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Citizen-Science Records Identify Al-Badi'ah and Namar Urban Lakes as Potential Aquarium-Release Hotspots for Non-Native Aquatic Organisms in Riyadh, Saudi Arabia

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Abstract

Urban freshwater systems in arid regions may function as focal points for the release and establishment of unwanted aquarium organisms, yet such pathways remain poorly documented in Saudi Arabia. This short communication integrates georeferenced citizen-science observations with publicly visible aquarium-trade and hobbyist signals to evaluate two urban water bodies in Riyadh—Al-Badi'ah Lake and Namar Lake—as potential aquarium-release hotspots. Two photograph-supported iNaturalist records of suspected non-native crayfish were retained (observations 264920283 and 265181171), approximately 3.90 km apart, with public coordinates corresponding provisionally to the Al-Badi'ah and Namar urban-water network. A nearby iNaturalist observation of a putative red jewel cichlid (Rubricatochromis sp.; Needs ID) occurred approximately 50 m from the first crayfish record, providing a second, taxonomically independent signal of an aquarium-associated introduction pathway. Publicly visible trade and hobbyist content further documented crayfish availability in Riyadh and Jeddah, including platform-reported Australian redclaw and dwarf Mexican crayfish. These evidence streams do not demonstrate establishment, reproduction, or ecological impact, and species-level identification of the crayfish remains unresolved. Instead, they identify publicly accessible urban lakes where targeted field verification is warranted using standardized trapping, fish surveys, environmental DNA, voucher specimens, and DNA barcoding. The study proposes a precautionary framework for distinguishing captive-trade evidence, suspected outdoor occurrence, and confirmed establishment, thereby supporting proactive surveillance of aquarium-mediated introductions in Saudi Arabia.

Keywords: aquarium release; urban lakes; citizen science; aquatic invasive species; crayfish; ornamental fish; Al-Badi'ah Lake; Namar Lake; Riyadh; Saudi Arabia

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1. Introduction

Freshwater ecosystems in arid and semi-arid regions are increasingly influenced by human water management, including dam construction, irrigation networks, and the creation of artificial reservoirs. These engineered habitats can enhance habitat connectivity and propagule pressure, thereby increasing susceptibility to biological invasions, particularly by aquatic invertebrates that are tolerant of environmental variability (Havel et al., 2015; Preston et al., 2021).

In Saudi Arabia, freshwater environments are spatially limited and largely artificial, concentrated in wadis, oases, reservoirs, and irrigation canals. Although non-native freshwater fish have been documented widely across these systems (Alharthi et al., 2024), comparable information on freshwater invertebrates remains largely absent. This lack of baseline data constrains ecological risk assessment and limits the ability of managers to detect emerging invasions at an early stage. Aligning early-warning efforts with national monitoring priorities, including those of the National Centre for Wildlife, would help translate preliminary occurrence signals into targeted management actions. Here, early-warning signals are defined as unverified occurrence records that indicate potential introductions but do not confirm establishment. The early detection and prevention of non-native aquatic species are also consistent with the environmental objectives of Saudi Vision 2030 and the Saudi Green Initiative (SGI), which emphasize biodiversity conservation, environmental protection, sustainable management of natural resources, and improved quality of life. Protecting freshwater biodiversity and strengthening biosecurity in engineered aquatic systems can further support the development of a sustainable blue economy by reducing ecological risks to fisheries, recreational waters, water infrastructure, and emerging aquatic-resource sectors.

Globally, freshwater invertebrates such as crayfish, mollusks, and planktonic taxa are among the most successful aquatic invaders, often introduced via aquarium and ornamental trade, aquaculture activities, and water transfers (Havel et al., 2015; Preston et al., 2021; Kotov et al., 2022). Climate warming further amplifies invasion risks by expanding the thermal suitability of recipient habitats and increasing per capita impacts of some invaders (Bellard et al., 2013; Vilizzi et al., 2021).

In regions with limited monitoring capacity, citizen-science platforms increasingly provide valuable early-warning information on potential biological invasions. While such records cannot substitute for verified occurrence data, they can reveal spatial patterns that help prioritize surveillance and guide management actions (Vilizzi et al., 2021).

Freshwater fisheries in arid regions are particularly vulnerable to biological invasions due to limited habitat redundancy and strong reliance on engineered systems. These patterns are consistent with the concept of “invasion hubs,” where anthropogenic habitats act as focal points for species introductions and subsequent spread across landscapes (Havel et al., 2015). In arid regions, such hubs may be disproportionately important due to the scarcity of natural freshwater habitats. This study establishes a foundational framework for using citizen-science observations as early-warning signals for freshwater crayfish introductions in arid, highly engineered ecosystems, integrating spatial occurrence records with anthropogenic freshwater infrastructure to support invasion-risk screening in a data-limited region.

The objective of this study is to evaluate whether convergent citizen-science, aquarium-trade, and local-knowledge signals identify Al-Badi'ah Lake and Namar Lake as priority sites for aquarium-mediated aquatic introductions. Specifically, we (1) document suspected outdoor crayfish records, (2) evaluate co-occurring aquarium-associated fish observations, (3) synthesize evidence that crayfish taxa are available within the Saudi aquarium trade, and (4) propose a tiered field-verification and management framework. All records are treated as preliminary signals unless supported by voucher specimens, molecular confirmation, and evidence of persistence or reproduction.

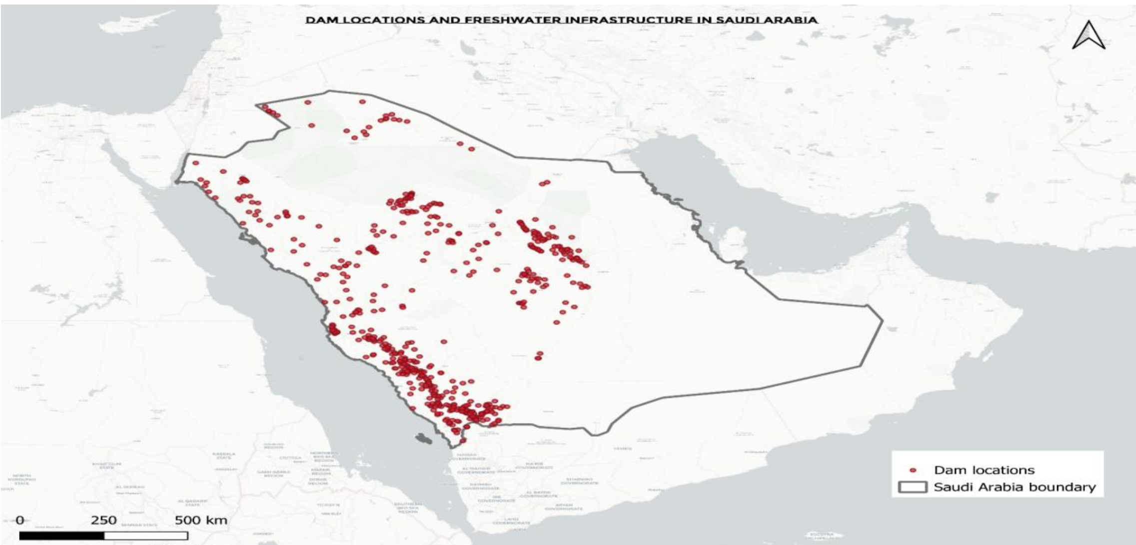

Figure 1 National distribution of engineered freshwater systems in Saudi Arabia and locations of early-warning occurrence signals.

2. Materials and Methods

2.1. Data source and record screening

Publicly available occurrence records of freshwater crayfish in the Riyadh region were compiled from a citizen-science biodiversity platform (iNaturalist). Records were screened for the presence of verifiable geographic coordinates, precise observation dates, and photographic documentation of sufficient quality for morphological inspection. Observations lacking adequate spatial information or clear images were excluded.

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The screening workflow is summarized in Table 1 and documented in full in Supplementary Table S1. Two iNaturalist records were retained: observations 264920283 and 265181171, both posted by the observer osama-altamimi. Their public coordinates were 24.60141° N, 46.66301° E (reported positional accuracy: 74 m) and 24.57389° N, 46.68698° E (reported positional accuracy: 243 m), respectively. The two records were approximately 3.90 km apart.

2.2. Digital aquarium-trade and hobbyist evidence scan

A supplementary digital scan was conducted to identify publicly visible evidence that freshwater crayfish and other aquarium-associated aquatic organisms are present in the Saudi pet trade or hobbyist community. Searches targeted Arabic and English terms related to crayfish, freshwater lobster, aquarium release, Al-Badi'ah Lake, Namar Lake, Riyadh, Jeddah, and ornamental aquatic animals. Sources included public social-media posts, aquarium-shop pages, online retail listings, hobbyist discussions, biodiversity databases, and scientific literature. Each item was classified as retail/trade evidence, captive/hobbyist evidence, suspected outdoor occurrence, or independently verified wild occurrence. Trade and captive evidence was used only to evaluate pathway plausibility and was not treated as proof of release, establishment, or invasiveness. Local knowledge indicating repeated releases at Al-Badi'ah and Namar lakes is retained as a testable pathway hypothesis pending documentary evidence, interviews, or direct field observations.

2.3. Study sites and local release context

Al-Badi'ah Lake and Namar Lake are publicly accessible urban freshwater systems within the highly modified Wadi Hanifah drainage landscape of Riyadh. Based on the supplied coordinates, observation 264920283 is provisionally assigned to Al-Badi'ah Lake and observation 265181171 to Namar Lake or its connected managed-water system. These assignments should be verified against authoritative site boundaries and the final GIS layers. The sites are interpreted as potential aquarium-release hotspots because suspected crayfish records, an aquarium-associated cichlid observation, Riyadh-wide trade availability, and local reports of repeated releases converge spatially and mechanistically. Local reports are used only as qualitative context and do not quantify release frequency or identify the responsible individuals.

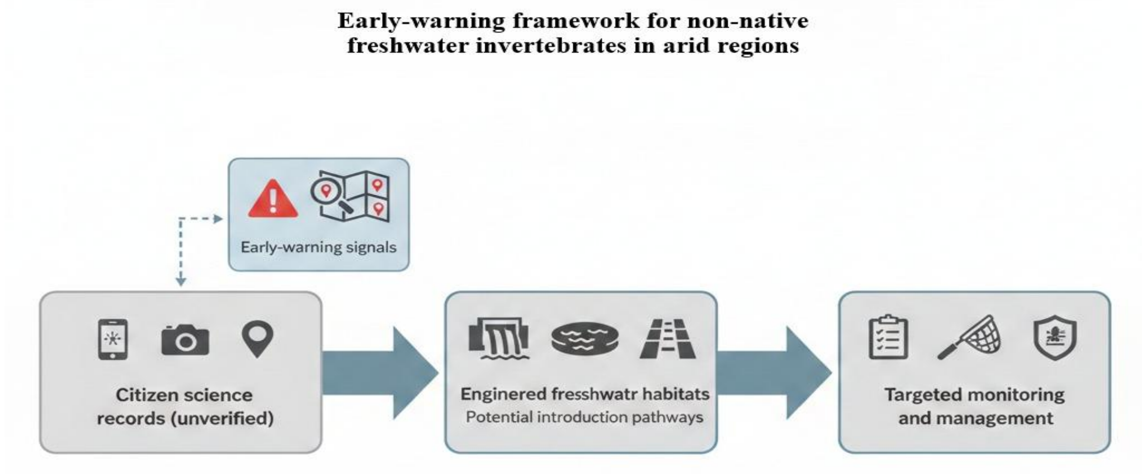

Figure 2 presents a conceptual framework that illustrates the role of citizen-science observations as early-warning signals for potential introductions of non-native freshwater invertebrates. Unverified occurrence records provide preliminary spatial signals that, when associated with engineered freshwater systems, can inform targeted monitoring and management actions prior to confirmed establishment.

Figure 3 Photograph associated with iNaturalist observation 265181171, recorded by osama-altamimi in Riyadh, Saudi Arabia, on 7 March 2025. The specimen was identified through the iNaturalist community-identification process as red swamp crayfish, Procambarus clarkii (Girard, 1852), with supporting identifications from three platform users. The occurrence is also indexed in GBIF as occurrence 5108099671. Because the

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identification is based on photographs and was not supported by a voucher specimen or molecular analysis, it is treated as a community-supported, provisional species-level record.

Photograph by osama-altamimi, reproduced with the observer's written permission.

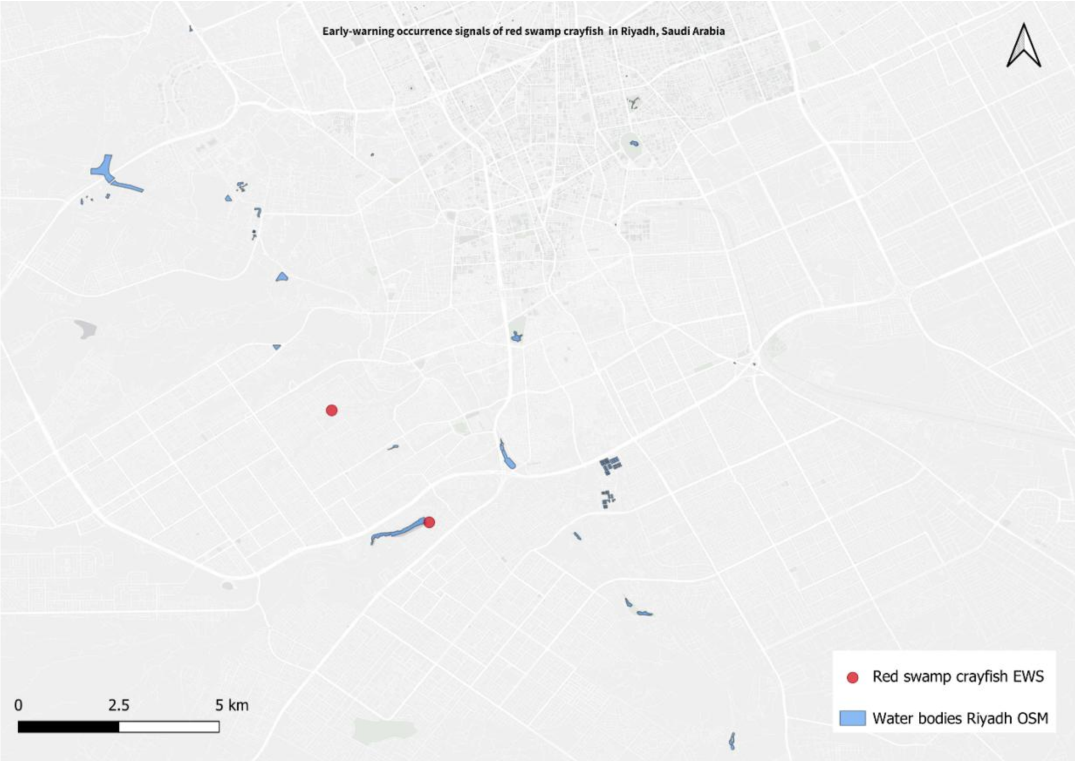

Figure 4. Generalized locations of suspected non-native crayfish records in Riyadh, Saudi Arabia, shown in relation to mapped urban water bodies.

Table 1. Record-level summary of the two suspected crayfish observations documented on iNaturalist. Observation dates, quality grade, captive/cultivated status, and media licenses were verified directly from the original source pages.; the full reproducible dataset is provided as Supplementary Table S1.

Record ID	Platform / Observer	Date	Latitude	Longitude	Platform identification	Photo quality	Verification status
264920283	iNaturalist; observer: osama-altamimi; site: Al-Badi'ah Lake (provisional)	3/11/2025	24.60141	46.66301	Community-identified as red swamp crayfish, *Procambarus clarkii*; species-level identification remains unverified by voucher specimen or molecular analysis.	Low	Community-supported photographic identification; not specimen- or molecularly verified.
265181171	iNaturalist; observer: osama-altamimi; site: Namar Lake / connected system (provisional)	3/13/2025	24.57389	46.68698	Community-identified as red swamp crayfish, *Procambarus clarkii*; species-level identification remains unverified by voucher specimen or molecular analysis.	Low	Community-supported photographic identification; not specimen- or molecularly verified.

Table 2. Publicly visible aquarium-trade and hobbyist evidence is relevant to freshwater crayfish introduction pathways in Saudi Arabia. These records document captive availability or trade exposure and do not demonstrate wild occurrence or establishment.

Evidence source	Location	Reported organism or product	Evidence type	Interpretation
Shamim Aquarium Shop social media content	Riyadh	Red crayfish; crayfish listed among aquarium animals	Retail/trade	Evidence that crayfish have been marketed in Riyadh; species identity requires image-based confirmation.
Instagram aquarium content	Riyadh	Australian redclaw crayfish	Captive/hobbyist	Supports presence

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Evidence source	Location	Reported organism or product	Evidence type	Interpretation
		(platform-reported Cherax quadricarinatus)		within the aquarium community; does not establish outdoor occurrence.
Instagram aquarium content	Riyadh	Dwarf Mexican crayfish (platform-reported Cambarellus sp.)	Captive/hobbyist	Supports taxonomic diversity in the hobby trade; identification remains platform-reported.
Hobbyist social-media content	Jeddah	Freshwater crayfish maintained in aquaria	Captive/hobbyist	Suggests ownership beyond Riyadh and a broader release or escape pathway.
Ubuy Saudi Arabia product listing	Saudi online market	Live freshwater crayfish for aquaria	Online trade signal	Shows consumer-facing availability; actual importation and delivery require independent confirmation.
Noon Saudi Arabia accessories	Saudi online market	Crayfish shelters and breeding products	Indirect market signal	Supports an aquarium market but does not prove sale of live animals.
Scientific literature and biodiversity databases	Saudi Arabia	No voucher-supported or molecularly confirmed wild population located	Absence of verified evidence	Supports a pathway warning, not a confirmed national wild occurrence.
iNaturalist observation 339671890 https://www.inaturalist.org/observations/339671890	Al-Badi'ah Lake area, Riyadh (24.60096° N, 46.66302° E; positional accuracy 71 m).	Red jewel cichlid, Rubricatochromis sp.	Suspected outdoor occurrence. Observed: 22 February 2026 at 02:17 (+03:00); submitted: 21 February 2026 at 19:17 PST.	Approximately 50 m from crayfish observation 264920283; supports a possible aquarium-release hotspot, but taxonomic identity, wild/captive status, persistence, and reproduction remain unconfirmed.

Table 3. Site-level evidence synthesis and verification requirements.

Site	Current evidence	Evidence strength	What it supports	What it does not support	Required verification
Al-Badi'ah Lake (provisional assignment)	Suspected crayfish record 264920283; Rubricatochromis sp. record ~50 m away; local release reports	Moderate pathway signal	Priority surveillance; plausible aquarium release	Confirmed taxonomy, establishment, reproduction, impact	Verify site boundary; repeat trapping and fish survey; eDNA; vouchers; document releases
Namar Lake / connected managed-water system (provisional assignment)	Suspected crayfish record 265181171; local release reports; public recreational access	Preliminary to moderate pathway signal	Priority surveillance; plausible aquarium release	Confirmed taxonomy, exact lake assignment, establishment, reproduction, impact	Verify site assignment; trapping, fish survey, eDNA, vouchers; document releases

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2.4. Taxonomic assessment

Taxonomic plausibility was assessed visually from the submitted photographs using morphological features characteristic of cambarid crayfish (a pointed rostrum, dark brownish-to-red coloration, and elongated chelae with red tubercles). The photographs were considered consistent with red swamp crayfish, *Procambarus clarkii*, based on overall body form, coloration, rostral appearance, and chela morphology. This interpretation was supported by three iNaturalist community identifiers and by the taxonomic name associated with the corresponding GBIF occurrence record. Nevertheless, image quality was insufficient for examination of all diagnostic characters, and no voucher specimen or genetic material was available. The identification is therefore classified as community-supported but not independently specimen-verified.

2.5. Independent identification review

The photographic records were reviewed through the iNaturalist community-identification process. Three platform users independently supported identification of the photographed crayfish as red swamp crayfish, *Procambarus clarkii*. These reviewers included the original observer (osama-altamimi) and two additional iNaturalist users, (petzenbeer) and (behes2025). This occurrence was also subsequently indexed by the Global Biodiversity Information Facility (GBIF occurrence 5108099671) under the name *Procambarus clarkii* (Girard, 1852).

The agreement among multiple identifiers provides stronger support for the provisional species-level assignment than a single-observer identification. However, these community identifications were based solely on the available photographs, and the reviewers' formal taxonomic qualifications were not independently verified. Furthermore, the GBIF record represents an indexed version of the underlying citizen-science occurrence rather than an independent specimen-based determination. The record is therefore treated as a community-supported identification of *P. clarkii*, but not as a voucher-confirmed or molecularly verified occurrence. Definitive confirmation will require collection of a voucher specimen, examination of diagnostic morphological characters, and preferably DNA barcoding.

2.6. Spatial data, coordinate system, and mapping

Spatial analyses and map production were conducted in QGIS (version 3.34, QGIS Development Team). Occurrence records were overlaid on independent layers representing major dams and reservoirs, managed wadis and other water bodies, and administrative boundaries. The supplied Riyadh map identifies OpenStreetMap as the source of the water-body layer, but its access date was not provided. The sources, access dates, and coordinate reference system (CRS) used for all GIS layers are reported in the Methods. The spatial data processing included duplicate screening, coordinate validation, identification of obscured or generalized coordinates, and removal or explicit flagging of captive or relocated observations. In all figures, dam/reservoir locations, water bodies, and iNaturalist crayfish records are shown as distinct, clearly labeled symbol classes.

2.7. Spatial analysis

Analyses were descriptive and exploratory, aimed at characterizing the geographic distribution of retained records relative to engineered freshwater systems rather than testing formal hypotheses. For each retained record, the straight-line distance to the nearest mapped water body was calculated in QGIS. Proximity was summarized using descriptive 1–5 km buffer zones around reservoirs, irrigation canals, and urban water bodies. Because the retained sample is small and citizen-science coverage is spatially biased toward populated areas, no formal test of spatial randomness was performed; the proximity summaries are therefore reported descriptively and should not be interpreted as evidence of a non-random association. Records spanned a limited temporal window and were evaluated for geographic consistency rather than temporal trends.

3. Results

Two geographically coherent occurrence signals for suspected non-native crayfish were retained in Riyadh (iNaturalist observations 264920283 and 265181171). Their public coordinates were 24.60141° N, 46.66301° E and 24.57389° N, 46.68698° E, with reported positional accuracies of 74 m and 243 m, respectively. The records were approximately 3.90 km apart. Based on the current place information, the first record is provisionally associated with Al-Badi'ah Lake and the second with Namar Lake or its connected managed-water system; final lake assignments require GIS verification. A separate iNaturalist observation (339671890), recorded on 22 February 2026 at 24.60096° N, 46.66302° E (reported positional accuracy: 71 m), was labelled Red Jewel Cichlids (*Rubricatochromis* sp.) and remained at Needs ID. This fish record was approximately 50 m from the first crayfish record, indicating co-location of two aquarium-associated taxonomic signals. Neither taxon was confirmed by voucher specimen or molecular evidence, and the records do not establish reproduction, persistence, or population-level spread.

3.1. Aquarium-trade and hobbyist pathway evidence

The digital pathway scan identified multiple independent records indicating that freshwater crayfish are available or maintained within the Saudi aquarium trade and hobbyist community. Evidence included retail content from Riyadh, hobbyist aquarium posts from Riyadh and Jeddah, and online listings for live crayfish or crayfish-specific husbandry products. Platform-reported taxa included Australian redclaw crayfish (Cherax quadricarinatus), dwarf Mexican crayfish (Cambarellus sp.), and nonspecific red crayfish. These names are retained only as platform-reported identifications unless diagnostic images permit independent confirmation. None of the trade or hobbyist records was interpreted as a wild biological occurrence. Instead, they provide convergent evidence that aquarium ownership and commerce constitute a plausible propagule pathway through intentional release, disposal, or accidental escape (Table 2). The scan did not identify a voucher-supported, molecularly confirmed, or peer-reviewed record of an established wild crayfish population in Saudi Arabia.

A finer-scale view of central Riyadh shows the retained records in relation to managed freshwater systems (Figure 4). Because interpretation of introduction pathways cannot be derived directly from these observations, such interpretation is deferred to the Discussion.

3.2. Figure legends

Figure 1. National context of major dams and reservoirs in Saudi Arabia, with the Riyadh study area highlighted. Dam and reservoir locations, administrative boundaries, and the study-area inset are displayed as separate, clearly labeled symbol classes. Layer

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sources, access dates, and the coordinate reference system (CRS) are reported in the Methods.

Figure 2. Conceptual framework that illustrates the role of citizen-science observations as early-warning signals for potential introductions of non-native freshwater crayfish. Unverified occurrence records provide preliminary spatial signals that, when associated with engineered freshwater systems, can inform targeted monitoring and management prior to confirmed establishment.

Figure 3. Citizen-science photograph of a suspected non-native cambarid crayfish from central Riyadh, treated as an unverified early-warning signal. The photograph represents a community-supported identification of *Procambarus clarkii* that has not been independently verified using voucher specimens or molecular analysis. The observer, observation identifier, image license, and required attribution are provided in the caption.

Figure 4. Generalized locations of two suspected non-native crayfish early-warning records in Riyadh, Saudi Arabia, shown in relation to managed freshwater systems. Records are labeled RYD-01 and RYD-02, and water bodies, roads, and observation symbols are clearly distinguishable at publication resolution.

4. Discussion

4.1. What the records indicate

The combined evidence identifies Al-Badi'ah and Namar lakes as priority surveillance sites rather than confirmed invaded ecosystems. Two suspected crayfish observations, a nearby aquarium-associated cichlid record, regional trade availability, and local reports of aquarium releases converge on a single plausible mechanism: intentional disposal or release of unwanted aquatic pets into accessible urban water bodies. This convergence strengthens the pathway hypothesis, but it does not establish the identity, origin, persistence, reproduction, or ecological impact of any recorded organism. The sites should therefore be described as potential aquarium-release hotspots and the taxa as suspected non-native occurrences pending verification.

4.2. Aquarium release as a plausible pathway

The aquarium-release hypothesis is supported by three independent evidence classes: (1) publicly visible sales or captive possession of crayfish taxa in Saudi Arabia, (2) suspected outdoor observations at accessible urban lakes, and (3) local knowledge describing repeated releases by aquarium keepers. Nevertheless, release frequency has not been quantified, individual release events have not been directly documented in this study, and trade availability cannot be linked to outdoor records. Future studies should document release behavior through structured interviews, municipal incident records, georeferenced photographs or videos, and repeated biological surveys.

Several introduction pathways are plausible for crayfish in managed desert freshwater networks, including aquarium or ornamental release, inter-basin water transfer, and informal stocking. However, the available records cannot distinguish among these mechanisms, and none can be inferred directly from the observations. If a non-native crayfish were confirmed, the ecological concern would be substantial: non-native crayfish are well documented to affect fish populations through predation on eggs and juveniles, competition for refugia, alteration of benthic habitats, and restructuring of food webs (Momot, 1995; Lodge et al., 2012; Twardochleb et al., 2013), and impacts may be amplified where native fish have evolved without crayfish and show limited predator recognition (Gherardi, 2007; Moorhouse et al., 2014). Because recruitment impacts—predation on eggs and early life stages can precede detectable adult declines—early detection is particularly valuable (Lodge et al., 2000; Matsuzaki et al., 2009; Ruokonen et al., 2018).

Trade pathway as a management-relevant early-warning signal

The trade and hobbyist evidence strengthens the pathway component of the early-warning framework. It does not validate the two iNaturalist observations as wild records, but it demonstrates that live freshwater crayfish are plausibly accessible to aquarium keepers in Saudi cities. The coexistence of local trade exposure with unverified outdoor observations in the same metropolitan region is sufficient to justify targeted surveillance. The appropriate inference is not that a wild population is established but that propagule supply is plausible and outdoor signals should be investigated promptly. Regulatory screening of live aquatic invertebrate imports, retailer outreach, public messaging against release, and a reporting mechanism for unusual freshwater crustaceans would reduce this pathway risk. Environmental Impact Assessment (EIA) procedures for new or modified dams, reservoirs, urban lakes, irrigation networks, and other water-infrastructure projects should also incorporate screening for non-native aquatic species and aquarium-release pathways. Integrating invasive-species surveillance into EIA processes would help identify biosecurity risks before hydrological connectivity, recreational access, or habitat modification facilitates establishment and secondary spread.

4.3. Uncertainties

The principal uncertainties are taxonomic and spatial. The photographs support a community-identified assignment to *Procambarus clarkii*, but the species-level identification remains unverified by voucher specimens or molecular analysis. Spatially, the records are few, unevenly distributed, and biased toward populated areas, and they may include duplicate images of the same individual or animals photographed in captivity or after relocation. These uncertainties are treated in full in the Limitations section and constrain every downstream interpretation.

4.4. Why these sites warrant field verification

Engineered freshwater habitats such as reservoirs and regulated wadis support recreational fisheries and can act as refugia for native and stocked fish in arid landscapes (Havel et al., 2015; Glamuzina et al., 2020). Interconnected dams and irrigation channels also maintain permanent water and reduce dispersal barriers, so an introduction at one node could, in principle, spread stepwise through managed systems rather than relying on natural hydrological connectivity. This corridor potential means the flagged sites are worth verifying promptly: control of crayfish becomes progressively more difficult once self-sustaining populations establish (Gherardi et al., 2011; Britton et al., 2023), and prevention and early detection are consistently the most cost-effective options (Lodge et al., 2006). Climate change may further raise establishment risk by increasing thermal suitability for non-native species while stressing native communities (Bellard et al., 2013).

4.5. Immediate verification steps

The most useful next step is not further synthesis of online records but rapid, targeted field verification at the flagged sites, coupling

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standardized sampling with molecular confirmation. Environmental DNA (eDNA) is a sensitive, non-invasive tool for detecting low-density populations within specific hotspot corridors and can bridge the gap between public observation and formal validation (Sepulveda et al., 2020). A concrete protocol is outlined below.

4.6. Recommended field-verification protocol

To convert these early-warning signals into actionable evidence, we recommend the following protocol at each flagged site:

- Visit each flagged site within 30–60 days of record review, prioritizing sites with the most recent or repeated observations.
- Conduct standardized nocturnal baited trapping (fixed trap number, soak time, and bait across sites) to allow effort-corrected comparison.
- Supplement trapping with standardized dip-netting and timed hand searches of littoral and refuge habitats.
- Collect eDNA water samples using a documented filtration and preservation protocol, with field and filtration negative controls.
- Retain voucher specimens and take standardized diagnostic photographs (dorsal, lateral, chelae, and rostrum) under consistent lighting and scale.
- Preserve specimens in ≥95% ethanol for morphological confirmation and DNA barcoding (COI) to confirm species identity.
- Report confirmed or strongly suspected detections to the National Centre for Wildlife and the relevant water management authority to enable a rapid response.

4.7. Post-verification research priorities

If field verification confirms the presence of a self-sustaining, reproducing crayfish population at one or more sites, we recommend that subsequent research move beyond presence/absence confirmation toward quantifying invasion extent and organismal tolerance. Mark-recapture population-estimation methods should be applied at confirmed sites to generate defensible estimates of population size, density, and growth rate, providing managers with a quantitative basis for prioritizing control effort rather than relying on presence-only data.

In parallel, we recommend laboratory-based physiological studies utilizing specialized rectangular acrylic testing tanks featuring permanent longitudinal dividers and junction chambers to precisely characterize thermal tolerance and shuttling behavior of any confirmed population under conditions representative of Riyadh's engineered freshwater systems. These systems may experience pronounced seasonal and diurnal temperature variation. Controlled thermal-gradient experiments would help determine how local temperature regimes may facilitate or constrain establishment, activity, and spread, thereby directly informing ecological risk assessment and management planning.

4.8. Limitations

This study is subject to several limitations that bound its conclusions:

- The number of retained records is small, limiting statistical power and generalizability.
- No voucher specimens were collected, and no molecular verification was performed; identifications are supported by multiple independent iNaturalist community identifiers but remain based solely on photographs and have not been verified using voucher specimens or molecular analysis.
- Photographic quality limited the examination of all diagnostic characters, despite community agreement at the species level.
- Citizen-science coverage is biased toward urban and populated areas, which can produce apparent clustering unrelated to true distribution.
- Observer activity on iNaturalist is uneven in space and time, and survey effort was not quantified.
- Repeated photographs may represent the same individual, and animals may have been photographed in captivity or after relocation.
- The records cannot demonstrate reproduction or establishment of a self-sustaining population.
- Social media and online market content is unevenly accessible, may be deleted or edited, and often lacks reliable species identification; the digital pathway scan therefore demonstrates availability and exposure rather than import volume or prevalence.
- Several procedural documentation items, platform extraction date, exact observation times, exclusion criteria, GIS layer provenance, and coordinate reference system were verified from the original sources.

Consistent with current guidance on citizen-science data, these records are therefore treated explicitly as unverified early-warning signals: raw occurrence points are not equated with distribution or occupancy estimates, and data quality, verification, and licensing are addressed transparently rather than assumed.

5. Conclusions

Publicly available evidence identifies two complementary warning signals: unverified outdoor crayfish observations in central Riyadh and independent evidence that freshwater crayfish are present in the Saudi aquarium trade and hobbyist community. Neither piece of evidence demonstrates a self-sustaining wild population, but together they establish a plausible introduction pathway and identify specific locations where field verification is warranted. The findings support a national early-warning system linking citizen-science reporting, aquarium-trade surveillance, standardized field sampling, eDNA screening, voucher-based identification, and rapid communication with relevant Saudi authorities. Where relevant, these measures are integrated into Environmental Impact Assessments (EIAs) and environmental-management plans for water-infrastructure development and rehabilitation projects.

6. Data Availability and Image Rights

Supplementary Table S1 provides observation identifiers, generalized geographic coordinates, screening decisions, and derived spatial measurements. Original photographs remain subject to the licenses specified by the source platform. Image attribution and licensing were verified directly from the original observation pages. Figure 3 is reproduced with the observer's written permission. To reduce the risk of collection or additional releases, precise coordinates are generalized in the public version of this article, with exact coordinates retained in a controlled supplementary file accessible to editors and reviewers on request.

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Supplementary Table S1. Reproducible record-level dataset

This table provides the full reproducible screening dataset referenced throughout the manuscript. Generalized coordinates are shown here for the public version of the article; exact coordinates are held in a controlled file available to editors and reviewers on request.

Public record ID:	iNaturalist observation	Date observed	Generalized coordinates	Community ID	Positional accuracy	Distance to water body	Decision
RYD-01	264920283	2/12/2025	24.60° N, 46.66° E	Procambarus clarkii	74 m	5	Retained
RYD-02	265181171	3/7/2025	24.57° N, 46.69° E	Procambarus clarkii	243 m	4	Retained

Supplementary Table S2. Digital evidence logs for aquarium-trade and hobbyist crayfish records

The supplementary evidence log should preserve, for each digital item, the platform, account or retailer, city, posting date, access date, URL, screenshot filename, reported taxon, evidence class, and any licensing or archiving restrictions. Because social media content is unstable, dated screenshots or archived copies should be retained for editorial review where legally permitted.

Web sources for Supplementary Table S2 (access dates added).

Facebook, Shamim Aquarium Shop red crayfish video: https://www.facebook.com/100064795296079/videos/red-crayfish-shamim-aquarium-shop/158175812373413/

Facebook, Shamim Aquarium Shop location/post: https://www.facebook.com/shamimaquatic/posts/312162874051841/

Facebook, Shamim aquarium livestock listing: https://www.facebook.com/100064795296079/posts/1013461384157029/

Instagram, Australian redclaw crayfish in Riyadh: https://www.instagram.com/reel/DRGe19xk-sz/

Instagram, dwarf Mexican crayfish in Riyadh: https://www.instagram.com/reel/DbDt2epyWzu/

Facebook, hobbyist crayfish content in Jeddah: https://www.facebook.com/a.masri91/posts/10162268573601206/

Ubuy Saudi Arabia live freshwater crayfish listing: https://www.ubuy.com.sa/en/product/8DWNXGCGW-swimming-creatures-live-freshwater-crayfish-for-aquarium-or-tanks-fire-ball

Noon Saudi Arabia crayfish husbandry accessory: https://www.noon.com/saudi-en/xmhf-aquarium-ceramic-small-fish-shrimp-crayfish-breeding-habitat-shelter-brown-xm163/ZBBCED5BDD56B5915EC3BZ/p/

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9. Conflict of Interest

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10. References

1. Alharthi, I., Cowx, I. G., & Harvey, J. P. (2024). Geographical distribution of freshwater fishes in Saudi Arabia. PLOS ONE, 19, e0311743. https://doi.org/10.1371/journal.pone.0311743
2. Bellard, C., Thuiller, W., Leroy, B., Genovesi, P., Bakkenes, M., & Courchamp, F. (2013). Will climate change promote future invasions? Global Change Biology, 19(12), 3740–3748. https://doi.org/10.1111/gcb.12344
3. Britton, J. R., Lynch, A. J., Bardal, H., Bradbeer, S. J., Coetzee, J. A., Coughlan, N. E., Dalu, T., Tricarico, E., Gallardo, B., Lintermans, M., Lucy, F., Liu, C., Olden, J. D., Raghavan, R., & Pritchard, E. G. (2023). Preventing and controlling nonnative species invasions nd the curve of global freshwater biodiversity loss. Environmental Reviews, 31(2), 310–326. https://doi.org/10.1139/er-2022-0103
4. Gherardi, F. (2007). Understanding the impact of invasive crayfish. Biological Invasions, 9(1), 1–15. https://doi.org/10.1007/s10530-006-9032-4
5. Gherardi, F., Aquiloni, L., Diéguez-Uribeondo, J., & Tricarico, E. (2011). Managing invasive crayfish: Is there a hope? Aquatic Sciences, 73(2), 185–200. https://doi.org/10.1007/s00027-011-0181-z
6. Glamuzina, B., Tutman, P., Glamuzina, L., Vidović, Z., Pavličević, J., Vilizzi, L., & Copp, G. H. (2020). Quantifying current and future risks of invasiveness of non-native aquatic species in highly urbanised estuarine ecosystems—A case study of the River Neretva Estuary (Eastern Adriatic Sea: Croatia and Bosnia–Herzegovina). Fisheries Management and Ecology, 27(1), 15–27. https://doi.org/10.1111/fme.12463
7. Havel, J. E., Kovalenko, K. E., Thomaz, S. M., Amalfitano, S., & Kats, L. B. (2015). Aquatic invasive species: Challenges for the future. Hydrobiologia, 750, 147–170. https://doi.org/10.1007/s10750-014-2166-0
8. Kotov, A. A., Karabanov, D. P., & Van Damme, K. (2022). Non-Indigenous Cladocera (Crustacea: Branchiopoda): From a Few Notorious Cases to a Potential Global Faunal Mixing in Aquatic Ecosystems. Water, 14(18), 2806. https://doi.org/10.3390/w14182806
9. Lodge, D. M., Taylor, C. A., Holdich, D. M., & Skurdal, J. (2000). Nonindigenous crayfishes threaten North American freshwater biodiversity: Lessons from Europe. Fisheries, 25(8), 7–20. https://doi.org/10.1577/1548-8446(2000)025<0007:NCTNAF>2.0.CO;2
10. Lodge, D. M., Williams, S., MacIsaac, H. J., Hayes, K. R., Leung, B., Reichard, S., & Mack, R. N. (2006).

DOI: 10.5281/zenodo.21859718

Biological invasions: Recommendations for U.S. policy and management. Ecological Applications, 16(6), 2035–2054. https://doi.org/10.1890/1051-0761(2006)016[2035:BIRFUP]2.0.CO;2

11. Lodge, D. M., Deines, A., Gherardi, F., Yeo, D. C. J., Arcella, T., Baldridge, A. K., & Zeng, Y. (2012). Global introductions of crayfishes: Evaluating the impact of species invasions on ecosystem services. Annual Review of Ecology, Evolution, and Systematics, 43, 449–472. https://doi.org/10.1146/annurev-ecolsys-111511-103919
12. Matsuzaki, S. I. S., Usio, N., Takamura, N., & Washitani, I. (2009). Contrasting impacts of invasive ecosystem engineers on freshwater ecosystems: An experiment and meta-analysis. Oecologia, 158(4), 673–686. https://doi.org/10.1007/s00442-008-1180-1
13. Momot, W. T. (1995). Redefining the role of crayfish in aquatic ecosystems. Reviews in Fisheries Science, 3(1), 33–63. https://doi.org/10.1080/10641269509388566
14. Moorhouse, T. P., Palmer, S. C. F., Travis, J. M. J., & Macdonald, D. W. (2014). Differential effects of invasive signal crayfish on sympatric native fish species. Freshwater Biology, 59(5), 1030–1041. https://doi.org/10.1111/fwb.12327
15. Preston, D. L., Henderson, J. S., & Johnson, P. T. J. (2021). Community ecology of invasions in freshwater ecosystems. Annual Review of Ecology, Evolution, and Systematics, 52, 203–224. https://doi.org/10.1146/annurev-ecolsys-012021-091015
16. Ruokonen, T. J., Karjalainen, J., & Hämäläinen, H. (2018). Effects of invasive signal crayfish on fish assemblages and benthic invertebrates. Hydrobiologia, 807, 245–258. https://doi.org/10.1007/s10750-017-3403-4
17. Sepulveda, A. J., Nelson, N. M., Jerde, C. L., & Luikart, G. (2020). The mandate for environmental DNA in invasive species management. Biological Invasions, 22(8), 2329–2335. https://doi.org/10.1007/s10530-020-02299-5
18. Twardochleb, L. A., Olden, J. D., & Larson, E. R. (2013). A global meta-analysis of the ecological impacts of non-native crayfish. Freshwater Science, 32(4), 1367–1382. https://doi.org/10.1899/12-203.1
19. Vilizzi, L., Copp, G. H., Hill, J. E., et al. (2021). A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions. Science of the Total Environment, 788, 147868. https://doi.org/10.1016/j.scitotenv.2021.147868

DOI: 10.5281/zenodo.21859718