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Banning Wildlife Trade Can Boost the Unregulated Trade of Threatened Species

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ABSTRACT

Banning wildlife trade is an immediate measure to protect species from overexploitation. Yet, regulations on the harvest and use of natural resources might have unintended side effects beyond the policy goals. Few causal inference studies have investigated the consequences of wildlife trade bans. We use the synthetic difference-in-differences causal inference approach based on an 11-year online trade dataset to explore whether trade bans on three threatened species in Japan—giant water bugs (*Kirkaldyia deyrolli*), Tokyo salamanders (*Hynobius tokyoensis*), and golden venus chub (*Hemigrammocypris neglectus*)—have spillover effects on trades of substitutable nonbanned species. We found spillover effects of wildlife trade bans, leading to an increase in sales of nonbanned species in each taxon. This effect lasted over a year only for water bugs. Our results raise concerns about the unintended consequences of trade bans and underscore the importance of additional efforts concerning consumer research, monitoring and enforcement beyond the policy-targeted species.

1 | Introduction

The wildlife trade is a multi-billion dollar industry that supports millions of livelihoods worldwide (Cawthorn and Hoffman 2015; UNODC 2020), but unsustainable trade is causing declines in wildlife population (Feddema et al. 2021; Liew et al. 2021; Scheffers et al. 2019). To mitigate this risk, governments commonly use trade bans at both the domestic and international levels to immediately manage wildlife trade (Oldfield 2003). Trade bans are expected to play a substantial role in supporting sustainable wildlife trade since they can help prevent overexploitation via enforcement. However, the introduction and existence of the bans might lead to unintended and/or negative consequences for species conservation (Challender, Harrop, and MacMillan 2015; Courchamp et al. 2006; Eskew and Carlson 2020; Rivalan et al. 2007). For example, trade bans often increase the perceived rarity of wildlife and its products on the market, incasing their value, and desirability (Courchamp et al. 2006; Rivalan et al. 2007), which can stimulate illegal markets (Rosen and Smith 2010; Underwood, Burn, and Milliken 2013). Furthermore, wildlife trade bans affect species distributions and ecological status of the species (Reino et al. 2017; Weber et al. 2015).

This study looks at another potential unintended consequence of trade bans, specifically spillover effects on trade of other species similar to those that were banned. Consumers who would have purchased the banned species may now seek other similar species, a phenomenon we call the "spillover" effect of trade bans. Although the study of spillover effects has a well-established history in biodiversity conservation and ecosystem management

(Reino et al. 2017; Manning and Ando 2022), research on wildlife trade remains limited. Most studies investigating the effect of trade ban policies have focused solely on banned species (Rivalan et al. 2007), neglecting the impacts on nonbanned species. This indicates that governments and researchers might have overlooked the risk of unintended side effects on legally tradable threatened species due to trade bans.

This study seeks to identify the causal spillover effects of a trade ban implemented in February 2020 in Japan—one of the largest wildlife trade countries (Andersson et al. 2021; McMillan et al. 2020; Tournant et al. 2012). Understanding the cause-and-effect relationships of policy interventions is at the heart of the effective development of conservation policies and regulations (Challender et al. 2022; Jones and Shreedhar 2024; Marshall, Strine, and Hughes 2020). Unfortunately, the lack of comprehensive datasets on wildlife trade has resulted in few policy evaluation studies (Challender et al. 2022). This study utilizes 11 years of online sales data and applies the recently developed causal inference approach, synthetic difference-in-differences (SDID) (Arkhangelsky et al. 2021b) to answer the question "Do trade bans have spillover effects on nonbanned species trade?".

2 | Methods

2.1 | Policy Background

The Japanese government has implemented the law, "The Act on Conservation of Endangered Species of Wild Fauna and Flora (ACES)," to conserve threatened species (for details, see the description by the Ministry of the Environment (MOE), Japan: https://www.env.go.jp/nature/kisho/kisei/en/species/index.html). Under the ACES, threatened wildlife species in Japan are classified as Nationally Endangered Species of Wildlife Fauna and Flora. A ban is imposed on the capture, trade, transfer, and export of these designated species, as well as on the display or advertising of such species for commercial trade. This regulation applies not only to living species, including both wild-caught and captive-bred, but also to dead biological specimens and products made from the designated species.

With the recent increase in wildlife trade (Harfoot et al. 2018; Hughes 2021; Lockwood et al. 2019), there is a growing concern that mass capture for commercial purposes can lead to species extinction. Particularly, semi-natural ecosystem species are now at risk of species extinction due to this commercial use in addition to the existing risk of habitat destruction. To regulate the commercial use of these species without discouraging conservation activities, the Japanese government amended the law to create a new framework, called "Class II Designated Nationally Endangered Species of Wild Fauna and Flora." On February 10, 2020, the regulations under this framework were introduced for three species—giant water bugs (*Kirkaldyia deyrolli*), Tokyo salamanders (*Hynobius tokyoensis*), and golden venus chub (*Hemigrammocypris neglectus*)—with consideration of their ecological status and characteristics. Under this regulation, the capture, trade, and transfer of the three species for commercial activities have been prohibited since February 10, 2020 (for details, see the press release on the policy amendment: https://www.env.go.jp/press/107622.html).

2.2 | Identification Strategy

This study analyzed the introduction of the trade ban policy on the three species in Japan using online sales data to answer the question, "Do trade bans have spillover effects on nonbanned species trade?". We used SDID to estimate the causal impact of the wildlife trade bans on the nonbanned species trade.

Our study design follows the Before-After Control-Impact (BACI) framework (Christie et al. 2019). The most widely used estimation approach for BACI is difference-in-differences (DID) (Feng et al. 2021; Scullion et al. 2011; Roth et al. 2023; Wauchope et al. 2021), with a more recent approach being the synthetic control method (SCM) (Abadie 2021; Ferris and Frank 2021; West et al. 2020). In this study, we use SDID, which effectively combines both approaches, addressing their potential weaknesses with minimal compromises in terms of statistical efficiency. Following SCM but unlike DID, SDID assigns weights to past observations, to construct more credible counterfactuals, thereby being more likely to satisfy the parallel trend assumption, which is crucial for the unbiased identification of treatment effects in DID-like estimation methods. Unlike SCM, SDID accounts for individual-specific fixed effects and constructs weights in a way that accommodates pre-existing differences in the dependent variable prior to treatment. Consequently, SDID is more robust than either SCM or DID (Arkhangelsky et al. 2021b), despite the small cost to statistical efficiency compared to SCM or DID. Due to these advantages, SDID has been increasingly applied across various fields, despite being a relatively new method (Dovern et al. 2023; Sun, Zhao, and Zheng 2024; Zeng et al. 2024). However, this approach has yet to be applied in biodiversity conservation.

In this SDID analysis, we control for seasonal trends, as typically more sales take place in the summer than winter; see Figures 1 and 2, for example. It has been shown that the two-step procedure developed by Kranz (2022) performs better than the original SDID method when there are other controls (here, seasonal dummies) other than individual fixed effects, year fixed effects, and the treatment variable (Arkhangelsky et al. 2021b; Kranz 2022). The two-step procedure works as follows:

First, we regress $Y_{i,y,q}$ on quarter dummies, individual fixed effects, and year fixed effects.

$$Y_{i,y,q} = \phi_q + \alpha_i + \gamma_y + \upsilon_{i,q,y} \tag{1}$$

$Y_{i,y,q}$ is the number of sales of species i in quarter q in year y; ϕ_q is the quarter fixed effects; α_i is species fixed effect; γ_y is year fixed effects; $\upsilon_{i,q,y}$ is the error term.

Once this model is estimated, we find the residuals of $Y_{i,y,q}$.

$$\tilde{Y}_{i,y,q} = Y_{i,y,q} - \hat{\phi}_q - \hat{\alpha}_i - \hat{\gamma}_y \tag{2}$$

We then use SDID (Arkhangelsky et al. 2021b), which solves the following minimization problem to identify the treatment effect:

$$Min_{\tau,\gamma,\alpha} \sum_i \sum_q (\tilde{Y}_{i,y,q} - \gamma_y - \alpha_i - \tau W_{i,y,q})^2 \times \omega_i \times \lambda_y \tag{3}$$

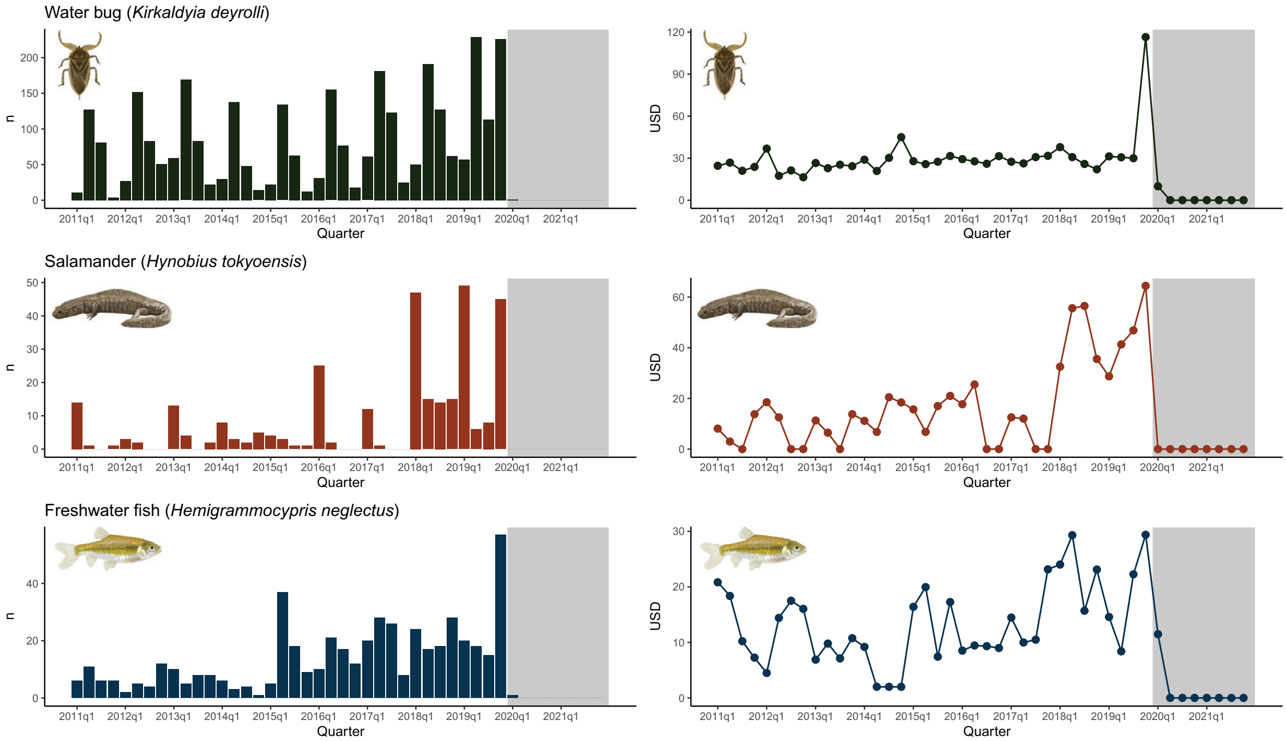

FIGURE 1 | The sales volumes of trade (left) and the mean prices (right), by quarter, for each banned species: giant water bugs (top), Tokyo salamanders (middle), and golden venus chub (bottom). When the species were not traded in a quarter, the prices are represented as zero. The shaded area is the trade-ban period (February 10, 2020–February 09, 2022).

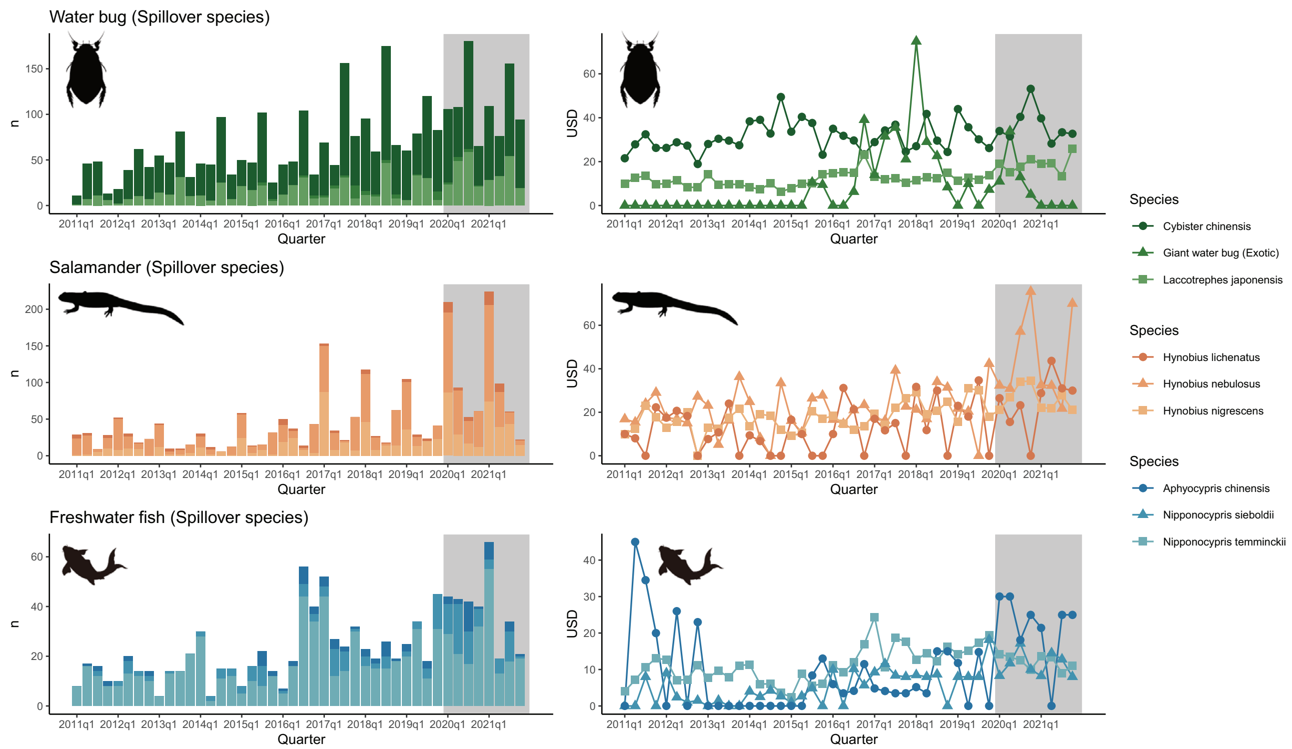

FIGURE 2 | The sales volumes of trade (left) and the mean prices (right) by quarter of each potential spillover species: the species in taxa of water bugs (top), salamanders (middle), and freshwater fish (bottom). When the species were not traded in a quarter, the prices are represented as zero. The shaded area is the trade-ban period (i.e., February 10, 2020–February 09, 2022).

Our ultimate interest is estimating τ, which is the average treatment (causal) effect; $W_{i,y,q}$ is the treatment dummy; ω_i is the weight on species i; λ_y is the weight on year y.

We excluded the last quarter of 2019 for the SDID analyses to mitigate the bias related to the announcement of the policy change. Sensitivity and placebo analyses for robustness checks (e.g., including the last quarter of 2019) were also conducted (see details in Figures S3–S8 and Tables S3–S6). All analyses were conducted using R version 4.1.2. The R packages "*synthdid*" and "*xsynthdid*" were used for the estimation (Arkhangelsky et al. 2021a; Kranz 2022).

Potential confounders in identifying the causal impact of trade bans include other policies or events (e.g., COVID-19) that occurred around the same time as the trade ban and may have influenced the market behavior towards the control and treated groups differently. However, while the COVID-19 pandemic and the trade ban may be correlated over time, it is unlikely to introduce bias in our estimation because there is no reason to believe that the COVID-19 pandemic would affect the treated and control groups differently. We conducted thorough reviews of any potential conservation policies that might have coincided with the trade ban and could have differentially affected the treated and control groups. We found no such policies.

2.3 | Data

We used an 11-year dataset from Japan's leading online auction platform Yahoo! Auction (https://auctions.yahoo.co.jp/). The dataset included the 9 years prior to the ban (February 2011–2020) and 2 years after the ban (February 2020–2022). The data were downloaded from the publicly accessible mirroring website Aucfan (https://aucfan.com/). The number of transactions composed of each taxon's potential spillover and control species (excluding the last quarter of 2019) is 385,713 for water bugs, 30,402 for salamanders, and 100,915 for freshwater fish (see Table S3 and Datasets in the Supporting Information for details). This dataset includes the following variables: traded dates, titles, traded categories, and final auction prices of each traded product. Traded categories, such as amphibian, were given by the auction website (i.e., https://auctions.yahoo.co.jp/list1/0-all.html). Using a Named Entity Recognition model trained with spaCy for natural language processing (https://spacy.io/models/ja#ja_core_news_trf), we extracted species names from the titles of the downloaded dataset and manually confirmed the names of the banned and potential spillover species.

The potential spillover species (i.e., treated units) were chosen based on three criteria. First, we selected species traded with the same Japanese name as the banned species on the market, but legally tradable. Even though they had the same "trade name," they were not under the trade ban because they are biologically different and do not have the same scientific name as the banned species; for example, giant water bug from Manaus, Brazil (*Belostoma grandis*). Second, to find the similar characteristics through a lens of human preference and searchability, we queried Google Trends for the banned three species and sales in Japanese for the relevant 10-year data period to identify species featured in related queries, using the R package "gtrendsR" (Massicotte, Eddelbuettel, and Massicotte 2016; see Note S2 for details). If at least one species was identified in the first two steps, we terminated the search. Otherwise, we applied a third criterion by selecting the phylogenetically closest species in the same family that featured in our trade dataset. For this, we used phylogenies from iNaturalist (https://www.inaturalist.org/) and OneZoom (https://www.onezoom.org/). We prioritize the first two selection criteria using marketing or human preference insights because this study explores online consumer behavior regarding wildlife trade. We found three potential spillover species in the water bug by applying the first two criteria, but no candidates in the other two taxa (see Table S1). Therefore, we used the third criterion and selected three species for each of the other taxa to make the number of potential spillover species consistent across the three taxa.

The control units were those traded in the same categories (as given by the auction website) as those of the banned species, excluding those of the potential spillover species. For example, the control units to identify the spillover effects of banning Tokyo salamander were the species in the amphibian category on the auction website excluding the trades of potential spillover species (*Hynobius nebulosus*, *Hynobius nigrescens*, and *Hynobius lichenatus*). Given the large volume of the datasets, not all species in the control units were identified by a scientific name; therefore, as a robustness check, we also analyzed the datasets with only the control units identified by the scientific names in the same taxonomic families as the trade banned species (see Figures S3, S4, S7, S8, and Datasets in the Supporting Information for details).

It is challenging to assess how effectively these criteria select the appropriate spillover or control species. Incorrect designation of species as the spillover species or control species will result in bias in our regression analyses. Specifically, we would tend to underestimate the spillover effects (see Note S2 for a detailed discussion). Therefore, our estimates are conservative measures of the true spillover effects.

Considering seasonality and the balanced panel requirements of SDID, the data were compiled on a quarterly basis, starting on the day the policy was implemented, February 10, 2020. The pretreatment period is therefore from February 10, 2011, to February 9, 2020, and the post-treated period is from February 10, 2020 to February 9, 2022. We implemented analyses not only with 1-year post-treated data but also with 2-year post-treated data to explore the duration of the impact. The trade volume of each species was aggregated by quarter. Additionally, as a robustness check, we conducted sensitivity and placebo analyses with different datasets to confirm our findings (see Tables S4–S6 for details). Given the discovery of new salamander species during the course of this study, we aggregated species into the oldest taxa (see Table S2 for the details).

3 | Results

3.1 | Preliminary Insights

Figure 1 presents the quarterly sales volumes and mean prices of the policy target banned species (i.e., giant water bugs, Tokyo salamanders, and golden venus chub) in the online auction market from February 2011 to February 2022. Banned species were not traded after the ban except for one giant water bug trade on February 22, 2020 and one golden venus chub trade on February 10, 2020. Prior to the ban, the trade volume of giant water bugs (n = 3056) was larger than those of the two (n = 306 for Tokyo salamanders; n = 505 for golden venus chub). The mean prices (price range) of each banned species prior to the ban were 33.3 (0.01–700), 32.8 (0.01–365), and 16.3 (0.01–350) US dollar (USD) for giant water bugs, Tokyo salamanders and golden venus chub, respectively. In this paper, we convert the Japanese yen (JPY) at an exchange rate of 100 to the USD despite fluctuations in the JPY–USD exchange rate during the research period (e.g., approximately 75 JPY/USD in 2012, and approximately 150 JPY/USD in 2022). There was a price spike for giant water bugs (116.9 USD) during the fourth quarter of 2019 (November 10, 2019–February 9, 2020: the last quarter before the ban), which includes the initial announcement day of this policy change (December 25, 2019).

Figure 2 shows the trade volumes and mean prices of the potential spillover species composed of three legally tradable species in each taxon, selected by considering the substitutability for the banned species (see Section 2.3 Data for details). The details of trade volumes and mean prices associated with Figures 1 and 2 are presented in the Supporting Information Datasets.

3.2 | Estimation of the Impact of the Ban

The SDID with 1-year postperiod data identified positive spillover effects concerning sales volumes for each of the three taxa (water bug: +17.54 mean effect, 95% confidence interval (CI) = [14.03, 21.06]; salamander: +10.06 mean effect, 95% CI = [2.73, 17.39]; freshwater fish: +6.19 mean effect; 95% CI = [0.12, 12.25]; see Figure 3). In contrast, the analyses with 2-year postperiod data identified positive spillover effects for the water bug (+22.01 mean effect, 95% CI = [17.62, 26.39]), with no statistically significant impacts for the other species (salamander: +3.58 mean effect, 95% CI = [−17.05 to 24.22]; freshwater fish: +6.22 mean effect; 95% CI = [−2.19 to 14.64]; see Figure 4). Our sensitivity and placebo analyses as robustness checks showed that the parameter signs and effects were virtually the same as our main results here (see Figures S4–S8 and Tables S4–S6 for details).

4 | Discussion

Our findings show that while the trade ban had its intended effect for the policy targeted species, it can cause unintended conservation side effects on nonbanned species, including threatened species. Bans on the three policy targeted species—giant water bugs, Tokyo salamanders, and golden venus chub—led to an increase in the trade volumes of nonbanned species in each taxon 1 year after the ban. However, the duration of the effects depends on the taxa. The effects on water bugs last over a year, whereas the effects on the other two taxa disappear over that same period.

Despite the heterogeneity of the spillover effects across taxa, our findings provide several important insights. First, banning wildlife trade can stimulate trade of nonbanned threatened species in countries where the ban is implemented. For example, a substitute for the giant water bugs *Cybister chinensis* is designated as vulnerable in the Japanese Red List and is locally extinct in five prefectures (Ohba et al. 2020). This effect potentially harms conservation of many legally tradable threatened species by activating the trade of substitute species, which can boost wild harvest. This concern is not limited to the country implementing trade bans. Spillover effects are not necessarily limited to native species; they also apply to exotic species, such as giant water bugs, from other countries. An increase in exotic species trade can increase overexploitation risk in source countries and lead to population declines unless appropriate management is implemented (Lockwood et al. 2019). Source countries, often developing countries, may face difficulties in meeting additional management needs because of trade bans elsewhere, as they often struggle to implement robust natural resource governance (Liew et al. 2021).

Besides overexploitation risk, the increase in importing and breeding of exotic species due to the policy change raises concerns regarding the potential impact of invasive species if these pets are released, whether intentionally or unintentionally (Gippet and Bertelsmeier 2021; Lockwood et al. 2019). Moreover, the more frequently exotic species closely related to the banned species are imported, the greater the risk of disease outbreaks that could impact the banned species (O'Hanlon Simon et al. 2018).

Considering all the concerns above, we highlight a potential feedback loop. That is, trade bans can stimulate sales of nonbanned species, triggering new regulations, and stimulating sales of other nonbanned species, thus creating a self-perpetuating loop. Indeed, the commercial trade of *Cybister chinensis*, for which we detected the positive spillover effects from the giant water bug, has been prohibited since January 2023. Although this prompt policy change can be thought of as a way to minimize threats to the species, it can also create additional concerns due to other feedback impacts at the same time like the Anthropogenic Allee Effect, where increased rarity enhances the value of wildlife products, leading to overharvesting and ultimately causing species extinctions (Courchamp et al. 2006). Therefore, these multiple feedback loops may create new challenges in combating unsustainable wildlife trade, underscoring the importance of proactive policy making (Scheffers et al. 2019).

To mitigate the risks of negative consequences caused by spillover effects, we note some policy and management implications. We first call for understanding market dynamics and recommend the use of behavioral science insights to manage demand prior to introducing a trade ban (Challender, Harrop, and MacMillan 2015; Greenfield and Veríssimo 2018; Veríssimo, Sas-Rolfes, and Glikman 2020). Our findings regarding the heterogeneity of effects across taxa suggest that an initial goal of interventions should be to reduce the demand for the species to be banned, therefore reducing the magnitude and the duration of any potential spillover. For example, public interest and sales in giant water bugs were considerably larger than those of the other two species (see Figures 1 andS1), potentially resulting in higher and prolonged leakage into the trade of nonbanned species trade following the ban. Therefore, demand management should focus on redirecting spillover demand towards legal and sustainable sources, either from well-managed wild populations, captive breeding, or synthetic alternatives. Such behavior change

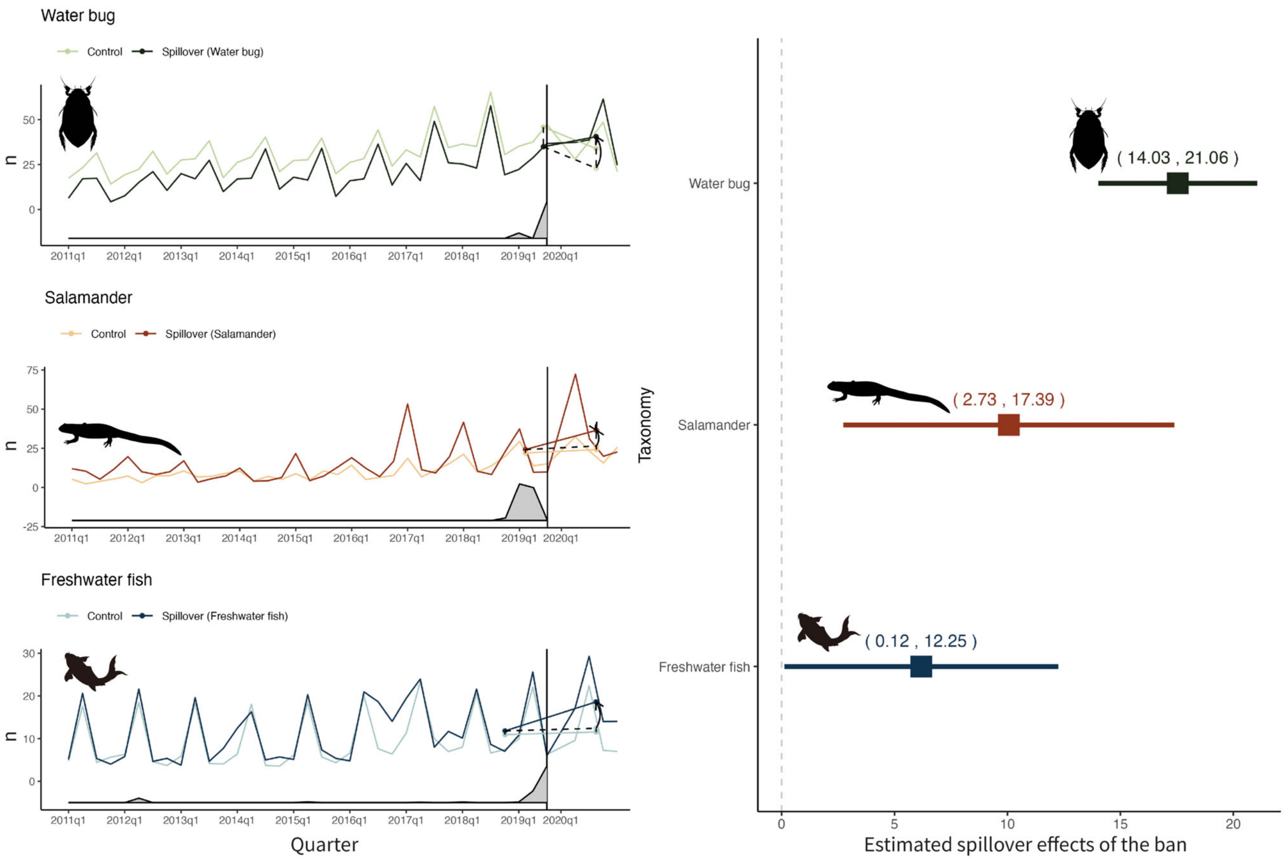

FIGURE 3 | Results of synthetic difference-in-differences (SDID) on the sales volume with 1-year postperiod data. To mitigate the announcement bias before the ban, 2019's fourth quarter was removed from the estimation. In the left column, each panel shows trends in relative sales volume by quarter over time for the spillover species and the relevant weighted average of control species. The arrows indicate the estimated spillover effects of the trade ban. The right column figure shows the estimated spillover effects with a 95% confidence interval (CI) in each taxon.

intervention would minimize any threats to biodiversity. Identifying these potential substitute sources requires a detailed understanding not only of the conservation status and trade sustainability of different wildlife populations and species but also of consumer motivations and preferences, which are often context-dependent and culture-specific.

The complexity of understanding substitutability is highlighted by ongoing debates regarding the potential of farmed products as substitutes for wild-sourced products (Davis et al. 2022; Hinsley and 't Sas-Rolfes 2020). These challenges in predicting substitutability emphasize the need for further consumer research to avoid situations where substitutes are considered either biologically unsuitable or undesirable by consumers (Hinsley and 't Sas-Rolfes 2020). Additionally, further research is needed to understand the mechanisms driving the supply side of the trade. Supply can be influenced by characteristics of wildlife and wildlife products, including accessibility, and price elasticity. Due to the relatively low capture cost for the taxa in this study, their transaction volumes can be impacted by the policy change (Mialon Hugo, Klumpp, and Williams Michael 2022). Policy makers and researchers need to contribute to the development of market-based approaches to managing supply (Cooney and Jepson 2006; Phelps, Biggs, and Webb 2016). For example, they could increase the transaction costs of potential spillover species through regulation. It is important to note that each policy and management strategy is not necessarily independent. While implementing a trade ban on threatened species, consumer behavior change can be further encouraged with other regulations and restrictions on the trade of potential spillover species. Further research is needed to understand which policy mix is likely to be effective in different contexts.

To develop effective interventions to manage wildlife trade, further efforts are needed to monitor the volume, composition, and prices of species being traded. Due to law enforcement efforts, substantial measures have been implemented for policy-targeted species, and this suggests they can be successful. However, our findings indicate that the monitoring should be extended to include unregulated threatened species trade (Cardoso et al. 2024). It is essential to enhance monitoring efficiency and management capacity, which is a challenge as conservation practices have faced substantial financial shortages (Dempsey et al. 2022). This is exemplified by the case of Japan, where the conservation budget has increased only marginally, even as the number of protected species continues to rise (Ministry of the Environment (MOE), Japan 2018). There are several ways to improve monitoring efficiency and management capacity. For example, computer science can be used to identify traded species (Di Minin et al. 2018; Hino, Benami, and Brooks 2018). Thus far, species identification has been challenging, even on online trade platforms, since species are traded using not only species

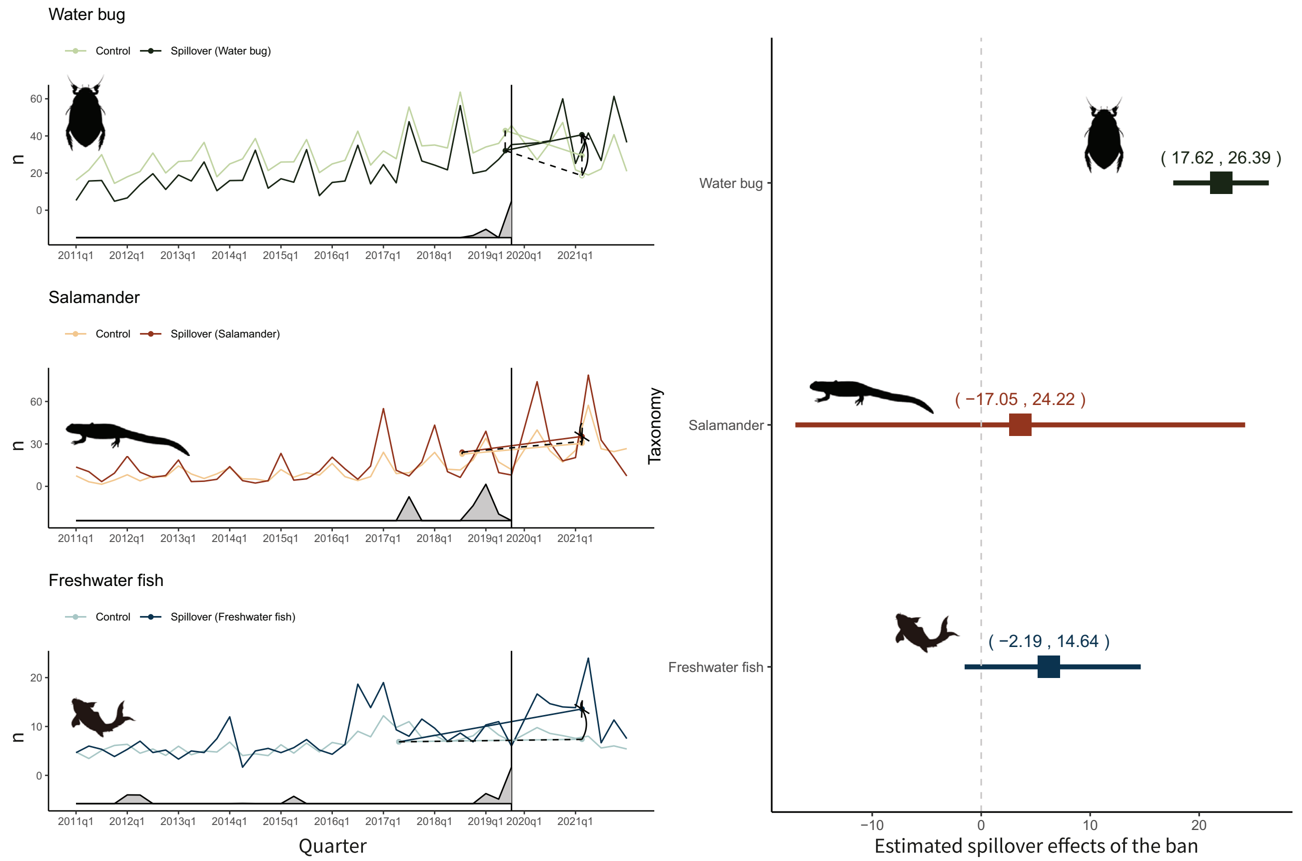

FIGURE 4 | Results of synthetic difference-in-differences (SDID) on the sales volume with 2-year postperiod data. To mitigate the announcement bias before the ban, 2019's fourth quarter was removed from the estimation. In the left column, each panel shows trends in relative sales volume by quarter over time for the spillover species and the relevant weighted average of control species. The arrows indicate the estimated spillover effects of the trade ban. The right column figure shows the estimated spillover effects with a 95% confidence interval (CI) in each taxon.

names but also common names and codified language designed to be understood only by those within specific pet owner and trader networks (Stringham et al. 2021). Our findings based on datasets processed using natural language processing can, in part, showcase the benefits of this approach.

Furthermore, the findings regarding cross-country spillovers call for international cooperation that extends beyond the current frameworks established by existing conventions. We propose the development of a database comprising the banned and nonbanned traded/tradable species with common names in multiple languages. This can help overcome language barriers in conservation science and practice (Amano et al. 2021), allowing for better sharing of information on policy interventions and better identification of species traded across borders.

At a time when biodiversity is being lost at an unprecedented rate, evidence-led policy evaluation is essential. Furthering discussions on research design and developing new statistical approaches will be to support the development of effective policy interventions. Although trade bans can play an important role, especially for threatened species facing high extinction risk, policy evaluations ignoring spillover effects might overstate the benefits of trade ban policies in conservation. Even when trade bans effectively reduce the trade of target species, our evidence raises concerns about the unintended consequences of wildlife trade bans through a feedback loop of spillover effects. These should be considered when developing new policy interventions against unsustainable wildlife trade. The introduction of legislation requires further consumer research, monitoring, and enforcement that goes beyond the species targeted by the policy while minimizing costs via the application of modern technologies and enhancing international cooperation.

Author Contributions

T.K., T.M., and D.V. designed research. T.K. performed research. T.K., T.M., and S.U. analyzed data. T.K., T.M., S.T., and D.V. wrote the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings will be available in the GitHub repository (https://github.com/nies-consplan).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.