# The impact of group size and invasiveness on the learning ability of Caribbean lionfish (*Pterois miles)*

MAJOR THESIS


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## Abstract

Cognitive abilities vary substantially in the animal kingdom and also within a species. What drives this variation is the focus of ongoing research. A prominent idea of what drives animal cognitive evolution is sociality. The Social Brain Hypothesis states that larger groups demand more cognitively challenging interactions, and hence group size should be linked to cognitive abilities. Recently, invasiveness has also been recognized as an important driver of cognitive abilities, as successful alien invasive species often show 'better' cognitive abilities than non-invasive species. What remains currently unexplored is the interplay between sociality and invasiveness in cognitive evolution. To investigate this, I studied learning abilities in the invasive Caribbean lionfish (*Pterois miles*). Apart from their phenomenal global invasive success, they also tend to form groups of varying sizes. I collected wild lionfish in Curaçao from different group sizes and examined their learning ability using a color-associative learning task. I found that group-living lionfish are more likely to learn and that invasiveness appears to enhance learning, when comparing learning rates to published data on non-invasive lionfish. While it seems that both invasiveness and group size determine cognitive abilities in lionfish, the fact that my results are based on a very small sample size means that targeted larger-scale studies are needed to elucidate how sociality and invasiveness impact cognitive evolution.

Keywords: Associative learning - Cognition - Group size - Invasive species – Lionfish

## Introduction

Understanding the evolution of cognition selection may be key to understanding animal evolution and species survival. Cognition is the perception, attention, memory, and executive function of information processing, such as using environmental information, learning, and problem-solving (Brown, 2015; Griffin et al., 2022). What drives the evolution of cognitive abilities is receiving much attention, and several important selection pressures have been identified. For instance, sociality is an important driver of cognitive evolution, explained by the Social Brain Hypothesis (Shultz and Dunbar, 2007; Dunbar, 2009). It suggests that while the formation of groups has been favoured evolutionary due to benefits like reducing predation risk (Creel et al., 2014), foraging success (Polyakov et al., 2022), or reproduction success (Domeier and Colin, 1997), it also selects for 'better' cognitive abilities as larger groups should associated with higher social complexity, causing evolutionary higher cognitive abilities to be favoured (Shultz and Dunbar, 2007; Dunbar, 2009). This theory is shown inter- and intra-species specific and has been extensively studied in mammals (Shultz and Dunbar, 2007), birds (Ashton et al., 2018), and fish (Bshary et al., 2014).

Apart from the challenges of complex social interactions, another driver of cognitive evolution may be invasiveness. Non-native or 'alien' species become invasive when they are able to establish in the invaded region, which requires successfully undergoing different stages of the invasion process (Szabo et al., 2020). Learning abilities and behavioural flexibility are considered crucial during the stages of invasion. These cognitive abilities allow

species to adjust to novel environments, solve novel problems, or invent novel solutions (Szabo et al., 2020). Besides ecological and biological factors, successful invasive alien species often exhibit higher cognitive abilities, respectively (Griffin et al., 2022). This is demonstrated in some highly invasive species, including the grey squirrels (Chow et al., 2018), Indian mynas (Griffin and Diquelou, 2015) and red-eared sliders (Lin et al., 2024). Whether higher cognitive abilities predispose certain alien species to become successful invaders or whether the invasive process shapes cognitive evolution is currently unresolved.

While both sociality and invasiveness are parsimonious drivers of cognitive abilities across animals, it is currently unknown how those factors may interact. I therefore tested it in the invasive lionfish (*Pterois miles and P. volitans*). Lionfish are the most successful invasive marine vertebrates, rapidly expanded their geographic range to a nearly global establishment facilitated by human activities (Samourdani et al., 2024). Native to the Indo-Pacific, lionfish were first spotted off the southeast coast of North America in 1985, before invading the North-Western Atlantic, the Caribbean, and the Mediterranean Sea (Semmens et al., 2004; Bariche et al., 2013). After invasion, they rapidly become top predators, posing a major threat to native species and coral reef ecosystems (Albins and Hixon, 2008; Morris and Akins, 2009; O'Farrell et al., 2014). Their high predation success is due to being generalist feeders, high consumption rates, being undetectable to prey, no natural predators (Albins and Hixon, 2011; McCormick and Allan, 2016). The role that cognition plays in lionfish invasive success is currently debated (Phillips et al., 2022). Lionfish cognitive abilities have been examined in experimental studies on learning abilities (Becker, 2020; DeRoy et al., 2020; Phillips et al., 2022) and lionfish exhibit individual behavioral characteristics with bold and explorative character linked to higher maze-solving abilities, showing personality-dependent learning (DeRoy et al., 2020). Studies also identified memory retention up to 6 weeks and learning ability to distinguish UV light (DeRoy et al., 2020; Phillips et al., 2022). Lionfish have also demonstrated plasticity behaviour in places where periodic culling is implemented as an eradication measure by which they displace to deeper water or hide to avoid predation by spear divers (Côté et al., 2014; Becker, 2020). This behavioural adaptation is a direct *in situ* demonstration of the cognitive abilities of the invasive lionfish. Apart from their prominent invasiveness, lionfish also seem to differ in social organisation (Lönnstedt et al., 2014). In the Mexican-Caribbean Sea, lionfish form groups depending on activity and age (García Rivas et al., 2018). While they prefer to hunt solitary, aggregating individuals can form groups of up to seven individuals and appear to have a larger body size than solitary individuals, although the functionality is still obscure (Hunt et al., 2019). Grouping tends to occur predominantly when conducting motionless behavior, while movement is mostly done in pairs (García Rivas et al., 2018).

Here, I tested the impact of invasiveness and sociality on the cognition of lionfish using a color associative learning assay on wild-collected invasive lionfish in Curaçao. I compared their learning rates to those of lionfish from the native range (Phillips et al., 2022) to assess how invasion impacts learning ability. To determine the link between sociality and learning abilities, I used fish from different group sizes. I predicted that individuals from larger group sizes would exhibit better learning abilities compared to individuals from smaller group sizes. If invasiveness selects for 'better cognitive abilities, I predicted that invasive lionfish would show higher learning performance compared to non-invasive lionfish.

## Methods

### Subjects and collection sites

Wild lionfish (N = 9) were collected from three sites inshore of southeast Curaçao (Figure 1) by trained spearfishermen and marine biology students. Sampling occurred during three organized diving trips at three different timeslots, including early am (09:00), early pm (18:00), and late pm (21:00) in 2020 (November and December). All lionfish were captured inshore (within 5 km) in a variety of habitats, using a hand net before being transferred into drybags (35 liters) or a ZooKeeper container (ZooKeeper LLC, USA) for transport back to the *Carmabi Marine Research Center* (Willemstad, Curaçao). Group size was defined as the number of individuals within two meter radius and was recorded *in situ* at the moment of capturing. Depth at the moment of capturing was also recorded *in situ* and ranged between 3 and 34 meters. The collected lionfish occurred in group sizes between 1 and 5 individuals. See details of collected lionfish in Appendix 1.


***Figure 1.*** *Lionfish collection sites off the coast of southern Curaçao indicated by red marks: Water Factory (12°10'88.27"N, 68°95'35.78"W), Carmabi Marine Research Centre (12°07'20.4"N, 68°58'09.4"W) and Boca Simon (12°05'47.1"N, 68°54'55.7"W).*

### Husbandry

Fish were housed in bare tanks with a size of 80 x 40 x 40 cm in the wet lab of the *Carmabi Marine Research Center*. A tank housed one big or two small lionfish, depending on the body size. In case two small lionfish shared the tank, it was lengthwise equally divided using a black polyvinyl chloride (PVC) wall placed in the center of the tank. Holes were punctured

in the black PVC separation wall to allow water to flow and ensure equal water conditions in the two compartments of the tank. Tanks were connected with a flow-through filtration system and running seawater. Because of running seawater, water conditions could not be controlled or monitored during the study. Lionfish were subjected to a natural photoperiod. Throughout the experimental study period, the wet lab was simultaneously used for other projects, therefore, visual or vocal distractions might have occurred during the experiments.

### Experimental protocol

The learning ability of lionfish was studied in an associative learning test where the fish received a food reward when correctly solving a color discrimination task. This task was chosen because it targets a well-understood cognitive process that influences a broad variety of behaviours (Morand-Ferron, 2017). The associative learning test consisted of three phases: 1) acclimatization, 2) pre-training, and 3) color discrimination phase. During all phases, the lionfish were housed in the same tank and tested individually to eliminate the potential confounding effect of social cues or social learning (Ingraham et al., 2016). Only individuals who completed all phases were included in the study (Table 1). Individuals who did not participate in the pre-training phase or showed physical damage, e.g., tail degradation or blurred eyes, were excluded from the experiment. Excluded lionfish (N = 5) and those who completed the experiment (N = 4) were euthanized with ice water and dissected within 8 hours. Before dissection, total length (TL), standard length (SL) (Näslund and Johnsson), and weight were measured. TL was defined as the length (cm) from the nearest point on the tip of the snout to the longest tip of the tail. ST was measured (cm) to the nearest tip of the snout till the start of the tail. For other research projects, the brain and retinal tissue were dissected for a subset of lionfish (N = 7) and transported to Wageningen University & Research for further processing. Lionfish were euthanized and dissected according to the lionfish handling procedure of Green (2012) (Green et al., 2012).

***Table 1.*** *Measurements of wild lionfish who completed the color-associative learning experiment (n=4). Depth (m) and group size were recorded in situ. Total length (cm) and weight (g) were recorded after completing the experiments, were excluded from the experiment, or were prematurely deceased.*
**Group size = the number of individuals within a 2 m radius.*

| Fish ID | Total length (cm) | Weight (g) | Depts (m) | Group size* |
|---|---|---|---|---|
| **Fish 1** | 10.4 | 9 | 3 | 1 |
| **Fish 3** | 14.6 | 22 | 4.5 | 1 |
| **Fish 4** | 9 | 7 | 13 | 1 |
| **Fish 8** | 21 | 147 | 26 | 5 |

### Experimental apparatus

For the experimental apparatus, two PVC sticks were covered with either yellow or green colored-electrical insulation tape. During the color discrimination task, these colored sticks were inserted into the tank and attached to the front glass of the tank with tape. The task was initiated with 20 cm between the colored sticks (Figure 2B), and midway after 4 sessions, the distance between the colored sticks was increased to 40 cm (Figure 2C). The colored sticks were swapped from left to right after each session. The initial distance of 20

cm was chosen because it prompted the fish to actively swim towards the stick and made the distinction between choices visible. To increase the challenge, the distance between the colored sticks was increased to 40 cm, which was still feasible in a shared tank.

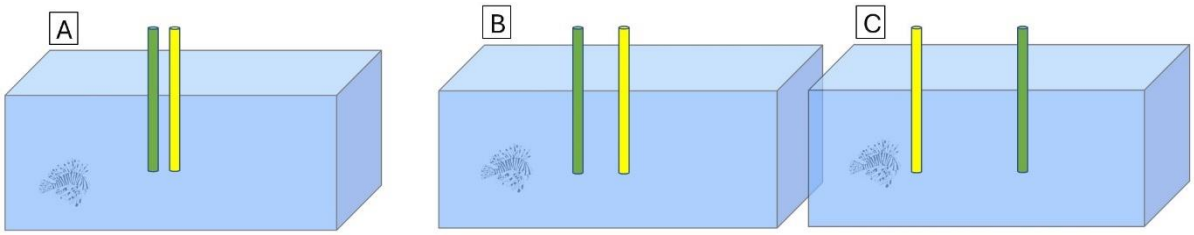


***Figure 2.*** *The experimental apparatus of the color-associative-learning test. A) Pre-training phase, B) Part 1: 20cm distance between sticks. Part 2: switch sides of the reward color stick, C) Part 3: 40cm distance between sticks. Part 4: switch sides of the reward stick. Food stimuli were provided when lionfish approached the green stick (rewarded color).*

**Associative Learning Test**

*Acclimatization phase*

Lionfish are extremely susceptible to barotrauma (Parker et al., 2006; Jarvis Mason and Lowe, 2008), therefore, all lionfish were brought slowly to the surface during collection and subsequently acclimated in the experimental tank for 3 or 18 days, depending on the available experimental time. Acclimatization also depended on the time needed for the fish to decompress. Lionfish were fed various live small fish (such as *Anchoa mitchilli*) captured each morning on the shore of the research station because lionfish did not show interest in dead prey.

*Pre-training phase*

After the acclimatization phase, lionfish were pre-trained to approach the colored sticks. During the pre-training phase, the yellow and green colored sticks were introduced to the fish by carefully inserting the sticks in the center of the tank near the front glass (Figure 2A). The sticks were taped side by side to the front glass of the tank and left for 5 minutes. Lionfish were required to approach the sticks to receive a food reward (live fish). An approach was rewarded regardless of the color. If the fish was not motivated to explore the sticks after 2 min, it was elicited by inserting a live prey near the sticks. After 5 minutes, the session ended and the sticks were carefully removed. Because of the limited time of the pre-training duration, all individuals continued to the next phase unless there were signs of physical degradation or the fish deceased.

*Color Discrimination phase*

During this phase, eight sessions of 10 minutes each were conducted over five days. A session was scheduled in the morning and in the afternoon, with an average of 10 hours between sessions. Each session was recorded using an action camera (GoPro Hero5) or a mobile device (Samsung S24+). Recording began once the yellow and green sticks were secured in the center of the tanks. The time when each approach to a stick occurred was

noted as response time, and the color of the approached stick was recorded. Approaching the green stick was considered a correct choice and was rewarded with a food stimulus (live small fish). A new reward was only provided if the previous one was consumed before the next correct choice, to prevent the accumulation of live prey. The following variables were quantified to assess lionfish learning ability: (1) the color of the approached stick, and (2) the time it took for the lionfish to approach a stick. An approach was defined as when the lionfish was motionless behind the chosen stick or was motionless within 5 cm of the stick, with its head oriented toward the stick (Figure 2, left and right).

### Statistical analysis

To test whether individual lionfish showed learning, a chi-squared goodness-of-fit test was performed, comparing the proportion of correct and incorrect responses to chance. Lionfish approaching the green stick was considered a correct choice (= 1), while approaching the yellow stick was deemed an incorrect choice (= 0). Each approach was recorded as a separate trial. To assess whether group size and individual attributes, including depth (m), length (cm), and weight (g), were associated with inter-individual variation in learning, I conducted a generalized linear regression model (GLM) using the `lme4` package with a binomial distribution. The trial number, group size, and total length (TL) were set as fixed factors, with approach (response) as the dependent variable. Depth was not included as a fixed factor due to collinearity with length. Fish ID could not be included as a random effect despite repeated use of the same fish across trials. Due to the small sample size (N = 4), the model lacked sufficient data to properly estimate the random effect. All analyses were performed with RStudio Version 4.0.3.

To evaluate the impact of invasiveness on the learning abilities of lionfish, I calculated the average percentage of correct color choices across all four lionfish and compared them with the average percentage of correct color choices of non-invasive lionfish from the cognitive study conducted by Phillips (2022) (Phillips et al., 2022).

## Results

### Individual learning and invasiveness

First, I studied the learning performance of each lionfish (N = 4) by experimentally observing correct color choices. In Figure 3, the total trials, correct (green filled circle) and incorrect choices (orange filled circle) are graphically depicted. The total trials ranged from 27 to 41 trials. Note, observations showed that lionfish 3, 4, and 8 had a mixed distribution of correct and incorrect choices, but lionfish 1 exhibited more correct choices in the first part, followed by a phase of nearly all incorrect choices. I statistically assessed whether the studied lionfish made significantly more correct choices, indicating learning performance, rather than random choices by chance. Findings showed that all four lionfish did not have a significantly observed distribution of choices (all P-values > 0.05) compared to a distribution based on random choice (Table 2). Thus, none of the lionfish demonstrated a significant

preference for the correct color throughout the trials. This implies that, based on the current data, the studied lionfish did not express individual learning.

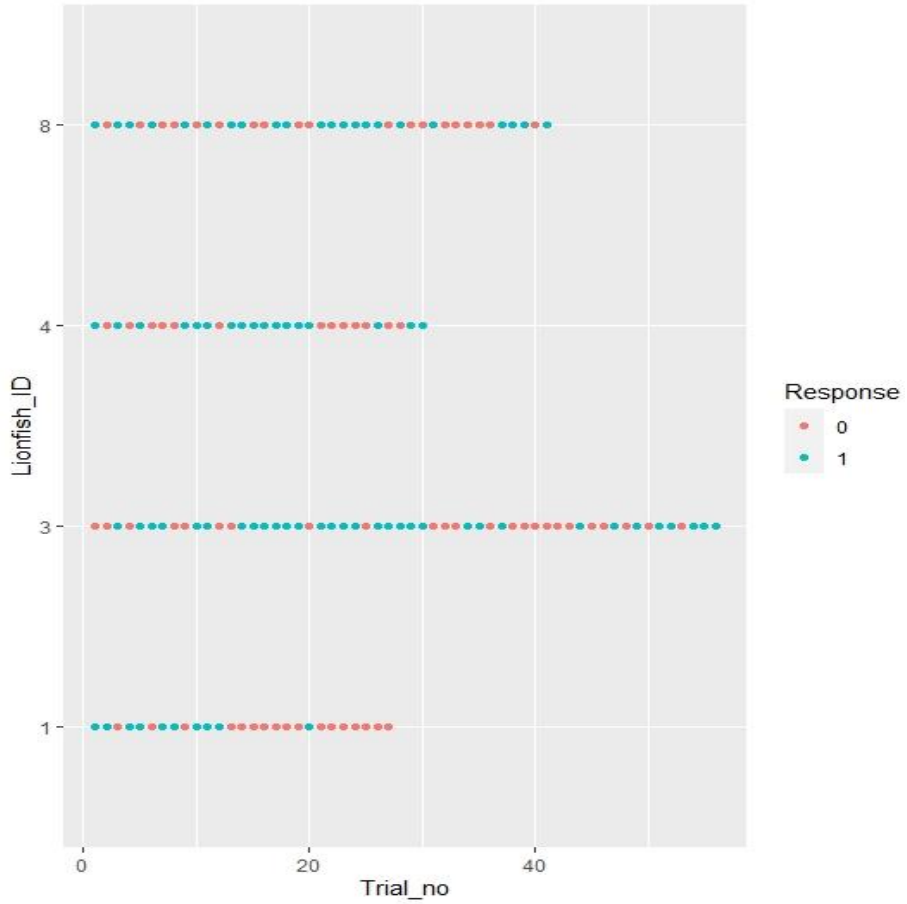


***Figure 3.*** *This schematic overview depicts the total trials of each individual lionfish displayed by colored circles. The orange-filled circle (= 0 ) resembles an incorrect choice, whereas the green filled circle (= 1) is a correct choice.*

***Table 2****. Individual learning data. Chi-square tests for goodness of fit were used to determine individual learning (n=4). Calculated values for each lionfish that completed the color associative learning experiment are listed. P-values ≤ 0.05 are significant.*

| Lionfish ID | Total trials | Number of correct choices | Number of incorrect choices | $x^2$ statistics | P-value |
|---|---|---|---|---|---|
| **1** | 27 | 12 | 15 | 0.333 | 0.564 |
| **3** | 56 | 32 | 24 | 1.143 | 0.285 |
| **4** | 30 | 17 | 13 | 0.533 | 0.465 |
| **8** | 41 | 22 | 19 | 0.220 | 0.639 |
| **Average** | **38.5** | **20.75 (54%)** | **17.75 (46%)** | | |

### Group size and other potential factors

It is acknowledged that the absence of evidence for individual learning in my experimental setup may be attributable to the potentially inadequate setup for facilitating learning trials in lionfish. Nonetheless, for the purposes of this thesis, I proceeded with the data analysis under the assumption that the experimental design was effective. Next, I studied whether individual learning was influenced by the number of trials, group size, or total length (TL) of the individual lionfish. Figure 4A-B shows the observed distribution of correct (1, green filled bars) and incorrect choices (0, orange filled bars) categorized by group size (1 versus 5 individuals), and TL of the lionfish (9, 10.4, 14.6 and 21 cm). Group size showed a trend towards a positive association with correct choice, implying that lionfish from larger groups might have a higher probability of better learning abilities (β = +0.81, SE = 0.52, P = 0.119). Data from the GLM shows that the TL of 14.6 cm was a significant predictor of the correct choices (β = +1.09, SE = 0.52, P = 0.038). The number of trials did not significantly affect the correct choice (β = -0.02, SE = 0.01, P = 0.173). This suggests that a specific body size is associated with enhanced cognitive abilities. Altogether, based on the current data, a total length of 14.6 cm was the main factor positively associated with the correct color choice.

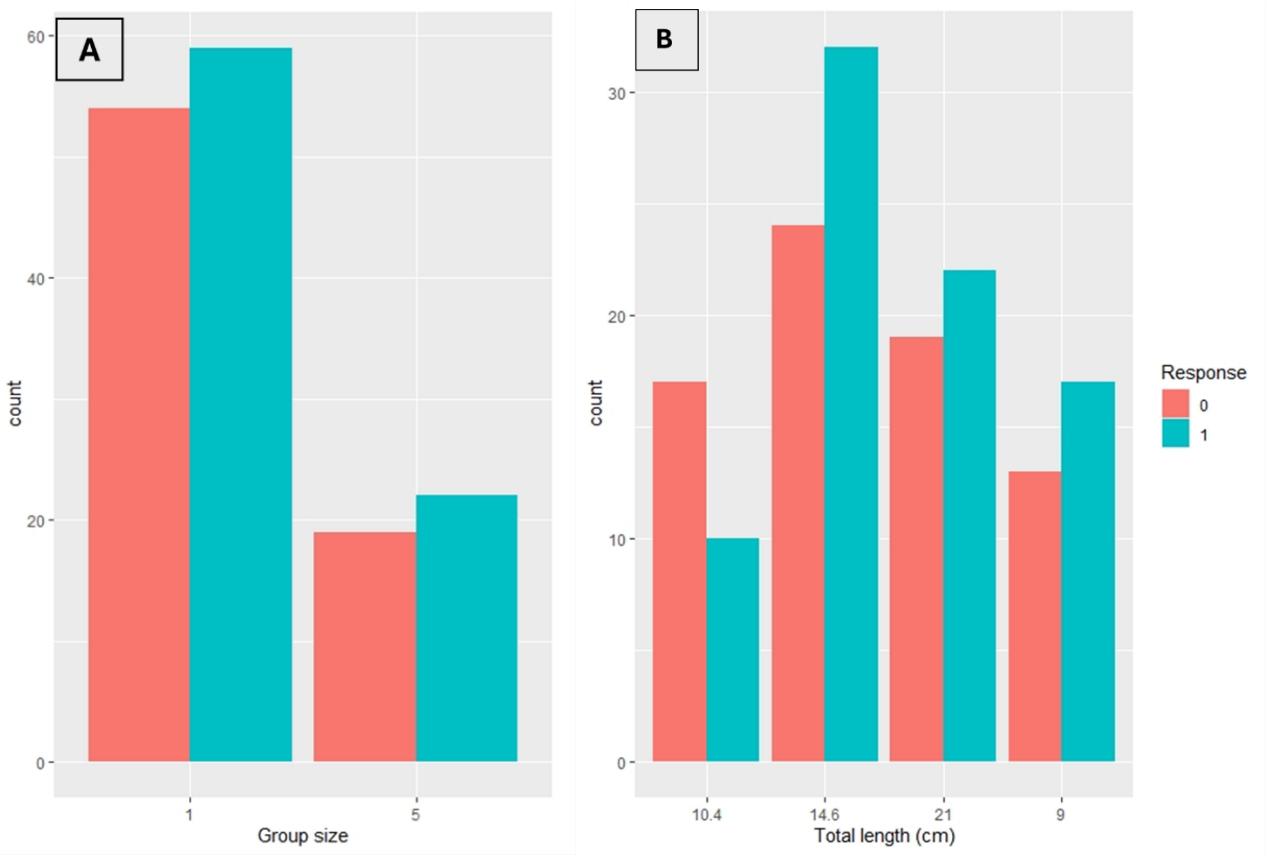


***Figure 4A-B.*** *The observed distribution of correct (1, green filled bars) and incorrect choices (0, orange filled bars) categorized by (A) group size (1 versus 5 individuals) and (B) Total length of the lionfish (9, 10.4, 14.6 and 21 cm). 0=incorrect choice, 1=correct choice*

## Discussion

Here, I tested the impact of invasiveness and sociality on lionfish cognition. To investigate this, I conducted a color-associative learning task on wild-caught invasive lionfish to assess how group size and invasiveness might impact learning abilities.

I found that invasive lionfish seem to have a cognitive advantage over non-invasive lionfish, as a greater proportion (54%) of correct choices (Table 2) was recorded in invasive lionfish compared to an average of 22% of correct choices from non-invasive lionfish in a similar cognitive assay conducted by Phillips (2022) (Phillips et al., 2022). This may reflect adaptive changes in invasive populations that have undergone generational selection for traits promoting survival in novel environments (Szabo et al., 2020). The invasive lionfish in Curaçao, present since the early 2000s (Carmabi Marine Research Station n.d), may have developed enhanced cognitive traits that support their successful establishment and proliferation. While invasive lionfish in Curacao exhibit plastic behavior, an indicator of well-developed cognitive ability (Becker, 2020; Griffin et al., 2022), I observed no individual learning in the captured Caribbean lionfish (Figure 1). The distribution of correct and incorrect choices appeared random, suggesting that decisions were likely made by chance rather than through learned behavior. The tendency for lionfish to retreat to deeper waters in areas subject to frequent culling aligns with observations that lionfish can recognize divers as threats and may adapt their distribution to avoid predation (Côté et al., 2014; Becker, 2020). Such behavioral avoidance could partly explain why lionfish are more abundant in mesophotic reefs compared to shallower waters around Curaçao (Andradi-Brown et al., 2017). Additionally, juvenile lionfish, often found in shallow waters and more easily captured, seem to display lower cognitive abilities and reduced behavioral plasticity (Claydon et al., 2012; Becker, 2020). This was confirmed as most of the collected lionfish in this study were juveniles (< 18,9 cm TL) and captured in shallow water (depths <10 m, Appendix 1) (Morris et al., 2008; Gardner et al., 2015). The predominance of juveniles among the sampled individuals in this study may have contributed to the overall low learning performance observed. Interestingly, a total length of 14.6 cm (lionfish 3, juvenile) was positively associated with learning, indicating that a certain total length may relate to higher cognition.

In invasive lionfish, I found a tendency towards an association between group size and the total number of correct color choices (Figure 4A), suggesting that lionfish collected from larger groups may be more successful in the learning assay. Although intriguingly, research on lionfish sociality is scares and more studies are needed to understand the grouping and social behavior of lionfish. Hunt et al. (2019) did not find evidence of a social driver for the aggregation behaviour of the invasive Caribbean lion and suggested it was driven by habitat complexity or rather by change (Hunt, 2019). Alternatively, individual behavioral characteristics might have contributed to this particular fish's learning ability, highlighting the potential role of intra-specific behavioral variation in cognitive performance (Sih and Del Giudice, 2012; DeRoy et al., 2020). The personality of lionfish 8 may be a factor in the higher learning performance, as boldness and explorative character are associated with higher cognitive abilities; however, decreased social attraction (Jolles et al., 2015). On the

other hand, a shy character is often linked to increased social attraction and reduced learning ability (Jolles et al., 2015; Hunt et al., 2019; DeRoy et al., 2020). This implies that solitary individuals or individuals of smaller groups are likely bolder with higher invasive success and could exhibit 'better' learning abilities (Daniels and Kemp, 2022). This elucidates the potential interplay between sociality, invasiveness and, additionally, personality traits in animal cognitive evolution.

A potential limitation of this study is that the cognitive task conducted, associative learning, might not have been the optimal cognitive assay for lionfish. An associative learning experiment assesses the ability to form associations between stimuli and outcomes (Morand-Ferron, 2017). Other types of cognitive tasks, such as spatial or reversal learning, might better capture the cognitive profile of lionfish. Previous research showed low participation rates in associative learning assay among lionfish (Phillips et al., 2022), but better participation rates in spatial learning assay (DeRoy et al., 2020). In guppies, a positive relationship between group size and cognitive plasticity (reversal learning) was shown, while no correlation with associative learning was recorded (Triki et al., 2024), suggesting that different cognitive domains may be more relevant for lionfish species. Stress may have also impacted the results. Despite efforts to prioritize animal welfare, the capture and acclimatization process likely induced stress in the fish, potentially affecting their cognitive performance (Salena et al., 2021). For example, high cortisol levels, a stress hormone, are linked to retention of conditional response in rainbow trout (Øverli et al., 2004). Some individuals exhibited signs of barotrauma and abnormal swimming behavior, likely due to the nature of their physiology and collection method. Furthermore, the semi-controlled conditions in the laboratory, including fluctuations in water quality due to power outages, exposure to UV light, and intermittent loud noises or human activity, could have further influenced their behavior and learning capacity. These environmental factors complicate the interpretation of results and highlight the importance of controlled conditions in future cognitive research.

In future studies, the use of wild-bred individuals in laboratory-based cognitive studies offers valuable ecological relevance by better reflecting natural behavior (Morand-Ferron, 2017). However, in situ cognitive testing may provide even deeper insights into how these fish function in their native and invasive habitats. Despite extensive research on cognitive traits in invasive species across various taxa, studies on fish, particularly invasive species like lionfish, remain limited (Griffin et al., 2022). Considering the rapid global spread and ecological impact of lionfish, understanding their cognitive abilities is crucial for developing effective management strategies (Szabo et al., 2020). Expanding research into cognitive ecology among invasive fish species can help elucidate mechanisms of invasion success and inform broader ecological and conservation efforts.

Overall, I found evidence that group-living lionfish tended to have better learning abilities, although the color-associative-learning experiment did not reveal individual learning. Additionally, invasiveness seems to enhance learning abilities in lionfish. Furthermore, a body size of 14.5cm was related to better learning abilities. Future studies with larger sample sizes and improved controlled experiments, if *ex-situ,* are needed to investigate the effects of sociality and invasiveness on the cognitive abilities of lionfish.

## Additional information and Declarations

### Animal Ethics

All lionfish used in this study were handled with respect to the three R's of animal welfare. Lionfish were euthanized most humanely and dissected according specified lionfish protocol (Green et al., 2012). Lionfish tissue was collected and transferred overseas to Wageningen University & Research, the Netherlands. This included lionfish brain samples and eye retina samples for scientific purposes. These samples were not collected from species listed as endangered species or any of the CITES appendices, and may be imported freely according to the 'Voedsel en Waren Autoriteit' (VWA). Travel with scientific samples was assisted with a sample transportation letter from the Carmabi Marine Research Center. Lionfish removals were encouraged by the state of Curacao, and lionfish collection locations did not require specific permissions. No endangered or protected species were harmed during this study.

### Data Deposition

The following information was supplied regarding data availability: Lionfish color-associative-learning test data.

### Declaration of AI use

For this report, AI-assisted technology Grammarly is used for language checks.

## Acknowledgments

I would like to thank all of the students and commercial spearfishermen who made this study possible through collecting lionfish, advice, and technical support. In particular, Lisette Keus, who has been active in organizing local lionfish derbies. Your work and generosity are very much appreciated. I am grateful to the Carmabi Marine Research Centre for facilitating the experiments. Finally, special thanks to my supervisor, dr. Alexander Kotrschal for his academic guidance, his patience, and for making this learning journey possible.

## Appendix 1

| ID | Collection site | collection time | Captured at depts (m) | Group size | Weight (g) | Standard length (cm) | Total length (cm) | Comment |
|---|---|---|---|---|---|---|---|---|
| **Fish 1** | **Water Factory** | **18-19u** | **3** | **1** | **9** | **7.5** | **10.4** | **Included** |
| **Fish 2** | Water Factory | 18-19u | 12 | | | | | Excluded: escaped, signs of barotrauma |
| **Fish 3** | **Water Factory** | **18-19u** | **4.5** | **1** | **22** | **10.6** | **14.6** | **Included** |
| **Fish 4** | **Water Factory** | **18-19u** | **13** | **1** | **7** | **6.7** | **9** | **Included** |
| **Fish 5** | Carmabi | 21 – 22u | 10.1 | 2 | 111 | 16.5 | 20.3 | Excluded: blurred eyes |
| **Fish 6** | Carmabi | 21 – 22u | 7,3 | | | | | Excluded: deceased |
| **Fish 7** | Boca Simon | 9 – 10u | 34 | 4 | 15 | 13.4 | 14.6 | Excluded: blurred eyes, tail degeneration |
| **Fish 8** | **Boca Simon** | **9 – 10u** | **26** | **5** | **147** | **18** | **21** | **Included** |
| **Fish 9** | Boca Simon | 9 – 10u | 16 | 1 | 41 | 11.5 | 15 | Excluded: no interaction |

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