests caution identifying these populations. The Iberian distribution includes some rivers in the Cantabrian Mountains and the Ebro River basin (Kottelat and Freyhof 2007). However, the origin (native or introduced) of Atlantic populations is unknown due to continuous introductions carried out by anglers (e.g. Cantabrian Rivers and Douro basin) who use the species as live bait or as food for trout (Doadrio and Garzón 1986; Doadrio 2001; SIBIC 2014). Moreover, species from *Phoxinus* genus can reproduce and generate hybrids, even intergeneric hybrids (Eisenhour and Piller 1997). For this reason, identifications based on morphometric characteristics can be misleading and genetic analysis represent the most reliable tool. Three individuals from *Phoxinus* genus were collected on May 1st 2008 (Table S1) in a right bank tributary of the



Figure 2. Minnow (*Phoxinus* spp.) specimens captured in the Guadalquivir basin (only two are shown) during the field session with emerging spawning characteristics: bright colours, reddish base of fins, darker band on the flanks, and yellow spots on the operculum.

Guadalquivir (Guadalbarbo River; Figure 1). Morphological measures taken from the sampled specimens (e. g. distance between the end of the first and last ray branched of the anal fin, see Kottelat 2007) did not allow unambiguous identification of the species since they could correspond to both *P. phoxinus* and *P. bigerri* as well as commercial hybrids. On this basis, we consider this population as *Phoxinus* spp. until additional studies based on genetic analysis can clarify this issue. The fish exhibited bright colours and emerging spawning characteristics, such as a reddish abdomen and base of fins, a darker band on the flank, yellow spots on the operculum with intensive colour and head tubercles (Figure 2), and thus reproduction is highly likely. After the capture, individuals were measured to the nearest 1 mm and weighed to the nearest 0.01 g. Length and weight measurements were: 44, 56 and 55 mm and 0.83, 1.70 and 1.60 g, respectively. Three native species: Iberian arched-mouth nase (*Iberochondrostoma lemmingii* – Steindachner, 1866), southern Iberian barbel (*Luciobarbus sclateri* – Günther, 1868), and calandino (*Iberocypris alburnoides* – Steindachner, 1866) and one non-native species, bleak (*Alburnus alburnus* – Linnaeus, 1758), were also captured in the same locality. Subsequent sampling has confirmed the establishment of a minnow population in this location (referred to as *P. phoxinus*, see Fernández-Delgado et al. 2014). The specimens were preserved in the ichthyological collection of the Department of Integrative Sciences (University of Huelva, Spain).

Chameleon cichlid – *Australoheros facetus* (Jenyns, 1842)

Chameleon cichlid was identified in the Guadalquivir River for the first time in 2007 during the implementation of control measures on non-native



Chinese mitten crab (*Eriocheir sinensis*) (see García de Lomas et al. 2009). Between 7 Oct. 2010 and 10 Mar. 2015, we have compiled in the same river section 9 new records, via angler captures, corresponding to 12 individuals (Table S1). These new records provide evidence on the survival and establishment of an emerging population in this locality (Seville city, Guadalquivir dock; Figure 1). Specimens of *A. facetus* captured coincide with identification characters reported by Doadrio (2001) and Fernández-Delgado et al. (2014); the dorsal fin is composed by 15–17 hard and 9–11 soft rays, the anal fin shows 5–6 hard rays and the caudal fin is rounded with a dark spot at the base. Some of these captures corresponded to reproductive individuals (> 20 cm) building nests in shallow areas (PS, *pers. obs.*). The chameleon cichlid is a highly valued species by aquarist, lacking any sporting value.

North American black bullhead – *Ameiurus melas* (Rafinesque, 1820)

The species was first detected in the lower part of the Guadalquivir River basin in 2007 (García de Lomas et al. 2009) and subsequently it has dispersed both upstream and downstream from this location (Fernández-Delgado et al. 2014). We report data from two new localities (Table S1). The first locality corresponds to the Viar River, a right bank tributary of the Guadalquivir (Figure 1) where the species first appeared in the spring of 2009 via angler captures. This species is currently reproducing in this location and has been observed performing parental care behaviours (*i.e.* guarding; PS, *pers. obs.*).

The second sub-basin corresponds to the Doñana National Park. On the 26th of July 2016 we observed a large shoal of bullhead individuals in the “La Rocina”, a shallow freshwater inland marsh (Figures 1, 3). During the sighting we were able to capture by hand some specimens for identification purposes and we estimate, based on field observation, abundance around several thousands of individuals (Figure 3).

Specimens of *A. melas* collected in the Guadalquivir basin coincide with identification reported by Elvira (1984) and Cucherousset et al. (2006): D I/6, P I/7, V 8, A 19–21 and C 19–20. Its presence in Doñana has been known since 2010 (MA Bravo, *pers. comm.*), however, during the last few years the species is spreading throughout the lower sections of the basin (Fernández-Delgado et al. 2014), where environmental conditions are most appropriate for the species (*i.e.* lentic or low-flow habitats with a mud substrate).

European catfish – *Silurus glanis* (Linnaeus, 1758)

This species, the largest European freshwater fish, reaches sizes up to 5 meters in length and more than 100 kilograms in weight. In the Iberian Peninsula this species was detected for the first time in 1974 in the Ebro River (Doadrio 2001). It is considered a serious threat to aquatic ecosystems (Copp

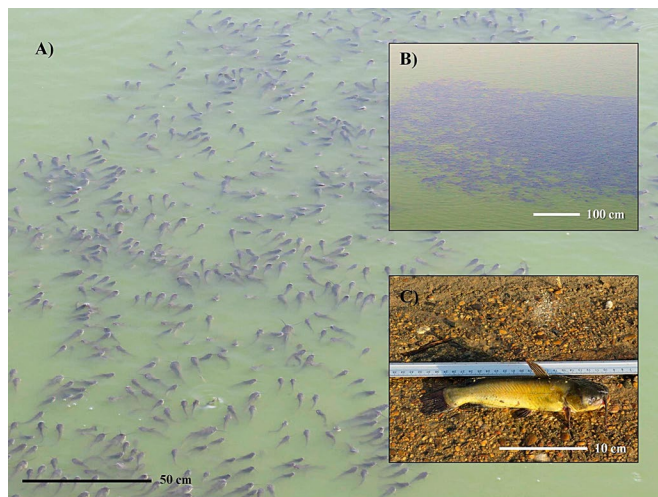


Figure 3. Near (a) and distant (b) views of a large group (> 2000) of young North American black bullheads in Doñana National Park (SW Spain). Many adults (> 20 cm length) were also found in the group (c).

et al. 2009). The first record of this species in the Guadalquivir was in 2011 in Iznájar reservoir, the largest in the basin (Moreno-Valcárcel et al. 2013). We report a new locality located 250 km downstream from Iznájar reservoir, in a lower stretch of a Guadalquivir right bank tributary (Riviera de Huelva; Figure 1). This new record, via angler captures in February 2015, corresponds to 3 adult individuals. Specimens were identified following Kobayakawa (1989) and Kottelat and Freyhof (2007). The weights of these specimens ranged from 3 to 8 kg. Until now, there was no evidence of the European catfish presence outside the Iznájar reservoir.

Concluding remarks

The information collected in this study provides evidence on the reproduction of three non-native species in the Guadalquivir River basin (*Phoxinus* spp., Chameleon cichlid and North American black bullhead). Therefore, the establishment of these species in different sections of the basin is highly likely. The presence of these invasive species (Leunda 2010) in different sections of the basin can be confirmed and their distribution ranges will probably increase in the next few years. Regardless of the taxonomy of *Phoxinus* specimens collected in this study, this genus has a high invasive potential in the Iberian Peninsula (see Clavero 2011). For this reason, the knowledge of this population by researchers and wildlife managers can help to avoid its expansion because there is currently only one population located in a small tributary. At the same time, genetic analyses and new samplings of this population are necessary to set the



taxonomy of this species. European catfish have been detected many kilometres downstream from the first recorded site, and there are no records between the two areas, so their presence there is likely to be due to new introductions. This species constitute a great threat to native fish fauna due to its voracity and wide dietary range, comprising up to 53 freshwater fish species reported by Copp et al. 2009. It is therefore critical to increase sampling effort, to improve our knowledge about the invasion degree by this species of the Guadalquivir basin.

Acknowledgements

This study was supported by the Junta de Andalucía, Convocatoria de Proyectos de Excelencia (P07-RNM-03309) and was carried out at the Centro Internacional de Estudios y Convenciones Ecológicas y Medioambientales (CIECEM) of the University of Huelva. We are grateful to two anonymous reviewers who made constructive comments improving this work.

References

- Carboneras C, Genovesi P, Vilà M, Blackburn TM, Carrete M, Clavero M, D'hondt B, Orueta JF, Gallardo B, Galdes P, González-Moreno P, Gregory RD, Nentwig W, Paquet J-Y, Pyšek P, Rabitsch W, Ramírez I, Scalera R, Tella JL, Walton P, Wynde R (2018) A prioritised list of invasive alien species to assist the effective implementation of EU legislation. *Journal of Applied Ecology* 55: 539–547, <https://doi.org/10.1111/1365-2664.12997>
- Clavero M (2011) Assessing the risk of freshwater fish introductions into the Iberian Peninsula. *Freshwater Biology* 56: 2145–2155, <https://doi.org/10.1111/j.1365-2427.2011.02642.x>
- Clavero M, Blanco-Garrido F, Prenda J (2006) Monitoring small fish populations in streams: a comparison of four passive methods. *Fisheries Research* 78: 243–251, <https://doi.org/10.1016/j.fishres.2005.11.016>
- Copp GH, Robert Britton J, Cucherousset J, García-Berthou E, Kirk R, Peeler E, Stakénas S (2009) Voracious invader or benign feline? A review of the environmental biology of European catfish *Silurus glanis* in its native and introduced ranges. *Fish and Fisheries* 10: 252–282, <https://doi.org/10.1111/j.1467-2979.2008.00321.x>
- Cowx IG, Collares-Pereira ML (2002) Freshwater fish conservation: options for the future. In: Collares-Pereira MJ, Cowx IG, Coelho MM (eds), Conservation of freshwater fishes: options for the future. Fishing News Books, Blackwell Science, Oxford, pp 443–452
- Cucherousset J, Paillisson JM, Carpentier A, Eybert MC, Olden JD (2006) Habitat use of an artificial wetland by the invasive catfish *Ameiurus melas*. *Ecology of Freshwater Fish* 15: 589–596, <https://doi.org/10.1111/j.1600-0633.2006.00199.x>
- Doadrio I (2001) Atlas y libro rojo de los peces continentales de España. Dirección General de Conservación de la Naturaleza, Museo Nacional de Ciencias Naturales, Madrid, 364 pp
- Doadrio I, Garzón P (1986) Nuevas localidades de *Phoxinus phoxinus* (L., 1758) (Ostariophysi, Cyprinidae) en la Península Ibérica. *Miscellanea Zoológica* 10: 389–390
- Eisenhour DJ, Piller KR (1997) Two new intergeneric hybrids involving *Semotilus atromaculatus* and the genus *Phoxinus* with analysis of additional *Semotilus atromaculatus*-*Phoxinus* hybrids. *Copeia* 1997: 204–209, <https://doi.org/10.2307/1447860>
- Elvira B (1984) First records of the North American catfish *Ictalurus melas* (Rafinesque, 1820) (Pisces, Ictaluridae) in Spanish waters. *Cybio* 8(1): 96–98
- Fernández-Delgado C, Rincón PA, Gálvez-Bravo L, De Miguel RJ, Oliva-Paterna FJ, Moreno-Valcárcel R, Pino E, Ramiro A, Peña JP (2014) Distribución y estado de conservación de los peces dulceacuicolas del río Guadalquivir. Principales áreas fluviales para su conservación. Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid, 275 pp
- Gago J, Anastácio P, Gkenas C, Banha F, Ribeiro F (2016) Spatial distribution patterns of the non-native European catfish, *Silurus glanis*, from multiple online sources—a case study for the River Tagus (Iberian Peninsula). *Fisheries Management and Ecology* 23: 503–509, <https://doi.org/10.1111/fme.12189>
- García de Lomas J, Dana ED, López-Santiago J, González R, Ceballos G, Ortega F (2009) First record of the North American black bullhead *Ameiurus melas* (Rafinesque, 1820) in the Guadalquivir Estuary (Southern Spain). *Aquatic Invasions* 4: 719–723, <https://doi.org/10.3391/ai.2009.4.4.23>
- Gozlan RE, Britton JR, Cowx I, Copp GH (2010) Current knowledge on non-native freshwater fish introductions. *Journal of Fish Biology* 76: 751–786, <https://doi.org/10.1111/j.1095-8649.2010.02566.x>



- Kobayakawa M (1989) Systematic revision of the catfish genus *Silurus*, with description of a new species from Thailand and Burma. *Japanese Journal of Ichthyology* 36: 155–170, <https://doi.org/10.1007/BF02914319>
- Kottelat M (2007) Three new species of *Phoxinus* from Greece and southern France (Teleostei: Cyprinidae). *Ichthyological Exploration of Freshwaters* 18: 145–162
- Kottelat M, Freyhof J (2007) Handbook of European Freshwater Fishes. Steven Simpson Books, Switzerland, 646 pp
- Leunda PM (2010) Impacts of non-native fishes on Iberian freshwater ichthyofauna: current knowledge and gaps. *Aquatic Invasions* 5: 239–262, <https://doi.org/10.3391/ai.2010.5.3.03>
- Moreno-Valcárcel R, De Miguel RJ, Fernández-Delgado C (2013) The first record of the European catfish *Silurus glanis* Linnaeus, 1758 in the Guadalquivir River basin. *Limnetica* 32(1): 23–26
- Ramos-Merchante A, Prenda J (2018) The Ecological and Conservation Status of The Guadalquivir River Basin (S Spain) Through The Application Of A Fish-based Multimetric Index. *Ecological Indicators* 84: 45–59, <https://doi.org/10.1016/j.ecolind.2017.08.034>
- Ribeiro F, Leunda PM (2012) Non-native fish impacts on Mediterranean freshwater ecosystems: current knowledge and research needs. *Fisheries Management and Ecology* 19: 142–156, <https://doi.org/10.1111/j.1365-2400.2011.00842.x>
- SIBIC (2014) Carta Piscícola Española. www.cartapiscicola.es (accessed 13 March 2019)
- van der Veer G, Nentwig W (2015) Environmental and economic impact assessment of alien and invasive fish species in Europe using the generic impact scoring system. *Ecology of Freshwater Fish* 24: 646–656, <https://doi.org/10.1111/eff.12181>
- Vinyoles D, Robalo JL, Sostoa AD, Almodóvar AM, Elvira B, Nicola GG, Fernández-Delgado C, Santos CS, Doadrio I, Sardà-Palomera F, Almada VC (2007) Spread of the alien bleak *Alburnus alburnus* (Linnaeus, 1758) (Actinopterygii Cyprinidae) in the Iberian Peninsula: the role of reservoirs. *Graellsia* 63: 101–110, <https://doi.org/10.3989/graellsia.2007.v63.i1.84>

Supplementary material

The following supplementary material is available for this article:

Table S1. Record list collected for each species including latitude and longitude in decimal degrees (coordinates), number of specimens (N), river name and data source.

This material is available as part of online article from:

http://www.reabic.net/journals/bir/2019/Supplements/BIR_2019_Saez-Gomez_Prenda_Table_S1.xlsx

