PODRUČJE KRETANJA I ODABIR STANIŠTA CRVENOKLJUNE ČIGRE (Sterna hirundo Linnaeus, 1758) TIJEKOM SEZONE GNIJEŽĐENJA U OKOLICI ZAGREBA

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PRIRODOSLOVNO-MATEMATIČKI FAKULTET
BIOLOŠKI ODSJEK

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DOKTORSKI RAD

Mentor:
Nasl. izv. prof. dr. sc. Jelena Kralj

Zagreb, 2024.

Ovaj doktorski rad izrađen je u Zavodu za ornitologiju Hrvatske akademije znanosti i umjetnosti pod vodstvom izv. prof. dr. sc. Jelene Kralj u sklopu Sveučilišnoga poslijediplomskog doktorskog studija Biologije na Biološkome odsjeku Prirodoslovno-matematičkoga fakulteta Sveučilišta u Zagrebu. Istraživanja su financirana iz sredstava Europskoga fonda za regionalni razvoj u okviru Programa suradnje Interreg V – A Slovenija – Hrvatska 2014. – 2020. u sklopu projekta “Očuvanje populacija čigri u porječju Save i Drave (ČIGRA)”.

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Voditeljica projekta HRZZ IP-2020-02-8793 „Kopno ili more: ekološki i genetički aspekti izbora staništa crvenokljune čigre (KiM:ČIGRE)"

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Prirodoslovno-matematički fakultet

Biološki odsjek

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Crvenokljuna čigra (*Sterna hirundo* Linnaeus, 1758) gnijezdi se u Hrvatskoj, često kolonijalno, na šljunkovitim i kamenitim otočićima duž Jadrana te u porječju Save i Drave. Najveće su kolonije ove vrste u Hrvatskoj kontinentalne, no te se populacije danas zbog ljudskoga pritiska gotovo u potpunosti gnijezde na umjetnim staništima. U sklopu ove disertacije, u trima znanstvenim publikacijama istraženi su odabir staništa kontinentalne populacije crvenokljune čigre i njihovo kretanje među kolonijama pomoću GPS-UHF uređaja za praćenje. Utvrđena su područja hranjenja crvenokljunih čigri koje se gnijezde u okolici Zagreba, od kojih je najvažnije područje Save kod Hruščice. Potvrđena je preferencija ptica koje se gnijezde na koloniji Siromaja 2 za hranjenje na plićim dijelovima rijeke. Prvi put dokumentirano je izviđanje odraslih ptica tijekom aktivnoga gniježđenja. Rezultati su ovoga istraživanja korisne spoznaje i smjernice za pozicioniranje umjetnih gnjezdilišta, aktivnosti restauracije riječnih ekosustava i procjenu utjecaja zahvata na crvenokljune čigre.

100 stranica, 19 slika, 10 tablica, 173 literaturna navoda, jezik izvornika: hrvatski

Ključne riječi: telemetrija, hidrologija, hranjenje, dubina vode, slatkovodna staništa, izviđanje

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HOME RANGE AND HABITAT CHOICE OF THE COMMON TERN (*Sterna hirundo* Linnaeus, 1758) DURING BREEDING SEASON NEAR ZAGREB

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The Common Tern (*Sterna hirundo* Linnaeus, 1758) breeds, often colonially, in Croatia on gravelly and rocky islands along the Adriatic Sea and along the Sava and Drava rivers. The largest colonies in Croatia are found inland in freshwater habitats, but due to human pressure these populations today breed almost exclusively on artificial sites. In this dissertation, represented by three scientific publications, the habitat selection and movements of an inland Common Tern population was investigated using GPS-UHF tracking devices. The area used by Common Terns breeding near Zagreb was identified, the most important of which was the area of Sava near Hruščica. A preference of birds which bred at the Siromaja 2 colony was established for foraging on shallow parts of the river. Prospecting of actively breeding adult birds was documented for the first time. The results of this study provide useful insights and guidance for the positioning of artificial breeding grounds, river ecosystem restoration activities, as well as for assessing the impact of interventions in habitats of Common Terns.

100 pages, 19 figures, 10 tables, 173 references, original in Croatian

Keywords: telemetry, hydrology, foraging, water depth, freshwater habitats, prospecting

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SADRŽAJ

1. UVOD

1.1. Opis vrste

Crvenokljuna čigra (*Sterna hirundo* Linnaeus, 1758; Slika 1.) vrsta je ptice iz porodice galebova Laridae. Karakteriziraju je crna *kapa*, šiljat crven kljun crnoga vrha te bijel račvast rep. Po repu i okretnome gracioznu letu, uglavnom iznad vodenih površina, podsjeća na lastavice. Dugačka je od 32 do 39 cm od vrha kljuna do vrha repa, a raspon joj je krila od 72 do 83 cm (Arnold i sur. 2020). Mužjaci se mogu razlikovati od ženki po nekim mjerama, no ne i po ruhu. Prema Nisbet i sur. (2007) za morfometrijsko određivanje spola najkorisnija je mjera dužine glave, a prema Kralj i sur. (2019) osim dužine glave i dužina te visina kljuna.

Slika 1. Crvenokljuna čigra. Autor: Davorin Tome

Crvenokljuna čigra selica je koja se gnijezdi diljem Europe, Azije i Sjeverne Amerike, dok zimuje duž obala južne polutke (Becker i Ludwigs 2004). Budući da je ova vrsta usko vezana za vodena staništa, gnijezdi se kolonijalno ili pojedinačno na tvrdim podlogama izvan dosega predatora. Uglavnom je riječ o priobalnim kamenitim otočićima na moru ili šljunkovitim riječnim i jezerskim otocima i sprudovima, no može se gnijezditi i na ljudskim tvorevinama nalik na otočiće. Na hranjenju ili izvan sezone gniježđenja može se opaziti na svim vodenim staništima uključujući ribnjake i tokove rijeka. U

Hrvatskoj se crvenokljuna čigra gnijezdi u priobalju te u porječju Save i Drave. Najveće poznate kontinentalne kolonije crvenokljune čigre nalaze se na šljunčarama Rakitje, Siromaja 2 i Šoderica te na rijeci Dravi nakon ušća Mure. Kolonije se povremeno pojavljuju i na drugim lokacijama, kada uslijed niskoga vodostaja iznad površine izbiju pogodni sprudovi i otočići. Ukupna gnijezdeća populacija u Hrvatskoj procijenjena je na 400 do 700 parova (Kralj i sur. 2013).

Crvenokljuna čigra na područje Hrvatske stiže tijekom travnja. S gniježđenjem uglavnom počinje početkom svibnja iako visoke razine vode u proljeće mogu odgoditi gniježđenje i do lipnja. Kad se na kontinentu stabiliziraju razine vode, na rijekama i jezerima pronalazi šljunkovite ili pjeskovite otočiće sa što manje vegetacije, pogodne za gniježđenje. Polaže 1 do 4 jaja (Slika 2.). Inkubacija uglavnom traje 21 do 23 dana. Ptići su djelomični potrkušci koji gnijezdo napuštaju stari 3 do 4 dana, dok su potpuno opernaćeni oko 25 dana nakon izlijeganja. Polaganje jaja te trajanje inkubacije i opernaćivanja mogu početi kasnije i trajati dulje, ovisno o vremenskim uvjetima, lokalitetu, dostupnosti hrane i uznemiravanju. Iako oba roditelja inkubiraju jaja i othranjuju ptiće (Becker i Ludwigs 2004), postoji podjela između spolova u njihovim poslovima. Tijekom inkubacije oba spola približno jednako vremena provode brinući se o gnijezdu, no ženke pritom više vremena provode inkubirajući jaja (Wiggins i Morris 1987). Prvih dana hranjenja ptića ženke više vremena provode uz gnijezdo, dok su mužjaci pretežno odgovorni za hranjenje ptića (Wiggins i Morris 1987; Riechert i Becker 2017). Imaju jedan polog u sezoni, a u slučaju propadanja pologa ili legla, mogu imati zamjenske pologe, najčešće na istoj koloniji (González-Solís i sur. 1999; Becker i Zhang 2011). Nakon gniježđenja okupljaju se na staništima bogatim plijenom te do sredine rujna napuštaju područje Hrvatske. Poznate su dvije glavne selidbene rute europskih populacija: zapadna ruta prati zapadne obale Europe i Afrike te ptice zimuju duž zapadne i južne obale Afrike (Becker i sur. 2016; Piro i Schmitz Ornés 2022); istočna ruta prati istočne krajeve Sredozemlja i Crveno more, a ptice zimuju duž istočne i južne obale Afrike (Kralj i sur. 2020; Piro i Schmitz Ornés 2022).

Slika 2. Gnijezdo crvenokljune čigre s dva jaja i nedavno izlegnutim ptićem. Autor: Maciej Szymański

1.2. Hranjenje

Crvenokljune čigre pretežno se hrane malom ribom, dužine do 15 cm. Često se hrane rakovima i kukcima, a povremeno i lignjama, dok rijetko love ostale beskralješnjake (Becker i Ludwigs 2004). Hranu uglavnom hvataju blizu površine vode, uranjanjem iz zraka tako da im krila ostanu iznad razine vode (engl. *plunge-diving*), s dubinama urona do 0,5 m (Cabot i Nisbet 2013), što ih ograničava na hvatanje plijena u najvišim dijelovima vodenoga stupca. Zbog toga crvenokljune čigre za osiguravanje dostupnosti hrane ovise o procesima koji njihov plijen približavaju površini: biološkim poput vertikalnih migracija plijena (npr. Stienen i sur. 2000), morskim predatorima koji tjeraju plijen bliže površini (npr. Safina i Burger 1985) te fizikalnim poput uzlaznih struja ili virova koje uzrokuju morske mijene (Irons 1998; Holm i Burger 2002; Zamon 2003). Budući da je crvenokljuna čigra kolonijalna gnjezdarica, na dostupnost plijena dodatno može utjecati veličina kolonije ako zbog velikoga broja ptica dođe do iscrpljivanja hrane u blizini kolonije (Ashmole 1963; Birt i sur. 1987). Mnogi predatori u vodenim staništima hrane se na jasno određenim područjima koja im omogućavaju veću dostupnost plijena (Becker i sur. 1993; Irons 1998), poput podvodnih izbočina i pragova (Kinder i sur. 1983;

Hunt i Harrison 1990; Thorne i Read 2013), usjeklina (Warren i sur. 2009) te područja oko otočića (Johnston i sur. 2005).

Najvažnija je razlika između hranjenja na slatkovodnim i hranjenja na morskim staništima u dostupnosti hrane – na slatkovodnim je staništima dostupnost hrane podjednaka tijekom čitavoga dana, dok na morskima često ovisi o morskim mijenama (Becker i sur. 1997). Istraživanja o morskim staništima na kojima se crvenokljune čigre hrane znatno su brojnija od onih o slatkovodnim staništima. Spoznaje o populacijama koje se gnijezde uz more upućuju na to da čigre mnogo vremena provode leteći iznad plićih dijelova (Becker i sur. 1993), bogatih klorofilom (McLeay i sur. 2010) te dijelova u kojima se voda ubrzava preko pličina (Urmy i Warren 2018), uglavnom u vrijeme izmjene plime i oseke (Schwemmer i sur. 2009), odnosno iznad blago uzburkanih voda (Dunn 1973). Nedostaje istraživanja, međutim, o značajkama slatkovodnih staništa na kojima se hrane crvenokljune čigre. Bracey i sur. (2020) utvrdili su da su čigre tijekom gniježđenja na jezeru Superior (SAD) hranu za svoje ptiće i gotovo pola hrane za sebe pretežno prikupljale duž rijeke umjesto na jezeru. Jednostavno promatranje ptica (Fasola i Bogliani 1984) pokazuje preferenciju ptica za pliće dijelove rijeke, no nedostaju detaljnija telemetrijska istraživanja o izboru područja hranjenja čigri sa slatkovodnih kolonija.

Čigre hvataju hranu za sebe i nose ju i svojim mladuncima. Budući da to podrazumijeva prikupljanje hrane na udaljenim mjestima i njezin prijenos do gnijezda (uglavnom po jedan komad plijena, rjeđe i do četiri (Hays i sur. 1973)), čigre smatramo vrstom čija je potraga za hranom ovisna o središnjemu mjestu (engl. *central place foraging,* Wetter 1989; Dänhardt i sur. 2011). Teorija optimalne ishrane govori da je udaljenost koju su čigre spremne preletjeti uvjetovana ekonomičnošću (Pyke 1984): mogu si priuštiti dalje letove ako je na tim mjestima hrana brojnija, jednostavnija za hvatanje ili energetski bogatija. Potrebe za hranom mijenjaju se ovisno o fazi gniježđenja i spolu ptice. Tijekom inkubacije ptice hrane samo sebe i eventualno partnera, stoga rjeđe moraju ići u potragu za hranom nego u fazi othrane ptića, kada moraju prikupljati hranu i za sebe i za svoje sve veće potomstvo. Potvrđeno je da tijekom othrane ptića čigre poduzimaju kraće letove te da su područja hranjenja bliža koloniji nego tijekom inkubacije, kada ptica koja trenutačno ne inkubira, ne mora tako često posjećivati koloniju (Becker i sur. 1993). Nadalje, ranije navedena podjela poslova između spolova tijekom gniježđenja, prema hipotezi specijalizacije reproduktivnih uloga, može biti povezana s razlikama između spolova u prikupljanju hrane (Paredes i sur. 2006; Burke i sur. 2015; Hernández-Pliego i sur. 2017). Militão i sur. (2023) utvrdili su da su mužjaci putovali dalje i brže te da je ovisnost njihovih letova o morskim mijenama bila varijabilnija nego kod ženki iako se oba spola hrane ovisno o morskim mijenama i vremenu u danu te imaju jednak broj letova i ukupni prijeđeni put. Ženke su se pritom hranile više od mužjaka, možda radi nadoknađivanja mase izgubljene polaganjem jaja, dok su mužjaci vjerojatno istraživali pogodna hranilišta radi pripreme za hranjenje mladunaca. U svakome slučaju, poznato je da se većina aktivnosti hranjenja gnijezdećih čigri obično odvija unutar 3 do 10 km od gnijezda, iznimno do 30 km (Thaxter i sur. 2012; Nisbet 2002). Za učinkovitu zaštitu i očuvanje kontinentalnih populacija čigri u Hrvatskoj potrebna su podrobnija saznanja o njihovu odabiru staništa prilikom boravka na ovim prostorima, uključujući i gnjezdilišta i hranilišta.

1.3. Pritisci i prijetnje

Opasnosti i prijetnje s kojima se tijekom gniježđenja u Hrvatskoj susreću morske i kontinentalne populacije crvenokljune čigre djelomično se razlikuju. Zajedničke pritiske predstavljaju im predatori poput galebova, štakora i vidri te ljudske aktivnosti poput odlaganja otpada i posjećivanja otočića u vrijeme gniježđenja. Ljudi koji posjećuju kolonije radi istraživanja na ptice utječu dvojako: ometaju ih i prekidaju brigu o gnijezdu, no istodobno rastjeruju grabežljivce te sprečavaju slučajne posjete i vandalizam (Palestis 2014). Također se pokazalo da se čigre s vremenom navikavaju na istraživače, što bi moglo smanjiti uznemiravanje koje čine slučajni prolaznici i posjetitelji (Nisbet 2000). Arnold i sur. (2022) utvrdili su da su male kolonije u blizini naselja najpodložnije propadanju uslijed predacije, dok su velike kolonije (preko 1000 parova) daleko od naselja (20 - 30 km) imale najveću produktivnost. Velike i homogene kolonije općenito su otpornije na predatore (Hernández-Matías i sur. 2003), što nije dobro za relativno malene kolonije u okolici Zagreba, kao ni za one raštrkane po jadranskim otočićima.

Osnovni su uzrok ugrožavanja kontinentalnih populacija crvenokljune čigre u Hrvatskoj zahvati na prirodnim vodotocima, koji zajedno s klimatskim promjenama (Mitchell i sur. 2020) unose sve više nesigurnosti u ionako već nestabilna slatkovodna staništa. Ta su područja pod velikim utjecajem čovjeka, koji uzrokuje izgradnju hidroelektrana, vađenje šljunka iz riječnoga korita, utvrđivanje obala, onečišćenje voda, širenje invazivnih vrsta biljaka, sportski ribolov itd. Crvenokljune čigre na takvim su staništima suočene s raznim opasnostima koje utječu na uspješnost njihova gniježđenja, primjerice naglim promjenama razine vode, eutrofikacijom, erozijom i otplavljivanjem kolonija te zaraštanjem pogodnih gnjezdilišta (BirdLife 2023; Arnold i sur. 2022). Navedene su aktivnosti dovele do situacije da su danas slatkovodni ekosustavi među najrjeđim i najugroženijim staništima u Europi (EEA 2015). Čigre se stoga sve češće gnijezde na strukturama poput umjetnih otočića i platforma za gniježđenje (Slika 3.), smještenima na umjetnim staništima poput akumulacijskih jezera i šljunčara (Coccon i sur. 2018; Brichetti i Fracasso 2018; Müller 2018; Kralj i sur. 2019). Opstanak tih staništa pak ovisi o stalnome održavanju jer su inače prepuštena zaraštanju i propadanju (Martinović 2018).

Slika 3. Platforma za gniježđenje čigri na jezeru Siromaja 2 u blizini Zagreba. Autor: Tomica Rubinić

1.4. Izviđanje staništa i vjernost koloniji

U prethodnim je poglavljima opisana prilagodljivost crvenokljunih čigri promjenjivim uvjetima na gnjezdilištima. Godinama je samo u okolici Zagreba, ovisno o vodostajima i dostupnim sprudovima, zabilježeno gniježđenje na šest lokaliteta: na riječnim sprudovima na Savi, na umjetnim otocima i sprudovima na šljunčari Rakitje, na plutačama na šljunčari Abesinija, na umjetnoj platformi za gniježđenje na šljunčari Siromaja 2, na otočiću i niskim sprudovima na jezeru Ontario nedaleko od naselja Blato te na neaktivnoj opremi za iskapanje šljunka na jezeru Čiče (Kralj i sur. 2019). Svaka od navedenih lokacija kao stanište za gniježđenje ima svoje prednosti i nedostatke, a upravo o kvaliteti staništa ovisi produktivnost čigri, odnosno mogućnost njihova uspješnoga gniježđenja na toj lokaciji (Kralj i sur. 2019). Opisano je kako mužjaci vjerojatno tijekom inkubacije jaja istražuju pogodna hranilišta radi pripreme za hranjenje mladunaca (Militão i sur. 2023). Jednako tako čigre moraju posvetiti određeno vrijeme i utrošiti energiju na odabir pogodne lokacije za gniježđenje, zbog čega prikupljaju ekološke i društvene informacije o kvaliteti dostupnih gnjezdilišta (Danchin i sur. 2004; Dall i sur. 2004). Taj proces prikupljanja informacija o kvaliteti dostupnih staništa, gnjezdilišta ili hranilišta, naziva se **izviđanje**. Osim kod ptica (Reed i sur. 1999; Doligez i sur. 2004; Parejo i sur. 2007; Calabuig i sur. 2010; Ponchon i sur. 2017), zabilježeno je i u mnogim drugim taksonomskim skupinama poput sisavaca, gmazova, vodozemaca i kukaca (Seeley i Buhrman 2001; Cote i Clobert 2007; Selonen i Hanski 2010; Mares i sur. 2014; Pizzatto i sur. 2016; Mayer i sur. 2017).

Ključne informacije koje jedinke prikupljaju izviđajući potencijalna gnjezdilišta u skladu su s poznatim pritiscima, no migratornim je kolonijalnim vrstama radi uštede vremena i energije isplativije odlučivati o odabiru staništa promatranjem drugih jedinki, odnosno prikupljanjem društvenih (socijalnih) informacija: o veličini gnjezdilišta i same kolonije, o lokalnoj kompeticiji unutar vrste, o kvaliteti potomstva te o uspješnosti gniježđenja jedinki iste vrste i drugih vrsta (Mönkkönen i sur. 1999; Cayuela i sur. 2018). Prikupljenim informacijama jedinke se služe prilikom tzv. *upućene disperzije* na područja na kojima će se sljedećih godina razmnožavati (Clobert i sur. 2009) te su kao takve posebno korisne za nedorasle jedinke koje prvi put odlučuju o lokalitetu za gniježđenje. Budući da one u početku poznaju jedino vlastiti natalni lokalitet, za odlučivanje o disperziji potrebna su im iskustva s drugih lokaliteta: odmorišta, hranilišta i gnjezdilišta (Reed i sur. 1999).

Kod ptica je izviđanje zabilježeno u različitih skupina (Reed i sur. 1999), i to osobito kod nedoraslih i mladih jedinki dugoživućih morskih vrsta ptica (Votier i sur. 2011; Campioni i sur. 2017). Pretpostavlja se da odgođeni početak gniježđenja mladim pticama omogućava više vremena za usporedbu potencijalnih lokaliteta prije nego što odluče gdje će se gnijezditi (Dittman i sur. 2005). Tako je izviđanje potvrđeno i kod nedoraslih jedinki crvenokljune čigre (Dittman i Becker 2003).

Izviđanje je kod odraslih ptica donedavno bilo znatno manje poznato. Zabilježeno je u troprstoga galeba (*Rissa tridactyla* Linnaeus, 1758) (Cadiou i sur. 1994; Ponchon i sur. 2017) kada se neuspješne gnjezdarice odlučuju za eventualnu disperziju na druga gnjezdilišta. Iako se pretpostavljalo kako uspješne gnjezdarice izviđaju staništa prije i nakon gniježđenja (Phillips i sur. 2017), zadnjih su godina Oro i sur. (2021) te Kralj i sur. (2023) utvrdili izviđanje tijekom aktivnoga gniježđenja kod raznih vrsta čigri i galebova, pa tako i kod crvenokljunih čigri. Prema *hipotezi optimalnoga vremena* (Campioni i sur. 2017) izviđanje je učinkovitije u kasnijim stadijima gniježđenja (primjerice u vrijeme hranjenja ptića), kada su na potencijalnim kolonijama uočljive kvalitetnije informacije o lokalnoj uspješnosti gniježđenja (Boulinier i sur. 1996). Ovu hipotezu potvrđuje većina istraživanja koja su bilježila izviđanje tijekom aktivnoga gniježđenja (Kralj i sur. 2023). Nadalje, izviđanje je bilježeno i tijekom inkubacije jaja (Oro i sur. 2021), kada ptice imaju više vremena za obilazak drugih gnjezdilišta jer još ne moraju hraniti svoje mlade. Ranije izviđanje također omogućava pticama da u slučaju neuspjeha prvoga pologa unutar iste sezone promijene koloniju zato što vjerojatnost i uspješnost ponovnoga gniježđenja ovise o tome koliko se rano ptice u njega upuštaju (Becker i Zhang 2011).

Na izviđanje i uspješnost gniježđenja još utječe o njima izravno ovisan čimbenik – vjernost gnjezdilištu, odnosno povratak jedinka radi gniježđenja na isti lokalitet na kojemu su se te jedinke prethodnih godina gnijezdile. Ovaj je fenomen također potvrđen u mnogih vrsta morskih ptica (Palestis 2014; Brooke 2018), no poznato je i variranje unutar vrste, ovisno o veličini kolonije, tipu staništa te produktivnosti (Palestis 2014; Coulson 2016). U crvenokljune čigre zabilježena je visoka vjernost gnijezdećoj koloniji, što znači da se većina jedinki svake godine vraća na isto gnjezdilište na kojemu su se gnijezdile prethodne godine (Tims i sur. 2004; Coulson 2016) iako stupanj filopatrije ovisi o uspješnosti kolonije (Palestis 2014). U slučaju neuspjeha prvoga pologa crvenokljune čigre obično polažu zamjenska legla na istoj koloniji (Becker i Zhang 2011), čak i na istome mikrolokalitetu odnosno teritoriju, unutar 4,3 m od prvoga gnijezda (González-Solís i sur. 1999).

Kao što je navedeno, crvenokljune čigre na slatkovodnim se staništima gnijezde na šljunkovitim otocima rijeka i jezera, gdje iznenadne promjene razine vode mogu upropastiti čitave kolonije (Atamas i Tomchenko 2015; Farnsworth i sur. 2016). U takvim nepredvidivim uvjetima u kojima se prilike za gniježđenje, osim između sezona, naglo mijenjaju i unutar pojedine sezone gniježđenja (Palestis 2014), prikupljanje informacija o trenutačnom uspjehu gniježđenja na ostalim potencijalnim gnjezdilištima moglo bi čigrama omogućiti uspješan eventualni zamjenski polog.

1.5. Ciljevi istraživanja

Osnovni ciljevi ovoga istraživanja:

1. utvrditi koja područja kontinentalnoj populaciji crvenokljune čigre služe za vrijeme gniježđenja u Hrvatskoj,
2. istražiti koje značajke staništa pogoduju crvenokljunim čigrama prilikom hranjenja
3. istražiti izviđanje staništa kod gnijezdećih crvenokljunih čigri u okolici Zagreba.

Ostvarivanjem navedenih ciljeva istraživanje će omogućiti određivanje ključnih lokaliteta i staništa za kontinentalne populacije crvenokljune čigre u Hrvatskoj, posebice za one koje se gnijezde u okolici Zagreba. Prva dva cilja pomoći će u određivanju hranilišta i letnih koridora, dok će treći cilj pružiti uvid u potencijalna nova gnjezdilišta koja ptice posjećuju prilikom svojih izviđanja. Sve navedeno, uključujući i nove spoznaje o ekologiji vrste, omogućit će kvalitetnije planiranje aktivnosti očuvanja crvenokljune čigre i njezinih slatkovodnih staništa.

Znanstvene su hipoteze ove disertacije:

H_1: kontinentalne populacije crvenokljune čigre u Hrvatskoj za vrijeme gniježđenja koriste se vodenim površinama unutar 10 km od svoje kolonije, iznimno do 30 km

H_2: crvenokljune čigre u okolici Zagreba najveći dio vremena prilikom hranjenja provode na plitkim dijelovima rijeka i jezera

H_3: crvenokljune čigre u okolici Zagreba za vrijeme aktivnoga gniježđenja (uglavnom hranjenja ptića) posjećuju druge kolonije.

Ova disertacija obuhvaća tri izvorne znanstvene publikacije (**I** – **III**) koje ispituju navedene hipoteze te ostvaruju navedene ciljeve istraživanja. Publikacije **I** i **III** povezane su s prvim ciljem te odgovaraju na prvu znanstvenu hipotezu istraživanja. Publikacija **III** također je izravno povezana s drugim ciljem te ispituje drugu hipotezu. Publikacija **II** povezana je s trećim ciljem i ispituje treću postavljenu hipotezu. U sljedećemu poglavlju, naslova **ZNANSTVENI RADOVI** predstavljene su sve tri publikacije, a njihov objedinjeni doprinos sagledan je u poglavlju **RASPRAVA**.

2. ZNANSTVENI RADOVI

I. Tome D, **Martinović M**, Kralj J, Božič L, Basle T i Jurinović L (2019) Area use and important areas for Common Tern *Sterna hirundo* inland populations breeding in Slovenia and Croatia. Acrocephalus 40(180/181):55–67.

II. **Martinović M**, Galov A, Svetličić I, Tome D, Jurinović L, Ječmenica B, Basle T, Božič L i Kralj J (2019) Prospecting of breeding adult Common terns in an unstable environment. Ethology Ecology & Evolution, DOI: 10.1080/03949370.2019.1625952

III. **Martinović M**, Plantak M, Jurinović L i Kralj J (2023) Importance of shallow river topography for inland breeding Common Terns. Journal of Ornithology 164:705–716. https://doi.org/10.1007/s10336-023-02060-0

I. Tome D, **Martinović M**, Kralj J, Božič L, Basle T i Jurinović L (2019) Area use and important areas for Common Tern *Sterna hirundo* inland populations breeding in Slovenia and Croatia. Acrocephalus 40(180/181):55–67.

Acrocephalus 40 (180/181): 55–67, 2019
10.1515/acro-2019-0003

Area use and important areas for Common Tern *Sterna hirundo* inland populations breeding in Slovenia and Croatia

Raba območij in pomembna območja celinske populacije navadne čigre *Sterna hirundo* v Sloveniji in na Hrvaškem v času gnezdenja

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During the breeding periods of 2018 and 2019 we investigated the extent of areas Common Terns *Sterna hirundo* use while searching for food. We used GPS-UHF tags to follow the movements of 23 terns from Slovenia (7 individuals) and Croatia (16 individuals). We investigated the movements of birds from three breeding sites, i.e. Lakes Ptuj, Siromaja 2 and Rakitje. Conclusions are based on 43,105 locations which were collected with a frequency of one reading per 20 minutes during the day and one reading per 4 hours during the night.

In Slovenia, terns used a 60 km long and narrow area over Stara struga Drave (former river-bed of the Drava River) between Ormož and Maribor as well as eleven fishponds / lakes in its surroundings, most of them in the Pesnica valley. The most distant location was 30 km of straight line from breeding islands, but it was visited only once by a single tern. The areas with the most locations, hence important areas, were Lake Ptuj, Drava at Ptuj, Stara struga Drave between Ptuj and Rošnja and about 20 km distant Lakes Radehova and Gradiško. These were probably the most important feeding areas for Common Terns breeding on Lake Ptuj.

In Croatia, terns were found along the Sava almost exclusively, with only a few visits more than 2 km from the river. The most distant locations were over 60 km away from the breeding grounds, but terns visited them only rarely. Most locations of terns nesting on Siromaja were within a 5 km radius, while terns from Rakitje were making regular flights to waters up to 23 km from their colony. The area with the most locations visited by terns from both colonies was the Sava at Hruščica. Besides, birds from the Rakitje colony were frequently recorded on the Sava near Savica and waterbodies within 5 km of the colony. These were probably the most important feeding areas for Common Terns breeding around Zagreb.

Key words: Common Tern, foraging areas, GPS-UHF tags, home range, Drava, Sava

Ključne besede: navadna čigra, območja prehranjevanja, GPS-UHF oddajniki, Drava, Sava

1. Introduction

Bird abundance and distribution is limited by suitable habitats. Among the most important factors affecting habitat suitability are quality of nest-site, food supply and "enemies", being predators, parasites or competitors (Newton 2007). Common Terns *Sterna hirundo* nest close to large water bodies on flat, scarcely vegetated surfaces (Nisbet 2002). Sea coast seems like a very spacious breeding area for them, but only very specific habitats meet all criteria for nest-site selection. In Croatia, for example, although abundant with sea coast, only 200–500 pairs are presumed to nest along the sea (Kralj *et al.* 2013). In marine ecosystems in Slovenia, terns nest at artificially maintained Sečovlje saltpans and in carefully managed Škocjanski zatok Nature Reserve (Škornik 2012).

Inland, the most often occupied natural breeding sites of Common Terns are gravel islands and banks in the areas of large rivers and lakes, where predators have limited access (Becker & Ludwigs 2004). Nowadays, due to countless changes made in freshwater ecosystems by humans, these are among the rarest and most endangered habitats in Europe (EEA 2015). Hence terns are more and more diverted to nest in artificial areas and structures like gravel pits and nesting rafts. In Slovenia, the only permanent breeding site of Common Terns are artificial islands on Lake Ptuj on the Drava River (Denac *et al.* 2019), where they've nested since the reservoir was created in 1978 (Janžekovič & Štumberger 1984). In 2017, another breeding island was created on Brežice HPP reservoir on the Sava River. Common Terns bred there in 2018 and 2019, but whether this is to become another regular breeding site for Slovenia remains to be seen. In Croatia, regularly nesting terns can be found on two locations near the Sava River (Hrušćica and Rakitje) and two on the Drava (Lake Ormož and Drava River close to Repaš), while occasional breeding in smaller numbers also occurs at various fishponds of continental Croatia. The population of inland breeding Common Terns in both countries is estimated at 300–500 breeding pairs. Being so scarce and vulnerable, most breeding sites are strictly protected by law (Božič 2003, Radović *et al.* 2005) and well managed (Denac & Božič 2018, Martinović 2018). Still, to run an efficient protective breeding program for Common Terns, other factors important for suitability of the habitat should be controlled, too, in particular food. In Slovenia and Croatia, there have been no reports in this respect, beside notes on sporadic observations of terns foraging on different locations during the breeding season (e.g. Vogrin 2016).

While breeding and when not on or near the nest, Common Terns spend a lot of their time flying over shallow waters, where they search for food, mainly fish up to 15 cm long (Becker & Ludwigs 2004), which they catch by plunge-diving from the air (Holbech *et al.* 2018). Beside for themselves, they use the catch for feeding their unfledged chicks. Since this means collecting food at some distant sources and carrying it to a nest (usually one by one), that makes them "central place foragers" (Wetter 1989, Dänhard *et al.* 2011). The optimal foraging theory predicts that the distance to which they fly during the hunt is somehow limited by economics (Pyke 1984) – they can afford longer flights if food there is more abundant, easier to catch or energetically more profitable. But in general, the radius of activity of breeding terns is usually between 3 and 10 km, exceptionally up to 30 km (Nisbet 2002) from the nest.

Locations of nests, numbers and breeding success are relatively well known for inland populations of Common Tern in Slovenia and Croatia (Kralj 2018, Mihelič *et al.* 2019). On the other hand, food and feeding habits are virtually unknown, so we designed this study to complement our knowledge appropriately. Our aim was (1) to find the whole extent of areas adult terns use during the breeding season (area use) and (2) to find which are the most used ones (i.e. most important). Since we did not observe the terns physically, we only presume that the majority of activities when not on or by the nest were to locate and catch the prey (feeding activity), although we realize that some were also due to other needs, like flying, prospecting, etc. (Martinović *et al.* 2019).

2. Study area

2.1. Slovenia

In Slovenia, the study was conducted on Lake Ptuj, where Common Terns nest, and in its surrounding areas (Figure 1). Lake Ptuj is an artificial water

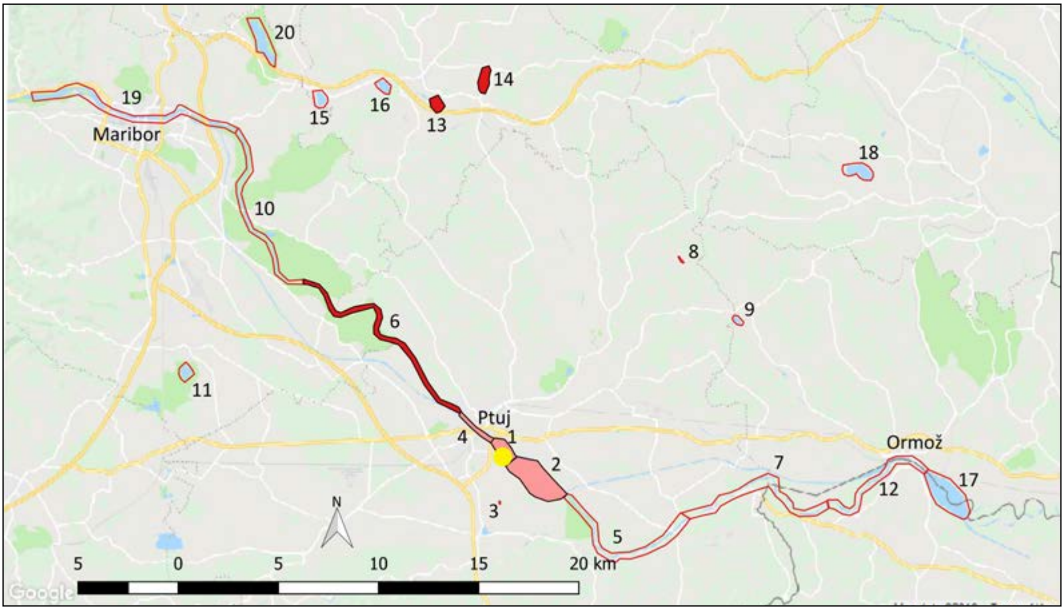

Figure 1: Areas used by Common Terns in Slovenia are presented with outlined polygons. Numbers correspond to numbers in Table 2. Filled in red important foraging areas, filled in pink important areas for foraging and as flying corridors. Yellow circle denotes position of breeding island.

Slika 1: Raba območij navadnih čiger v Sloveniji, označena s poligoni. Številke ustrezajo območjem v tabeli 2. Rdeča so območja, pomembna za prehranjevanje, rožnata pa območja, pomembna za prehranjevanje in kot preletni koridorji. Rumeni krog označuje položaj gnezdišča.

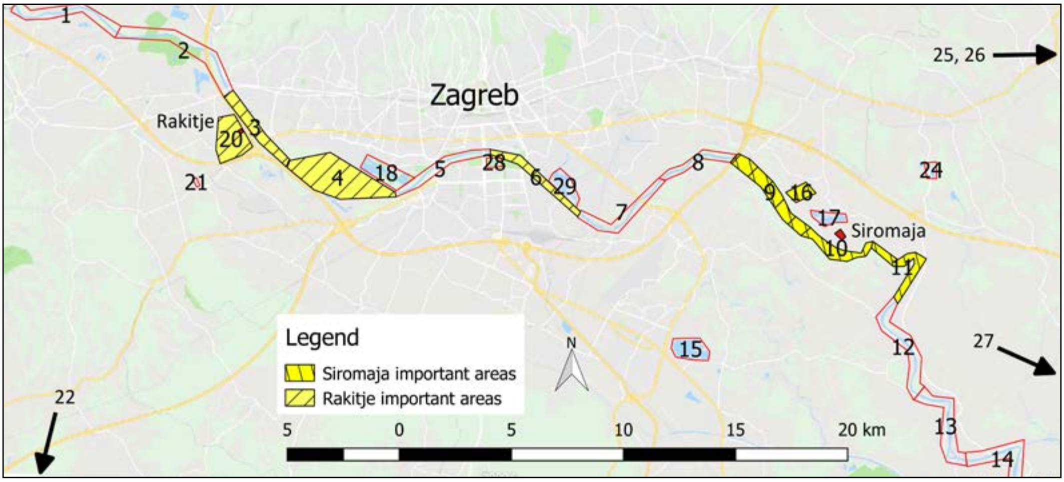

Figure 2: Areas used by Common Terns in Croatia are presented with outlined polygons. Numbers correspond to numbers in Tables 3 and 4. Important foraging areas are filled in yellow, with crossbars indicating the colony for which these areas are deemed important (see Legend). Breeding colonies are filled in red.

Slika 2: Raba območij navadnih čiger na Hrvaškem, označena s poligoni. Številke ustrezajo območjem v tabelah 3 in 4. Rumena so območja, pomembna za prehranjevanje z različnimi šrafurami za obe koloniji (glej legendo). Rdeči poligoni označujejo položaj gnezdišč.

body constructed in 1978 on the Pannonian stretch of the Drava River as reservoir for the channel-type hydropower plant Formin. It is 7.3 km long and 1.2 km wide, with its surface area covering 346 ha. In recent years, terns have been nesting there on two gravel islands (both covering 1,100 m^2) constructed in 2014, while other islands are occupied mainly by Black-headed Gulls *Larus ridibundus* (Božič & Denac 2014).

To the north of the lake spreads the town of Ptuj, while other parts of its surroundings are mostly intensive cultural landscapes with many fields, some hedgerows and villages. About 19 km further north is a series of seven lakes in the Ščavnica and Pesnica valleys. About 18 km to the W is a series of fish-ponds near the village of Rače and Medvedce reservoir. In other directions within this perimeter are some other small fish ponds, mostly without official names. The Drava River represents both the inflow and the outflow to and from Lake Ptuj. The original riverbed is in both sections complemented with an artificial, concrete channel, used to bring water to the power plant. Most of the water throughout the year is diverted to the channel, leaving the riverbed with only a small volume of water flow (20 m^3/s upstream and 10 m^3/s downstream of Lake Ptuj during the Common Tern breeding season).

2.2. Croatia

The Croatian part of the study was conducted along the Sava River in the surroundings of Zagreb (Figure 2). Terns were tagged on Lake Siromaja 2, a gravel pit with a floating breeding platform about 15 km downstream (SE) from the city of Zagreb, and on Lake Rakitje just off the W edge of Zagreb with a fairly large colony on an artificial island. The Sava River is mostly regulated and canalized all the way through Zagreb, with semi-natural flows upstream from Rakitje, about 10 km to the Slovenian border, as well as downstream from Ivanja Reka (Slukan Altić 2010). The part downstream from Ivanja Reka is protected as a Natura 2000 site "Sava kod Hrušćice" (Radović *et al.* 2005.), and this area includes numerous small gravel pits, including Siromaja 2. There are numerous other gravel pits all along the Sava through and around Zagreb. The air distance between Siromaja 2 and Rakitje lakes is 27 km and 31.5 km along the river.

3. Material and methods

3.1. Field work

We used the GPS-UHF solar-powered Nano-tags produced by Milsar, attached to birds with Teflon chest harness, to collect data on the movements by Common Terns. The device with harness weighed about 4 g, representing about 3.5% of body mass of the tern. While fitting the tags, we also marked the birds with stainless steel on one and plastic ring on the other leg.

Adults were captured on the nest using nest traps as late as possible during the incubation period. According to observations from a distance and some visits to the breeding colony, not all terns with tags successfully fledged their chicks. If a tagged bird deserted the nest before chick was hatched or in case of malfunction of the tag, the collected data was not included in the analysis.

Loggers collected GPS fixes every 20 min during daylight (4 am to 10 pm) and every 4 hrs during nighttime. GPS location accuracy was 10 m for 90% of the records (manufacturer specifications). We regularly downloaded data to a computer using an omnidirectional antenna connected to a base station.

3.2. Data analysis

We define a location as a single geographic coordinate recorded by a tag. We used Google Earth and QGIS (QGIS Development Team 2016) to graphically present distribution of all locations of all terns within the study site. As expected, locations were clustered around different water bodies (rivers, lakes, submerged gravel pits, fish ponds, etc.). We visually defined each cluster within separate water body as a separate area. In Slovenia, large areas (in particular long water courses) were further separated into two or three smaller sub-areas (in the text referred to as "the area" for sub-areas too). In Croatia, the Sava River was divided into 14 segments, each of roughly 5 km in length. Additionally, as a nesting area, we defined islands or rafts where Common Terns nested, even if they were located within one of the larger areas.

We used MS Excel to analyze distribution of locations according to the defined areas. Each area was geo-fenced with a four corner polygon. For each location and each line of the polygon, we computed the value

$$d=(x-x1)(y2-y1)-(y-y1)(x2-x1)$$

(x, y = coordinates of location; x1,y1 = coordinates of one end of the line; x2,y2 coordinates of the other end of the line)

to determine on which side of the line is the given location. If $d > 0$ the location was on one side, if $d < 0$ the location was on the other side, and if $d = 0$ the location was exactly on the line. The final result after testing for all four lines of a particular polygon was information whether the location was inside or outside the polygon surrounding a specific area.

To find which areas within home range were most often used, hence important for Common Terns (beside nesting area which was regarded as important by default), we first removed all locations from within the nesting area. For remaining locations, we used three aspects to highlight the level of importance of particular area:

(1): Cumulative number of locations of all terns in a specific area. Subjectively we considered the area as an important site if it contained more than 10% of all locations.

(2): The number of terns detected within a specific area. Subjectively we considered an area as a candidate for an important site if more than half of terns (4 for Slovenia, 2 for Croatia-Rakitje and 6 for Croatia-Siromaja) had at least one location within a specific area.

(3): Number of terns commonly present in a specific area. As commonly present we considered birds with at least 10% of locations in the particular area. With this aspect also birds with short monitoring period influence a selection of important areas. A candidate for an important site should have at least one regular visitor.

In the end we defined an area as an important site for Common Terns during the breeding season if it corresponded with the first aspect or if it was a candidate according to both other aspects.

4. Results

We analyzed data from 23 loggers (7 in Slovenia and 16 in Croatia) which were collecting locations of terns for 5 or more consecutive days (Table 1). In Slovenia, loggers attempted to record location 10,781 times. In 631 of these attempts (5.8%), GPS unit failed to connect to satellites within the pre-programmed time and record coordinates, or the registered location was erroneous. The rest were valid locations. 701 valid locations (6.9%) were disregarded due to being outside the selected areas mostly from birds recorded while flying from breeding areas over land to foraging areas or

Table 1: Statistics of tracking effort of Common Terns with GPS tags; CN = individual code number of the tern, CO = country, FD = date of first record; LD = date of last record; NR = Number of readings

Tabela 1: Statistika zbiranja GPS podatkov na navadni čigri; CN = individualna koda osebka, CO = država, FD = datum prvega podatka; LD = datum zadnjega podatka; NR = število podatkov

CN	CO	FD	LD	NR
961002	SI	5/27/2018	7/21/2018	2019
961003	SI	5/19/2018	7/11/2018	2313
961004	SI	5/19/2018	7/2/2018	1809
961007	SI	5/19/2018	5/23/2018	184
961009	SI	5/23/2018	5/27/2018	239
961014	SI	5/23/2018	7/2/2018	1897
961020	SI	5/20/2019	6/15/2019	988
961020	CRO	6/20/2018	7/19/2018	1535
961021	CRO	6/5/2018	7/20/2018	2634
961022	CRO	6/6/2018	8/1/2018	2470
961023	CRO	6/5/2018	7/12/2018	1082
961024	CRO	6/5/2018	7/26/2018	2894
961025	CRO	6/17/2018	8/1/2018	1758
961026	CRO	6/11/2018	7/20/2018	1061
961028	CRO	6/26/2018	8/12/2018	2315
961029	CRO	6/5/2018	8/1/2018	2720
961030	CRO	6/8/2018	7/12/2018	2085
961031	CRO	6/8/2018	7/20/2018	2387
961032	CRO	6/8/2018	7/19/2018	2372
961033	CRO	6/8/2018	8/1/2018	2905
961034	CRO	6/11/2018	7/26/2018	2308
961035	CRO	6/11/2018	7/20/2018	1490
961036	CRO	6/11/2018	7/14/2018	1690

Table 2: Number of locations in particular areas for Common Terns from Lake Ptuj. Area – geographic name of the area (RD – former Drava river-bed); distance – from breeding island/raft to centroid of the area; % locations – percentage of locations (according to column "all terns"); N >= 10% – number of terns with >= 10% of locations in particular area (common visitors of the area); N – number of terns recorded in the area. Shaded are important areas and numbers reaching the threshold for selection of important area.

Tabela 2: Število lokacij v posameznih območjih za čigre s Ptujskega jezera. Area – ime območja (RD – stara struga Drave); distance – razdalja med gnezdiščem in centroidom območja; % locations - odstotek lokacij (iz kolone "all terns"); N = 10 % . število čiger, ki so imele >= 10 % lokacij v izbranem območju (redne obiskovalke); N – število čiger, zabeleženih v območju. Osenčena so pomembna območja za čigre in vrednosti, ki dosegajo mejo za določanje pomembnih območij.

	Area		Code number of individual tern								statistics			
		distance (m)	961002	961003	961004	961007	961009	961014	961020	all terns	% locations	N >=10%	N	Cummulative %
	breeding islands	0	1035	654	1132	87	111	261	700	3980	100,0			
1	lake Ptuj - N	800	258	273	55	45	30	114	41	816	14.9	5	7	14.9
2	lake Ptuj - S	1700	59	544	29	9	0	3	21	665	12.2	1	6	27.1
3	fish pond near Ptuj	2000	57	2	0	0	0	0	0	59	1.1	0	2	28.2
4	Drava at Ptuj	2100	187	129	5	4	34	94	49	502	9.2	3	7	37.3
5	RD Markovci to Ormož - E	5500	1	31	0	1	0	1	0	34	0.6	0	4	38.0
6	RD Ptuj - Rošnja	7600	269	378	5	13	59	1147	176	2047	37.4	6	7	75.4
7	RD Markovci to Ormož - C	9500	0	1	0	0	0	2	0	3	0.1	0	2	75.4
8	fish ponds at Bodkovci	13200	1	89	0	0	0	0	0	90	1.6	0	2	77.1
9	lake Savci	13500	1	36	0	0	0	0	0	37	0.7	0	2	77.8
10	RD Rošnja - Maribor	15700	1	2	0	0	5	11	0	19	0.3	0	4	78.1
11	fish ponds at Rače	16500	1	103	0	0	0	0	0	104	1.9	0	2	80.0
12	RD Markovci to Ormož - W	16500	0	4	0	3	0	13	0	20	0.4	0	3	80.4
13	lake Radehova	19000	129	0	406	10	0	198	0	743	13.6	4	4	94.0
14	lake Gradiško	19500	10	0	87	5	0	46	1	149	2.7	1	5	96.7
15	lake Pristava	21000	1	0	6	0	0	6	0	13	0.2	0	3	96.9
16	lake Komarnik	21200	0	0	3	0	0	0	0	3	0.1	0	1	97.0
17	lake Ormož	22000	0	32	0	7	0	1	0	40	0.7	0	3	97.7
18	Gajševsko lake	23000	0	22	0	0	0	0	0	22	0.4	0	1	98.1
19	Drava at Maribor	25000	0	13	0	0	0	0	0	13	0.2	0	1	98.4
20	lake Pernica	25000	9	0	81	0	0	0	0	90	1.6	1	2	100.0
	all areas w/o breeding islands		984	1659	677	97	128	1636	288	5469				

vice versa. In Croatia there were 38,172 recording attempts, 1,186 (3.1%) of them failed to record valid coordinates, 3,421 (9.2%) valid records were disregarded for the same reason as in Slovenia. After exclusion of erroneous and disregarded readings, we were left with 43,105 locations used for analysis (9,449 in Slovenia and 33,565 in Croatia).

4.1. Slovenia

In Slovenia, we determined 21 areas of activity (Figure 1, Table 2). One area was composed of two breeding islands, located within the larger area of Lake Ptuj. The most distant areas from breeding islands were Lake Pernica (20 in Table 2) and the Drava River at Maribor (19), which both have centroids about 25 km of straight line from breeding islands.

A little more than 42% of analyzed locations were from breeding islands (Table 2). More than one third of the remaining recordings were from the Drava Riverbed between Ptuj and Rošnja (6 in Table 2; 2,047 locations or 37%) which was, beside breeding islands, the most used area. From the section of the Drava river-bed between Rošnja and Maribor (10) there were only 19 recorded locations.

Within Lake Ptuj (without breeding islands), terns were documented 1,481 times (27% of locations), with the N part of the lake (1) having only marginally more locations than the S part (2; 815 or 15% compared to 665 or 12%). The only other area with over 10% of locations was Lake Radehova (13; 743 locations or 14%), while the Drava at Ptuj (4) came very close to 10% threshold (502 locations or 9%).

Of the remaining areas, Lake Gradiško (14), fish ponds at Rače (11), small fishponds at Bodkovci (8), Lake Pernica (20) and a small fish pond near Ptuj (3) each had more than 1% of locations. The remaining ten areas combined had 3.6% locations. The entire Stara struga Drave between Markovci and Ormož, although more than 20 km in length, had only 57 locations.

The part of the Drava river-bed between Ptuj and Rošnja (6), the Drava at Ptuj (4) and N part of Lake Ptuj (1) were used by all 7 terns, although the percentage of locations was rather unequally distributed among individual birds (from 1% to 70%). Five or six birds used the S part of Lake Ptuj (2), the part of Stara struga Drave between Rošnja and Maribor (10) and Lake Gradiško (14). Four birds used the E part of Stara struga Drave between Markovci and Ormož (5), as well as Lake Radehova (13). Two areas with a relatively high number of locations, a small fish pond at Bodkovci (8) and fish ponds at Rače (11), were used mostly by one bird only (individual code number 961003). This bird was responsible for 99% of all locations in these two areas.

The areas where at least one tern was commonly present were: Lake Ptuj (1,2), the Drava at Ptuj (4), part of Stara struga Drave between Ptuj and Rošnja (6), Lake Gradiško (14), Lake Radehova (13) and Lake Pernica (20).

4.2. Croatia

Results from colonies around Zagreb are shown in Tables 3 and 4 and Figure 2. We identified 28 areas where terns were recorded during the study (20 for birds breeding on Siromaja 2 and 24 for birds breeding on Rakitje). Two were the breeding colonies themselves, although each also served as a visiting area for birds from the other colony. The Rakitje colony was itself situated within the larger Lake Rakitje (20 in Tables 3 and 4). The most distant areas from breeding islands were Sišćani (26) and Garešnica-Poljana fishponds (27), the former with a centroid of about 60 km of straight line from Rakitje, and the latter about 65 km from Siromaja 2.

For birds breeding on Siromaja, 70.9% of all GPS fixes were within boundaries of the colony lake. Almost half of all other fixes were on the Sava at Hruščica (9). The next most popular sites were Abesinija Lake (16), the Sava at Siromaja (10) and the Sava at Rugvica (11). The remaining 23 areas accounted for only 6.4% of locations outside the colonies.

Birds breeding at the Rakitje colony had 57.0% of all GPS locations at the colony itself. They also had the highest share of their non-colony fixes, one quarter of them, on the Sava at Hruščica (9). Rakitje Lake (20) was the next most popular site, while the rest of the locations were slightly more evenly scattered along the Sava River, most notably the Sava near Savica (6) and the Sava at Blato (4). More than a quarter of non-colony locations were spread out along the seven other areas of the Sava between Strmec and Rugvica, as well as on Lakes

Table 3: Number of locations in particular areas for Common Terns from Siromaja 2. Abbreviations the same as in Table 2.

Tabela 3: Število lokacij v posameznih območjih za čigre s Siromaje 2. Okrajšave enake kot v tabeli 2.

	Area								
		distance (m)	961021	961023	961024	961026	961029	961030	961031
	Siromaja colony		2160	667	1794	898	1506	1769	2134
10	Sava at Siromaja	700	125	34	234	35	152	85	58
17	Rugvica lakes	1000	3	2	27	4	5	3	2
16	Abesinija lake	2700	5	268	326	22	220	9	7
11	Sava at Rugvica	3100	48	18	4	32	45	4	67
9	Sava at Hruščica	3900	274	35	509	68	750	211	92
12	Sava Novaki-Oborovo	5500	3	6	0	1	1	0	0
8	Sava at Ščitarjevo	7200	4	2	0	1	4	1	0
15	Čiče lake	8200	0	0	0	0	37	0	0
13	Sava Oborovo-Prevlaka	9400	1	0	0	0	0	0	0
7	Sava at Petruševec	9700	3	3	0	0	0	2	3
14	Sava Prevlaka-Prerovec	13500	0	1	0	0	0	0	0
6	Sava near Savica	14500	6	3	0	0	0	1	1
5	Sava Jarun-Bundek	18000	0	1	0	0	0	0	2
4	Sava at Blato	23100	0	3	0	0	0	0	11
3	Sava at Rakitje	26500	0	2	0	0	0	0	0
	Rakitje colony	27100	0	17	0	0	0	0	5
20	Rakitje lake	27500	0	3	0	0	0	0	0
21	Kerestinec	28800	0	0	0	0	0	0	0
27	Garešnica-Poljana fishponds	65200	0	0	0	0	0	0	0
	all areas w/o colony		472	398	1100	163	1214	316	248

Abesinija (16) and Jarun (18). The remaining 15 areas made up the remaining 3.8% of non-colony locations.

The Sava at Siromaja (10), Rugvica lakes (17), Abesinija Lake (16), the Sava at Rugvica (11) and the Sava at Hruščica (9), all within 5 km of the colony on Siromaja 2, were used by all 12 birds breeding there. They spent a vast majority of their time (94.1% of all locations) in these areas closest to their colony. All five remaining parts of the Sava River between Savica and Prevlaka, within 15 km of the colony, were used by half or more of the tagged birds, although far less regularly (3.7% of all locations). The Sava at Hruščica (9), the Sava at Siromaja (10), the Sava at Rugvica (11) and Abesinija Lake (16) were the only areas commonly used by birds breeding on Siromaja 2.

A much larger number of areas, 12 of them, were used by all four birds breeding at Rakitje. A further 7 were used by two or more birds, completing the entire stretch of the river from the Slovenian border to Prevlaka. Apart from the most popular areas the Sava at Hruščica (9), Rakitje Lake (20), the Sava near Savica (6) and the Sava at Blato (4), one bird was present commonly on the Sava at Rakitje (3), and another at Abesinija Lake (16).

Code number of individual tern									statistics
961032	961033	961034	961035	961036	all terns	% locations	N	>=10%	Cummulative %
1377	2050	1529	932	1316	18132	100.0			
82	107	178	181	37	1308	17.6	12	10	17.6
14	11	9	3	1	84	1.1	12	0	18.7
499	53	116	7	7	1539	20.7	12	6	39.5
178	128	28	66	48	666	9.0	12	7	48.4
161	442	419	287	142	3390	45.6	12	11	94.1
8	11	6	2	4	42	0.6	9	0	94.6
1	12	4	0	11	40	0.5	9	0	95.2
0	0	13	11	5	66	0.9	4	0	96.0
8	25	2	1	1	38	0.5	6	0	96.6
4	32	2	0	20	69	0.9	8	0	97.5
3	2	1	0	0	7	0.1	4	0	97.6
3	1	1	0	7	23	0.3	8	0	97.9
2	0	0	0	3	8	0.1	4	0	98.0
3	0	0	0	2	19	0.3	4	0	98.3
4	0	0	0	8	14	0.2	3	0	98.4
11	0	0	0	29	62	0.8	4	0	99.3
3	0	0	0	15	21	0.3	3	0	99.6
0	0	0	0	2	2	0.0	1	0	99.6
0	31	0	0	0	31	0.4	1	0	100.0
984	855	779	558	342	7429				

5. Discussion

A little more that 42% of locations obtained by tags in Slovenia were from breeding islands, while terns spent more time in Croatian colonies (70.9% on Siromaja 2 and 57% on Rakitje). To some point the number of locations on breeding islands is a consequence of the time when terns were caught and fitted with the tag. Our aim was to do this as late during incubation period as possible, preferably in the last two days of incubation. To minimize disturbance, we did not monitor the colony on a daily basis, so we were not able to determine hatching day/last days of incubation period with great precision. The earlier we caught the terns during incubation period, the more days it spent incubating the eggs, which increased the number of locations from this area. This rationale might seem to clash with data from Croatia: birds from the Rakitje colony were tracked from the first day of nesting because they had been equipped with devices beforehand on Lake Siromaja 2. Birds breeding at Siromaja 2, on the other hand, were tagged in mid-incubation and yet they had more colony points than birds at Rakitje. A possible cause for that might be polygon outlining – the Siromaja 2 colony polygon includes the entire lake since smaller platform size, GPS error and lake size led to "colony" points being scattered across almost half of the lake, while the Rakitje and Ptuj colony polygons included only the breeding islands. It is thus inevitable to surmise that Siromaja 2 points include foraging activity as well, while Rakitje and Ptuj colony points include only breeding activity and resting.

At any rate, breeding islands that were determined by us as separate areas within Lakes

Table 4: Number of locations in particular areas for Common Terns from Rakitje. Abbreviations the same as in Table 2.

Tabela 4: Število lokacij v posameznih območjih za čigre z Rakitja. Okrajšave enake kot v tabeli 2.

	Area		Code number of individual tern								statistics
		distance (m)	961020	961022	961025	961028	all terns	% locations	N	>=10%	Cumulative %
	Rakitje colony		772	999	1299	1492	4562	100.0			
20	Rakitje lake	500	74	399	23	59	555	16.1	4	2	16.1
3	Sava at Rakitje	700	21	61	95	38	215	6.2	4	1	22.4
21	Kerestinec	2900	0	6	0	0	6	0.2	1	0	22.5
2	Sava at Strmec & Orešje	4000	3	16	25	2	46	1.3	4	0	23.9
4	Sava at Blato	4700	34	127	51	136	348	10.1	4	2	34.0
18	Jarun lake	6800	3	14	7	17	41	1.2	4	0	35.2
5	Sava Jarun-Bundek	9100	23	65	26	40	154	4.5	4	0	39.7
1	Sava 1	9700	0	3	7	0	10	0.3	2	0	39.9
5	Bundek	11300	0	7	1	3	11	0.3	3	0	40.3
6	Sava near Savica	13100	28	210	65	104	407	11.8	4	3	52.1
29	Savica reserve	14700	0	2	0	4	6	0.2	2	0	52.3
7	Sava at Petruševec	17400	51	99	24	77	251	7.3	4	0	59.6
8	Sava at Ščitarjevo	20500	12	32	14	13	71	2.1	4	0	61.6
22	Crna Mlaka fishponds	22700	0	3	3	0	6	0.2	2	0	61.8
9	Sava at Hrušćica	23700	186	375	76	215	852	24.8	4	4	86.5
10	Sava at Siromaja	23700	37	42	18	32	129	3.7	4	0	90.3
16	Abesinija lake	25200	89	0	0	0	89	2.6	1	1	92.9
	Siromaja colony	27100	25	2	0	54	81	2.4	3	0	95.2
11	Sava at Rugvica	27500	42	8	9	20	79	2.3	4	0	97.5
12	Sava Novaki-Oborovo	30200	3	0	4	8	15	0.4	3	0	98.0
24	Puhovec lakes	30900	36	0	0	0	36	1.0	1	0	99.0
13	Sava Oborovo-Prevlaka	31100	0	0	9	1	10	0.3	2	0	99.3
26	Sišćani fishponds	66400	24	0	0	0	24	0.7	1	0	100.0
	all areas w/o colony		691	1471	457	823	3442				

Ptuj and Rakitje and the entire Siromaja 2 Lake, are, for obvious reasons, regarded as important for Common Terns by default, regardless of the number of recorded locations. We excluded those data for the analysis of other areas, so that a difference in the number of days terns spent incubating eggs did not influence further results.

As expected, area use of terns during breeding season relates closely to large water bodies like rivers, lakes and fishponds.

In Slovenia, some areas were dislocated from Lake Ptuj. Terns reached them only after flying up to 26 km over cultural landscape, where they crossed villages, highways and small forest patches. Sequences of locations showed that they were following the route in a rather straight line, indicating that they must have had previous experience about the location. The largest and continuous part of used area stretched along the Drava from Lake Ormož to Maribor. This is about 60 km long and very narrow part which terns seem to exploit simply by following the course of the Drava River. The most remote location from nesting ground was the Drava close to the village of Bresternica, NW of Maribor. It was about 30 km of straight line from nesting ground and was visited once by one tern only.

The most used areas (beside nesting islands) were the Drava river-bed between Ptuj and Rošnja, the Drava at Ptuj and Lake Ptuj. These are all neighbouring areas, together forming a large important area, which also includes breeding islands. Two areas that were almost 20 km of straight line away from the Drava, Gradiško Lake and in particular Lake Radehova, turned out to be important as well. The latter was used by 5 terns, four of which were commonly present in the area . As expected, the artificial channel with fast and deep water flow, which runs almost parallel to the Drava river-bed, turned out to be a totally inappropriate habitat for terns.

Compared to birds from Ptuj, terns in Croatia usually stayed much closer to the Sava River, very rarely straying more than 2 km from the river. The single most important area for birds from both Croatian colonies was part of the Sava River at Hruščica, which is not surprisingly a Natura 2000 protected area (Radović *et al.* 2005.). Apart from breeding within the boundaries of this Important Bird Area, 85% of localities of birds from the Siromaja colony were there as well, aligned along the river or at Lake Abesinija, and another 9% immediately downstream. Even birds from the Rakitje colony regularly travelled 25 km to have a third of their locations there. Other areas identified as important for birds breeding on Rakitje were the Sava near Savica and, closer to their own colony, the Sava at Blato and the Sava at Rakitje, as well as Lake Rakitje itself.

There is a catch in our data which should be considered when interpreting the results. While tags gave us relatively exact locations of terns in exact time, there was no way we could read from them what they were doing while on the location. For locations within nesting area we can more or less accurately say that birds were involved in breeding routine, whether incubating the eggs or caring for their chicks. A certain proportion of readings from this area was possibly also recorded during resting time. On the other hand, it is impossible to interpret activities of terns in other locations with such ease. But we believe that the majority of them belong to two types of activity: hunting (catching and searching for prey) and flying.

Several locations outside the nesting site were definitively recorded during hunting activity, but some were almost certainly recorded also during flights, when terns were on their way to reach more distant hunting areas. In practice this means that some locations on Lake Ptuj and on the Drava at Ptuj were possibly obtained during flights to a hunting place on the Drava river-bed between Ptuj and Maribor and not during a hunt. The ratio between flying and hunting activity is impossible to quantify, but we presume that a higher proportion of flying activity was recorded closest to the nesting area than in more distant areas. It is thus possible that importance of some areas near the nesting place is both as a flying corridor toward hunting locations as well as a hunting area itself, while more distant ones probably had greater proportion of hunting activities as opposed to flying.

With this in mind, we believe that the most important hunting areas for Common Terns in Slovenia were the Drava river-bed from Ptuj to Rošnja, Gradiško Lake and Lake Radehova. Lake Ptuj and the Drava at Ptuj were definitely important as flying corridors and, to a certain level, as hunting areas too. The latter is confirmed by regular observations of terns foraging in these areas.

Taking this into account with Croatian colonies, the importance for terns breeding at Rakitje of the far-away Sava at Hrušćica becomes even more obvious, and to a lesser extent that of the Sava near Savica. On the other hand, the Sava at Rakitje and the Sava at Blato both probably serve a dual purpose of feeding area and flight corridor.

Common Terns mostly fish within 3 to 10 km of the breeding grounds, with longest foraging distances being over 30 km (Becker & Ludwigs 2004). The longest distances to the most frequently visited areas in this research were in this range, although rather different between locations: from 4 km at Siromaja, to 20 and 24 km in Ptuj and Rakitje, respectively. The overall longest distance (it was made by two terns) was stunning 65 km. This distance corresponds roughly to the distance between Slovenian and Croatian breeding colonies at Ptuj and near Zagreb. Nevertheless, we did not find any evidence that terns from these colonies were in any kind of contact. On the other hand, results showed possible interactions between terns from the colony at Ptuj with the ones on Croatian side of Lake Ormož. Also, although not a single location of terns from Croatia was found on Slovenian side of the Sava, recoveries of ringed birds (Archives of Ringing Centers Zagreb and Ljubljana) showed that terns from Rakitje and Blato colonies do disperse to the colony on the Sava near Brežice.

We recommend conducting further studies of how environmental factors such as hydrology and productivity influence area use. These are necessary in order to explain why areas like the Sava at Hrušćica and the Sava near Savica in Croatia, and Gradiško and Radehova Lakes in Slovenia are so favourable that birds are willing to fly 20–25 km to reach them instead of staying closer to their colony. More detailed analyses of home range are also necessary.

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6. Povzetek

V sezonah 2018 in 2019 smo raziskovali območja, ki jih navadne čigre (*Sterna hirundo*) obiskujejo med gnezdenjem. Z GPS-UHF-oddajniki smo sledili 23 čiger iz Slovenije (7 osebkov) in Hrvaške (16 osebkov). Ptice smo ujeli na treh gnezdiščih: Ptujsko jezero, Siromaja 2 in Rakitje. Zaključki so narejeni na osnovi 43.105 podatkov o lokacijah, ki smo jih zbirali s frekvenco en odčitek na vsakih 20 minut podnevi oz. en odčitek na vsake 4 ure ponoči.

V Sloveniji so čigre letale nad 60 km dolgim, ozkim območjem Drave od Ormoža do Maribora in nad enajstimi ribniki / jezeri v okolici, večinoma v dolini Pesnice. Najbolj oddaljena lokacija od gnezdišča je bila 30 km v ravni črti, a tako daleč se je odpravila le ena čigra, in to enkrat samkrat. Najpogosteje so se čigre zadrževale na stari strugi Drave med Ptujem in Rošnjo, na Ptujskem jezeru, na Dravi pri Ptuju ter na jezerih Radehova in Gradiško. Slednji sta oddaljeni okoli 20 km od gnezdišča. To so bila v celinskem delu Slovenije verjetno najpomembnejša območja, na katerih so čigre v času gnezdenja iskale hrano.

Na Hrvaškem so čigre večinoma letale nad Savo, le izjemoma so se oddaljile tudi več kot 2 km stran od struge. Najdaljša razdalja od gnezdišča je bila več kot 60 km, a tam smo zabeležili zelo majhno število obiskov. Ptice iz kolonije Siromaja 2 so se večinoma zadrževale v radiju do 5 km od gnezdišča, medtem ko so ptice iz kolonije Rakitje redno letale do 23 km oddaljenih območij. Najpogosteje obiskano območje za čigre iz Siromaje in Rakitja je bila Sava pri Hruščici. Ptice iz kolonije v Rakitju so redno obiskovale tudi Savo pri Savici in nekatere vodne površine v radiju 5 km. To so bila v okolici Zagreba verjetno najpomembnejša območja, na katerih so čigre v času gnezdenja iskale hrano.

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Prospecting of breeding adult Common terns in an unstable environment

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With increasing advances in telemetry technology, prospecting behaviour was identified in many seabirds; mostly in immatures, but also in adults – during pre-breeding and post-breeding periods and among failed breeders. However, prospecting has not yet been documented among active breeders. We equipped 17 Common terns *Sterna hirundo* with GPS-UHF data-loggers and tracked their movements during late incubation and chick rearing in continental Croatia. We monitored the fate of their clutches until chicks left the nest. Birds of both sexes visited other breeding colonies within relatively short distances, while they still had active nests. These results confirm for the first time the presence of prospecting trips during incubation and chick-rearing in active breeders. Such behaviour probably developed because quick and unpredictable changes in their freshwater habitats can cause failure of whole colonies, forcing them to renest at other sites during the same breeding season. Prospecting during the first breeding attempt might shorten the renesting interval, and increase renesting success when multiple breeding sites are available on an easily accessible area. With increasing vulnerability of colony sites due to climate change, studies of scattered colonies are needed to better understand renesting and adult prospecting strategies.

KEY WORDS: common tern *Sterna hirundo*, seabirds, freshwater habitats, climate change, renesting, GPS-UHF loggers.

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INTRODUCTION

Prospecting behaviour is the process of gathering information about potential breeding sites within an area (Reed et al. 1999) and is present in most seabird species during their early years (Dittman & Becker 2003; Campioni et al. 2017). During prospecting, young birds compare potential breeding sites and decide on which colony to settle (Dittman et al. 2005; Votier et al. 2011). Prospecting of adults, however, is much rarer. It was confirmed for failed breeders which collect information needed for potential dispersal decisions (Cadiou et al. 1994; Ponchon et al. 2014, 2015, 2017). It is considered that successful breeders only undertake prospecting trips during the pre-breeding or post-breeding period, gaining information needed for the upcoming season (Fijn et al. 2014; Phillips et al. 2017; Patterson et al. 2018). According to the "optimal-timing hypothesis" (Campioni et al. 2017) prospecting occurs most frequently in later stages of the breeding cycle (e.g. during chick-rearing), when the quality of information about local breeding success increases (Boulinier et al. 1996). Breeding site fidelity, confirmed in many seabird species (Palestis 2014; Brooke 2018), also diminishes the importance of prospecting trips in breeding adults. However, the degree of site fidelity varies within species depending on colony size and habitat type (Palestis 2014; Coulson 2016).

The Common tern *Sterna hirundo* is a colonial seabird that breeds in Europe, Asia and North America and winters along seacoasts of the Southern hemisphere. It inhabits different coastal habitats but also breeds in freshwater habitats, where it readily accepts artificial sites (Becker & Ludwigs 2004). It shows high breeding site fidelity and in the case of nest failure, replacement clutches are often laid at the same colony (González-Solís et al. 1999; Becker & Zhang 2011). Several studies of Common tern movements described prospecting in immatures (Dittman & Becker 2003; Dittman et al. 2005) and confirmed high adult nest-site fidelity (Tims et al. 2004; Coulson 2016) but also adult dispersal between closely spaced breeding colonies (Breton et al. 2014). However, all of these studies were confined to coastal colonies. At freshwater habitats, Common terns breed on gravel islands on rivers and lakes, where sudden changes in water level can destroy whole colonies (Atamas & Tomchenko 2015; Farnsworth et al. 2016). In such unpredictable environments, with opportunities for breeding varying both between and during a single season, it might be advantageous to gather information about the current breeding success on all potential breeding localities. Using tracking devices on breeding adult Common terns, we studied the prospecting behaviour in a small inland colony.

METHODS

We studied prospecting behaviour in a population of about 120 pairs breeding in a 250 km^2 area, on gravel pits along the river Sava around Zagreb, Croatia (45°42′–45°48′N, 15°49′–16°11′E, Fig. 1). This population has been monitored since 2004. Terns commonly arrive in early April, egg-laying lasts from early to mid-May, and chicks fledge from late June to mid-July. Annual changes in water level affect phenology and in some years the breeding season can be delayed up to 1 month. The biggest and most stable colony is situated at Rakitje gravel pit, but in different years colonies were found to form at up to four other localities in the study area, depending mostly on water level and vegetation. The area hosted the last natural inland colony on the river itself, but that site hasn't been active for the last 2 years. Instead, the birds have taken to breeding on surrounding gravel pits. The river's water level changes quickly due to precipitation and

Fig. 1. — Map with Common tern breeding sites (black dots) along the Sava river in the vicinity of Zagreb, Croatia (45°42′–45°48′N, 15°49′–16°11′E) in 2018. Bottom left – location of Zagreb on map of Europe.

upstream hydropower plants activities, while the gravel pits water level depends on groundwater level, also influenced by winter and spring precipitation. Vegetation on the islands changes due to succession, but overgrowing on the colony at Rakitje gravel pit is prevented by regular vegetation clearing.

During the spring of 2018, the groundwater level was extremely high, so all islands that usually host breeding colonies were flooded until mid-June. Three colonies were formed on gravel pits: at Siromaja (30 nests on an 8 × 8 m breeding platform installed in mid-May 2018), Čiče (51 nests on a metal gravel excavator) and Rakitje (106 nests on a gravel island, including some replacement clutches). Breeding started on Čiče around 10 May, at Siromaja on 21 May and around mid-June on Rakitje.

Between 5 and 11 June 2018, we captured incubating adults using nest traps on the newly established colony on the breeding platform at Siromaja, and fitted them with GPS-UHF transmitters. We measured, weighted and ringed the terns with stainless steel and coloured plastic rings. The GPS-UHF solar-powered Nano-tags produced by Milsar were deployed using a Teflon chest harness. The devices with harness weighed 4.0 g, representing 3.47 ± 0.236% of the terns body mass (115.09 ± 8.25 g). We took blood samples in order to perform molecular sexing (Fridolfsson & Ellegren 1999). All nests were monitored through six visits from early incubation to early chick-rearing period. We monitored breeding success of the colony by four additional visits until late July. Since our study covers the movements of birds during the incubation and early chick-rearing period, a “successful breeding pair” was one which reared at least one chick until it left the nest. We monitored breeding success at the other two colonies with lower effort: two visits to Čiče and five to Rakitje. Colony breeding success was calculated as the number of near-fledged chicks per nest (Walsh et al. 1995). Colony breeding success was not calculated for Čiče as we didn’t visit the colony during peak fledging dates in order not to negatively influence chick survival due to circumstances at the location. The distance from Siromaja to Čiče is 9 km and to Rakitje 27 km.

Loggers collected GPS fixes every 20 min during daylight (4 am to 10 pm) and every 4 hr during nighttime. GPS location accuracy was 10 m for 90% of the records (manufacturer specifications). We regularly downloaded data using an omnidirectional antenna connected to a base station. Trips were defined as at least two consecutive GPS fixes beyond 100 m from the nesting colony. All data analysis tasks were performed in the R programming environment (R Core Team 2018). Data manipulation was performed with the package dplyr (Wickham & Francois 2016). Manipulation and analysis of spatial data were performed with the packages raster (Hijmans 2016), sp (Pebesma & Bivand 2005; Bivand et al. 2013), rgeos (Bivand & Rundel 2017) and rgdal (Bivand et al. 2017). Data visualisation was performed using QGIS (QGIS Development Team 2016). At least two consecutive GPS fixes (20 min apart) collected from another colony with speed lower than 1.6 m/sec (Shaffer et al. 2017) were determined as prospecting, as long as the entire trip began and ended at Siromaja. Such a conservative approach might cause exclusion of potential prospecting flights from the analysis, but it also minimises the risk of misidentifying foraging or overflights as prospecting.

RESULTS

We equipped 17 terns with loggers. Data from 16 birds (6 males and 10 females) was regularly downloaded. The birds stayed at Siromaja colony for 6–54 days (median: 39). Together they made 1591 trips (median: 97, range: 7–224) performing 2.9 trips per bird per day (median; range: 0.8–4.2). During incubation and chick-rearing, birds mostly foraged along the Sava river, at distances of up to 5 km from the colony, with the other two colonies (Rakitje and Čiče) being outside of their foraging range. Colony breeding success was 1.15 fledged chicks per breeding pair on Siromaja and 0.7 on Rakitje. At Čiče we recorded failure of at least 40% of clutches, mostly due to overheating or soaking of eggs placed on metal surfaces.

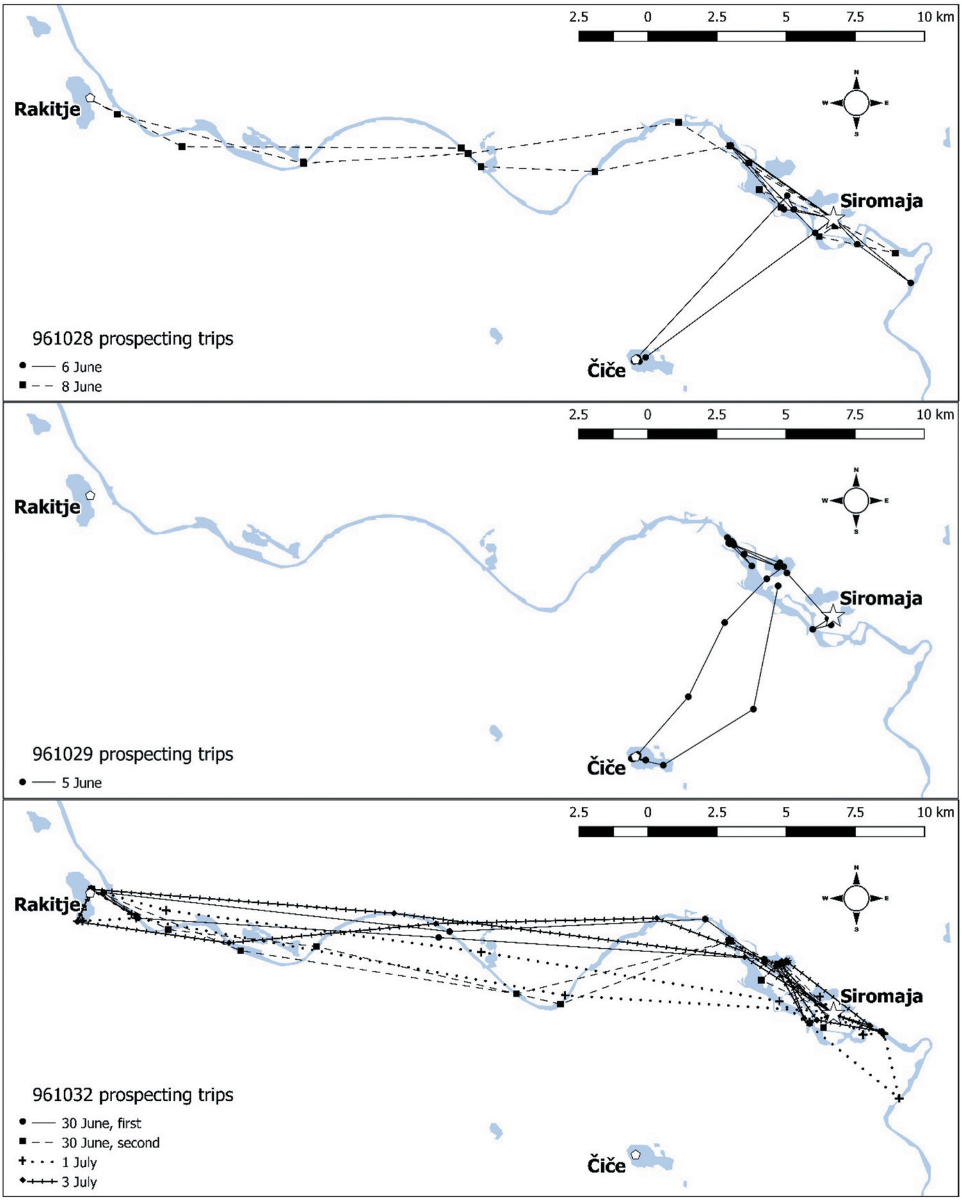
Six birds (37.5%, N = 16), 3 males (50% of tracked males) and 3 females (30% of tracked females), visited other two colonies in the study area (Čiče and Rakitje) during incubation and chick-rearing periods, while they still had active clutches on Siromaja (Table 1, Fig. 2). Together they made 12 prospecting flights (average: 2.0, range: 1–4). They undertook these visits in the evening, spending the night there and returning to Siromaja in the morning (median duration 8:23 hr, range 3:58–10:34), or during the day (median 1:01 hr, range 0:26–1:31). During evening trips they often headed directly to the other colony, but while returning next morning they spent some time foraging. Time spent at the other colony lasted 29.3–78.8% (median: 75.2%) of the trip duration for night trips and 14.2–59.5% (median: 27.7%) for shorter daytime visits that were

Table 1.

Prospecting flights of breeding Common terns from Siromaja colony during the incubation and chick rearing period.

Device Id	Sex	Dates of visits to Čiče	Dates of visits to Rakitje	Date of the last record at Siromaja	Breeding success
961028	F	6 June (night)	8 June (day)	26 June	Failed, renested at Rakitje
961029	M	5 June (night)		2 August	Successful
961032	F		30 June (day 2 times) 1 July (day) 3 July (day)	19 July	Successful
961034	M	13 June (night)		27 July	Successful
961035	M	11 June (night)		20 July	Successful
961036	F	13 June (day)	12 June (night) 30 June (night)	14 July	Successful

commonly combined with foraging prior or after prospecting. Majority of prospecting flights were undertaken during the incubation period, with only two females prospecting during the chick-rearing period (Table 2). Both sexes undertook overnight visits, while only females undertook daytime visits. Females had more prospecting flights (75% of all flights). Median duration of prospecting flights was 1:20 hr (range 0:26–



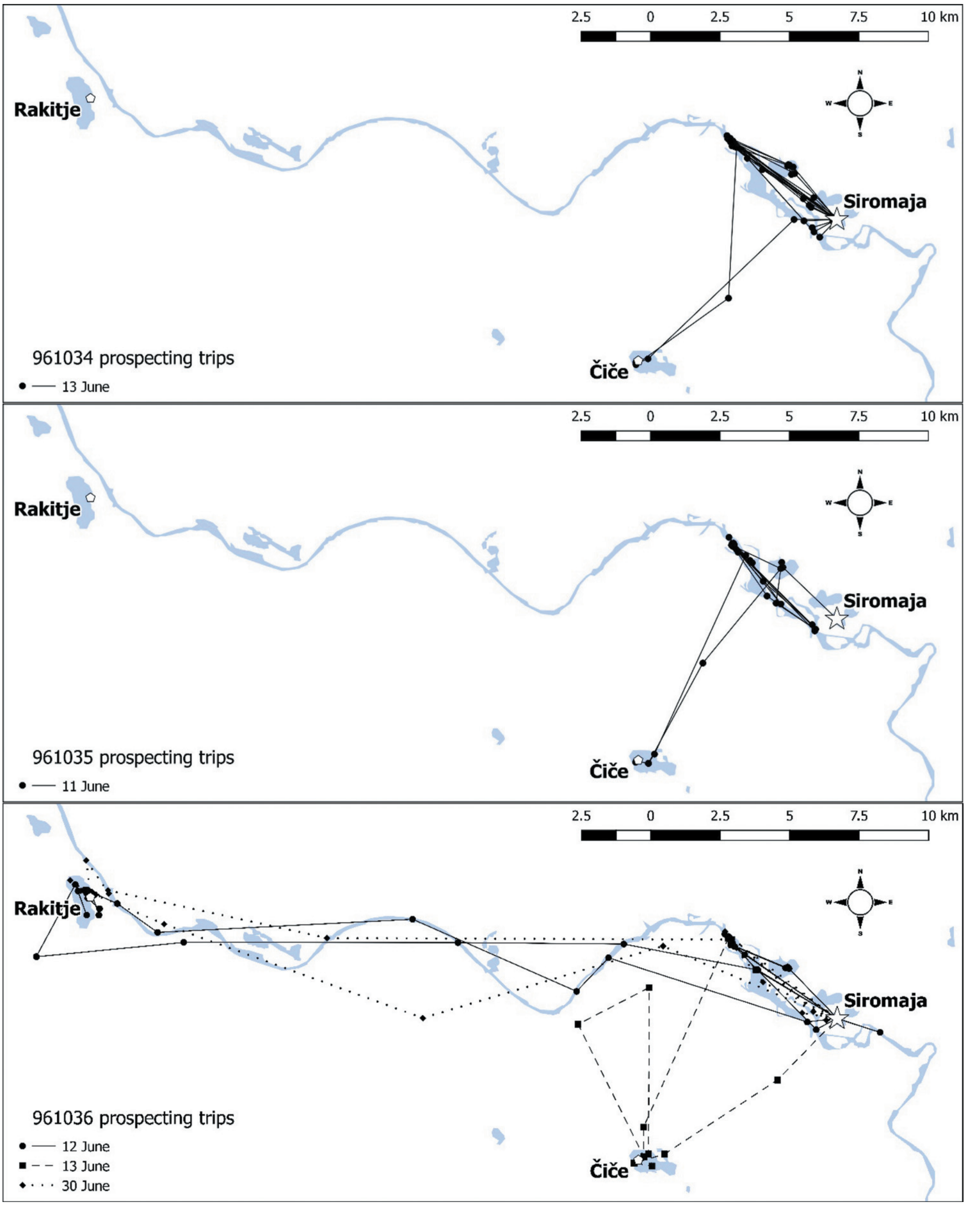


Fig. 2. — Common tern prospecting trips performed by six breeding adults from Siromaja colony (star symbol).

10:34) for females and 8:02 hr (range 3:58–9:00) for males. The average distance of a prospecting flight was 19.5 km (8.5–27 km), while the total area covered was 77.5 km^2.

From the 16 tracked birds, four (two males and two females) lost their clutches on Siromaja and renested on Rakitje. A male which lost its clutch early in the season spent 2 days visiting Čiče and Rakitje and then renested at Raktije. (Fig. 3, these flights

Table 2.

Distribution of prospecting flights of adult Common terns with regard to breeding phase.

	No. of individuals	%	No. of visits	%
Incubation period	5	83.3	7	58.3
Chick-rearing period	2	33.3	5	41.7
Total	6		12	

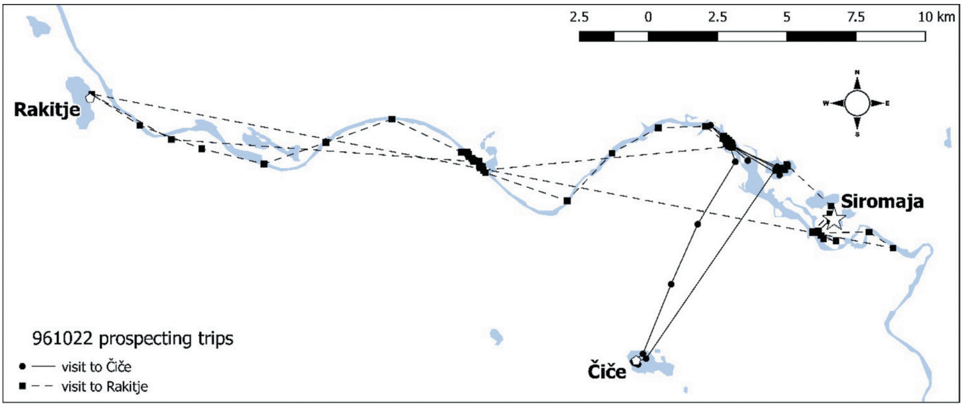


Fig. 3. — Prospecting trips performed by male adult Common tern after the loss of its clutch at Siromaja colony (star symbol).

are not included in Table 1 because they didn’t occur during active breeding). The other three birds lost their clutches in mid or late June and then moved directly to colony Rakitje, without visiting any other colony. One of them (Id 961028) had had prospecting flights during the incubation period, 20 days earlier.

DISCUSSION

This study is the first confirmation of prospecting behaviour among successfully breeding adults during incubation and chick-rearing periods. Birds visited conspecific colonies located 9 and 27 km from their breeding colony, away from regular foraging areas. Terns usually foraged on the shallow part on the river, among gravel shoals 4.5 km upstream from the colony.

The regular presence of immature seabirds at colonies is well-proven, as it is often possible to discern their age on the basis of plumage (Brooke 2018). Contrary, confirmation of the presence of non-breeding adults requires recognition of individual birds. Colour-ringing yields very few such data, therefore, study of prospecting of adults became possible only with the development of tracking devices.

All birds, including breeding adults, while moving across a general breeding area, gather information which could affect their choice of future breeding sites (Reed et al. 1999). However, birds often avoid visiting other sympatric colonies in their home range, keeping away from areas with high conspecifics density. A study on the Northern gannet *Morus bassanus* showed that birds from different colonies even forage in mutually exclusive areas (Wakefield et al. 2013). Studies of Sandwich terns *Thalasseus sandvicensis* (Fijn et al. 2014) and Caspian terns *Hydroprogne caspia* (Patterson et al. 2018) revealed pre-breeding and post-breeding prospecting, the latter among failed breeders and presumably also among successful breeders upon finished breeding. During this period, Sandwich terns visited colonies at distances up to 870 km, while Caspian terns covered an average area of 235,000 km^2. High inter-annual variability in habitat availability and large-scale connectivity of studied populations were suggested as drivers of such behaviour. The same drivers probably motivated adult Common tern prospecting observed during our study. In this case, however, prospecting helped the birds change colonies within the same breeding season (a fact not observed in previous studies). This might be because the colonies in our study were on a much smaller area (77.5 km^2, greatest distance 27 km). We didn't observe visits to other colonies on greater distances from Siromaja (51.3 km to lake Brežice, Slovenia and 73.3 km to lake Ptuj, Slovenia). Similarly, prospecting Black-browed albatrosses mostly visited colonies within 10 km from the natal place (Campioni et al. 2017). Prospecting during breeding is thus favoured when multiple sites are available on an easily accessible area, providing higher chances of successful renesting. Both sexes undertook prospecting, but only females undertook shorter daytime visits. The role of sex in choosing replacement clutch location should be further studied. Previous studies showed high mate- and nest-site fidelity in renesting Common terns, but were restricted to single colonies (González-Solís et al. 1999; Wendeln et al. 2000). As we hadn't marked both adults of a pair, we could not check for eventual mate changes during renesting.

Contrary to the "optimal-timing hypothesis" (Boulinier et al. 1996; Campioni et al. 2017), the number of prospecting flights was lower in chick-rearing phase than during incubation. However, the theory was based on behaviour of immature birds that can prospect during the whole breeding season, while breeding adults have less time for prospecting once chicks are hatched. Yet, we cannot exclude an increase in prospecting activity of adult terns during the post-breeding phase.

The only prior observation of possible prospecting during breeding comes from a study of intraseasonal movements between colonies by Caspian terns on Lake Michigan (Cuthbert 1985), where a majority of birds that visited other colonies were non-breeders or failed breeders, but five birds (12% of observed individuals) had eggs or chicks on another colony. However, the reason for such behaviour was not elucidated.

Previous studies confirmed the importance of prospecting in young Common terns for future selection of breeding colony (Dittman et al. 2005). Colony site fidelity was proven to be very high in this species, with adult local return rate up to 90% (Breton et al. 2014; Becker et al. 2016). Somewhat higher breeding dispersal in some years (up to 0.27) was found for three closely spaced breeding colonies in Massachusetts, USA (Breton et al. 2014). Although terns are often regarded as highly philopatric, the degree of site fidelity varies between colony sites (Coulson 2016), being higher in large, stable colonies than in small colonies and/or colonies in unstable habitats (Palestis 2014). Coastal habitats are more stable than freshwater ones, so they have higher philopatry than freshwater colonies (Patterson et al. 2018). Because it is difficult to detect dispersing individuals, and because most research has focused on large, stable colonies, most measures of philopatry are biased toward high values (Palestis 2014). Research on smaller and less stable sites is thus required to clarify the role of tern philopatry.

Successfully breeding terns, even with a low number of raised chicks, usually don't change their colony site (Palestis 2014). Contrary, sites with frequent and/or heavy losses as a result of flooding, predation or human disturbance may be abandoned or experience higher rates of dispersal (Palestis 2014). Common terns breeding on rivers frequently face failure of entire colonies, because of a water-level rise during the breeding season. Up-to-date information about other potential sites may shorten renesting periods for birds nesting in unpredictable environments and increase their breeding success. Therefore, prospecting behaviour might be evolutionarily favoured in unpredictable environments which cause frequent breeding failures. Individuals which renested at least once were observed to have higher survival, longevity, lifetime reproductive success and fitness, compared to birds without replacement clutches (Becker & Zhang 2011). Since renesting is time-constrained, birds tend to keep the same territory, avoiding competition with new neighbours (González-Solís et al. 1999). However, the majority of renesting studies concentrated on single colonies and it was not possible to record changing of colonies in the same breeding season (González-Solís et al. 1999; Wendeln et al. 2000). In our study, failed breeders had replacement clutches at Rakitje, where breeding success was higher than on Čiče. Also, Rakitje was the largest colony in previous years, so historical success might be another factor in deciding where to breed/renest. Our observation that birds, which later in the season had replacement clutches, flew from Siromaja directly to Rakitje suggests that the birds knew exactly where to go upon failure of their first clutch. Considering that only one of them undertook prospecting flights beforehand, and that Rakitje had been flooded during any possible pre-breeding prospecting, it is possible they flew there based only on memory. Another hypothesis is an information exchange (as discussed by Waltz 1987) on the breeding colony at Siromaja. Investigating both possibilities requires longer-term movement tracking during pre-breeding, breeding and post-breeding. Additionally, our findings' sample size is quite small and more data are needed to further generalise our results.

Issues related to climate change, such as increased severity of storms, rising water levels and changes in aquatic prey availability, may negatively affect Common terns (Erwin & Smith 1985; Becker & Anlauf 1988; Bracey et al. 2018). Inland colonies are threatened by both high and low water levels, and by severe storms that can erode or inundate breeding islands. Reduced availability of nesting sites increases competition with gulls (Bracey et al. 2018). Effects of rising sea levels and unfavourable weather, as well as flood hazard are also likely to increase in the future (Dankers & Feyen 2008; Palestis 2014; Reynolds et al. 2015), causing failure of whole colonies. Affected colony sites might temporarily become unsuitable for breeding, thus preventing renesting. Studies of renesting strategies and prospecting in breeding adults should thus target populations breeding in scattered colonies on unstable habitats. If colony sites continue to become more vulnerable in the future, prospecting of actively breeding adults could become evolutionary favourable behaviour in other seabirds as well.

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ETHICAL STANDARDS

Tagging of Common terns was done with the approval of the Ministry of Environment and Energy of the Republic of Croatia (No. 517-07-1-1-1-18-4).

AUTHOR CONTRIBUTION

M. Martinović and J. Kralj designed the study, with contributions by other authors. M. Martinović, J. Kralj, L Jurinović, I. Svetličić, A. Galov and B. Ječmenica conducted fieldwork. M. Martinović and J. Kralj wrote the manuscript. All authors read, edited and approved the final version of the manuscript.

DATA ACCESSIBILITY

Tracking data are available at the Movebank Data Repository at: http://bit.ly/2H0CTUL

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ORIGINAL ARTICLE

Importance of shallow river topography for inland breeding Common Terns

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Abstract

An increasing number of inland Common Tern *Sterna hirundo* populations nowadays breed in artificial habitats. Inland breeding Common Terns still intensively use rivers while foraging, but the characteristics of their preferred foraging habitats are not well known. In this study we combined telemetric field research and river hydrology modelling to investigate whether Common Terns breeding near Zagreb show a preference for shallow river topography. Our results show that Common Terns breeding close to a preferred foraging area visit shallower parts of the river more when foraging than a random distribution of points along the river would suggest. Furthermore, we show that terns breeding on an artificial island further away from a preferred foraging area exhibit higher distance and duration of foraging trips. They also have a larger foraging range and shorter nest presence. The observed changes in foraging and nesting efforts may affect breeding success as well as adult fitness and survival, influencing the health of the entire population. These findings facilitate the identification of preferred feeding areas as those shallower than 1 m, and indicate that positioning artificial breeding sites closer to these areas could increase population fitness. Furthermore, our results offer useful input for river restoration projects, as well as for analysing the environmental impact of interventions in the riverbed.

Keywords *Sterna hirundo* · River hydrology · Foraging · Water depth · Raft

Zusammenfassung

Die Bedeutung seichter Flussbereiche für im Binnenland brütende Flussseeschwalben Binnenlandpopulationen der Flussseeschwalbe *Sterna hirundo* brüten heutzutage zunehmend in künstlichen Habitaten. Auch binnenländische Flussseeschwalben sind bei der Futtersuche immer noch eng an Flussläufe gebunden; die Eigenschaften ihrer bevorzugten Nahrungsgebiete sind allerdings nicht sehr gut bekannt. Für diese Studie verbanden wir telemetrische Feldarbeit mit der hydrologischen Modellierung von Flusssystemen, um zu erforschen, ob in der Nähe von Zagreb brütende Flussseeschwalben eine seichte Flusstopografie bevorzugen. Unsere Ergebnisse belegen, dass Flussseeschwalben, welche in der Nähe eines bevorzugten Nahrungsgebiets brüten, bei der Futtersuche häufiger seichtere Flussbereiche aufsuchen, als eine Verteilung von Zufallspunkten entlang des Flusses erwarten ließe. Außerdem können wir zeigen, dass Seeschwalben, die auf einer vom bevorzugten Nahrungsgebiet weiter entfernten künstlichen Insel brüten, bei der Futtersuche längere und weitere Flüge durchführten. Zudem nutzen sie bei der Nahrungssuche größere Bereiche und halten sich kürzer am Nest auf. Die beobachteten Veränderungen im Nahrungssuch- und Nistverhalten könnten sowohl den Bruterfolg als auch Fitness und Überlebensraten im Erwachsenenalter und somit das Wohlergehen der ganzen Population beeinflussen. Diese Befunde ermöglichen die Feststellung, dass bevorzugte Nahrungsgebiete flacher als 1 m sind, und deuten darauf hin, dass es die Fitness der Populationen erhöhen könnte, wenn man künstliche Nisthilfen dichter an diesen Gebieten errichtet. Darüber hinaus liefern unsere Ergebnisse nützliche Hinweise sowohl für Flussrenaturierungsprojekte als auch für Untersuchungen des Umwelteinflusses von Eingriffen in das Flussbett.

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Introduction

Since its very beginnings, human civilisation has been closely tied to rivers. Today, natural rivers have become among Europe's rarest and most endangered habitats (EEA 2015). The biggest pressures rivers encounter are urban land take, nutrient pollution, and loss of natural areas (Grizzetti et al. 2017). Healthy aquatic ecosystems have been identified as a prerequisite for the long-term availability of water resources and their many benefits for people (Millennium Ecosystem Assessment 2005; Guerry et al. 2015).

Monitoring the status of underwater systems is difficult, and it often uses indicator species such as macrozoobenthos and fish. Terns, as well as other wetland birds, have been suggested as indicators of contamination levels (Kushlan 1993; Gochfield and Burger 1996). Inland breeding terns are useful sentinels of freshwater ecosystems, for example because of their importance as zooplankton dispersal vectors (Moreno-Linares et al. 2019). They are easy to observe and to study, as well as relatively easy to trap in order to equip and study their movements with telemetry devices. As breeders of bare river islands, tern colonies are an indicator of the river's hydrological and topographical reliability (Roché and Frochot 1993; Heinänen et al. 2008). The Common Tern *Sterna hirundo* in particular has an almost-holarctic breeding distribution, which makes it a widely utilisable indicator species with easy transfer and comparison of findings (Arnold et al. 2020). Furthermore, as a charismatic species, terns provide a medium for communicating problems of their riverine habitats to the public and to decision makers.

In many parts of their range, terns breeding on rivers have been displaced from their natural habitats by river regulation and hydropower development (Gochfeld et al. 2018; Müller 2018). As a result, some countries nowadays have a significant part of their inland tern populations (Coccon et al. 2018; Brichetti and Fracasso 2018; Kralj et al. 2019), if not all of them (Müller 2018), breeding in artificial habitats. Terns still intensively use rivers while foraging, although the characteristics of their preferred habitats aren't completely understood. Common terns mostly feed on the wing, either by plunge-diving, diving-to-surface or contact-dipping (Cabot & Nisbet 2013). Dives are not deep, they take prey just beneath the water surface; Dunn (1972) estimated maximum dive depths at 50 cm. There has been considerably more research on foraging habits and habitat preferences of terns breeding in marine habitats than for those breeding and foraging in freshwater. Research at marine habitats suggests terns choose shallower areas for foraging (Becker et al. 1993), rich in chlorophyll (McLeay et al. 2010), and the tendency of timing their foraging trips with ebb and flood tides (Schwemmer et al. 2009). A study conducted by Urmy & Warren (2018) on marine sites in NY, USA indicated that terns mostly foraged in areas where water accelerated over shallow topography, again linking foraging behaviour with tidal currents. Similarly, Dunn (1973) observed a higher foraging success of adults off the coast of the UK when the sea surface was moderately choppy as opposed to when it was calm. A study of least terns *Sternula antillarum* in central USA indicated a preference for foraging on river sites over sandpit sites, as well as for locations with high turbidity (Sherfy et al. 2012.), while Fasola and Bogliani (1984) observed a preference of Common and Little Terns *Sternula albifrons* for shallower parts of the river when foraging. However, the mentioned findings of both freshwater studies regarding turbidity and water depth were primarily based on visual observations of birds. It is therefore necessary to analyse habitat use by more robust methods, utilising telemetry technology.

Availability of preferred foraging habitats can vary between sites, and as a result, observed Common Tern foraging ranges vary widely (Englington and Perrow 2014). The positioning of artificial sites with regard to preferred foraging areas can thus affect foraging range and effort, which in turn may influence breeding success. It was previously shown that Common Terns breeding on multiple artificial sites near Zagreb, Croatia, show a preference for visiting certain parts of the river (Tome et al. 2019), but habitat characteristics of those parts were not investigated. The aims of this study are to test (1) whether Common Terns show a preference for shallow river topography for foraging, (2) whether Common Terns breeding further away from a preferred foraging site exhibit a higher foraging effort than terns breeding closer to that area, and (3) whether Common Terns breeding further away from a preferred foraging site spend a lower percentage of their time at the nest than terns breeding closer to that area.

Methods

Study area

Field research was conducted at two Common Tern breeding colonies, Rakitje (45.797176 N, 15.840208 E) and Siromaja 2 (45.756645 N, 16.184723 E), situated along the river Sava in the vicinity of Zagreb, Croatia (Fig. 1). Common Terns historically bred at natural river islands downstream from Zagreb, near Hruščica (45.779363 N, 16.137512 E), in the area assigned as a Special Protection Area (SPA; Radović 2005). After several years of colony failure due to flooding caused by hydropower plants further upstream, the site was abandoned in 2016. As far back as 2004, terns started to colonize an island at the Rakitje gravel pit, which now hosts their largest colony in Croatia, with 100–140 pairs. In early May 2018 a breeding raft was set up at the Siromaja 2 gravel pit, close to Hrušćica, and it was immediately colonised by 30 pairs (Kralj et al. 2019). In the following years, the colony at Siromaja 2 steadily increased in size, up to 64 pairs in 2022 (own unpublished data). Common Terns also occasionally breed at other gravel pits in the vicinity of Zagreb.

Data collection

In May 2018 we captured 17 incubating Common Terns using walk-in nest traps at the Siromaja 2 colony. We equipped the birds with GPS-UHF solar-powered Nanotags produced by Milsar, Gdańsk, Poland, using a Teflon chest harness (Thaxter et al. 2014). The logger with harness weighed 4.0 g, representing 3.47 ± 0.236% of the birds' body mass. From each bird we took a blood sample for genetic sexing (Fridolfsson and Ellegren 1999)—several drops of blood via capillary from the brachial vein, stored on bloodstain storage cards (NucleoCard, Machery Nagel; for details, see Svetličić et al. 2019). We tagged one individual per nest, except for one pair in which we inadvertently tagged both individuals (the pair had a successful breeding attempt). Four birds abandoned their nests 1, 6, 14 and 20 days after tagging, and commenced a second breeding attempt at Rakitje gravel pit. After some initial battery testing, all loggers were set to record points every 20 min during daytime (04-22 h) and every 4 h overnight. Data were regularly downloaded with a base station connected to an omnidirectional radio antenna (range 200 m), from 16 birds by regular visits to both breeding colonies. We never received any data from the last bird, which abandoned the nest on the day of tagging, and was never re-sighted. Although the remaining 16 birds were successfully tracked until the end of the breeding season, none of the tracked birds returned to the colony in the following years. In the two studied colonies we monitored breeding success of pairs with tagged and untagged birds, using the methodology described in Martinović et al. (2019).

Input data for interpolation of water surfaces and calculation of water depths were the hourly water level readings for six hydrological stations along the river Sava, four depicted on Fig. 1 and two additional: Drenje Brdovečko (further upstream) and Dubrovčak (further downstream). Input data for the initial water level along the investigated area were water surface from a 4 m^2 digital Lidar elevation model (DEM; Sava Commission 2018a). For defining river cross sections, we used bathymetry of the river Sava from 2008 (Sava Commission 2018b). This was merged with Lidar DEM using the Mosaic To New Raster tool because the bathymetric survey was conducted during very low flow and cross sections were not complete from left to right bank.

Data analysis

The collected telemetry data were prepared, analysed and visualised using the R programming language (R Core Team 2020) with R packages dplyr (Wickham et al. 2021), raster

Fig. 1 Location of the two studied Common Tern colonies on lakes Siromaja 2 and Rakitje (black squares), in the vicinity of Zagreb, Croatia. The red diamond represents a historical (recently abandoned) breeding site on the river and blue dots are locations of hydrological stations used for sampling hourly water levels. Contours of the Special Protection Area "Sava kod Hrušćice sa šljunčarom Rakitje " are indicated by a dashed black line

(Hijmans 2020), sp (Pebesma & Bivand 2005; Bivand et al. 2013), rgeos (Bivand and Rundel 2020), rgdal (Bivand et al. 2021), adehabitatHR (Calenge 2006), amt (Signer et al. 2019), ctmm (Fleming and Calabrese 2021), lme4 (Bates et al. 2015), emmeans (Lenth 2021), ggplot (Wickham 2016), and ggbiplot (Vu 2011), while maps were generated in QGIS (QGIS.org 2022). We excluded points with missing values and obvious errors such as positions with device speed above 21 m/s. For each point, we calculated distance from the centre of the colony ("distance from colony", DFC), distance from the previous point, and elapsed time. From the latter two we calculated straight-line speed (SLS). Dividing the device's speed (calculated automatically for each point via GPS) with our SLS we estimated tortuosity. We defined nest bouts as consecutive points within 100 m from the colony's centre, and trips as consecutive points outside that area. For nest bout and trip analyses we excluded dates after the bird had stopped exhibiting breeding behaviour (i.e. regularly visiting the breeding colony). For the birds which renested on Rakitje we analysed nest bouts and trips of their first and second breeding attempts separately. We then calculated, per trip, total distance covered, median and maximum DFC, median and maximum SLS, and trip duration. From nest bout data we calculated total daily nest presence per bird by excluding nest bouts with different start and end dates, i.e. overnight stays. We performed a principal component analysis using the six variables describing trip statistics. The resulting principal components were taken as indicators of foraging effort, and daily nest presence was taken as an indicator of nesting effort. To account for the fact that birds on Rakitje were tracked since the very start of incubation, while birds on Siromaja 2 were tracked only from mid-incubation, we grouped the trips and nest bouts according to breeding phase: the first 10 days since tagging for birds breeding on Siromaja 2 and 21 days since start of breeding for birds breeding on Rakitje were characterised as "incubation", and the rest was characterised as "chick rearing".

We calculated 50% and 95% utilization distributions (UDs) for each individual using the Autocorrelated Kernel Density Estimation (AKDE) to account for tracking data autocorrelation (Silva et al. 2021.), with the Ornstein–Uhlenbeck forage (ouf) process model. We averaged individual UDs to obtain UDs of the overall colony sample. While making this calculation we excluded nest bouts and stationary points (device speed below 1 m/s) in order not to skew results toward resting places. We also excluded points taken less than 20 min from the previous (i.e. points from the early battery-testing period) so as not to skew results toward locations visited during that period. In order to estimate foraging range and minimise the impact of flight corridors, we also excluded points taken during direct flight (tortuosity < 2).

For each point along the river Sava, we calculated the water depth for the hour and location at which the point was taken. This analysis was done with ArcMap 10.7 (Esri, Redlands, CA, USA). The initial water surface altitude was taken from Lidar DEM for the specific time of the Lidar survey, and it was compared with water levels from hydrological stations at the same time to eliminate potential errors in water surface. Smaller corrections were made with tools Fill and Topo To Raster. Hourly water levels were subtracted from those at the time of the Lidar DEM survey and a new surface difference was made from the obtained values with tools TIN and TIN to Raster. This was then summed with the corrected Lidar DEM using Raster Calculator. These results were subtracted with corrected bathymetry using Raster Calculator to create water depth for every hour. Merging data of water depth and GPS points from birds was made using the Extract Multi Values to Points tool and later in Excel using INDEX and MATCH.

For the depth analysis, we again excluded stationary points (speed < 1 m/s), points taken less than 20 and more than 23 min from the previous, as well as points with a negative depth calculation (i.e. birds flying over dry land). We used the thresholding method (Edelhoff et al. 2016) to separate flight points into "foraging behaviour" (tortuosity > 2) and "direct flight" (tortuosity < 2). For each point along the river we generated one additional random control point within the corresponding section of river, for which we also calculated water depth on the same day and in the same hour as the original (real) point. For analysing the depth preferences of each foraging area, we selected points inside the most intensively used area (50% UD).

In order to test our hypotheses regarding foraging effort and nesting effort, we fit the data to three linear mixed-effects models. The models included sex, home colony, and breeding phase as fixed effect variables, while individual birds were set as random effect variables to avoid pseudoreplication. In order to find the simplest and most relevant models, those with the lowest Akaike information criterion (AIC) were chosen (Burnham and Anderson 2002). Foraging trip characteristics between males and between sexes on Rakitje were later excluded because of small sample size (only one tracked male on Rakitje). Data were checked for normality and, where necessary and possible, transformed in order to approach normality (Kozak & Piepho 2018). In order to test our hypothesis regarding selection of depth, we conducted one-tailed Wilcoxon rank sum tests between real and control point water depths for each home colony. For these analyses we calculated medians of real and an equivalent number of random control point water depths by home colony for each bird to avoid pseudoreplication, but also to reduce the large sample size which would have always made the test result statistically significant (Lin et al. 2013).

Results

Siromaja 2 trip statistics

We recorded 19 661 GPS positions within Siromaja 2 colony boundaries and 8 835 outside, collected from 15 birds (10 females and 5 males) tracked for 38.35 days on average (range 6–61). From these we calculated and analysed 1 583 daytime nest bouts for 473 days and 1 930 trips. Average daily nest presence was 15.73 (± 4.77 SD) hours. Median trip duration was 0.68 h, during which the birds covered a median distance of 3.44 km. Median maximum distance from colony (DFC) was 2.71 km, absolute maximum DFC was 66.24 km and trip median DFC was 1.92 km. Median trip speed was 1.11 m/s, while median maximum speed was 1.81 m/s (Online Resource 1).

While foraging, terns from the Siromaja 2 colony used in average a 63 km^2 area (95% UD), with the most intensively used area (50% UD) of 10 km^2 concentrated around Sava near Hrušćica, a nearby part of the river rich in islands and gravel bars, inside the Sava kod Hrušćice sa šljunčarom Rakitje Natura 2000 Special Protection Area (SPA; Radović 2005) (Fig. 2).

Rakitje trip statistics

We recorded 4 599 GPS positions within Rakitje colony boundaries and 3 451 outside, collected from four birds (3 females, 1 male) tracked for 44.25 days on average (range 30–55). From these we calculated and analysed 274 daytime nest bouts for 132 days and 494 trips. Average total daytime nest presence was 13.48 (± 4.74 SD) hours. Median trip duration was 1.35 h, during which birds covered a median distance of 6.79 km. Median maximum DFC was 5.27 km, absolute maximum DFC was 64.15 km and trip median DFC was 3.23 km. Median trip speed was 1.24 m/s, while median maximum speed was 3.10 m/s (Online Resource 1).

While foraging, terns from the Rakitje colony used in average a 271 km^2 area (95% UD), with the most intensively used area (50% UD) of 59 km^2 separated into four clusters: lake Rakitje and nearby downstream river reaches, Sava near the Savica protected area, Sava near Petruševec, and Sava near Hrušćica (Fig. 3).

Depth analysis

In the depth utilisation analysis, one-way Wilcoxon rank sum tests between points taken while foraging and random control points found a significant difference for birds breeding on Siromaja 2 ($W = 45$, p value = 0.0071), but no significant difference for birds breeding on the Rakitje colony ($W = 5$, p value = 0.2429).

Points of birds breeding on Siromaja 2 while foraging had a median depth of 1.23 m (Q1 0.66 m; Q3 1.93 m), while random control points had a median depth of 1.66 m (Q1 0.93 m; Q3 2.41 m). Frequency distributions of the two groups showed that points of foraging birds peak at water depths between 0.5 and 1 m, while random control points peak at water depths between 1.5 m and 2 m (Fig. 4).

Although there was no significant difference in water depths between foraging and random control points for birds breeding on Rakitje, frequency distributions showed a similar tendency of peaking before 1 m while foraging at Sava near Savica and Hrušćica (Online Resource 3). The absolute range of river depths observed in this study, both for bird locations and for random control points, was from less than 0.01 m to 11.35 m.

Foraging effort analysis

Principal component analysis produced two components which had a cumulative proportion of variance of 93.64% (77.46% for PC1 and 16.18% for PC2). The first component was most described by variables: total distance covered, median DFC, maximum DFC and maximum speed (all negatively), while the second component was heavily loaded by trip duration (positively) and median speed (negatively). PC1 was thus taken to represent "less distance", and PC2 was taken to represent "more time" (Fig. 5). Trip duration and median speed also contributed to PC1 to a smaller extent.

The model selected for PC1 with the lowest AIC included interactions between all of the fixed variables (Table 1). Results of the model showed that trips of females from Rakitje were at a greater distance from the colony than trips of females from Siromaja 2. Additionally, trips of females from both colonies were at a greater distance during chick rearing than during incubation. There were no differences in trip distances among sexes for birds from Siromaja 2, as well as between breeding phases for males from Siromaja 2.

The model selected for PC2 with the lowest AIC also included interactions between all of the fixed variables (Table 2). Results of the model showed that during the incubation phase, trips of females from Rakitje took more time than trips of females from Siromaja 2. There were no differences in trip duration among sexes for birds from Siromaja 2, as well as between breeding phases for either colony.

Nesting effort analysis

The model selected for nest presence with the lowest AIC ignored any interaction between fixed variables, and the results are presented in Table 3. Birds from Siromaja 2 had significantly longer daily nest presence than birds from

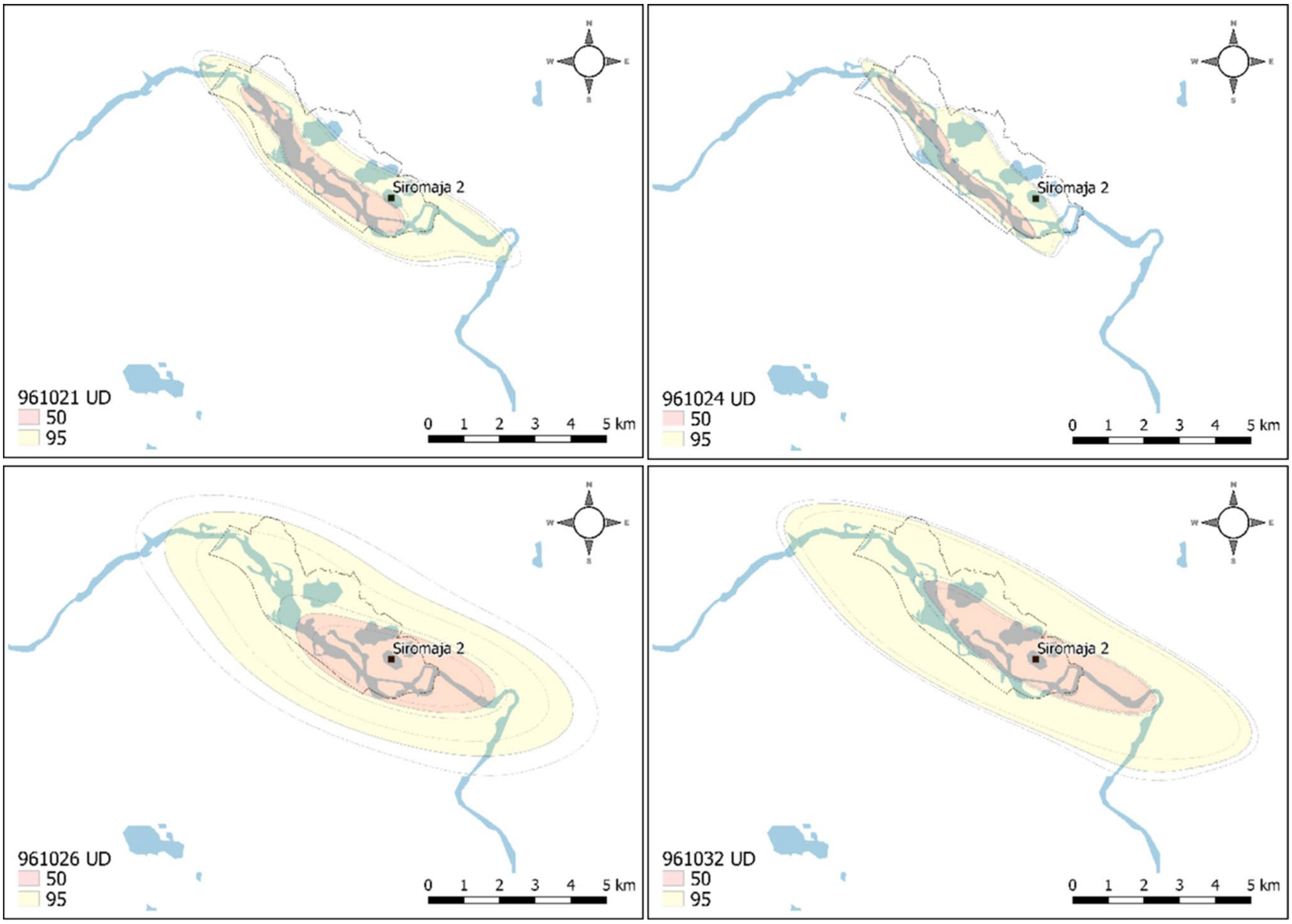


Fig. 2 Foraging behaviour utilisation distributions (UD) of four GPS-tracked Common Terns breeding on lake Siromaja 2 near Zagreb in 2018, during incubation and chick rearing. UD is presented with 50% and 95% cumulative distributions. Contours of the Natura 2000 Special Protection Area (SPA) are indicated by a dashed black line. Grey dotted lines represent 95% confidence intervals of their respective UDs. $N_{961021} = 368$ points over 44 days; $N_{961024} = 739$ points over 48 days; $N_{961026} = 117$ points over 36 days; $N_{961032} = 355$ points over 37 days. Maps for nine remaining birds are provided in Online Resource 2

Rakitje (estimated 2.73 h longer). The same is true for females over males (estimated 3.47 h longer), as well as for birds during incubation over chick rearing (estimated 2.03 h longer).

Discussion

Our findings show that Common Terns breeding on an artificial island further away from a preferred foraging area exhibit higher distance and duration of foraging trips, while also having a larger foraging range and shorter nest presence than birds breeding on a raft closer to the preferred foraging area. Furthermore, in the context of our study area, the findings confirm that Common Terns breeding in the vicinity of Zagreb show a strong preference for foraging at Sava near Hrušćica, as was initially indicated by Tome et al. (2019). That area is a historical breeding site (Kralj et al. 2019) rich in gravel bars. Of the other three clusters regularly visited by birds breeding on Rakitje, Sava near Savica is characterised by artificially made river rapids, while Sava downstream from Rakitje and Sava near Petruševec also have gravel bars and banks. Based on 22 studies, and with moderate confidence, Thaxter et al. (2012) state the mean foraging range of Common Terns is 4.5 ± 3.2 km, while the mean maximum range is 15.2 ± 11.2 km, with a maximum foraging range of 30 km. Additionally, according to Arnold et al. (2020), trips usually last 10–27 min. In our study, birds from Siromaja 2, which is situated close to the historical natural breeding place, had a lower median trip distance from colony (DFC) than previously established, most probably because of the closeness to preferred foraging grounds. However, trips of birds from Siromaja 2 took more time than previously established. This is likely due to the 20-min interval between GPS positions in our study, which means that our study treated trips that lasted less than 20 min as having lasted 20 min.

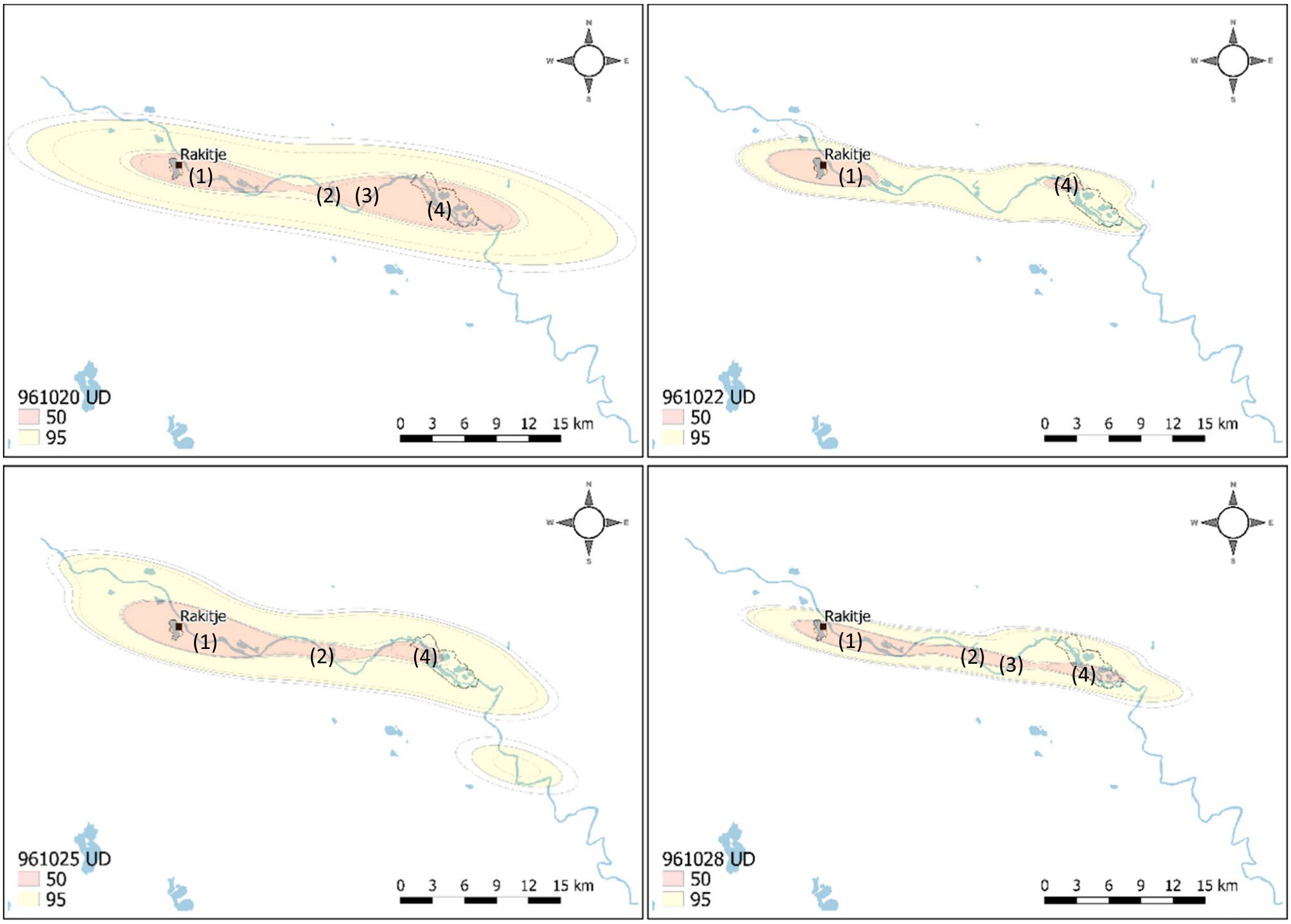
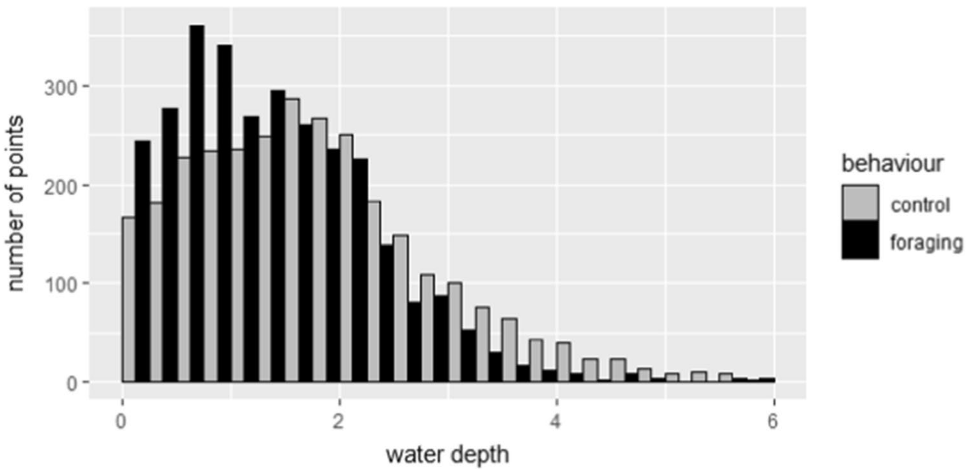


Fig. 3 Foraging behaviour utilisation distribution (UD) of four GPS-tracked Common Terns breeding on lake Rakitje near Zagreb in 2018, during incubation and chick rearing. UD is presented with 50% and 95% cumulative distributions. Contours of the Natura 2000 Special Protection Area (SPA) are indicated by a dashed black line. Grey dotted lines represent 95% confidence intervals of their respective UDs. Numbers in brackets represent four clusters of the intensively used area (50% UD): (1) lake Rakitje and nearby downstream river reaches, (2) Sava near the Savica protected area, (3) Sava near Petruševec, and (4) Sava near Hruščica. $N_{961020} = 317$ points over 34 days; $N_{961022} = 659$ points over 52 days; $N_{961025} = 280$ points over 45 days; $N_{961038} = 450$ points over 46 days

Fig. 4 Point water depth frequency distributions of Common Terns breeding on Siromaja 2 and foraging on the river ($N = 2\,959$), and of an equal amount of random control points ($N = 2\,959$)



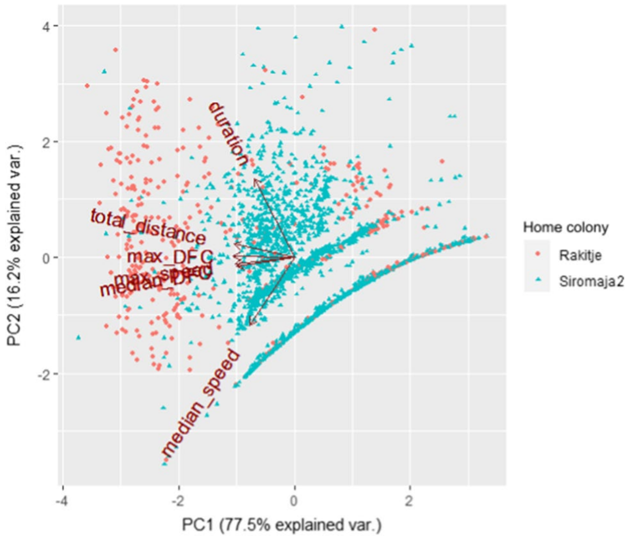


Fig. 5 Biplot visualisation of Common Tern trips in terms of PC1 ("less distance") and PC2 ("more time") from Principal Component Analysis of foraging effort variables. Green triangles represent trips by birds from the Siromaja 2 colony, orange dots represent trips by birds from Rakitje. Arrows show how the initial foraging effort variables contribute to each principal component

Birds from Rakitje had median trip DFC similar to those from previous studies, but their median trip lasted over three times longer. Birds from Rakitje regularly used lake Rakitje and the nearby river reaches for foraging, but they also frequently foraged in areas 15–25 km away, intensively using a 5.78 times larger area for foraging (50% UD) and covering a 4.29 times larger foraging range in the process (95% UD). This lead to median distance covered and trip duration of birds from Rakitje both being twice as large as those of birds from Siromaja 2.

Longer foraging flights of birds from the Rakitje colony could be interpreted in light of Kavelaars et al. (2020) who found that in Lesser Black-backed Gulls *Larus fuscus*, birds that had recently changed colonies travelled further for foraging than longer-term residents. These birds still visited foraging sites used by residents breeding in their natal colony. Since in our study all breeders from Rakitje were renesting birds, they might have been using the same foraging site as during their first breeding attempt. However, Siromaja 2 was itself a new colony in the study year (the raft had been constructed that same spring), and observations of colour-ringed birds confirmed that it was colonised by terns from Rakitje or other surrounding colonies (Archive of the Croatian Bird Ringing Centre). Rakitje itself was most probably colonised by birds from the former Hrušćica colony, which were familiar with favourable foraging areas in the vicinity of the colony. Since median age of breeders is about 8 years (Arnold et al. 2020), and considering the species'

Table 1 Results of the selected linear mixed-effects model for PC1 ("less distance")

Home colony	Breeding phase	Sex	Contrast	Estimate	SE	df	*t*.ratio	*p* value
Siromaja 2	Incubation		Male–Female	−0.645	0.449	231.2	−1.439	0.7380
Siromaja 2	Chick rearing		Male–Female	0.391	0.209	12.1	1.868	0.4762
	Incubation	**Female**	**Siromaja 2—Rakitje**	**1.379**	**0.362**	**137.2**	**3.806**	**0.0024**
	Chick rearing	**Female**	**Siromaja 2—Rakitje**	**1.834**	**0.267**	**44.4**	**6.871**	**< 0.0001**
Rakitje		**Female**	**Chick rearing—incubation**	**−1.33**	**0.258**	**840.3**	**−5.158**	**< 0.0001**
Siromaja 2		**Female**	**Chick rearing—incubation**	**−0.874**	**0.263**	**2394.2**	**−3.328**	**0.0095**
Siromaja 2		Male	Chick rearing—incubation	0.163	0.332	2406.3	0.489	0.9993

Statistically significant differences are highlighted by bold text

SE standard error, *df* degrees of freedom

Table 2 Results of the selected linear mixed-effects model for PC2 ("more time")

Home colony	Breeding phase	Sex	Contrast	Estimate	SE	df	*t*.ratio	*P* value
Siromaja 2	Incubation		Male–Female	0.588	0.2102	220.7	2.799	0.0552
Siromaja 2	Chick rearing		Male–Female	0.225	0.0995	12.2	2.257	0.2835
	Incubation	**Female**	**Siromaja 2—Rakitje**	**−0.591**	**0.1700**	**136.8**	**−3.473**	**0.0074**
	Chick rearing	Female	Siromaja 2—Rakitje	−0.265	0.1258	45.3	−2.110	0.3011
Rakitje		Female	Chick rearing—incubation	−0.176	0.1205	871.2	−1.461	0.7231
Siromaja 2		Female	Chick rearing—incubation	0.149	0.1226	2396.5	1.216	0.8675
Siromaja 2		Male	Chick rearing—incubation	−0.215	0.1552	2407.9	−1.384	0.7740

Statistically significant differences are highlighted by bold text

SE standard error, *df* degrees of freedom

Table 3 Results of the selected linear mixed-effects model for nest presence

Contrast	Estimate	SE	df	*t*.ratio	*P* value
Siromaja 2—Rakitje	**2.73**	**0.677**	**146.6**	**4.03**	**0.0003**
Male–Female	**−3.47**	**0.924**	**13.6**	**−3.752**	**0.0071**
Chick rearing–incubation	**−2.03**	**0.349**	**664.9**	**-5.823**	**< 0.0001**

Statistically significant differences are highlighted by bold text

SE standard error, *df* degrees of freedom

documented high breeding site fidelity (DiCostanzo 1980; Wendeln and Becker 1998; Nisbet and Cam 2002), a part of the local population may still remember the natural breeding and connected foraging areas. This is supported by personal observations of Common Terns foraging near Savica and Hruščica before the platform at Siromaja 2 was set up in 2018 (unpublished), as well as by observations on citizen science platforms (eBird 2021; fauna.hr 2022) from 2014 to 2017, when Rakitje was the only stable colony.

Another possible explanation of the difference in foraging ranges between the two studied colonies could be the difference in colony sizes due to "Ashmole's halo" effect (Ashmole 1963). However, following Jovani et al. (2016), colony size is unlikely to significantly affect foraging ranges in this study, as the effect is strong only in large colonies.

Whatever the case may be, our results on nesting effort show that birds breeding on Rakitje spent less time per day in the colony than birds breeding on Siromaja 2. This was observed despite the fact that our sample from Rakitje included a disproportionate number of females (since females spent more time in their colonies than males), and also despite the fact that we tracked birds on Rakitje during their whole incubation phase, as opposed to just the later part of the incubation phase on Siromaja 2 (since incubating birds spent more time in their colonies than birds feeding chicks). Such results indicate that, while covering a larger foraging range, birds tend to their nests less, and this may lead to lower nesting success. Data on breeding success from these two colonies (Martinović et al. 2019) support this idea, since they show a higher apparent productivity on Siromaja 2 than on Rakitje. However, breeding success and adult survival can also be influenced by other factors that we did not evaluate, such as predation, disturbance, flood risk, etc., so more detailed studies investigating these questions are required.

The trips of females from Siromaja 2 were at a greater distance during chick rearing than during the incubation phase, which is in line with Bracey et al. (2020), wherein Common Terns breeding on Lake Superior foraged more extensively along the river during chick-rearing than during incubation. The lack of difference in trips between sexes for birds from Siromaja 2 might be caused by the vicinity of favourable foraging sites. It has been shown that in several seabird species, females, being the smaller sex, undertake longer foraging trips during incubation and the chick-rearing period (Shaffer et al. 2001; Wearmouth & Sims 2008; Phillips et al. 2017).

The observed preference for feeding around the historical breeding site Sava near Hruščica might be explained by water depth. As detailed earlier, the effects of water depth, water flow velocity, and tidal currents on the foraging of Common Terns were studied in marine environments (Urmy & Warren 2018; Schwemmer et al. 2009), while for inland populations such findings were mostly based on bird observations (Fasola & Bogliani 1984; Sherfy et al. 2012). Our results represent the first data-driven confirmation that inland breeding Common Terns show a preference for foraging on shallow river stretches, at least in the case of birds from Siromaja 2.

Absolute depth preferences are not comparable with those from previous studies in marine habitats, since Becker et al. (1993) observed a preference for shallows under 5 m of depth, while Schwemmer et al. (2009) observed the highest frequency of birds at depths shallower than 5 m and between 15 and 20 m, with low frequencies at depths greater than 20 m. The lack of comparability is almost certainly due to topographical differences between riverine and marine habitats. In any case, the observed preference of birds from the Siromaja colony for foraging at depths shallower than 1 m can be explained by the already stated fact that plunge-diving Common Terns take prey just beneath the water surface, with dive depths up to 50 cm Dunn (1972).

The fact that we found no significant depth preference for birds breeding on Rakitje may be explained by the methods used, i.e. the tortuosity cut-off selected as a threshold between direct flight and foraging behaviour. This might explain water depth frequency distributions of birds from Rakitje at Savica and Hruščica (Online Resource 3), which peak twice: first at depths shallower than 1 m and again where control points also peak, at depths between 1.75 m and 2 m. Birds from Rakitje covered larger distances and flew at greater speeds, so applying the same tortuosity threshold for defining behaviour as with birds from Siromaja 2 may have contributed to blurring behavioural data for birds from Rakitje. Furthermore, birds predominantly follow the river course during trips rather than flying directly overland, which may generate opportunistic foraging opportunities. Additionally, a 20-min interval between GPS locations may have contributed to obscuring the data, since temporally more precise data would have enabled a better distinction between behaviours. Finally, a sample of only four birds breeding at Rakitje may have been too small to produce statistically significant results. At any rate, a more detailed study should be conducted when further device miniaturisation and battery life improvements enable taking more frequent GPS locations to test and improve upon our findings on a larger sample.

Considering previous research from marine habitats, additional factors which may influence foraging habitat selection, and thus also require detailed investigation, include water flow velocity and water transparency, as well as prey distribution. Furthermore, Becker et al. (1997) found that around 7% of Common Tern foraging flights in freshwater and 15% in marine habitats lasted less than 30 min. Adding to this trip times summarised in Arnold et al. (2020), a proportion of short flights may have remained unrecorded in our study, potentially underestimating the importance of foraging areas in the vicinity of colonies.

In conclusion, all of our results highlight the importance of choosing an adequate location for artificial nesting sites for Common Terns. The further away a new colony is from preferred foraging grounds, the more effort birds will have to put in during foraging trips, and the less time they will have to look after their incubating partner and young. Nest attendance is an important component of parental quality, which directly affects chick survival (Riechert & Becker 2017). During the incubation period, nest attendance enhances hatching success by reducing predation and maintaining a constant incubation temperature, while brooding during the chick rearing period prevents predation and hypothermia of chicks. Also, shorter distances to foraging areas enable higher feeding rates, affecting chick growth (Riechert & Becker 2017). Therefore, positioning artificial breeding sites closer to preferred foraging grounds could increase breeding success and, as a result, population health.

Our results also indicate that areas shallower than 1 m attract foraging terns, although it is important to keep in mind that foraging habitat preference can also be influenced by food availability, disturbance and other factors, so a specific study is required to test this question. These findings provide insight into which habitat characteristics contribute to making an area a preferred foraging site, for which the importance of shallow riverbed topography is noticeable. As a rule of thumb, such areas might often be found around historical natural breeding grounds rich in low-lying gravel or sand islands and bars. These ephemeral habitats might have been lost as breeding grounds due to their vulnerability to water flow regulation, but here we confirm their continuing importance as foraging grounds. For the same reasons, our findings are also of use for river restoration projects, as well as for assessing the environmental impact of interventions in the riverbed. Since the Common Tern is listed in Annex 1 of the EU's Bird Directive (European Parliament & Council of the European Union 2019), these processes and the conservation of Common Terns are an obligation of every member state.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10336-023-02060-0.

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Author contributions MM, JK and LJ: designed the study; MM, JK and LJ: performed fieldwork; MP: performed point water depth extrapolation; MM: conducted data processing and the statistical analyses; MM: wrote the manuscript; JK, MP and LJ: discussed the results and provided suggestions on the manuscript.

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Data availability Tracking data are available on the Movebank Data Repository at: http://bit.ly/2H0CTUL.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

Ethical and legal approval The study protocol and procedures employed were ethically reviewed and approved by the Committee for Bioethics and Animal Welfare of the University of Zagreb Faculty of Science, Division of Biology (No. 251-58-10617-20-251). Tagging of Common Terns was done with the approval of the Ministry of Environment and Energy of the Republic of Croatia (No. 517-07-1-1-1-18-4).

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3. RASPRAVA

3.1. Crvenokljuna čigra kao modelni organizam i indikatorska vrsta

Istraživanja objavljena u publikacijama u ovoj disertaciji potvrđuju vrijednost crvenokljune čigre kao modelnoga organizma za telemetrijska istraživanja te kao indikatorsku vrstu za stanje slatkovodnih ekosustava. Kao što su istraživanja pokazala, čigre je relativno jednostavno promatrati i istraživati izravnim promatranjem i praćenjem gnijezda te hvatanjem u zamke na gnijezdu radi opremanja telemetrijskim uređajem. Budući da se gnijezde na golim riječnim otocima, kolonije čigri predstavljaju indikator hidrološke i topografske pouzdanosti rijeke (Roché i Frochot 1993; Heinänen i sur. 2008). Pojavnost izviđanja u vrijeme aktivnoga gniježđenja između ostaloga može upućivati na nestabilnost trenutačnoga gnjezdilišta te opasnost od propadanja legla. Crvenokljune čigre gnijezde se po gotovo čitavome holarktiku, pa je istraživanja i njihove rezultate jednostavno prenositi i uspoređivati na drugim područjima (Arnold i sur. 2020). Tako se spoznaje o odabiru staništa za hranjenje jednostavno mogu primijeniti za upravljanje na drugim slatkovodnim lokalitetima. Konačno, karizmatičnost čigre kao vrste izaziva zanimanje javnosti i pridonosi boljoj komunikaciji sa zakonodavnim tijelima o rješavanju problema riječnih staništa.

3.2. Korištenje prostora

Prvi je cilj ove disertacije bio utvrditi koja područja kontinentalnoj populaciji crvenokljune čigre služe za vrijeme gniježđenja u Hrvatskoj. Za tu potrebu postavljena je hipoteza *kontinentalne populacije crvenokljune čigre u Hrvatskoj za vrijeme gniježđenja koriste se vodenom površinom unutar 10 km od svoje kolonije, iznimno do 30 km.*

Dvije kolonije obuhvaćene ovim istraživanjem, Rakitje i Siromaja 2, smještene su na istoimenim šljunčarama na 27 km međusobne zračne udaljenosti u okolici Zagreba. Na Rakitju se svake godine gnijezdi 100 do 140 parova, a na jezeru Siromaja 2 nešto manje, 30 do 64 para crvenokljune čigre (Kralj i sur. 2019; Martinović i sur. 2023). Očekivano, najvažnija područja za čigre tijekom gniježđenja predstavljaju same kolonije: čak 70,9 % svih točaka ptica koje su se gnijezdile na jezeru Siromaja 2 te 57 % svih točaka ptica koje su se gnijezdile na jezeru Rakitje nalazi se na kolonijama. Čigre na kolonijama traže partnera, izgrađuju gnijezdo, polažu i inkubiraju jaja, brinu se o mladima i inkubirajućem partneru (što sve zajedno čini *gnijezdeće aktivnosti*) te se čiste i odmaraju.

Točke zabilježene na kolonijama isključene su iz daljnjih analiza korištenja staništa kako bi se povećala razlučivost važnosti drugih područja izvan same kolonije. Više je mogućih uzroka razlika među kolonijama u ukupnome udjelu točaka na koloniji (70,9 % u odnosu na 57 %). Prvi i najočitiji razlog leži u ocrtavanju područja: na Rakitju je kolonijom opisan samo otok na kojemu su se gnijezdile čigre, dok je na Siromaji 2 kao kolonija opisano čitavo jezero zbog slučajne disperzije točaka i znatno manje ukupne veličine jezera. Rakitje sačinjavaju tri bliska jezera ukupne površine 1,18 km^2, dok jezero Siromaja 2 ima površinu od 0,13 km^2. Kolonija s pojasom od 100 m oko nje jezeru Siromaja 2 obuhvaća veći dio tog jezera, dok na Rakitju taj pojas predstavlja samo manji dio tog dijela jezera. Tako su vrlo kratki letovi i hranjenja na samome jezeru Siromaja 2 ubrojeni u točke na koloniji, dok je na jezeru Rakitje određen poseban poligon koji uključuje cijelo jezero osim otoka. Zato se točke na koloniji odnose samo na gnijezdeće aktivnosti i odmaranje. Drugi je moguć razlog nesrazmjera vjerojatnost da su ptice na Siromaji 2 imale više vremena za posvećivanje gnijezdećim aktivnostima i odmaranju jer su rezultati u publikaciji **III** (Prilog 1.) pokazali da su ptice s Rakitja zbog dužih i daljih putovanja na hranjenje dnevno provodile manje vremena na koloniji nego ptice sa Siromaje 2. U svakome slučaju, gnijezdeće su kolonije iz očitih razloga važna područja čigrama s obiju kolonija.

U skladu sa svojom ekologijom, čigre su se tijekom ovoga istraživanja koristile prostorom koji se uvelike podudara s tokom rijeke Save te obližnjim jezerima, ribnjacima i drugim vodnim tijelima. Ptice su se rijetko udaljavale više od 2 km od Save. Najvažnije područje korištenja izvan samih kolonija za ptice s obiju kolonija bio je tok rijeke Save kod Hrušćice. Više od 45 % svih lokacija ptica sa Siromaje 2 izvan kolonije zabilježeno je na ovome području, kao i gotovo 25 % svih lokacija ptica s Rakitja. Ovo područje obuhvaća povijesno gnjezdilište čigri na rijeci Savi (Kralj i sur. 2019) te uključuje i najpogodnija hranilišta za čigre, kako je kasnije pokazano istraživanjima druge hipoteze ove disertacije. Ovaj dio toka Save iz tih je razloga uključen u Natura 2000 ekološku mrežu (Radović i sur. 2005) zajedno s najbližim nizvodnim dijelom Save, kod Siromaje te obližnjim rugvičkim jezerima. Čak 85 % svih točaka ptica sa Siromaje 2 zabilježeno je unutar ovog Natura 2000 područja te je još 9 % točaka zabilježeno u nizvodnom dijelu toka Save kod Rugvice. Čak su i ptice s Rakitja redovito putovale preko 25 km do hranilišta unutar Natura 2000 područja, gdje je zabilježena gotovo trećina svih njihovih točaka. Ostala su važna područja za ptice s Rakitja bila Sava kod Savice, bliže vlastitoj koloniji, Sava kod Blata i Sava kod Rakitja te samo jezero Rakitje.

Pri interpretaciji rezultata publikacije **I** važno je istaknuti da pri analizi podataka nije promatrana distinkcija između ponašanja čigri na zabilježenim lokacijama. Dok možemo pretpostaviti da se u gnjezdilištu radilo o gnijezdećim aktivnostima ili odmaranju, podatci izvan kolonija, između ostaloga, mogu se odnositi na aktivan let, hranjenje i odmaranje. Pretpostavlja se da su područja bliža gnijezdećoj koloniji važna i kao letni koridori i kao hranilišta, dok je na udaljenijim područjima vjerojatno veći udio aktivnosti hranjenja u odnosu na letenje, uz povremene izlete radi izviđanja, kako je predstavljeno u publikaciji **II**. Ova činjenica dodatno naglašava važnost Save kod Hruščice i, u manjoj mjeri, Save kod Savice za hranjenje ptica koje se gnijezde na Rakitju, dok Sava kod Rakitja i Sava kod Blata vjerojatno imaju dvojaku ulogu, letnoga koridora i hraništa. U publikaciji **III**, međutim, uzeto je u obzir ponašanje ptica tako da su iz analize isključene točke u mirovanju i točke u izravnome letu. Dodatno, izračunana su područja korištenja za svaku jedinku posebno. Rezultati su potvrdili da se ptice koje se gnijezde na Siromaji 2 gotovo isključivo koriste tokom rijeke Save unutar 6 km od kolonije, dok sve praćene ptice s Rakitja radi hranjenja redovito lete do više od 20 km udaljenoga područja Save kod Hruščice, a leteći uz tok rijeke, kako su to činile čigre, i više od 25 km. Također je potvrđena važnost Save kod Savice (13 km od kolonije Rakitje, više od 15 km uz tok rijeke) za tri od četiri praćene ptice te je utvrđeno još jedno važno područje za dvije od četiri praćene ptice, na Savi kod Petruševca (18 km od kolonije, 21 km uz tok rijeke). Ne iznenađuje činjenica da su se sve praćene ptice koje se gnijezde na Rakitju također intenzivno koristile jezerom Rakitje i bližim dijelovima toka Save nizvodno od Rakitja, do 5 km od kolonije.

Crvenokljune čigre, prema Beckeru i Ludwigsu (2004), uglavnom traže ribu unutar 3 do 10 km od gnjezdilišta iako katkad traže hranu i na udaljenostima većima od 30 km. Thaxter i sur. (2012) procijenili su prosječnu udaljenost na kojoj crvenokljune čigre traže hranu na 4,5 ± 3,2 km, s prosječnom najvećom udaljenosti od 15,2 ± 11,2 km te apsolutnom najvećom udaljenosti 30 km od gnjezdilišta. Glede razlike među spolovima, Militão i sur. (2023) opazili su da mužjaci putuju dalje i brže iako oba spola imaju jednak broj letova i ukupni prijeđeni put dnevno. Utvrđena prosječna udaljenost na kojoj su se hranile ptice s kolonije Siromaja 2, koja je smještena blizu povijesnoga gnjezdilišta čigri na Savi, manja je od prethodno utvrđenih, najvjerojatnije zbog blizine pogodnih hranilišta i ujednačene dostupnosti plijena tijekom dana. Ptice s Rakitja imale su sličnu prosječnu udaljenost od kolonije onima iz ranijih istraživanja, no redovito su se hranile i na području udaljenome 15 do 25 km od kolonije. Slične su udaljenosti zabilježene i u Sloveniji kod crvenokljunih čigri koje se gnijezde na Ptujskom jezeru (Tome i sur. 2019), gdje su se ptice uglavnom hranile duž rijeke Drave unutar 2 do 8 km od kolonije. Također su redovito obilazile i dva jezera udaljena više od 19 km od gnjezdilišta. S obzirom na navedeno, nismo utvrdili segregaciju hranilišta među kolonijama, opisanu u drugim istraživanjima (Bolton i sur. 2019; Wakefield i sur. 2013). Budući da su se ptice na Rakitje preselile upravo s kolonije Siromaja 2, prema Kavelaars i sur. (2020) moguće je da su se praćene ptice s Rakitja koristile poznatim hranilištem oko Siromaje 2 zato što su se ranije u sezoni gnijezdile na toj koloniji. Međutim, budući da je kolonija Siromaja 2 te godine bila novouspostavljena, pretpostavka je (temeljem nalaza prstenovanih ptica) da su se ptice ranijih godina najvjerojatnije gnijezdile upravo na Rakitju, pa je prema istome izvoru (Kavelaars i sur. 2020) vjerojatnije da su se sve ptice te populacije koristile hranilištem oko povijesnoga prirodnog gnjezdilišta na Savi kod Hrušćice. Uz to su obje kolonije, prema Jovani i sur. (2016), premalene da bi razlike u području hranjenja bile uvjetovane *Ashmole's halo efektom* (Ashmole 1963).

Čigre tijekom inkubacije imaju dulje letove nego u vrijeme othrane ptića, kada su ograničene obvezom hranjenja ptića (Sudmann i Becker 1992; Paiva i sur. 2008). Razliku u duljini letova između ptica s Rakitja i Siromaje 2 moglo bi se objasniti činjenicom da su ptice s Rakitja praćene tijekom čitave inkubacije i othrane ptića, dok one sa Siromaje 2 nisu praćene tijekom početnoga dijela inkubacije, zbog čega bi se kod ptica s Rakitja i očekivao veći udio duljih letova. Međutim, rezultati pokazuju da su čigre s Rakitja i tijekom inkubacije i tijekom hranjenja ptića imale dulje letove od ptica sa Siromaje 2. Prema Militão i sur. (2023) moglo bi se argumentirati da su mužjaci s Rakitja tijekom inkubacije izviđali na daljim hranilištima, no na Rakitju je praćen samo jedan mužjak i podatci o njegovim letovima nisu utjecali na razliku niti su odstupali od podataka ostalih ptica s Rakitja. Mužjaci na Siromaji 2 doista jesu u vrijeme inkubacije imali duže letove od ženki i općenito su manje vremena provodili na koloniji.

Još je jedno moguće objašnjenje razlike starost kolonija zato što su i u ranijim istraživanjima ptice s mlađih kolonija (poput one na jezeru Siromaja 2) imale kraće trajanje letova za hranjenje od ptica na starijim kolonijama (Tims i sur. 2004). Međutim, u tim istraživanjima nije analizirana kvaliteta dostupnih hranilišta te njezin eventualni utjecaj na trajanje letova. Na kraju, nije moguće isključiti utjecaj individualnih specijalizacija zabilježenih kod morskih ptica (Ceia i Ramos 2015), no treba imati na umu da morska staništa imaju puno veće potencijalno pogodno područje od slatkovodnih staništa. U svakom slučaju, zbog svega navedenog u publikaciji **III** predstavljena su područja korištenja za svaku praćenu jedinku te je preporučljivo provesti istraživanje na većemu uzorku, osobito za koloniju Rakitje.

Predstavljeni rezultati potvrđuju postavljenu hipotezu da se kontinentalne populacije crvenokljune čigre u Hrvatskoj za vrijeme gniježđenja koriste vodenom površinom unutar 10 km od svoje kolonije, iznimno do 30 km. Kao što je spomenuto, čigre sa Siromaje 2 koristile se su područjem unutar 6 km od kolonije, a ptice s Rakitja, iako su se u prosjeku zadržavale unutar 5 km od gnijezda, redovito su obilazile od 15 do 25 km udaljena pogodna hranilišta duž Save. Time je utvrđeno kojim se područjima kontinentalne populacije crvenokljune čigre koriste za vrijeme gniježđenja u Hrvatskoj te je ostvaren prvi cilj ove disertacije.

3.3. Značajke pogodnih hranilišta

Drugi cilj ove disertacije bio je istražiti koje značajke staništa pogoduju crvenokljunim čigrama prilikom hranjenja. Za tu potrebu postavljena je hipoteza da *crvenokljune čigre u okolici Zagreba najveći dio vremena prilikom hranjenja provode na plitkim dijelovima rijeka i jezera*.

Istraživanje ove hipoteze bio je primarni cilj publikacije **III,** međutim, bilo ju je potrebno prilagoditi jer za šljunčare nisu dostupni batimetrijski i hidrološki podatci. Stoga se istraživanje usmjerilo samo na točke i dubine u koritu rijeke Save. U svakome slučaju, rezultati ovoga istraživanja u slučaju ptica sa Siromaje 2 predstavljaju prvu potvrdu, temeljenu na preciznome telemetrijskom praćenju ptica, o tome kako kopnene crvenokljune čigre tijekom gniježđenja pokazuju preferenciju za pliće dijelove rijeke. Kao što je već spomenuto, ranija istraživanja utvrdila su vezu između hranjenja crvenokljunih čigri i dubine vode, brzine toka vode te morskih mijena, no gotovo isključivo na morskim staništima (Urmy i Warren 2018; Schwemmer i sur. 2009), dok su se spoznaje o kontinentalnim populacijama uglavnom temeljile na jednostavnom promatranju ptica (Fasola i Bogliani 1984).

Prethodna istraživanja provedena na morskim staništima nisu usporediva s ovim istraživanjem glede samih dubina na kojima se ptice preferencijalno hrane jer su Becker i sur. (1993) utvrdili preferenciju za pličine s manje od 5 m dubine, dok su Schwemmer i sur. (2009) zabilježili najveću frekvenciju ptica na dubinama manjim od 5 m te između 15 i 20 m, a na dubinama većima od 20 m zabilježene su male frekvencije ptica. Uzrok ovakve neusporedivosti rezultata gotovo su sigurno topografske razlike između riječnih i morskih staništa. U svakome se slučaju zabilježena preferencija ptica sa Siromaje 2 za hranjenje na dubinama manjim od 1 m može objasniti činjenicom da crvenokljune čigre prilikom lova zaranjaju tek do 50 cm ispod površine gdje hvataju plijen (Dunn 1972).

Činjenicu da za ptice s Rakitja nije utvrđena značajna preferencija za plićake moglo bi se objasniti primijenjenom metodom, odnosno granicom krivudavosti leta (engl. *tortuosity*), prema kojoj smo razlikovali izravan let od hranjenja. Ptice s Rakitja prelazile su veće udaljenosti i letjele su brže od ptica sa Siromaje 2, stoga je primjena jednake granice krivudavosti za određivanje ponašanja za obje kolonije moglo rezultirati nejasnijim podatcima o ponašanju ptica s Rakitja. Nadalje, ptice su tijekom svojih letova uglavnom pratile tok rijeke umjesto pravocrtnoga leta preko kopna, što im je možda pružilo prilike za oportunističko hranjenje. Dodatno je nejasnoći podataka mogla doprinijeti razlika od 20 minuta između bilježenja GPS lokacija jer bi vremenski preciznijim podatcima mogli jasnije razlikovati hranjenje od izravnoga leta. Naposljetku, na Rakitju su praćene samo četiri ptice, što bi mogao biti premalen uzorak za stjecanje statistički značajnih rezultata. U svakome slučaju, frekvencijska raspodjela dubina za ptice s Rakitja kod Savice i kod Hrušćice ima dva vrhunca: prvi na dubinama ispod 1 m, kao i kod ptica sa Siromaje 2 te opet između 1,75 m i 2 m, gdje kontrolne točke imaju svoj vrhunac (Prilog 3.). Budući da su Savica i Hrušćica najudaljenija hranilišta ptica s Rakitja, možemo pretpostaviti da točke s tih lokacija predstavljaju najveći udio hranjenja u odnosu na aktivan let. Stoga je velik udio točaka na dijelovima Save bliže Rakitju, koje vjerojatno i dalje često predstavljaju aktivan let, najvjerojatnije *zamutio* rezultat za ptice s Rakitja kad se podatci razmatraju kao cjelina.

Uzmu li se u obzir ranija istraživanja na morskim staništima, dodatni su čimbenici koji mogu utjecati na odabir staništa za hranjenje: brzina toka vode, prozirnost vode i raspodjela plijena. Nadalje, Becker i sur. (1997) ustanovili su da je 7 % hranidbenih letova crvenokljunih čigri na slatkovodnim staništima te 15 % takvih letova na morskim staništima trajalo manje od 30 minuta. Uzme li se u obzir i prosječno trajanje letova sažeto u Arnold i sur. (2020), moguće je da je određen udio kratkih letova u ovome istraživanju ostao nezabilježen, čime bi potencijalno podcijenili važnost hranilišta bližih kolonijama. Na kraju, s obzirom na razlike u hranjenju među spolovima (Militão i sur. 2023), moguće je da je neravnomjerni omjer između broja praćenih mužjaka i ženki na Rakitju utjecao na rezultate.

Predstavljeni rezultati djelomično potvrđuju postavljenu hipotezu da crvenokljune čigre u okolici Zagreba (barem veći od dvaju uzoraka, ptice sa Siromaje) najveći dio vremena prilikom hranjenja provode na plitkim dijelovima rijeka i jezera. Uz opisana ograničenja postoje naznake da bi se jednak zaključak mogao donijeti i za ptice s Rakitja, barem dok se hrane na udaljenijim dijelovima rijeke. Zaključci ovoga istraživanja za obje će se kolonije moći unaprijediti na većemu uzorku te kada daljnji napredci u minijaturizaciji uređaja i radnome vijeku baterija omoguće češće bilježenje GPS lokacija. Budući da su utvrđene značajke staništa koje pogoduju crvenokljunim čigrama prilikom hranjenja, ostvaren je drugi cilj ove disertacije.

3.4. Izviđanje staništa tijekom aktivnog gniježđenja

Treći cilj ove disertacije bio je istražiti izviđanje staništa kod gnijezdećih crvenokljunih čigri u okolici Zagreba. Za tu potrebu postavljena je hipoteza *crvenokljune čigre u okolici Zagreba za vrijeme aktivnoga gniježđenja (uglavnom hranjenja ptića) posjećuju druge kolonije*.

Istraživanje ove hipoteze bio je primarni cilj publikacije **II** i predstavlja prvu potvrdu izviđanja staništa kod odraslih ptica koje su se uspješno gnijezdile za vrijeme inkubacije i othrane ptića. Ptice su posjećivale druge kolonije crvenokljunih čigri udaljene 9 i 27 km od vlastite kolonije, i to izvan redovnoga područja hranjenja. Kao što su publikacija **I** i publikacija **III** pokazale, čigre su se uglavnom hranile na plićim dijelovima duž rijeke te pritom nisu obilazile druge kolonije.

Ranijim je istraživanjima već utvrđena redovita prisutnost nedoraslih morskih ptica na kolonijama jer ih je moguće razlikovati prema ruhu (Brooke 2018). Ipak, za potvrdu prisutnosti odraslih ptica koje se tamo ne gnijezde, potrebna je sposobnost prepoznavanja jedinki. Prstenovanje u boji pruža vrlo malo takvih podataka, stoga je istraživanje izviđanja kod odraslih omogućeno tek razvojem uređaja za telemetrijsko praćenje. Jedino ranije opažanje mogućega izviđanja tijekom gniježđenja zabilježeno je tijekom istraživanja velikih čigri (*Hydroprogne caspia* Pallas, 1770) na Velikim jezerima (Cuthbert 1985), kada je pet ptica među onima koje su posjećivale druge kolonije imalo jaja ili ptiće na nekoj drugoj koloniji. No u tom istraživanju nije se raspravljalo o razlozima takvoga ponašanja.

Sve ptice tijekom leta kroz šire područje gniježđenja prikupljanju informacije o potencijalnim gnjezdilištima (Reed i sur. 1999). Međutim, ptice često izbjegavaju druge kolonije svoje vrste i ostala područja s visokom gustoćom jedinki iste vrste, pa su tako Wakefield i sur. (2013) uočili da se blune (*Morus bassanus* Linnaeus, 1758) s različitih kolonija hrane na različitim, međusobno isključivim područjima. Druga su istraživanja na dugokljunim čigrama (*Thalasseus sandvicensis* Latham, 1787) (Fijn i sur. 2014) i velikim čigrama (Patterson i sur. 2018) utvrdila izviđanje prije i poslije gniježđenja, i to do 870 km udaljenih kolonija za dugokljune čigre te na području od 235,000 km^2 za velike čigre. Pretpostavlja se da su uzroci ovakvoga ponašanja visoka promjenjivost dostupnosti pogodnih staništa tijekom godina te veliki razmjeri povezanosti istraživanih populacija. Iako pretpostavljamo da su isti čimbenici doveli do izviđanja odraslih crvenokljunih čigri u ovome istraživanju, u našem je slučaju, za razliku od prethodnih istraživanja, izviđanje zabilježeno tijekom same sezone gniježđenja. Uzrok tome vjerojatno je postojanje nekoliko kolonija na manjem području (77,5 km^2, najveća udaljenost 27 km). Nismo uočili posjete udaljenijim kolonijama (51,3 km do otoka kod Brežica te 73,3 km do otočića kod Ptuja, oboje u Sloveniji). Campioni i sur. (2017), uglavnom slično, bilježili su izviđanje žutokljunih albatrosa (*Thalassarche melanophris* Temminck, 1828) na kolonijama unutar 10 km od natalne kolonije. Stoga pretpostavljamo da je izviđanje tijekom gniježđenja prihvatljivo kada na lako dostupnom području postoji više pogodnih gnjezdilišta, što povećava vjerojatnost uspješnoga ponovljenoga gniježđenja u slučaju propadanja prvoga legla.

Stabilnost staništa vjerojatno je još jedan važan pokretač izviđanja tijekom gniježđenja. Ranija su istraživanja potvrdila važnost izviđanja kod mladih crvenokljunih čigri za odabir buduće gnijezdeće kolonije (Dittman i sur. 2005) te visoku vjernost odraslih ptica svojoj gnijezdećoj koloniji (Breton i sur. 2014; Becker i sur. 2016). Međutim, utvrđeno je kako stopa filopatrije varira među kolonijama (Coulson 2016) te da je ta stopa viša u velikim, stabilnim kolonijama nego u malim kolonijama i/ili kolonijama na nestabilnim staništima (Palestis 2014). Isto je istraživanje pokazalo da čigre koje se uspješno gnijezde obično ne mijenjaju kolonije, dok kolonije sa čestim i/ili značajnim gubitcima zbog plavljenja, grabežljivaca ili uznemiravanja, mogu imati više stope disperzije ili čak biti napuštene. Crvenokljune čigre koje se gnijezde na rijekama često su zbog naglih porasta razine vode tijekom sezone gniježđenja suočene s propadanjem čitave kolonije. Aktualne informacije o drugim mogućim gnjezdilištima kod ptica na nestabilnim staništima ubrzavaju potragu za novim gnjezdilištem i povećavaju im uspješnost gniježđenja. Izviđanje bi stoga mogla biti evolucijska prednost na nepredvidivim staništima na kojima često propadaju pokušaji gniježđenja. Ovome u prilog idu i zaključci istraživanja izviđanja više vrsta čigri i galebova, koje je dokazalo da su se ptice iz populacija koje se gnijezde na područjima s redovitim promjenama u dostupnosti lokacija gnjezdilišta tijekom godina češće upuštale u izviđanje (Kralj i sur. 2023).

Iako je prema *hipotezi optimalnoga razdoblja* (Boulinier i sur. 1996; Campioni i sur. 2017) pretpostavljeno da je najveći udio izviđanja u fazi othrane ptića, u ovom je istraživanju zabilježeno više izviđanja tijekom inkubacije nego tijekom othrane ptića. Uzrok tome najvjerojatnije je činjenica da je teorija zasnovana na ponašanju nedoraslih ptica koje mogu izviđati tijekom čitave sezone gniježđenja, dok odrasle ptice zbog hranjenja ptića imaju manje vremena za izviđanje nego što su imale tijekom inkubacije jaja. Također, izviđanje u ranijoj fazi gniježđenja omogućuje brže ponovno gniježđenje u slučaju propasti prvoga pologa. Međutim, budući da je ovo istraživanje obuhvatilo samo razdoblje gniježđenja, nije isključen porast aktivnosti izviđanja odraslih ptica nakon završenoga gniježđenja. Kralj i sur. (2023) na većem su uzorku vrsta i populacija zabilježili izviđanje i tijekom inkubacije i tijekom othrane ptića, no najčešće tijekom ranih dana othrane ptića. Ovakvo ponašanje korisno je kako bi ptice tijekom različitih stadija gniježđenja prikupljale cjelovitije informacije o kvaliteti drugih gnjezdilišta.

Predstavljeni rezultati djelomično potvrđuju postavljenu hipotezu da crvenokljune čigre u okolici Zagreba za vrijeme aktivnoga gniježđenja (ugl. hranjenja ptića) posjećuju druge kolonije. Izviđanje staništa zabilježeno je kod šest aktivnih gnjezdarica na jezeru Siromaja 2, odnosno kod 37,5 % praćenih ptica koje su tijekom gniježđenja 12 puta posjetile kolonije Čiče i Rakitje. Međutim, većina izviđanja zbila se tijekom inkubacije jaja (58,3 %), dok su samo dvije jedinke, s ukupno pet letova, izviđale tijekom hranjenja ptića. U svakome slučaju, ovim je istraživanjem uspješno utvrđeno izviđanje staništa kod gnijezdećih crvenokljunih čigri u okolici Zagreba.

3.5. Važnost postavljanja zamjenskih gnjezdilišta bliže dobrim hranilištima

Kao što je već raspravljeno, rezultati istraživanja predstavljeni u ovoj disertaciji jasno upućuju na važnost Save kod Hrušćice kao dobroga hranilišta za čigre s obiju kolonija. Također je raspravljeno kako ptice s Rakitja redovito lete dalje od prosjeka zabilježenoga u literaturi kako bi se hranile u plitkim vodama ovoga dijela Save. Ptice s Rakitja zbog toga dnevno provode manje vremena na koloniji nego ptice koje se gnijezde na Siromaji 2. Kraće dnevno razdoblje (i za više od dva sata) koje ptice na Rakitju posvete svojemu gnijezdu i ptićima može uzrokovati manju uspješnost gniježđenja, na što upućuju podatci o produktivnosti na tim dvjema kolonijama (Martinović i sur. 2019b.), prema kojima kolonija Siromaja 2 ima nešto višu uspješnost gniježđenja od kolonije na Rakitju. Sve ovo ističe važnost odabira odgovarajuće lokacije za umjetna gnjezdilišta crvenokljunih čigri. Što je nova kolonija dalje od dobrih hranilišta, ptice će morati ulagati više truda u hranjenje te će imati manje vremena za brigu o partneru koji inkubira i o ptićima. Prisutnost na gnijezdu važna je sastavnica kvalitete roditeljstva koja izravno utječe na preživljavanje ptića (Riechert i Becker 2017). Prisutnost na gnijezdu tijekom inkubacije povećava uspješnost izlijeganja smanjivanjem opasnosti od predacije i održavanjem konstantne temperature jaja, a tijekom othrane ptića također smanjuje opasnost od predacije i hipotermije ptića. Također, kraće udaljenosti do hranilišta omogućavaju češće hranjenje, što utječe na rast ptića (Riechert i Becker 2017). Smještaj umjetnih gnjezdilišta bliže dobrim hranilištima mogao bi povećati uspješnost gniježđenja i, posljedično, vijabilnost populacije. Dodatno, postavljanje novih gnjezdilišta bliže dobrim hranilištima olakšalo bi pticama i izviđanje jer bi one uz hranjenje *usput* mogle prikupljati informacije o stanju na drugim kolonijama. Ovo bi pak ubrzalo ponovno gniježđenje i povećalo njegovu uspješnost, što opet povoljno utječe na vijabilnost populacije.

3.6. Preporuke za buduća istraživanja

Iako rezultati publikacije **III** upućuju na važnost predjela s dubinom manjom od 1 m kao pogodnih hranilišta za crvenokljune čigre, potrebno je provesti dodatna istraživanja o utjecaju drugih okolišnih čimbenika na odabir područja i staništa za hranjenje, poput dostupnosti hrane i ometanja. Nadalje, istraživanjima utjecaja dubine na pogodnost hranilišta nisu bila obuhvaćena jezerska staništa, pa je i na njima potrebno ispitati postojeću hipotezu. Također, kao što je spomenuto, zaključci ovih istraživanja za obje će se kolonije moći unaprijediti kada daljnji napredci u minijaturizaciji i radnom vijeku baterija omoguće češće bilježenje GPS lokacija na većem uzorku.

Glede izviđanja staništa, istraživanje u okviru publikacije **II** utvrdilo je razlike u spolovima među jedinkama koje su se upuštale u izviđanje, no potrebno je dodatno istražiti ulogu spola u odabiru lokacije zamjenskoga legla. Ranija su istraživanja ponovnoga gniježđenja crvenokljunih čigri uputila na visoku vjernost partneru i lokaciji prethodnoga gnijezda, no ta su istraživanja bila ograničena na samostalne kolonije (González-Solís i sur. 1999; Wendeln i sur. 2000). Budući da klimatske promjene povećavaju opasnost od pojava ekstremnih vremenskih uvjeta poput oluja i nagloga porasta razine vode, istraživanja ponovnoga gniježeđenja, filopatrije i izviđanja u odraslih gnjezdarica sve bi se više trebala usmjeravati na manje i raštrkane kolonije na nestabilnim staništima.

4. ZAKLJUČAK

1. Telemetrijskim istraživanjem utvrđeno je kako se crvenokljune čigre tijekom gniježđenja na kolonijama u okolici Zagreba uglavnom koriste prostorom rijeke Save, s vrlo malo letova dalje od 2 km od rijeke.

2. Većina kretanja čigri koje se gnijezde na Siromaji 2 bila je unutar 5 km od kolonije, dok su ptice s Rakitja redovito letjele na područja udaljena i do 25 km od svoje kolonije.

3. Ptice s obiju kolonija za hranjenje su najviše koristile područje Save kod Hrušćice. Ptice s Rakitja osim toga su se redovito koristile i područjem Save kod Savice te vodnim tijelima unutar 5 km od svoje kolonije.

4. Ptice koje su se gnijezdile bliže dobrim hranilištima (kolonija Siromaja 2) češće su se hranile na plićim dijelovima rijeke u odnosu na distribuciju nasumičnih kontrolnih točaka.

5. Letovi u potrazi za hranom ptica koje su se gnijezdile na umjetnom otoku udaljenijem od dobroga hranilišta (Rakitje), trajali su duže i obuhvaćali su veće udaljenosti od letova ptica bližih dobrom hranilištu (Siromaja 2). Ptice s Rakitja također su imale veće područje korištenja i manje su bile prisutne na koloniji.

6. Prvi put je potvrđeno izviđanje staništa kod aktivno gnijezdećih odraslih jedinki u vrijeme inkubacije jaja i hranjenja ptića. Ptice obaju spolova posjećivale su druge gnijezdeće kolonije na relativno manjoj udaljenosti od kolonije na kojoj su imale aktivna gnijezda.

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6. ŽIVOTOPIS AUTORA

Miloš Martinović rođen je 25. studenog 1987. godine u Zagrebu.

Nakon završene Osnovne škole Ivana Filipovića te XVI. gimnazije u Zagrebu, 2006. godine upisuje studij Poslovne ekonomije na Ekonomskom fakultetu u Zagrebu, gdje 2010. godine upisuje i diplomski studij Poslovne ekonomije, smjer Menadžerska informatika. Diplomski rad *Alati otvorenog koda za oglašavanje elektroničkom poštom* brani 2012. godine pod mentorstvom prof. dr. sc. Mirjane Pejić Bach te stječe zvanje magistra poslovne ekonomije (mag. oec.).

Pred kraj studija Poslovne ekonomije 2011. godine usporedno upisuje Studij biologije na Prirodoslovno-matematičkom fakultetu u Zagrebu, koji nastavlja upisom diplomskog Studija ekologije i zaštite prirode, modul Kopno, 2014. godine. Diplomski rad *Struktura zajednica ptica pjevica šumskih staništa Petrove gore* pod mentorstvom dr. sc. Jelene Kralj brani 2016. godine te stječe i zvanje magistra ekologije i zaštite prirode (mag. oecol. et prot. nat.).

Nakon studija zaposlio se kao pripravnik ekolog u Udruzi *Biom*, gdje je radio na prijevodu i prilagodbi knjige *Ptice Hrvatske i Europe*, zatim kao asistent ornitolog u Zavodu za ornitologiju Hrvatske akademije znanosti i umjetnosti na INTERREG projektu *Očuvanje populacija čigri u porječju Save i Drave*. Godine 2017. istodobno upisuje poslijediplomski studij Biologije na PMF-u Sveučilišta u Zagrebu te vodi praktikumsku nastavu iz kolegija Vertebrata, Kralješnjaci i Terenska nastava.

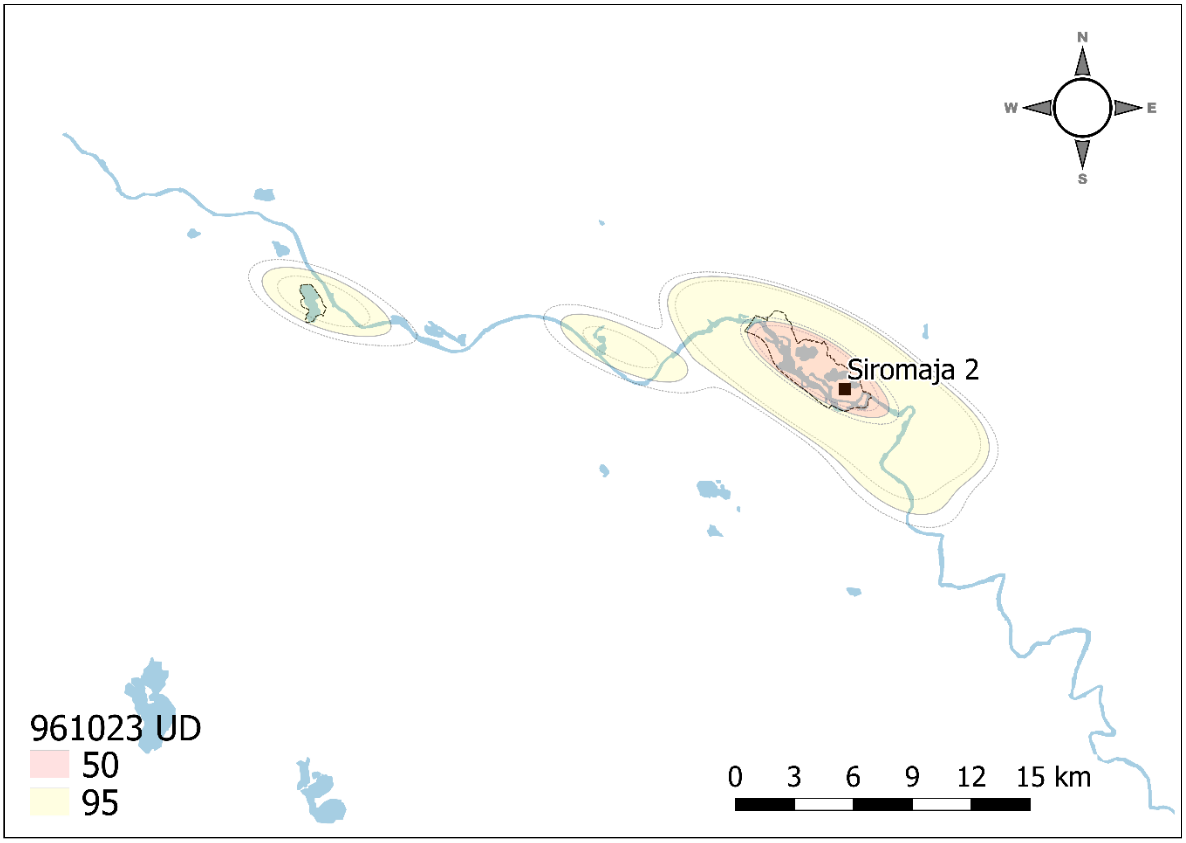
Završetkom projekta u HAZU-u 2020. godine zapošljava se kao vanjski suradnik u Zavodu za zaštitu okoliša i prirode današnjega Ministarstva gospodarstva i održivog razvoja, gdje je od 2022. godine zaposlen kao viši stručni savjetnik na projektu LIFE CONTRA Ailanthus – Uspostava kontrole invazivne strane vrste *Ailanthus altissima* (pajasen) u Hrvatskoj.

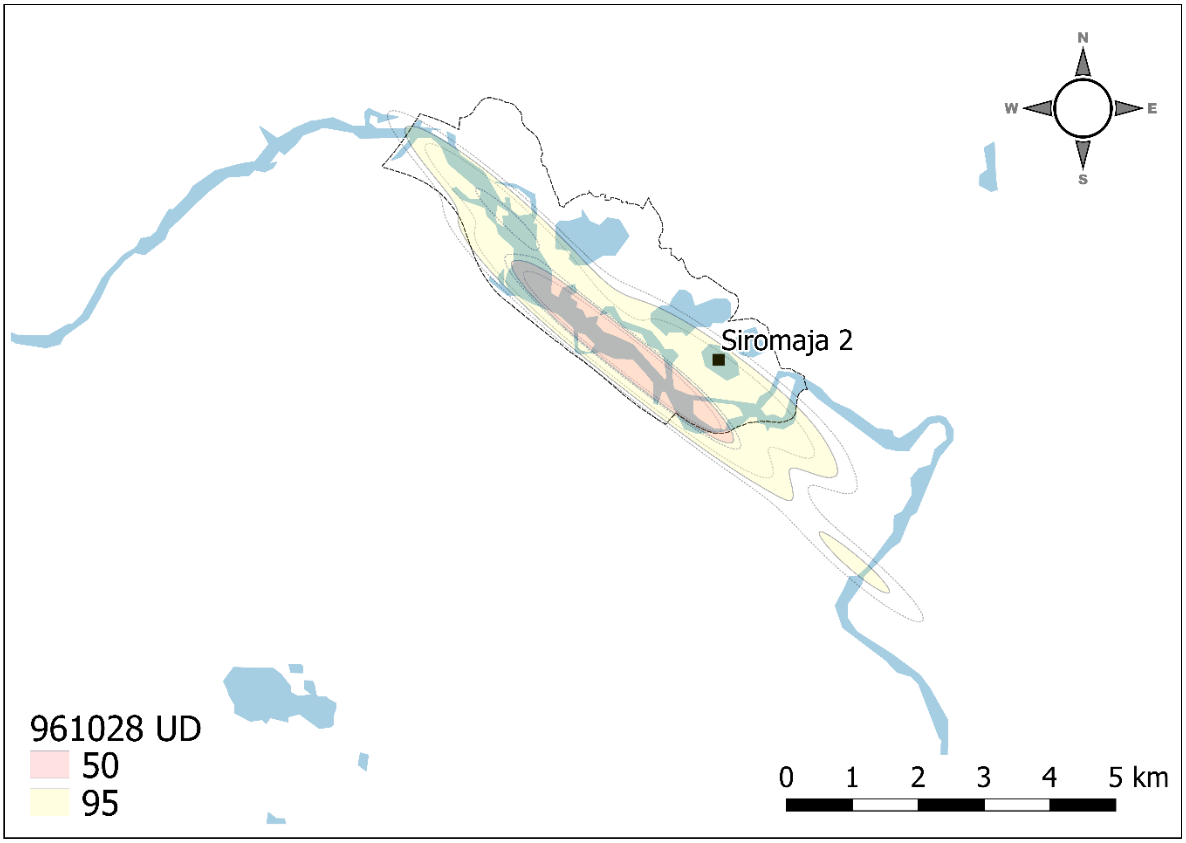
7. PRILOZI

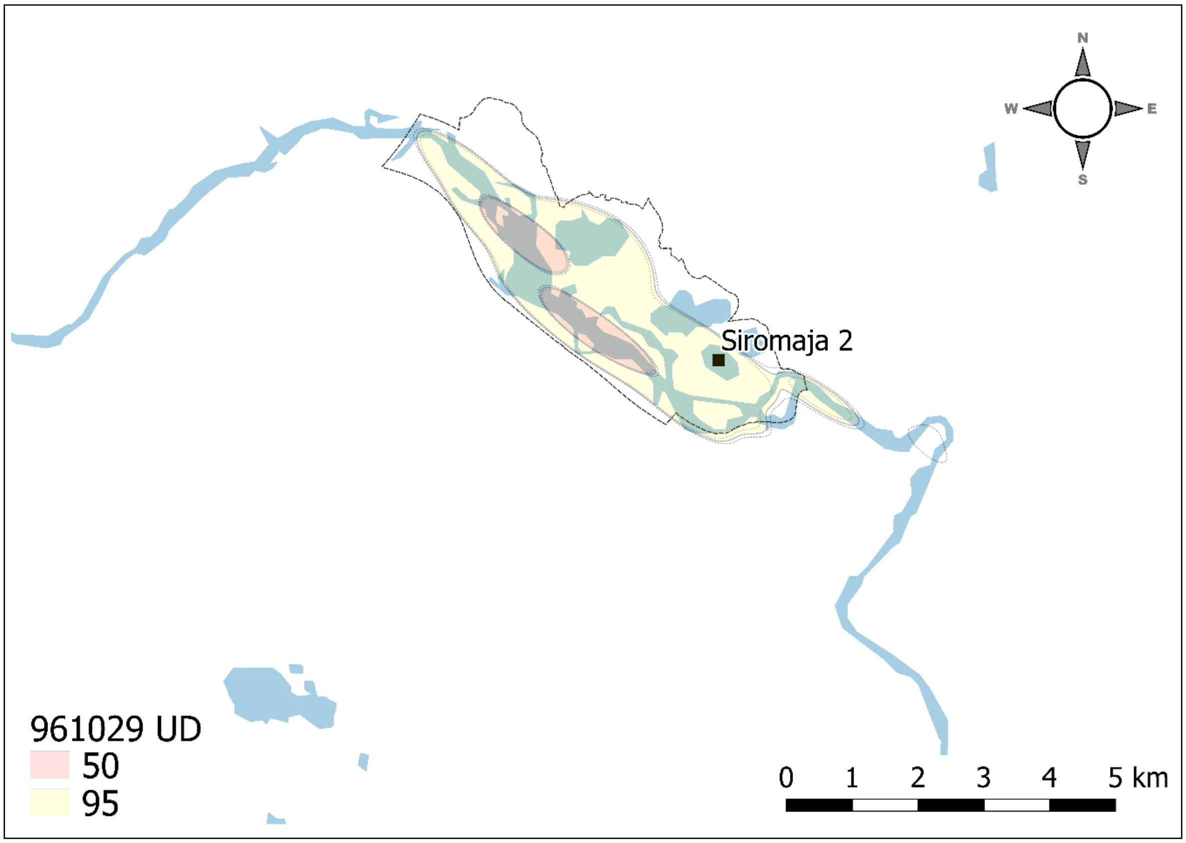
Prilog 1. Statistike varijabli napora hranjenja i gniježđenja crvenokljunih čigri koje su se gnijezdile na kolonijama Siromaja 2 (15 ptica; 10 ženki, 5 mužjaka) i Rakitje (4 ptice; 3 ženke, 1 mužjak). Brojevi u zagradama predstavljaju prve i treće kvartile. DFC – udaljenost od kolonije (engl. *distance from colony*). Objavljeno u *Martinović M, Plantak M, Jurinović L, Kralj J (2023) Importance of shallow river topography for inland breeding Common Terns. Journal of Ornithology 164:705–716. https://doi.org/10.1007/s10336-023-02060-0*

	Distance covered (km) *median (Q_1–Q_3)*	Trip duration (h) *median (Q_1–Q_3)*	DFC (km) *median (Q_1–Q_3)*	Max DFC (km) *median (Q_1–Q_3)*	Speed (m/s) *median (Q_1–Q_3)*	Max speed (m/s) *median (Q_1–Q_3)*	Nest presence (h) *mean ± SD*
Siromaja 2	**3.44 (1.76 – 6.02)**	**0.68 (0.34 – 1.06)**	**1.92 (1.03 – 3.10)**	**2.71 (1.50 – 4.48)**	**1.11 (0.69 – 1.90)**	**1.81 (0.98 – 3.01)**	**15.74 ± 4.77**
Female	3.46 (1.85 – 6.26)	0.67 (0.34 – 1.03)	1.93 (1.28 – 3.29)	2.77 (1.77 – 4.57)	1.28 (0.72 – 2.10)	2.00 (1.19 – 3.45)	17.01 ± 4.35
incubation	1.94 (0.84 – 4.33)	0.50 (0.34 – 0.68)	1.60 (0.83 – 2.66)	1.83 (0.83 – 3.45)	0.92 (0.66 – 1.92)	1.51 (0.66– 2.98)	18.22 ± 3.99
chick rearing	3.57 (1.86 – 6.43)	0.68 (0.34 – 1.04)	1.94 (1.38 – 3.34)	2.85 (1.81 – 4.57)	1.31 (0.72 – 2.11)	2.06 (1.30 – 3.46)	16.46 ± 4.40
Male	3.38 (1.59 – 5.82)	0.68 (0.34 – 1.34)	1.89 (0.95 – 2.97)	2.67 (1.06 – 4.03)	1.01 (0.67 – 1.74)	1.70 (0.84 – 2.86)	13.61 ± 4.70
incubation	3.49 (2.00 – 5.32)	0.76 (0.39 – 1.62)	2.47 (1.19 – 2.92)	2.75 (1.90 – 3.59)	0.93 (0.59 – 1.53)	1.56 (0.97 – 2.27)	14.94 ± 5.38
chick rearing	3.37 (1.56– 5.85)	0.68 (0.34 – 1.34)	1.87 (0.95 – 2.97)	2.64 (1.06 – 4.07)	1.01 (0.67 – 1.76)	1.72 (0.84– 2.87)	13.18 ± 4.39
Rakitje	**6.79 (0.84 – 40.64)**	**1.35 (0.34 – 3.07)**	**3.23 (0.63 – 13.75)**	**5.27 (0.69 – 22.10)**	**1.24 (0.41 – 3.25)**	**3.10 (0.56 – 8.82)**	**13.48 ± 4.74**
Female	12.03 (0.84 – 42.86)	1.36 (0.34 – 3.04)	4.70 (0.63 – 15.50)	8.03 (0.66 – 23.13)	1.57 (0.42 – 3.44)	4.07 (0.54 – 9.15)	15.11 ± 4.22
incubation	3.39 (0.62 – 39.18)	1.01 (0.34 – 2.71)	1.87 (0.56 – 17.73)	3.11 (0.57 – 23.24)	0.73 (0.33 – 2.18)	2.32 (0.46 – 9.02)	16.47 ± 4.42
chick rearing	19.78 (1.59 – 44.54)	1.42 (0.35 – 3.37)	7.27 (0.95 – 13.86)	13.79 (1.12 – 20.30)	2.11 (0.58 – 4.11)	6.95 (0.84 – 9.19)	13.86 ± 3.63
Male	3.90 (0.83 – 33.52)	1.34 (0.35 – 3.42)	1.00 (0.62 – 9.30)	3.01 (0.69 – 17.75)	0.72 (0.41 – 2.90)	1.88 (0.57 – 8.39)	10.02 ± 3.89
incubation	2.63 (0.78 – 18.42)	0.84 (0.34 – 2.00)	0.85 (0.70 – 8.72)	1.68 (0.76 – 12.90)	0.65 (0.41 – 3.81)	0.99 (0.52 – 5.68)	11.46 ± 4.96
chick rearing	4.17 (0.84 – 39.65)	1.34 (0.67 – 3.71)	1.09 (0.62 – 9.59)	3.09 (0.69 – 17.77)	0.75 (0.41 – 2.78)	2.06 (0.57 – 8.79)	9.12 ± 2.77

Prilog 2. Područje korištenja prilikom hranjena (PK, engl. *utilization distribution* (*UD*)) devet crvenokljunih čigri koje su se gnijezdile na jezeru Siromaja 2 blizu Zagreba 2018. godine, praćenih uređajima za satelitsko praćenje. PK su predstavljena 50-postotnim i 95-postotnim kumulativnim raspodjelama. Crno su iscrtkane granice Natura 2000 Područja važnog za očuvanje ptica (POP). Sivo su istočkana 95-postotna odstojanja pouzdanosti pripadajućih PK. Karte preostalih četiriju ptica, uz ovaj prilog, predstavljene su u radu *Martinović M, Plantak M, Jurinović L, Kralj J (2023) Importance of shallow river topography for inland breeding Common Terns. Journal of Ornithology 164:705–716.* https://doi.org/10.1007/s10336-023-02060-0. N_{961023} = 127 točaka kroz 34 dana; N_{961028} = 54 točaka kroz 20 dana; N_{961029} = 993 točaka kroz 55 dana; N_{961030} = 220 točaka kroz 31 dana; N_{961031} = 174 točaka kroz 36 dana; N_{961033} = 659 točaka kroz 54 dana; N_{961034} = 543 točaka kroz 44 dana; N_{961035} = 386 točaka kroz 38 dana; N_{961036} = 212 točaka kroz 32 dana.




N
W
E
S
Siromaja 2
961028 UD
50
95
0
1
2
3
4
5 km


N
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Siromaja 2
961029 UD
50
95
0
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2
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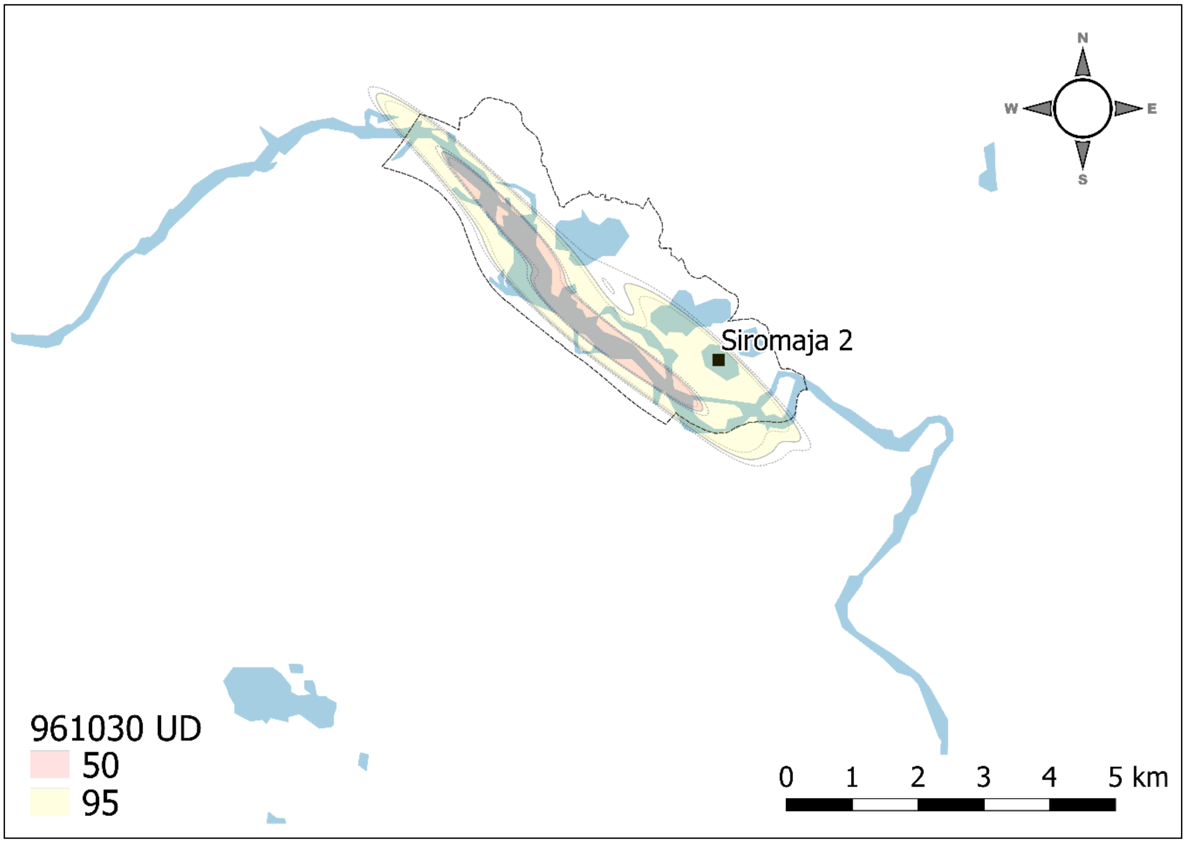
5 km


N
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Siromaja 2
961030 UD
50
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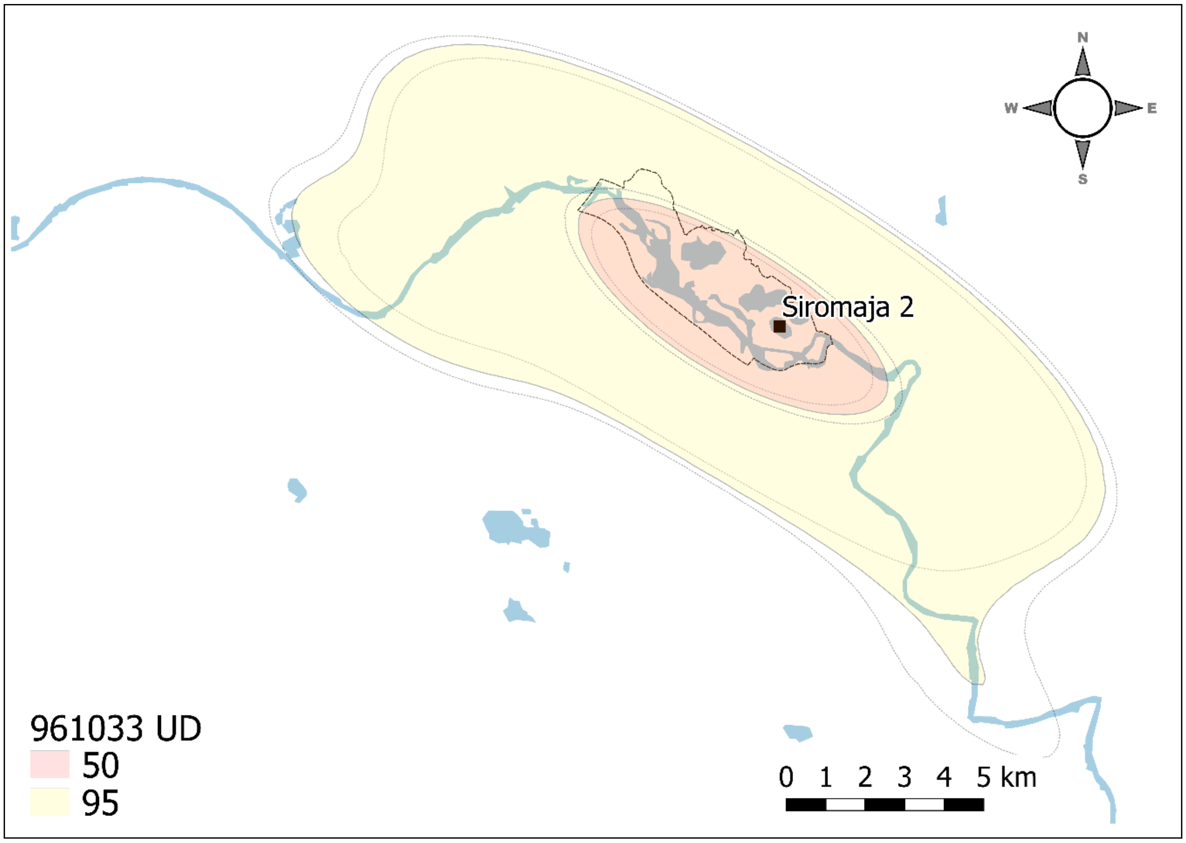
0 1 2 3 4 5 km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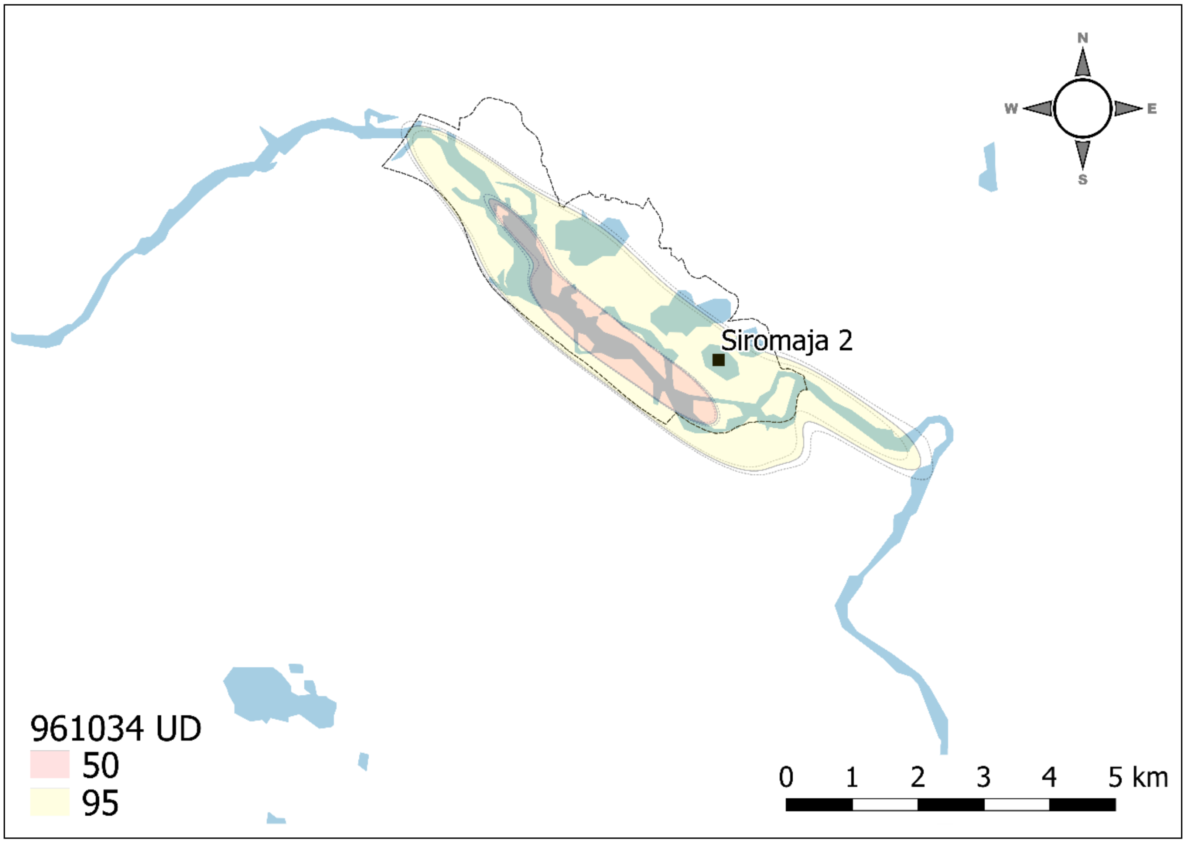
N
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961034 UD
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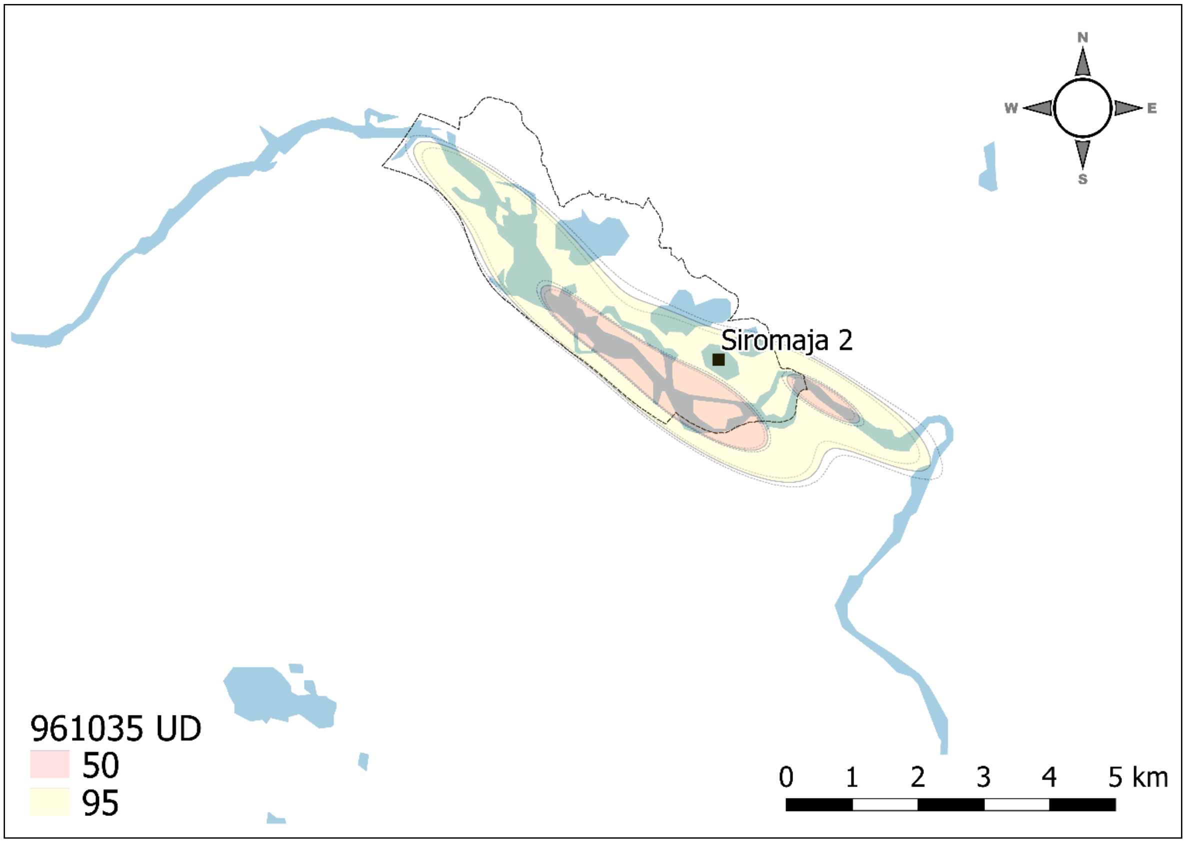
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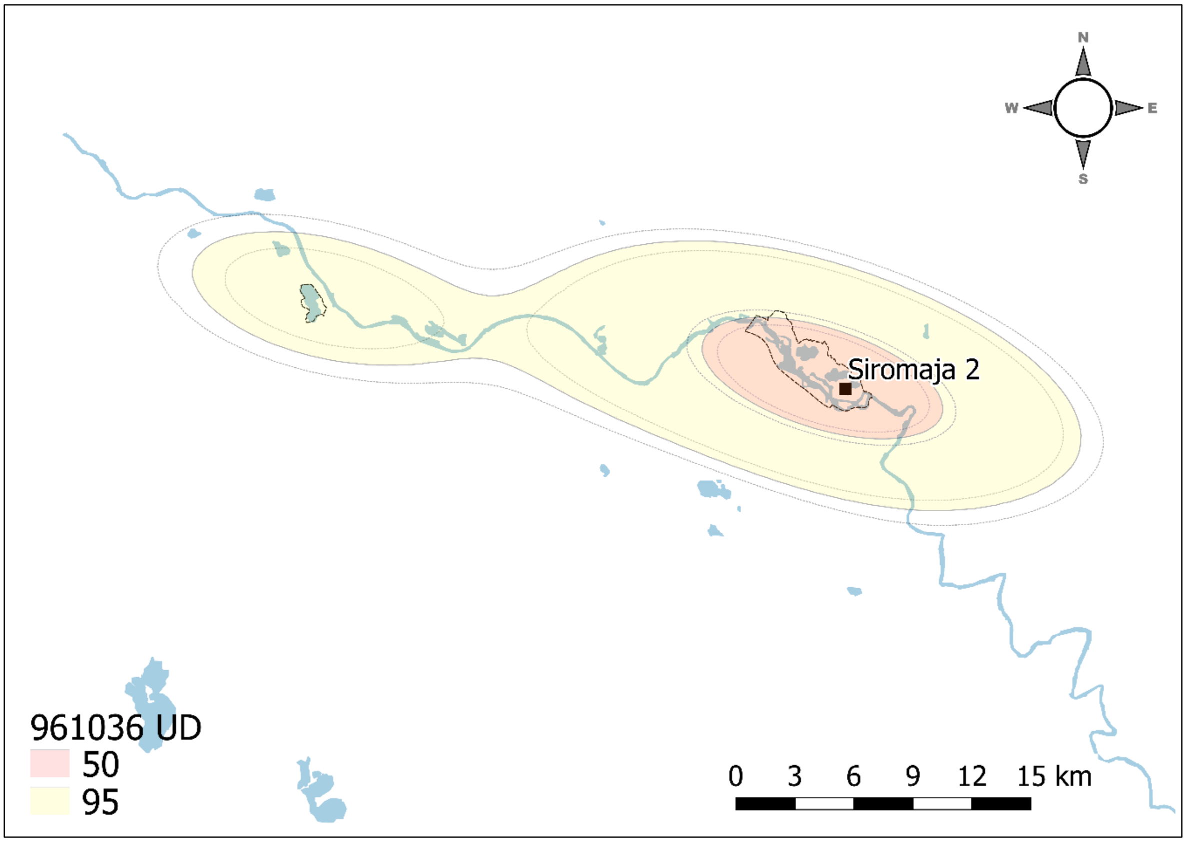
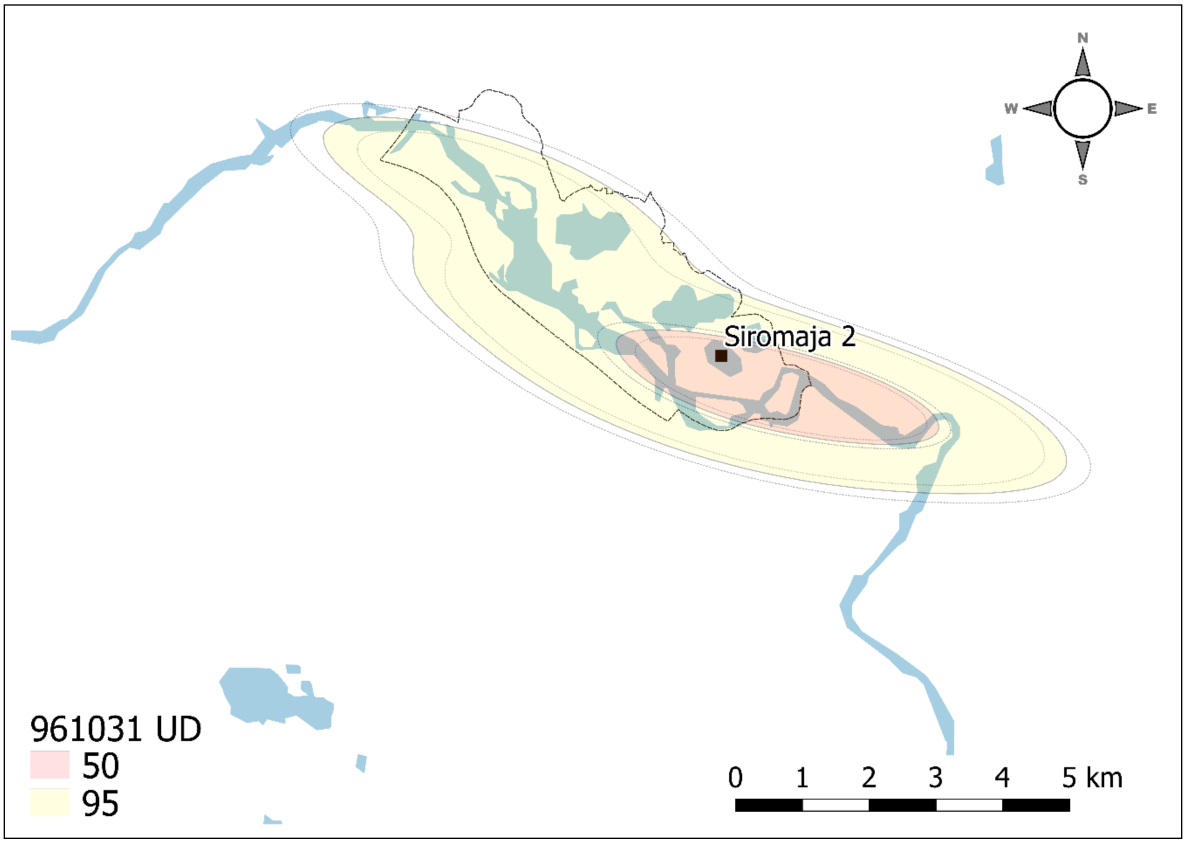
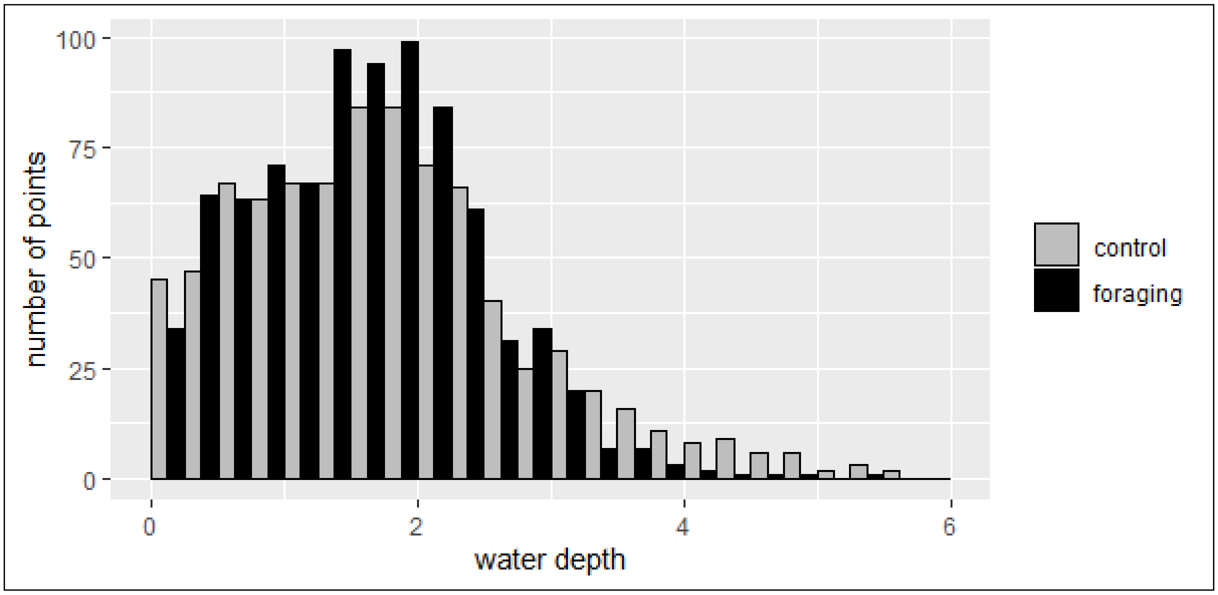
Siromaja 2
961035 UD
50
95
0
1
2
3
4
5 km

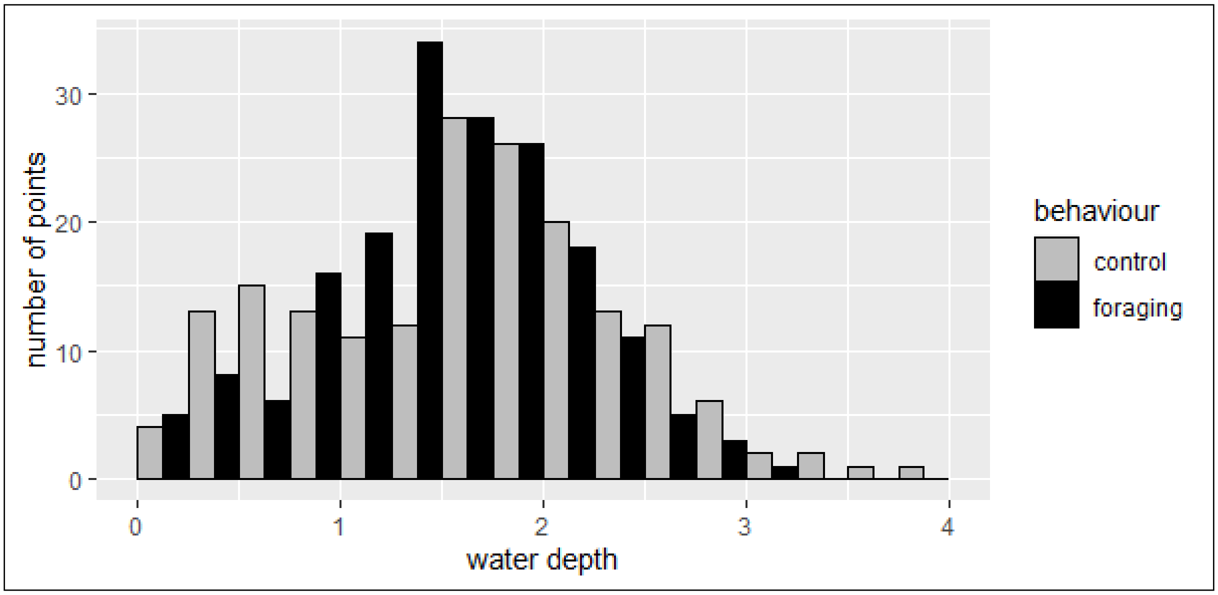

N
W
E
S
Siromaja 2
961036 UD
50
95
0 3 6 9 12 15 km


N
W
E
S
Siromaja 2
961031 UD
50
95
0 1 2 3 4 5 km

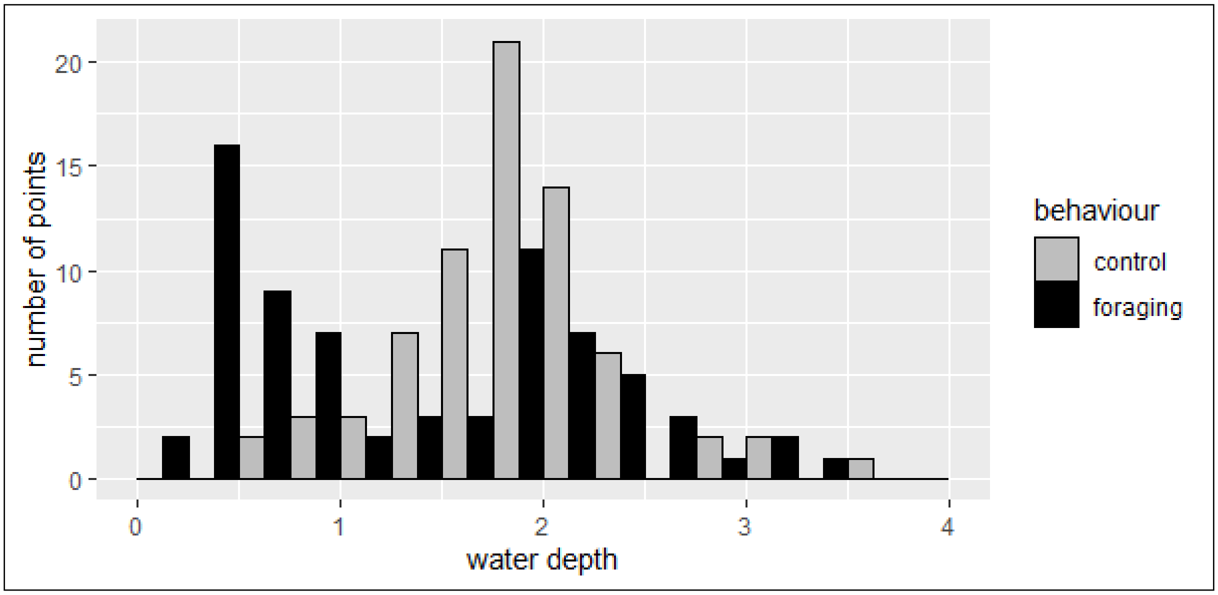
Prilog 3. Raspodjela učestalosti dubina za točke crvenokljunih čigri koje su se gnijezdile na Rakitju i hranile na rijeci (sve točke) te na najkorištenijim (50 % PK) dijelovima rijeke.



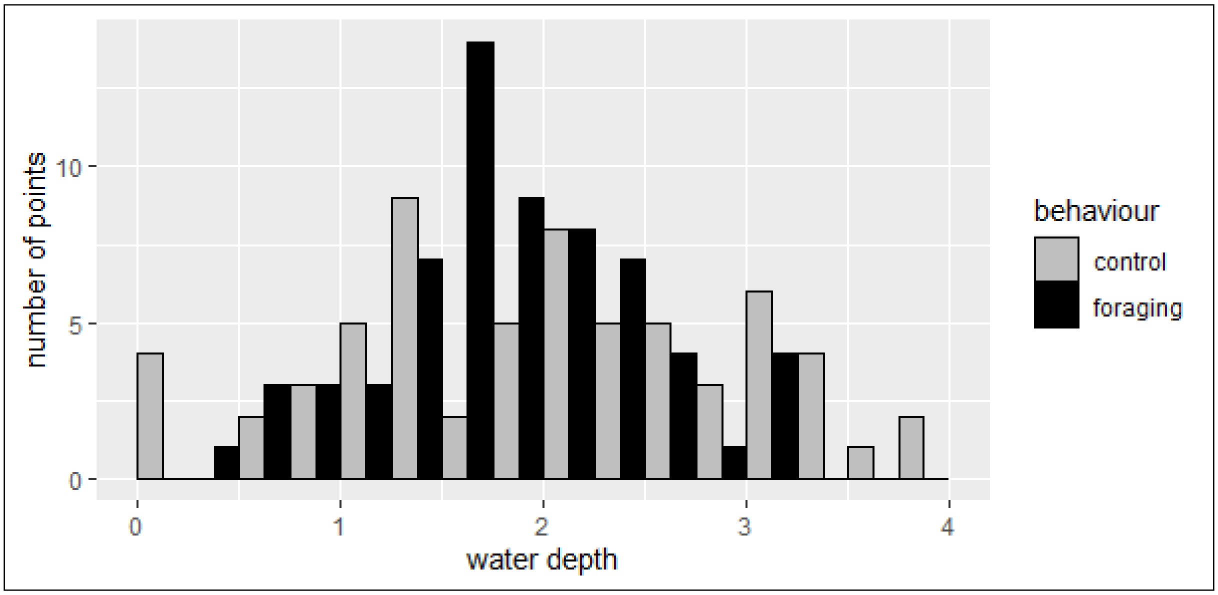
Slika P3.1. Crvenokljune čigre koje su se gnijezdile na Rakitju i hranile na rijeci (sve točke, N = 842) te jednak broj nasumičnih kontrolnih točaka (N = 842).



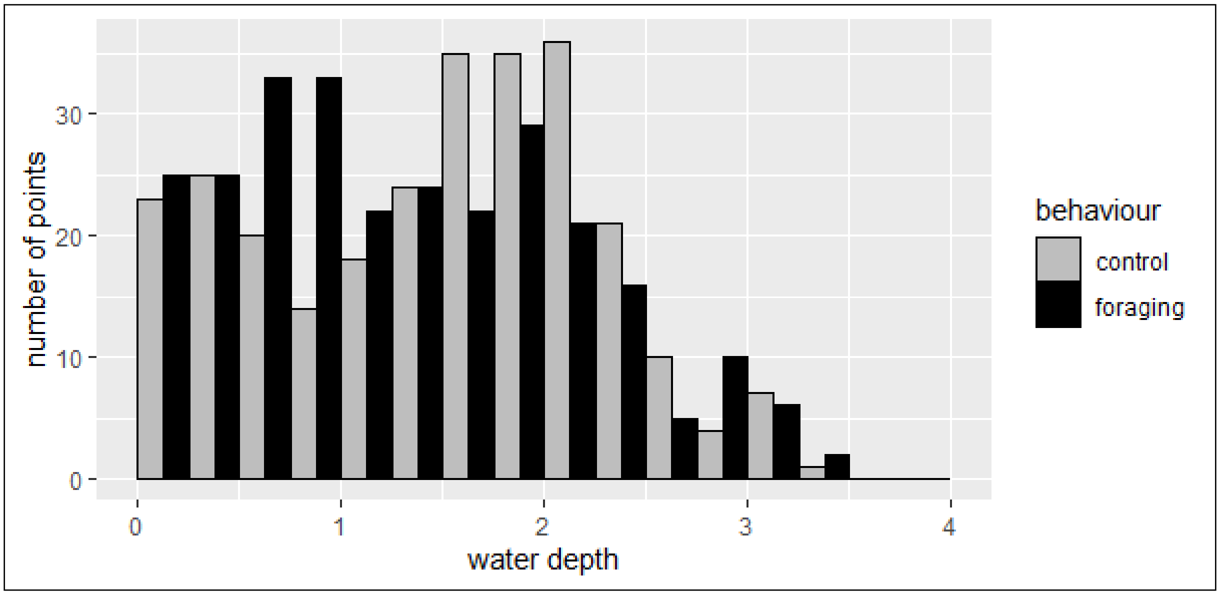
Slika P3.2. Crvenokljune čigre koje su se gnijezdile na Rakitju i hranile blizu Rakitja (N = 180) te jednak broj nasumičnih kontrolnih točaka (N = 180).



Slika P3.3. Crvenokljune čigre koje su se gnijezdile na Rakitju i hranile na Savi kod Savice (N = 72) te jednak broj nasumičnih kontrolnih točaka (N = 72).



Slika P3.4. Crvenokljune čigre koje su se gnijezdile na Rakitju i hranile na Savi kod Petruševca (N = 64) te jednak broj nasumičnih kontrolnih točaka (N = 64).



Slika P3.5. Crvenokljune čigre koje su se gnijezdile na Rakitju i hranile na Savi kod Hrušćice (N = 273) te jednak broj nasumičnih kontrolnih točaka (N = 273).