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Analysis of the efficiency of trap location and baiting for red swamp crayfish capture (*Procambarus clarkii* Girard 1852)

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ABSTRACT

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The red swamp crayfish is an invasive species that poses significant ecological and economic threats to freshwater ecosystems. In 2014 and 2015, a culling campaign was carried out in a lake in the northern Iberian Peninsula, where more than 165 000 individuals (4029 kg) were captured. Without losing sight of the primary objective of the work (culling), we were authorised to conduct some controlled tests to evaluate the efficiency of traps depending on their location, baiting methods, and the type and amount of bait used. We observed that traps located near reed and rush shorelines were significantly more effective (with captures ranging from 20%-354%) than those located farther from the shore. The use of lake fish as bait resulted in a 39% increase in captures compared with the use of beef heart. Using three portions of bait per trap resulted in a 59% increase in captures compared with using a single portion of bait. Furthermore, we found that when bait was placed in permeable containers that were out of reach of the crayfish's mandibles, the attractiveness of the bait was not reduced, and the number of captures was increased. Improving methods for capturing invasive exotic species, such as red swamp crayfish, is essential for optimising culling efforts and controlling these species.

KEY WORDS: invasive species management, trap siting, bait type and quantity, CaicedoYuso – Arreo Lake, Álava - Basque Country, *Procambarus clarkii*

RESUMEN

Análisis de la eficiencia de la localización y del cebado de las trampas en la captura de cangrejo rojo (*Procambarus clarkii *Girard 1852).

El cangrejo rojo es una especie invasora que supone importantes amenazas ecológicas y económicas para los ecosistemas de agua dulce. En 2014 y 2015 se llevaron a cabo labores de descaste en un lago del norte de la península ibérica, donde se capturaron más de 165 000 ejemplares (4029 kg). Sin perder de vista el objetivo principal del trabajo (descastes), fuimos autorizados a realizar algunos ensayos controlados para evaluar la eficiencia de las trampas en función de su localización, el método de cebado y el tipo y cantidad de cebo utilizado. Observamos que las nasas situadas cerca de las orillas de juncos y carrizos fueron significativamente más efectivas (capturas entre el 20% y el 354% mayores, según jornadas) que las situadas más alejadas de la orilla. El uso de pescado de lago como cebo generó un aumento del 39% en las capturas en comparación con el uso de corazón de vacuno. El uso de tres porciones de cebo por trampa produjo un aumento del 59% en las capturas en comparación con el uso de una sola porción. Además, descubrimos que colocar el cebo en recipientes permeables, fuera del alcance de las mandíbulas de los cangrejos, no solo no re-

dujo su atractivo, sino que incluso aumentó el número de capturas. Mejorar los métodos de captura de especies exóticas invasoras, como el cangrejo rojo, es esencial para optimizar los esfuerzos de descaste y controlar con éxito estas especies..

PALABRAS CLAVE: *gestión de especies exóticas invasoras, ubicación de trampas, tipo y cantidad de cebo, lago Caicedo Yuso – Arreo, Álava – País Vasco,* Procambarus clarkii.

INTRODUCTION

The red swamp crayfish *Procambarus clarkii*, Girard, 1852, is native to the eastern coast of the USA and Mexico. It was introduced into Europe for the first time in 1973 and 1974, specifically in Spain (Habsburgo-Lorena, 1978), and it expanded to other European countries, mainly through illegal introductions (Souty-Grosset et al., 2006; Kouba et al., 2014). Two additional routes into Europe from non-European areas have been detected, resulting in a complex pattern of introductions of the species in Europe (Oficialdegui et al., 2020). The red swamp crayfish is among the most successful invasive crayfish species in terms of colonisation, causing adverse effects on autochthonous flora and fauna, and even leading to the local extinction of particular species (Souty-Grosset et al., 2016; O'Hea Miller et al., 2024).

A wide variety of methods have been employed to eradicate or control invasive crayfish populations, including mechanical methods such as traps, nets, electrofishing (Caruana et al., 2024; Egly & Keller, 2025; Morbidelli et al., 2025), physical methods such as drying and barriers (Dana et al., 2011), biological methods such as the introduction of predatory fish (Neveu, 2001), chemical methods such as biocides (Peay et al., 2006), and autocidal approaches such as the use of pheromones as attractants, and male sterilisation (Stebbing et al., 2014). However, the effectiveness of these methods has been limited in most cases (García de Lomas et al., 2020; Chadwick et al., 2021; Caruana et al., 2024), and comparison of the efficiency between approaches are lacking (García de Lomas et al., 2020; Egly & Keller, 2025; Morbidelli et al., 2025).

Seeking to address this gap, the aim of this study was to compare the efficiency of crayfish trapping by evaluating modifications in trap placement and the presentation, type, and amount of bait offered. Our findings highlight key variables in trapping methods that should be considered for achieving more effective population control of this invasive species and minimising its impact on ecosystems.

Study Area

CaicedoYuso–Arreo Lake is one of the few examples of a sinkhole lake formed over a salt diapir on the Iberian Peninsula, and the only one of its kind in the Basque Country (González Mozo et al., 2000; Camacho et al., 2009).

Located on the Mediterranean slope of the Historical Territory of Álava, Basque Country, Spain (42°46'42.4"N 2°59'28.4"W), and at an altitude of 655 m above sea level (Fig. 1), CaicedoYuso–Arreo Lake covers an area of 6.57 ha. The lake is nearly circular in shape and, despite reaching a maximum depth of 24.8 m, more than 60% of its surface is shallow (0–2 m) with a very gentle slope, which has facilitated colonisation by emergent hydrophytes such as *Cladium mariscus* and *Phragmites australis* (Rico et al., 1995). The charophyte green algae Chara hispida had previously covered almost the entire colonizable area of the lake; currently, it has almost completely disappeared (Agencia Vasca del Agua, 2005–2019).

In contrast, the northern shore is characterised by steep slopes associated with an ENE-WSW fault line (Martínez Torres et al., 1992).

The surrounding environment features minimal anthropogenic inputs; there are holm (*Quercus ilex rotundifolia*) and gall oak (*Quercus faginea*) forests to the north, and former agricultural land undergoing natural ecosystem recovery following public acquisition in the rest of its perimeter (Sarriegi & Carreras, 2016). The lake is subsaline, with a conductivity ranging from 1.3 to 1.6 mS/cm, and exhibits stable thermal stratification. The thermocline disappears only in January and February, resulting in anoxic conditions at the bottom for most of the year (González Mozo et al., 2000).
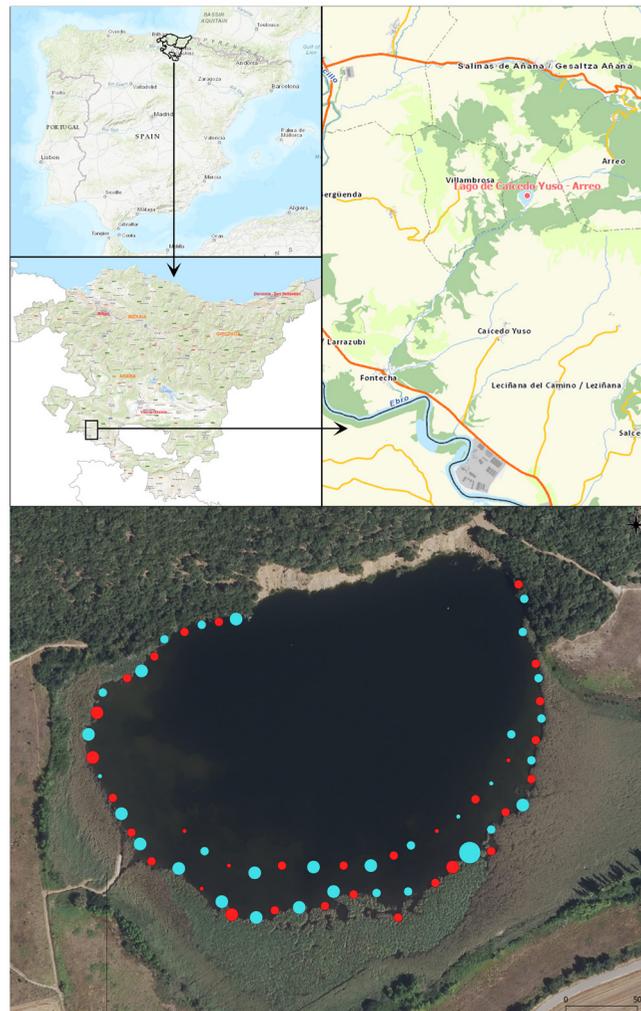
Figure 1. Geographic location of Lake Caicedo Yuso–Arreo (42°46'42.4"N 2°59'28.4"W) and aerial photograph of the lake. The circles indicate the locations of the 70 traps during the week of July 24, 2015. The circle colours represent the type of bait used that day (blue: fish from the lake; red: beef heart), and the circle size indicates the catch weight obtained in each trap. Note the extensive littoral zone of reeds and rushes, particularly toward the southern area.*Ubicación geográfica del lago de Caicedo Yuso – Arreo (42°46'42.4"N 2°59'28.4"O) y foto aérea del lago. Los círculos hacen referencia a la ubicación de las 70 nasas la semana del 20 al 24 de julio de 2015. El color de dichos círculos indica el tipo de cebo empleado en esa jornada (azul: pescado del lago; rojo: carne de corazón de vacuno), y el tamaño indica el volumen de capturas en peso obtenidas en cada nasa. Obsérvese la extensión de la franja litoral de carrizos y juncos, especialmente hacia el sur.*

The red swamp crayfish was introduced into CaicedoYuso–Arreo Lake between 1993 and 1998 (Montes et al., 1994; E. Rico, pers. comm.). Initially, it maintained a low density (0.05 crayfish per trap per day –CPUE– in 2002 and 2006; Cañón, 2012), but its population experienced a striking surge for undetermined reasons, increasing from 1.3 CPUE in 2012 (Cañón, 2012) to 46.8 CPUE in 2013 (Asensio, 2013). One of the most detrimental consequences of the increasing abundance of the red swamp crayfish in the lake has been the near-complete disappearance of *Chara hispida* meadows, as previously mentioned.

MATERIALS AND METHODS

Trap Design

Red swamp crayfish were captured using collapsible cylindrical traps from the Evia brand (product code ULZ3260), measuring 60 cm in length and 32 cm in diameter, with conical entrances 23

cm deep and 9 cm in diameter at each end of the cylinder (6 mm mesh size). Initial tests with the original traps revealed that the crayfish's mandibles easily damaged the fragile nylon pouches intended for holding the bait. The original commercial model was modified to improve the durability and catch rate: the two zipper openings were sewn shut with nylon cord, as they were weak points where traps typically tore. Additionally, the original nylon pouch for holding the bait was replaced with a 250 ml wide-mouth cylindrical translucent plastic container with a screw black cap (commonly referred to as "duquesa" in Spanish). This plastic container was perforated 16 times with a punch to facilitate sinking and diffusion of the bait's odour. Each trap was equipped with a plastic cord ending in a small, numbered buoy, which floated on the surface to aid in locating the traps during harvest activities (Fig. 2).

Trap Placement and Location Strategy

In the first weeks of the culling campaign, a zoning plan was designed in which traps were placed in the western area of the lake for one week, followed by the southern area the following week, and the eastern area the week after that. This type of trap was not suitable for the northern area because of the steepness of the lakebed. The traps placed near the reed and rush shorelines consistently captured more and larger crayfish than those located in concentric lines towards the centre of the lake.

The flooded surface extended far beyond the limit of the marsh vegetation, especially the southern shores, reaching up to several dozen metres of submerged terrain covered with rushes and reeds, which is an ideal environment for crayfish refuge but impractical for navigation (Fig. 1). Moreo-

Figure 2. Photographs of the traps used in the study. The upper image shows the trap in a controlled setting, highlighting the modifications made to the original commercial model. The lower image captures the trap deployed in the lake shortly before the catches were retrieved. *Fotografías de las nasas empleadas en el trabajo, la superior tomada en estudio, en la que se aprecian las modificaciones practicadas al modelo comercial original, y la inferior instalada en aguas del lago poco antes de recoger las capturas.*

ver, trap installation was carried out in shallow areas that were accessible by boat, and that featured good visibility of the lakebed, which was uniformly silty and had few dead plants. During culling operations, it was rare to observe crayfish moving across these silty bottoms, while observations of crayfish moving under the protection of reeds and rushes were more common. Based on these findings, the method of trap distribution in the lake was modified to apply a two-line arrangement of traps as described below.

Trap Deployment and Harvesting

The culling was planned in weekly sessions. On Mondays, the traps were installed sequentially, according to each trap's number, in two concentric lines in the shallow areas of the lake (Fig. 1): one along the reed and rush shoreline (L1, n = 45-48 traps) and another approximately 20 metres from the shoreline towards the centre of the lake (L2, n = 15-24 traps). Location data (GPS Garmin eTrex) and depth for each trap were recorded (average depth in line 1 = 1.02 ± 0.03 m, n = 708; average depth in line 2 = 1.65 ± 0.06 m, n = 334). On Fridays, four days after the traps were set, the traps were retrieved using an inflatable boat with an electric motor. Every 24 hours, the traps were checked, the captured crayfish were collected, and the bait was replaced. The captures from each trap were weighed using a digital dynamometer (Rapala 12 kg ± 10 g) and expressed in grams per trap per day ($g.t^{-1}.d^{-1}$). The averages for this variable reported in the text are presented with a 95% confidence interval (±1.96SE). Additionally, in three traps from the outer line and two from the inner line, all captured individuals were counted daily (CPUE), individually phenotyped (sex, sexual state in males, presence of eggs or larvae in females, anatomical abnormalities), and measured (from the front of the rostrum to the midpoint of the posterior end of the cephalothorax using a digital calliper with an accuracy of 0.1 mm). During 2015, 8247 crayfish were sexed and measured individually from these five traps.

Bait Placement Experiment

To contrast the efficiency of plastic containers ("duquesa") and safety pins, on 30 July 2015, beef heart was placed on safety pins within the reach of the crayfish in 35 odd-numbered traps. In comparison, the 35 even-numbered traps had beef heart placed inside the plastic containers. The next day, the bait was swapped between the traps: safety pins with beef heart in the even-numbered traps, and beef heart in the plastic containers in the odd-numbered traps. One week later, the same experiment was repeated, but lake fish were used instead of beef heart as the bait.

Bait Type Experiment

To assess the effect of bait type (beef heart vs. lake fish) on captures, on 24 July 2015, thirty-two odd-numbered traps were baited with beef heart, while 31 even-numbered traps were baited with lake fish (*Lepomis gibbosus* and *Micropterus salmoides*), and perforated plastic containers were used to hold the bait in all cases (Fig.1).

Bait Quantity Experiment

To test whether the amount of bait influenced the captures, on 27 August 2015, a single piece of beef heart (approximately 50–60 g) was placed in the odd-numbered traps, while three pieces (approximately 150–180 g) were placed in the even-numbered traps.

Data Analysis

Each data series was cleaned by removing anomalous data (broken traps or traps where fish were captured and eaten by crayfish). A normality test (Shapiro–Wilk test) and variance homogeneity test (Snedecor's F test) were performed before selecting a parametric (Student's t–test) or nonparametric (Mann–Whitney U) statistical test for the simple paired comparisons.

To compare the average catches between two lines of traps during all sampling events, an analysis of covariance test was conducted, considering date as a covariate. To analyse the results of the bait presentation and type experiment, the data were analysed with a two-way ANOVA test, including line and bait presentation or type as factors.

Statistical analyses were conducted with PAST 4.05 statistical software (Hammer et al., 2001).

RESULTS

During 2014 and 2015, we conducted 158 fishing days in a lake in northern Iberia, using between 50 and 70 traps daily, resulting in a total effort of 9101 day-traps. More than 165 000 red swamp crayfish were captured, with a combined weight of 4029.36 kg (Asensio, 2015).

Without other sources of variation beyond the trap placement along different lines (two pieces of beef heart in each plastic container), the average catches were consistently higher in trap line 1 than in trap line 2 (by 20% to 354%, depending on the day; Fig. 3). ANCOVA analysis reveals that the adjusted means in the two groups differed significantly (F = 726; $p <$ 0.001). The equality of slopes cannot be rejected (F = 4.759; $p = 0.292$). The differences between the trap lines increased as the culling campaign
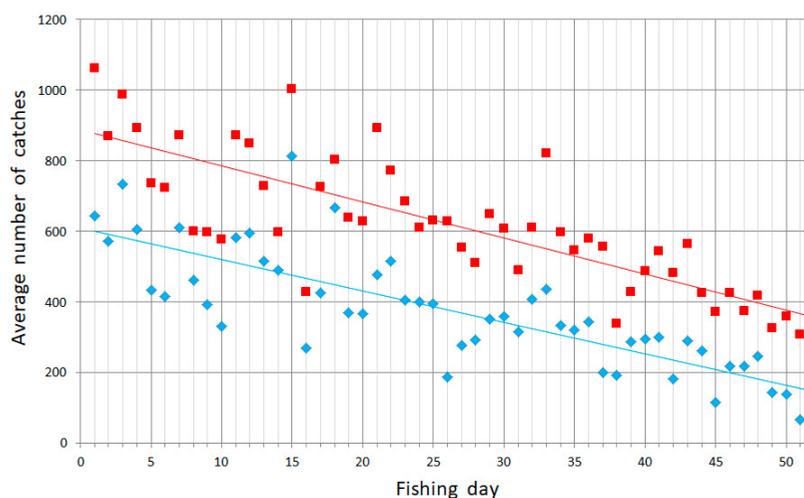

Figure 3. Average catches (g) per trap over 52 fishing days, based on trap location (red squares = line 1 of the traps; blue diamonds = line 2 of the traps). Significant differences ($p < 0.015$) were observed in the average catches between line 1 and line 2 on all days except the 8th ($p = 0.066$) and 15th ($p = 0.070$) days. Trend lines for both data series are included. *Capturas medias (g) por nasa, en 52 jornadas de pesca, según la ubicación de las nasas (cuadrados rojos = línea 1 de nasas; rombos azules = línea 2 de nasas). En todas las jornadas se registraron diferencias significativas (*p < 0.015*) en las capturas medias entre la línea 1 y la línea 2, salvo en las jornadas 8ª (*p = 0.066*) y 15ª (*p = 0.070*). Se incluyen las líneas de tendencia de ambas series de datos.*
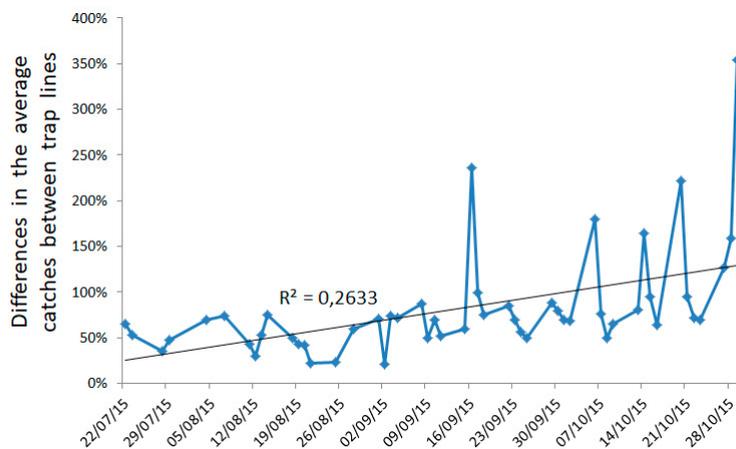

Figure 4. Evolution of the weekly average catch differences between the traps located in line 1 and those in line 2 throughout the culling campaign. *Evolución de las diferencias entre las capturas medias semanales obtenidas por las nasas ubicadas en la línea 1 y las correspondientes a la línea 2 a lo largo de la campaña de descastes.*

progressed (Fig. 4).

For traps selected for biometric analysis, significant size differences were found between the catches from the two trap lines (F = 85.26; *p* < 0.005) and sex (F = 410.2; *p* < 0.005), with the average size being larger for the specimens collected in line 1 and males being larger than females. The interaction effect of line and sex was not significant (F = 0.426; *p* = 0.514).

Regarding bait presentation, on July 30 and 31, 2015, when beef heart was used as bait, the average catches were higher in the traps where the bait was placed in plastic containers than when it was directly accessible to the crayfish (F = 6.369; *p* = 0.012), and there were more catches in the first line of traps (F = 8.036; *p* = 0.005). The interaction effect of bait presentation between lines was not significant (F = 0.018; *p* = 0.892). On 5 and 6 August 2015, when lake fish was used as bait, significant differences were observed between the presentation types (F = 13.85; *p* < 0.005), whereas the differences among the lines were not significant (F = 3.564; *p* = 0.062) (Fig. 5 -top panel-). Similarly, the
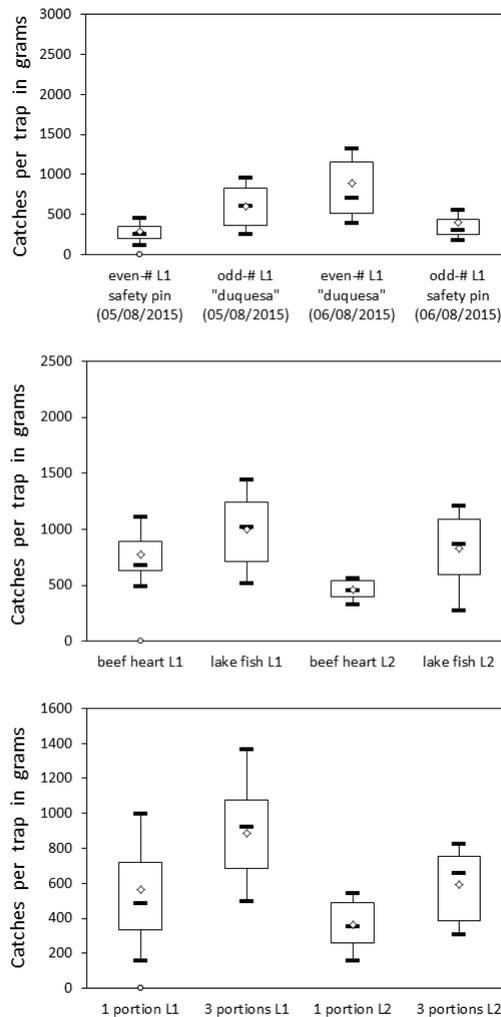

Figure 5. Box plots from the contrasts of bait presentation (fish inside a "duquesa" plastic container vs. anchored by a safety pin), bait type (beef heart vs lake fish in both trap lines), and bait quantity (3 portions of meat vs single portion of meat in both trap lines). The Y-axis represents daily captures per trap in grams (g.t⁻¹.d⁻¹). *Diagramas de caja obtenidos en los contrastes de presentación del cebo (pescado dentro de una duquesa vs en un imperdible), del tipo de cebo (carne vs pescado en las líneas 1 y 2 de nasas), y de cantidad de cebo (3 porciones de carne vs porción simple de carne en las líneas 1 y 2 de nasas). El eje de Ordenadas representa, en los tres casos, las capturas diarias por nasa en gramos (g.t⁻¹.d⁻¹).*

interaction between lines and bait presentation was not significant (F = 1.385; p = 0.242).

With respect to bait type (Fig. 5 -middle panel-), significant differences were observed in both trap lines (F = 8.220; p = 0.006) and bait types (F = 13.36; p < 0.005). The interaction between lines and bait types was not significant, as in the previous analyses (F = 0.559; p = 0.457).

Regarding bait quantity, catches were significantly greater in traps baited with three portions of bait than in those baited with single portions (Fig. 5-bottom panel-). Significant differences were observed between the bait quantity groups (F = 18.15; p < 0.005) and lines (F = 13.18; p < 0.005). The interaction between lines and bait quantity was not significant (F = 1.82; p = 0.182).

DISCUSSION

This study highlights the importance of optimising trap placement, bait type, and bait quantity in improving the efficiency of capturing red swamp crayfish, an invasive species with significant ecological impacts, through passive trapping methods.

Our findings indicate that trap placement plays a critical role in maximising catches. Specifically, our analysis underscores how the spatial distribution of traps significantly influences their efficacy. Shallow areas protected by marsh vegetation along the western, eastern, and especially the southern shores of the lake serve as primary refuges and feeding areas for red swamp crayfish. These areas provide shelter, from which crayfish seem to venture towards the lake's centre, attracted by the bait's scent. Our results suggest that the first line of traps captures more specimens than the second line does. The placement of traps in two concentric lines might create a barrier to intercept foraging crayfish.

Additionally, the first line of traps not only yielded higher catches but also captured more males and larger individuals than the second line. This pattern could be attributed to competitive exclusion, where dominant crayfish prevent subordinate individuals from accessing traps. This behaviour, well documented in previous studies (e.g., Ogle & Kret, 2008; Price & Welch, 2009;

Chucholl, 2011), is likely more pronounced near refuges, where larger, more aggressive crayfish occupy the nearest traps without needing to travel farther.

The widening differences between the two trap lines as the campaign progressed might reflect a gradual decline in population density due to continued extraction. Lower crayfish abundance reduces intraspecific competition, making it less necessary for individuals to bypass the first line of traps to access the second line.

Bait presentation also plays a key role in determining the efficacy of this method. De Palma-Dow et al. (2020) emphasised the effectiveness of the trap model used in this study, particularly highlighting the utility of nylon mesh bait bags. However, our observations revealed that these bags were quickly damaged by crayfish, highlighting the need for a more durable solution. We opted for perforated plastic containers to hold the bait and compared their effectiveness to bait presented directly to the crayfish.

The access of crayfish to the bait was expected to release particles into the water as a result of the chewing process, which would likely increase the attraction of surrounding crayfish towards the trap, leading to more captures (Pfister & Romaire, 1983). Contrary to expectations, traps with bait in plastic containers consistently outperformed those with accessible bait. This discrepancy can be explained by the complete consumption of accessible bait, which leaves traps ineffective once the bait is depleted. In contrast, bait secured in containers retained its attractiveness throughout the fishing period, ensuring sustained functionality. While larger quantities of bait might mitigate this depletion issue, the practicality of daily operations led us to use bait containers as a more efficient strategy.

The choice of bait has been extensively studied, yielding varied results (Larson & Olden, 2016; Egly & Keller, 2025). While prior research suggests limited differences in capture rates among bait types, even in terms of meat preference (Egly & Keller, 2025), our findings indicate that the use of fish sourced from the lake was significantly more effective than the use of beef heart, the latter being a traditional and practical choice in recreational crayfish fishing in the

Basque Country. However, the use of wild fish extracted from a natural place in these management actions raises bioethical considerations and requires consideration and authorisation from the responsible institution. In our study, all the fish used as bait were specimens of two invasive alien species collected during a simultaneous culling campaign that was conducted by other technicians under the direction of the local administration.

The relationship between bait quantity and capture success is inconsistent in the literature. While some studies report no significant differences with varying accessible bait amounts (e.g., Romaire & Osorio, 1989), others demonstrate increased catches with larger accessible bait portions (e.g., Beecher & Romaire, 2010). In our study, increasing bait quantity inside the plastic containers by 3-fold led to a 59% increase in catches. Despite this clear advantage, the additional time required to handle larger bait portions made routine use impractical. The use of meat expanded significantly after prolonged water exposure, complicating the daily bait replacement process and slowing operations.

Interestingly, anecdotal evidence suggests that abundant fish bait is more attractive. Traps containing lake fish that had been accidentally trapped and partially or totally consumed by crayfish (16 traps throughout the study period) yielded four times the average catch compared with other traps. This underscores the potential for enhanced effectiveness with more abundant and appealing bait.

In conclusion, our study suggests significant differences in crayfish capture success based on trap placement, bait presentation, type, and quantity. These findings can increase the efficiency of control measures aimed at managing invasive crayfish populations (Egly & Keller, 2025; Morbidelli et al., 2025). Effective control of invasive species, such as red swamp crayfish, is vital for preserving freshwater ecosystems, which are particularly vulnerable to ecological disruptions (Capon et al., 2021; O'Hea Miller et al., 2024). Strategic allocation of resources and informed use of available tools are essential to achieving management goals (García de Lomas et al., 2020; Morbidelli et al., 2025).

AUTHOR CONTRIBUTIONS

R.A.: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing - original draft; Writing - review & editing; S.G.: Investigation; Supervision; Validation; Writing - review & editing; A.A.: Formal analysis; Investigation; Methodology; Supervision; Validation; Visualization; Writing - review & editing; R. M.: Formal analysis; Methodology; Supervision; Validation; Visualization; Writing - review & editing.

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