California kingsnake. © Julien C. Piquet.

Invasive alien snakes

Information on measures and related costs in relation to species considered for inclusion on the Union list

Scientific name(s)	*N.a.*
Common names (in English)	Invasive alien snakes
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Illustrations	Massimiliano Lipperi, Studio Wildart (*Reproduction is authorized provided the source is acknowledged.*)
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Table of contents

This note aims at introducing the reader to the main methods, strategies and tools for alien snake management developed worldwide, yet it is not intended to be an exhaustive survey of all the literature on the topic. It builds on a previous note on the management of Lampropeltis getula (Robertson *et al.*, 2017a).

Measures for preventing the species being introduced, intentionally and unintentionally.

This section assumes that the species is not currently present in a Member State, or part of a Member State's territory.

Management of key pathways (pathway management plans, codes of conduct, and voluntary measures)

MEASURE DESCRIPTION

Invasive alien snakes are usually kept as pets or for display in private or public zoological collections, from where they are known to escape or occasionally be released into the wild. There are several examples worldwide of invasive populations of snakes released or escaping captivity (Cabrera-Pérez *et al.*, 2012; van Doorn *et al.*, 2021; Van de Koppel *et al.*, 2012b; Dubey *et al.*, 2017; Asato *et al.*, 2022; Willson *et al.*, 2011; Dorcas *et al.*, 2012; Snow *et al.*, 2007; Friebohle *et al.*, 2020; Bushar *et al.*, 2015; Rose & Todd, 2014).

Besides the adoption of awareness raising campaigns on the risks associated with the release of alien species into the wild (see *Public awareness* section), the adoption and enforcement of appropriate pathway management plans and codes of best practice are considered key to supplement other regulatory frameworks, such as the EU policy legislation on IAS, and reduce the risks posed by these pathways, so to reduce the probability of further introduction. Importantly, islands often lack the snake species that occur as native species on the continent, therefore legislation needs to be region/island specific (and can be more stringent in such isolated biodiversity hotspots and more generic taxonomically, see further).

Codes of conduct for the pet trade (including e-commerce) and the zoo sectors were developed at the European level by the Bern Convention within the Council of Europe[1]. Examples of such codes are:

- Davenport, K., Collins, K. 2016[2]. European Code of Conduct on Pets and Invasive Alien Species. T-PVS/Inf(2011)1rev. Council of Europe.
- Scalera, R., De Man, D., Klausen, B., Dickie, L., Genovesi, P. 2012[3]. European code of conduct on zoological gardens and aquaria and invasive alien species. T-PVS/Inf(2011)26rev. Council of Europe, New edition November 2016. Pages 40.
- Monaco, A. 2021[4]. Guidance document on e-commerce and IAS. T-PVS/Inf(2021)39. Council of Europe, Strasbourg, France.

Additionally, a Pet Code of Practice has been developed by the Ornamental Aquatic Trade Association (OATA) and the Reptile and Exotic Pet Trade Association (REPTA) to advice and guide pet owners including traders to responsible keeping of non-native pets to prevent the spread of invasive non-native species[5].

The implementation of such plans should be accompanied by the adoption of specific recommendations, as well as by dedicated awareness-raising and behaviour change campaigns.

Most importantly, dedicated communication campaigns should discourage people to dispose of unwanted pets by dumping them into the environment and amplify the "no release" message. One example is provided by the Beware of Aliens campaign of the European Commission, where communication messages were drafted co-creatively with key players in the pet trade sector[6].

Pathways management plans are mostly dedicated to unintentional introductions, according to the EU Regulation on IAS[6B], therefore they are discussed under the section *Biosecurity measures and pathway action plans* below. They should ideally be grounded in pathway identification, analysis and prioritisation, for example, based on the number of introduction events and/or the number of species in a pathway, which could highlight

[1] https://www.coe.int/en/web/bern-convention/on-invasive-alien-species
[2] https://rm.coe.int/1680746297
[3] https://rm.coe.int/168074679e
[4] https://rm.coe.int/inf39e-2021-guidance-document-e-commerce-and-ias-final/1680a3a8e7
[5] https://www.nonnativespecies.org/assets/Document-repository/Pet-Code-of-Practice-helping-to-prevent-the-spread-of-invasive-non-native-species.pdf
[6] https://easin.jrc.ec.europa.eu/easin/BewareofAliens
[6B] Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species https://eur-lex.europa.eu/eli/reg/2014/1143/oj

risky donor regions, products or commodities for alien snake introductions, and also data on snake species that are prone to be introduced through certain mechanisms, for example as stowaway or pet escapes.

SCALE OF APPLICATION

Relevant codes of conduct are being developed and implemented at both the national and European scale (extending beyond Europe, in the case of the codes of conduct adopted by the Council of Europe). No examples regarding the impact of such codes are available in relation to the relevant topics (pets, zoos) and/or with reference to the management of invasive alien snakes.

EFFECTIVENESS OF THE MEASURE

Unknown or not yet applied.

There are no specific experiences on the effectiveness of implementation of the codes of conduct of alien species in the pet trade sector and with the zoo community. However, the application of this voluntary based approach has been used successfully in the context of botanical gardens and the horticultural industry (Niemiera & VonHolle, 2009; Halford *et al.*, 2014). The lessons learned regarding such voluntary codes emphasised that, to be fully effective and to increase the likelihood of a long-term behavioural change, a code should be widely disseminated, and that it is important to build partnerships for its continuous promotion with relevant stakeholders. The effectiveness in terms of changes in attitude and perception by the target audience can be measured using baseline and evaluation surveys.

EFFORT REQUIRED

In order to guarantee the effectiveness of the implementation of the codes of conduct (along with the associated information campaigns), this measure would need to be implemented on a permanent basis.

RESOURCES REQUIRED

Information on costs for the implementation of codes of conduct at either the national or European level is not available (see *Biosecurity measures and pathway action plans* section).

ADDITIONAL COST INFORMATION

No information available for Europe, but data from experiences in the USA has shown that resources are best spent on educating the public, for example educating pet owners, and preventing releases (Hegan, 2014). This is also true for invasive alien species in general, with authors acknowledging that money spent on preventing accidental and intentional introductions of potentially harmful exotic species, focused on educating the public and inspectors at airports and seaports, is a good investment and requires resources in proportion to the risks (Pimentel *et al.,* 2005).

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Positive
Social effects: Positive
Economic effects: Positive

The aim of voluntary codes of conduct and best practices is to ensure responsible, proactive policies, and apply these in a coherent manner across Europe (Shine *et al.,* 2010) by stimulating the involvement of stakeholders (e.g. public bodies, industry federations, user groups and/or NGOs), disseminating best practices, supplementing existing regulations or filling a regulatory gap. In addition, implementing such fundamental flexible tools is cheaper than managing species once introduced and established. Moreover, the impact of implementing voluntary codes of conduct (along with the associated information campaigns) would extend to many other non-target alien species which are moved through the same pathway.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Voluntary tools developed in collaboration with the relevant stakeholders increase the opportunities for wider acceptability of the relevant measures. For example, the two codes of conduct described above on pets and zoological gardens have been developed by the Council of Europe in collaboration with representatives of the pet trade sector and the zoo community, in an open process that could count on the active involvement of representatives of all Bern Convention parties, as well as other stakeholders and the scientific community, hence in principle they should be overall acceptable to wider audiences. Moreover, in contrast with other management options, preventing new introductions of IAS would fulfil the goals and values of both animal rights groups and conservation biologists, thus overcoming a number of potential critiques based on ethical and emotional grounds and conflicts from different stakeholders, in particular from animal rights advocates (Perry & Perry, 2008).

LEVEL OF CONFIDENCE*

Established but incomplete.

Although this kind of measure has worked relatively well for other sectors (such as ornamental plants, see Halford *et al.*, 2011), the lack of information on the actual implementation of the codes mentioned for the management of invasive alien snakes does not allow this measure to be considered as well established.

* See Appendix

A ban on importing (pre-border measure), selling, breeding, growing, and cultivation, targeting intentional introduction of invasive alien snakes

MEASURE DESCRIPTION

Snakes are popular pets and as such are intentionally traded and moved across countries. As a result, releases (e.g. dumping pets) and escapes from private and public collections and other establishments (including zoos and wildlife parks) may happen and are considered among the most important pathways of introduction of invasive alien snakes in Europe and beyond. The keeping of snakes as pets, and/or in private and public holdings such as zoos and similar establishments, has already resulted in invasive alien snakes being introduced and, in some cases, spreading within Member States. Examples are *Lampropeltis getula* in the Canary Islands (Spain), *Elaphe taeniura* in Belgium, *Pituophis catenifer, Vipera aspis* and *E. schrenckii* in the Netherlands etc. (see Cabrera-Pérez *et al.*, 2012; van Doorn *et al.*, 2021; Van de Koppel *et al.*, 2012a, 2012b).

SCALE OF APPLICATION

Therefore, to address any additional introductions through releases (or escapes) and the consequent potential spread of invasive alien snakes, an EU-level ban on importing, keeping, breeding, growing, and selling would be needed (as required for the species on the Union list under Article 7 of IAS Regulation 1143/2014). So far, only one snake, the species complex *L. getula*, which includes the subspecies *L. g. getula*, *L. g. nigra*, *L. g. holbrooki*, *L. g. splendida* and *L. g. californiae* (Pyron & Burbink, 2009), is listed as an invasive alien species of Union concern[7], but this measure could be extended to other alien species of snakes shown to be invasive elsewhere (see Roy *et al.,* 2019 on the identification of species that may become invasive in the EU following a EU Horizon scanning exercise, and Capinha *et al.,* 2017 for an overview of invasive snake populations).

Within the EU, a ban for keeping the species would help develop the right tools to deal with this threat and allow Member States to have contingency plans for potential escape situations. For example, it would oblige Member States where invasive alien snakes are present to prevent their spread to neighbouring countries, would harmonise efforts and action for managing species found at the border of a Member State, and would reinforce the legal framework at the regional level for those Member States that may have already included snakes in their national alien species lists (like Spain, for instance, that included the "family Colubridae *sensu lato*" on their national list of IAS for the Canary Islands, Ibiza and Formentera[8]).

An asp viper found in St. Martin-Vesubie, Provence-Alpes-Cote d'Azur, France. © Bernard Dupont (CC BY-SA-2.0) via Encyclopedia of Life.

Head of *Elaphe schrenckii.* © Michał Bielawski (CC BY-SA-3.0) via Encyclopedia of Life.

In accordance with Article 7 of the EU IAS Regulation 1143/2014, the following measures will automatically apply to *Lampropeltis getula* in the EU:

Invasive alien species of Union concern shall not be intentionally:

a. brought into the territory of the union, including transit under customs supervision;
b. kept, including in contained holding;
c. bred, including in contained holding;
d. transported to, from or within the union, except for the transportation of species to facilities in the context of eradication;
e. placed on the market;
f. used or exchanged;
g. permitted to reproduce, grown or cultivated, including in contained holding; or
h. released into the environment.

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02016R1141-20220802&from=EN
[8] https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-exoticas-invasoras/ce_eei_reptiles.html

Kingsnake. © R. Gallo Barneto, STOPCULEBRAREAL.

Also note that, in accordance with Article 15(1) of the IAS Regulation – as of 2 January 2016, Member States should have in place fully functioning structures to carry out the official controls necessary to prevent the intentional introduction into the Union of invasive alien species of Union concern.

SCALE OF APPLICATION

The ban should be implemented at both the national and EU scale. Island archipelagos need to consider inter-island biosecurity measures to prevent spread from established populations to other islets or archipelagos. No information on the effectiveness of the measure is available so far in relation to the situation with *L. getula*, which is the only snake included within the Union list for the time being. However, it is clear that on the Canary Islands *L. getula* is still spreading despite control actions have been undertaken. Besides the species being established in Gran Canaria, some individuals also occasionally appeared in other islands in the archipelago too, for example in Fuerteventura, La Gomera, Lanzarote and Tenerife, where in most cases they were promptly removed (pers. comm. Ramón Gallo Barneto, 2017; pers. comm. Julien Piquet, 2023). It is to be noted that trade bans, should they be effective in limiting introduction events, will not prevent secondary introductions from already established populations within a territory. To prevent secondary introductions, general bans on species introductions in the environment are a possibility and are established in many Member States.

EFFECTIVENESS OF THE MEASURE

Effective.

Banning invasive alien snakes from being kept in private collections, zoos, wildlife parks, and similar establishments could prevent escapes and unlicensed releases and further spread of the species within and between Member States (but see Maceda-Veiga *et al.,* 2019). A ban will only be effective in practice if it is duly enforced and extensively communicated; hence, the general public and establishments must be educated on the potential for local extinctions of threatened species due to predation from and competition with invasive alien snakes. For example, Maceda-Veiga *et al.* (2019), based on an analysis of exotic fish, crayfish and herptiles (including turtles and snakes such as the ball python *Python regius* and red corn snake *Pantherophis guttata*) in northeastern Spain, assessed the effectiveness of 2011 legislation[9] intended to ban the sale of a prioritised list of invasive alien species in retailers, which aimed at reducing the release of exotic species into recipient ecosystems. Although effective (the species were not found in retailers anymore) the authors found little evidence of a

[9] Real Decreto 1628/2011 de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras and Real Decreto 630/2013 de 2 de agosto, por el que se regula el Catálogo español de especies exóticas invasoras

change in exotic pet releases into urban lakes (and animal shelters) after that. They suggest that legislation has been effective at curbing the sale of listed invasive alien species by retailers but the release of prioritised listed species into urban lakes continued virtually unabated, possibly because educational campaigns were not conducted at the same time. Maceda-Veiga *et al.* (2019) therefore state that legislation is reactive (i.e. prohibits species already known to be invasive) rather than proactive (i.e. reducing the likelihood of a species being released). As a result, it might take some time before trade bans effectively minimise the number of releases related to the pet trade, and this requires extensive communication. When bans come into effect, mechanisms should be installed to prevent panic releases of pets (e.g. shelters or rescue centres for unwanted pets, communication through stakeholder organisations on the new rules, permit schemes). Strikingly, some well known invasive alien snakes are only invasive in a few specific places: *B. irregularis* on Guam, *L. getula californiae* on Gran Canaria, *P. molurus* in the Everglades and Puerto Rico. It is questionable whether a trade ban would have prevented these invasions (pers. comm. Julien Piquet, 2023). Instead of basing trade bans on risk assessments that largely depend on documented invasion histories, a more proactive approach would be to use results of horizon scans. For outermost territories, more stringent regulations would make sense on top of actionable biosecurity (early detection and rapid response teams, see further), especially snake-free islands that represent biodiversity hotspots globally. For example, as mentioned above, the entire Colubridae family is regulated on Ibiza, Formentera and the Canary Islands. Evidently, such measures require to be grounded in evidence provided by broad scale risk assessment, pathway prioritisation or horizon scanning.

For a species to be listed among the species of Union concern, it is necessary to perform a detailed risk assessment. Hence it is unlikely that an entire taxonomic group (or even a large number of species) will be considered for listing. It is more likely that species may be listed among those of Union concern one by one based on their actual or potential risk of introduction, establishment, spread and impact, which in fact may limit the possibility of listing a group of species with the highest risk and priority. Likewise, the listing of species on a national list probably requires an evidence base from horizon scans or risk assessments, so will likely also be slow to implement. Some Member States (such as Spain, Netherlands, Belgium, Malta, Luxemburg, Croatia) have specific legislation in this regard (Toland *et al.,* 2020), including in relation to pet trade. No information is available on the impact or effectiveness of these legal instruments.

Ladder snake from Formentera, Balearic Islands. © COFIB-Ibiza.

Although banning a species could be effective for reducing the prevalence of species in the official pet trade, (part of) the trade could move to unofficial markets which could still maintain an (illegal) flow of listed species to and within the EU. Indeed, wildlife trade has been shifting from physical markets to (social) media platforms (Facebook, Instagram, Twitter and YouTube) in recent decades. Trade via non-traditional marketplaces (such as websites, fairs, social media) has vastly expanded directly to consumer sales, raising the importance of this pathway for analysis and enforcement (Lockwood *et al.,* 2019). For example, several alien birds listed on the National Catalogue of invasive alien species are still commonly sold in Spain through social media (Elkhouri-Vidarte *et al.,* 2023) and even in stores and most likely this is also happening with reptiles. A rapid online survey of online trade on 20 pre-selected Facebook groups specialising in the trade of live birds and reptiles in the Philippines, found that 73% of the reptile taxa advertised on Facebook's traders were non-native (Canlas *et al.,* 2017). Regular monitoring of social media which can greatly be facilitated by software tools for media monitoring, could enable the assessment of demand and trends, and help detect the sale of banned invasive alien species (Elkhouri-Vidarte *et al.,* 2023).

Another way of affecting the demand for exotic pets would be to provide information on unwanted consequences to prospective pet owners. Moorhouse *et al.* (2017) showed that providing information on potential illegality and zoonotic disease risk associated with the purchase of exotic pets could reduce purchase likelihood by potential prospective pet purchasers by up to 40%, whereas information on potential welfare and conservation impacts (species decline) did not significantly lower purchase likelihood.

Other initiatives to prevent releases based on voluntary measures exist. In Florida (USA), for example, a service provided by the state to re-home unwanted pets exists, e.g. the Exotic Pet Amnesty Program[10]. This initiative supports Florida pet owners who need to rehome non-native pets. The program connects owners with qualified adopters who can provide non-native pets with new homes (no penalties or fees for owners).

EFFORT REQUIRED

The measures and regulations adopted will need to be maintained indefinitely and will probably be subject to updates.

RESOURCES REQUIRED

No quantitative details are available on the resources required, but it can be anticipated that they have to cover the following elements:

- Administrative and staff costs of implementing the ban and costs for enforcing the ban.
- Locating all establishments that currently keep invasive alien snakes in order to enforce the ban.
- Developing mechanisms to ensure effective implementation of measures to prevent further releases/escapes.
- Developing and implementing mechanisms to prevent panic releases and legalise or collect animals that were in possession before the ban.
- Costs for communication campaigns.
- The costs for developing risk assessments for priority species should also be considered as a precondition for the species being listed among those of Union concern.

ADDITIONAL COST INFORMATION

Cost of inaction: Any escapes/releases lead to the need for early detection, rapid eradication measures, and monitoring. Given the difficulty in recording the occurrence of invasive alien snakes (and in some cases distinguishing them from native species, especially for the laypeople), all detection, eradication, and monitoring measures require the use of specific tools and methodologies (such as genetic testing or other measures for species determination, special boxes for captures, etc). These are both costly and time-consuming. Nevertheless, it should always be considered that prevention is cheaper than eradication or control.

Cost-effectiveness: High.

Socio-economic aspects: Difficult to evaluate because there are no data concerning the profit from the presence of (invasive) alien snakes in zoos, wildlife parks, and other establishments, but is very likely that both the pet trade sector and the zoo community may challenge the adoption of strict provisions against the keeping of alien snakes in captivity.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Mixed
Social effects: Mixed
Economic effects: Negative

Environmental: A small chance exists that establishments/individuals keeping invasive alien snakes would release them once they are listed for a ban and in case there are no policies in place to prevent panic releases (e.g. permit systems, recognised shelters for taking in unwanted pets), which may lead to illegal introductions.

Social: This measure could potentially decrease health concerns related to invasive alien snakes (bites and pathogens), but would very likely lead to conflicting interests

[10] https://myfwc.com/wildlifehabitats/nonnatives/amnesty-program/

with the pet trade sector and the zoo community, as they may oppose to measures preventing the keeping and trade of alien snakes. Likewise, there could be upset from the amateur herpetological community who want to keep snakes.

Economic: Establishments that decide not to apply for permits and instead decide to give up raising invasive alien snakes may incur income losses. Also, possible negative economic effects may be incurred by establishments involved in keeping invasive alien snakes by having to pay for costly anti-escape measures.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

In general, stakeholders (particularly pet trade industries and zoos) may not easily accept a ban, even if it will help prevent future impacts to native biodiversity and related ecosystem services. The general public, particularly terrarium amateurs or specialist breeders, will mostly be affected by a ban and may therefore not easily accept it. Other people not involved in activities focusing on pet trade and the management of zoological collections may regard a ban particularly favourably. It is fundamental for the public and stakeholders to understand the need to ban a species. The conservation of biodiversity (along with risks for human health in case of snake bites or the spread of pathogens) should be emphasised in awareness and education campaigns.

LEVEL OF CONFIDENCE*

Well established.

Information is well established for the effectiveness of banning the species to prevent introduction events and unlicensed releases and for the effectiveness of preventing escapes. Information of invasive alien snake prevalence in establishments is difficult to source.

* See Appendix

A yearling Black pastel ball python mutation. © Kaorte (CC BY-SA-3.0) via Encyclopedia of Life.

Managing captive animals

MEASURE DESCRIPTION

The reproduction of snakes kept in captivity may be achieved by **isolating sexes** in separate environments. Neutering or maintaining same sex populations may prevent any escaping animals from reproducing and is one of the measures considered in pet codes of practice (e.g. code of conduct from OATA and REPTA; Davenport & Collins, 2016). However, this may not work with all species, such as those known to (facultatively) reproduce parthenogenetically and have the ability to perform long term sperm storage (Booth & Schuett, 2011; Levine *et al.*, 2021). Some of which are also known to be invasive, like the Burmese python (*Python bivittatus*) or the boa constrictor (*Boa constrictor*) (Booth & Schuett, 2016).

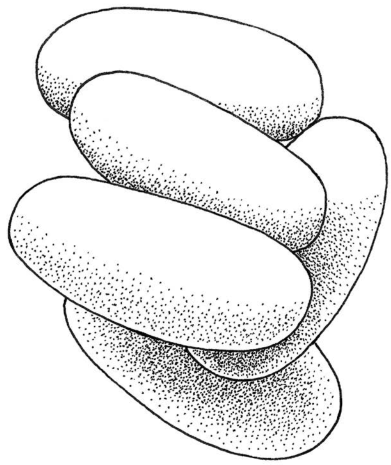
Other measures applied to prevent reproduction may be the **surgical sterilisation**[11] **of specimens** (for example a vasectomy). However, the application of this measure may be limited to a low number of individuals due to costs. As with cats and dogs, sterilisation could be included as a mandatory measure or as part of a code of conduct. Such a measure could be accepted provided a certification mechanism ascertains only certified and authorised breeders can reproduce snakes, thereby reducing market competition. Routine sterilisation could be introduced as part of voluntary measures for pet breeders, stores, zoos etc. so snakes on the market are not able to reproduce, or to reduce the sale of snake food (frozen or live mice) or equipment (terraria, light bulbs) in pet stores thereby limiting the attractiveness of snakes as pets (pers. comm. Julien Piquet, 2023).

Keepers can **replace an egg** with a decoy or choose not to incubate.

Limiting the availability of **nesting habitat** (sandy soil) where to lay their eggs may be another option to prevent reproduction.

Immunocontraception as a potential tool for controlling the brown tree snake in Guam is being investigated, but results are not definitive (Anonymous, 2005).

The (obligatory) implant of passive integrated transponders (**PIT**) in reptiles kept as pets or in zoological facilities (duly reported in a register in association with the names of the owners) may be a useful side-measure to identify individual animals, and discourage owners from letting their snakes reproduce and escape from captivity (see Hegan, 2014). For example, the use of PIT tags (in association to enhanced biosecurity measures) is mandatory in Florida (USA) for people keeping high-risk non-native reptiles that are not allowed for personal use anymore, but that may continue to be in the possession of the owner for the life of the animal with a valid license[12,13].



Lampropeltis getula eggs. © Massimiliano Lipperi, Studio Wildart.

SCALE OF APPLICATION

These measures can only be applied locally, in target facilities and establishments. Surgical sterilisation will often require a veterinarian and might therefore be more useful for large facilities such as zoos.

EFFECTIVENESS OF THE MEASURE

Unknown or not yet applied.

Overall, there is little readily available information on the control of fertility of snakes. Isolating sexes, sterilisation, taking eggs or preventing the availability of nesting habitats should often work (at least for specific species), whereas this is not known for immunocontraception. However, the effectiveness of such measures will largely depend on the target species and the overall context. One important point is that some snake species are able to perform sperm storage. Many pet snakes are reproducing after long periods in captivity without contact with another snake, suggesting sperm can be stored for years. For example, long-term (5 years) sperm storage was documented in the eastern diamond-backed rattlesnake (*Crotalus adamanteus*) (Booth & Schuett, 2011). Hence, isolating sexes might not be a fool-proof way of preventing reproduction.

[11] https://www.youtube.com/watch?v=JErw7qoM3vw
[12] https://www.flrules.org/gateway/ChapterHome.asp?Chapter=68-5,
[13] https://myfwc.com/wildlifehabitats/nonnatives/rule-development/

EFFORT REQUIRED

In principle, surgical sterilisation or the housing of different sexes in separate facilities is a one-time operation. Isolating sexes, taking eggs and preventing the availability of nesting habitats should be done regularly (the same is likely for immunocontraception).

RESOURCES REQUIRED

Veterinary surgical expertise and appropriate tools and facilities.

ADDITIONAL COST INFORMATION

No information available, but surgical sterilisation and immunocontraception are likely to be relatively expensive measures to undertake, while isolating sexes, taking eggs and preventing the availability of nesting habitats should be relatively cheap.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: None
Social effects: None
Economic effects: Negative

No side effects are expected in general, although the lack of reproduction may lead to a lack of income for those private or public facilities reproducing snakes for profit.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

It may be expected that these measures will not be popular among pet traders or within the zoo community, as they would affect the actual recruitment of other snakes for their business. For the zoo community, it might be less acceptable to prevent breeding from the perspective of the need to breed species for ex-situ conservation. For commercial breeders it would evidently be problematic and could inadvertently cause the increase of wild caught animals in trade which could have biodiversity impacts in those areas (pers. comm. John Measey, 2023). However, these measures will probably be acceptable to the general public and likely to those stakeholders who are concerned about the welfare of animals kept in captivity. Mandatory sterilisation could be accepted provided a certification mechanism ascertains only certified and authorised breeders can produce snakes, thereby reducing market competition.

LEVEL OF CONFIDENCE*

Established but incomplete.

There is limited information available on surgical sterilisation for the species, as well as for the other techniques.

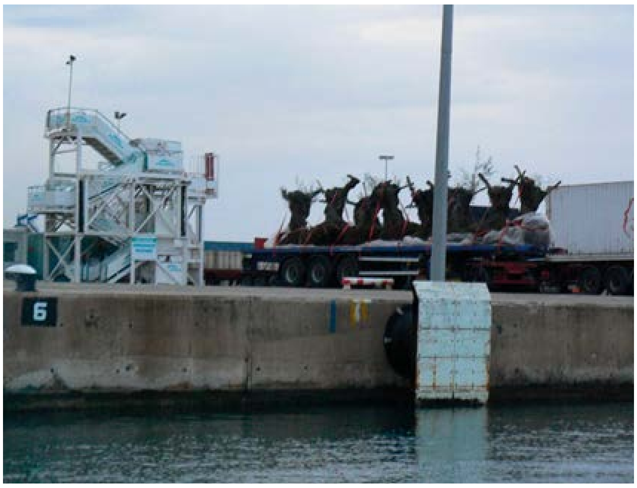
* See Appendix

Biosecurity measures and pathway action plans

MEASURE DESCRIPTION

Invasive alien snakes have been introduced to new areas either unintentionally through a variety of pathways, including the pet trade (see measures above), contaminants on plants (such as olive trees in the Mediterranean) or habitat materials (such as *Natrix maura* on shipments of wood chips used in gardening; unpublished data) and on transport commodities via airports, seaports, roads, railways, canals, pipelines (Hulme, 2009), and stowaway in air and sea cargo (Hegan, 2014; Atkinson & Atkinson, 2000). These are important pathways for invasive alien snakes. Examples worldwide are the brown tree snake (*Boiga irregularis*) in Guam, where it was probably transported in ships with salvaged war material after World War II (Rodda *et al.,* 1992) and which probably represented a single origin introduction from the Admiralty Archipelago off the north coast of Papua New Guinea (Richmond *et al.,* 2015). Other examples include the common wolf snake (*Lycodon capucinus*) in New Guinea (O'Shea *et al.,* 2018), and possibly the beauty rat snake (*E. taeniura*) in Russia and Korea (Schulz, 1996), transported in Chinese cargo to New Zealand (Gill *et al.,* 2010) or via military pathways in Asia (Pitt *et al.,* 2010). But there are examples also within the EU. In Spain, three species of alien snakes were introduced as stowaways (as contaminant of hundreds of large ornamental olive trees imported from the southern Iberian Peninsula) to the island of Ibiza: Montpellier snake (*Malpolon monspessulanus*) (now likely disappeared), ladder snake (*Zamenis scalaris*) and horseshoe whip snake (*Hemorrhois hippocrepis*) (Montes *et*

Olive trees arriving at Ibiza harbour, Balearic islands. © COFIB-Ibiza.



Three individuals of horseshoe whip snakes captured in the snake traps used in the Balearic Islands. © COFIB-Ibiza.

Horseshoe whip snake captured in a trap in the Balearic Islands. © COFIB-Ibiza.

al., 2021). In fact, most of the records of these three species, and importantly their first appearance in the Balearic Islands, have been recorded by environmental authorities inside trunks or root balls of olive trees deposited in nursery centres (Silva-Rocha *et al.,* 2015). This was also the pathway for the introduction of the horseshoe whip snake (*H. hippocrepis*) on Madeira and the Azores. In the context of alien snakes (and lizards) the olive tree trade is considered a powerful vector for biological invasions across the Mediterranean (Silva-Rocha *et al.,* 2015, 2019). The subterranean Brahminy blind snake (*Indotyphlops braminus*), also known as "flowerpot snake", provides another well known example of an alien snake species that is currently being introduced in Europe (and potentially being much more common already) through the horticultural trade, for example in Malta (Vella *et al.,* 2020) and Ischia Island, Italy (Paolino *et al.,* 2019).

The presence of such species in the EU can pose a risk of further transportation to neighbouring snake-free countries or islands. An example is *L. getula californiae* introduced as a stowaway in 2017 in Lanzarote from Gran Canaria on a pallet of pumpkins (pers. comm. Ramón Gallo Barneto, 2017; Verzelen *et al.*, 2018). There is a record of an introduction of a closely related species, the milksnake (*L. triangulum*), in Indiana, USA, as a cargo stowaway (Kraus, 2009). Similarly, the Indian wolf snake (*Lycodon aulicus*), introduced on Réunion island (an EU outermost territory) from India with shipments of rice around 1830, is believed to have been moved unintentionally to Mauritius in 1879 (Vogel *et al.,* 2021).

Control for pathways of unintentional introduction and spread can be performed through increased **biosecurity measures** to prevent new introductions, along with the implementation of **pathway action plans** (as foreseen by Article 13 of the EU Regulation on IAS). Such measures require grounding in evidence provided by broad scale risk assessment, pathway identification and prioritisation or horizon scanning. As described in the case of intentional introductions, there are codes of conduct and best practice which can supplement other regulatory frameworks, and can be implemented at either the national or regional level. Examples of codes that may be relevant in relation to the unintentional introduction of snakes, besides those for the pet trade and the zoo sectors, are:

– Scalera, R. 2017. European Code of Conduct on International Travel and Invasive Alien Species. Council of Europe, Strasbourg, France. T-PVS/Inf(2017)1[14].
– Heywood, V., Brunel, S. 2008. European Code of Conduct on Horticulture and Invasive Alien Plant. Council of Europe, Strasbourg, France. T-PVS/Inf(2008)2[15].

In the Balearic Islands (Spain) for example, specific measures regulating the entry of ornamental trees have been recently adopted by law (pers. comm. Víctor Colomar, 2023). More specifically, the measure concerns controls on the import of ornamental trees susceptible of carrying snakes in the trunk holes, i.e. *Olea europaea*, *Ceratonia silica* and *Quercus* spp., (with a trunk perimeter larger than 40cm). These trees are not allowed to enter the archipelago during the nesting period of snakes (1st of April - 15th of June and 15th of September – 15th of October). During this period, it is mandatory to certify that trees are free from ophidians with a special permission awarded by the Regional Environment Department, following a 4 week quarantine with exposure to snake traps (1 trap /20 trees or 1 trap/500m^2) and inspections by specialised sniffer dogs. Apart from that, the documentation has to be completed with all the information relative to each tree, i.e. origin, date and time of extraction and arrival, traceability. In case of detection of ophidians without meeting the expected requirements, the trees will be either destroyed or returned back to the point of origin. Violations of these rules will be punished by different ranges of fines depending on gravity (Decreto-ley 1/2023, BOE[16]).

[14] https://rm.coe.int/european-code-of-conduct-on-international-travel-and-invasive-alien/168075e833
[15] https://rm.coe.int/1680746a50
[16] Decreto-ley 1/2023, de 30 de enero, de medidas extraordinarias y urgentes para la protección de la lagartija pitiusa (*Podarcis pityusensis*) y la lagartija balear (*Podarcis lilfordi*) y para la prevención y lucha contra las especies de la familia Colubridae sensu lato. Boletín Oficial del Estado, 140, de 13 de junio de 2023. https://www.boe.es/boe/dias/2023/06/13/pdfs/BOE-A-2023-13967.pdf

Establishing biosecurity measures is already mandatory for outermost regions under the EU IAS Regulation. However, effective implementation of these measures is lagging behind (Medina *et al.,* 2018). Lower investment rates in biodiversity conservation in such regions but also lack of scientific capacity could represent hindrances to implementation (pers. comm. Julien Piquet, 2023). The latter could perhaps be solved by supporting panels of experts (local as well as foreign experts, managers) to perform specific horizon scans and establish pathway action plans. One such example of closing biosecurity gaps is the way the United Kingdom Darwin+ fund mobilises expertise for systematic horizon scans of their Overseas Territories[17]. In general, given the obvious knowledge gaps and paucity of data on the management of invasive reptiles and snakes in particular (Crystal-Ornelas & Lockwood, 2020), general measures for knowledge transfer are needed and could be very beneficial for the management of new snake invasions. Managers will often have to make decisions without prior knowledge of the ecology and behaviour of a (novel) snake species they are confronted with, as was the case with *L. getula californiae* (Cabrera-Pérez *et al.,* 2012). They will have to apply adaptive management and start doing something without perfect understanding of the species ecology or the impact of management measures on the population. Establishing and supporting such mechanisms for knowledge transfer, for instance at global or European level could reduce time lags between snake detection and field interventions and this applies to all preventative or control measures.

Checking for stowaway specimens of invasive alien snakes in airports and harbours from within (and outside) the EU is a potential method for preventing new accidental introductions. For example, the presence and impact of the Montpellier snake (*M. monspessulanus*) introduced to Mallorca highlights the need for implementing biosecurity measures (along with control) to prevent new arrivals of snakes and to avoid the invasion not only on the entire island, but also in the rest of the archipelago (Febrer-Serra *et al.,* 2021). The same recommendations are found in a risk assessment for the asp viper (*V. aspis*) made in the Netherlands (Van de Koppel *et al.,* 2012a), where the species has been eradicated, which suggests to consider thorough controls of the cargo before shipment to prevent the species from hitch-hiking in cargo transport (although chances of introduction of asp vipers through transport are considered very low). Similar risks exist for the California kingsnake (*L. getula californiae*) on Gran Canaria (Canary islands, Spain), yet Friebohle *et al.* (2020) were not aware of any plans, to their knowledge, to increase port biosecurity to prevent kingsnakes from moving to other islands of the Canary Islands Archipelago. The lack of control mechanisms (outside airports) was also illustrated by the numerous documented movements of Barbary ground squirrel (*Atlantoxerus getulus*) from Fuerteventura to other islands between 1996 and 2016. If movements of these medium-sized vertebrates are taking place regularly, the number of smaller species transported within the archipelago could potentially be much greater (Medina *et al.,* 2018). The actual incidence of this phenomenon (introductions of snakes through stowaways) in Europe is largely unknown and possibly natural colonisation and spread from populations resulting from pet trade is a much more important pathway of introduction. However, it is known from experience in other countries beyond Europe, that the spread of alien snakes as a contaminant or as a stowaway can be a serious threat and requires the adoption of a number of biosecurity measures. A major example is the brown tree snake (*B. irregularis*), native to Australia, introduced in the Pacific island of Guam as a stowaway in ship cargo shortly after World War II.

Basically, under this measure, transported goods should be regularly checked for stowaways. The checking of invasive alien snakes for stowaways can be done manually/visually or via new techniques such as environmental DNA (eDNA) (see measures described under the *Surveillance for early detection* and *Management* sections). Samples from the consignment can be visually checked for unwanted species, however this is very difficult when the stowaway species is present in small quantities or when the container to be checked is very big, so unwanted species can be easily overlooked. New tools like **eDNA** are promising. Depending on the technique used, one can test for the presence of one species, several unwanted species, or the whole array of invasive alien snakes present in the containment. Unfortunately, at the moment, these tests are not quick enough to be used as an instant tool to detect stowaways. Temporary **quarantine** of newly arrived consignments is necessary to wait for the results (at least 48 hours). The use of **artificial intelligence**[18] to recognise the shapes of animals when scanned at international frontlines such as airports and mail centres may also support the detection of invasive alien snakes. Apart from increased inspections and control of goods, **awareness raising** can be performed with pet trade dealers and pet amateurs about the risk of accidental translocation of invasive alien snakes. Additionally, pathway risk analysis can reveal the riskiest pathways and commodities. As unintended contaminants and secondary movements of snakes are very likely to occur, raising awareness with staff that receive and handle risky consignments is important. This can be achieved, for instance, by displaying posters with a wide range of potential contaminant/stowaway species, the provision of identification materials (apps, leaflets) and the increase in capacity through training. For example,

[17] https://www.nonnativespecies.org/overseas-territories/#

Stringham and Lockwood (2018) found that among reptiles and amphibians in the pet trade, species with the highest probability of being released are usually those that are both prevalent in the pet trade (for example, because they are imported at higher quantities and cheaper retail prices) and large-bodied or long-living. This result may aid in addressing the problem through awareness-raising campaigns and other solutions with the aim of decreasing the risk of releases of pets.

The limits and potentialities of biosecurity measures are well documented in the case of the brown tree snake in Guam. Because of its huge impact on the island's biodiversity, this species is now the target of important biosecurity measures to prevent it from accidentally spreading as a stowaway in cargo from Guam to other Pacific islands, where many incursions have been repeatedly intercepted throughout the years (Atkinson & Atkinson, 2000; Rodder & Lotters, 2010). Such measures include maintaining strict cargo checks of boats and searches at airports, as well as increased awareness and careful inspection of materials and baggage shipped from or through Guam (Wittenberg & Cock, 2001). This can be achieved through many different methods and tools, such as **physical and electrical barriers** that keep snakes out of the areas where cargo, aircraft, or maritime vessels are kept (Perry *et al.,* 1998; Clark *et al.,* 2018), and the use of **sentinel traps, detection dogs or fumigants** to stop unseen snakes in shipments and supplement **visual searches** at inspection points (Campbell *et al.*, 1999; Engeman & Vice, 2001b; Stanford & Rodda, 2007). Ports and airports could be made less attractive to brown tree snakes by reducing **prey availability** around cargo and vessels or using deterrents, such as **chemicals or bright lights** (Campbell *et al.*, 1999; Engeman & Vice, 2001b; Clark *et al.*, 2018). There are also methods employed for the verification and capture of a snake, once a detector dog has identified its presence in a cargo, that do not require dismantling the container or the pallets (Clark *et al.,* 2018). They include the use of **thermal fumigation** (or alternatively, radiant energy) which are simple, chemical-free methods of sanitising cargo through extreme temperature exposure (between 48°C and 52°C at 3.4 m^3/min) that can induce snakes to escape from cargo within five minutes (Kraus *et al.*, 2015a; Clark *et al.*, 2018). Other methods used for killing brown tree snakes include the fumigation of cargo with active ingredients such as methyl bromide, sulfuryl fluoride and magnesium

[18] https://theconversation.com/lizard-in-your-luggage-were-using-artificial-intelligence-to-detect-wildlife-trafficking-189779?fbclid=IwAR0AJRmIjzkLhlctuhwnb

Dog Russel marking a vehicle in Mercalaspalmas (Canary Islands). © Sara Ordoñez Losada

phosphide, or the use of **chemical barrier** systems to expose snakes to chemical irritants (such as camphor, naphthalene, or sulphur), sticky tactile products (such as polybutenes) or other aerosolised or vaporised repellents such as a "**tear gas**".

In Guam, specially trained dogs are used to detect brown tree snakes around ports and in cargo handling areas to reduce the risks of dispersal to other islands (Engeman & Vice, 2001b), while authorities have also begun to evaluate the utility of dogs in early detection and rapid response activities on islands not yet impacted by snakes (Clark *et al.,* 2018). For additional details on detection dogs see *Sniffer dogs* section.

SCALE OF APPLICATION

Regarding the implementation of biosecurity measures, besides the experiences described in Guam (showing that such measures may work relatively well at the scale of an island as large as 549 km^2, or a specific area), no data is available on whether these measures have been applied yet in Europe. Most Member States should have some form of preventive measures to avoid unintentional introductions of stowaway species in consignments at points of entry (airports and harbours), but it is unclear how and whether they are enforced. As part of the EU Regulation on IAS, pathway management plans for invasive alien species in general (hence not exclusively on invasive alien snakes) are being adopted and implemented in all EU Member States; however, no information is available yet on the impact of such tools.

Voluntary or mandatory measures to reduce the chances of snakes escaping from contained holdings can potentially be applied at all spatial scales. At the European level, awareness-raising campaigns can be run (for example, Beware of Aliens). On islands, where the origin of snake introductions through escapes is potentially more easily sourced (due to fewer pet stores and zoos), it is perhaps easier to regulate.

EFFECTIVENESS OF THE MEASURE

Neutral.

It is important to recognise that biosecurity application plans for snakes are quite complicated, since they are quite elusive and difficult to detect (pers. comm. Víctor Colomar, 2023). They can come in the adult stage, or as eggs, which are even more difficult to detect. Moreover, it was noted that the low detectability of reptiles, associated with potentially high cost and low efficacy, can limit the management options for alien reptiles. This was documented on Christmas Island (Australia) for some reptile species, including the flowerpot snake (*Indotyphlops braminus*) and the wolf snake (*Lycodon capucinus*), although such conclusions are considered applicable more generally to many other contexts (García-Díaz *et al.,* 2019). This also emphasises the importance of implementing strict biosecurity measures to detect incoming alien reptiles at quarantine border controls before those individuals can escape and establish into the wild.

Manual and visual checking for stowaways is difficult and unwanted species can easily be overlooked (for instance, import control of large trucks has proven to be very difficult). Therefore, the screening of goods and consignments is not fully efficient. New tools like eDNA are promising, but at the moment these tests are not quick enough to be used as an instant tool to detect stowaways. Testing for eDNA of unwanted species is ideally combined with temporary quarantine of newly arrived consignments. In the future, this measure may become more effective through the use of these new molecular techniques.

As summarised by Stanford and Rodda (2007) on the experience with the brown tree snake in Guam, despite the efforts and relative success in reducing the likelihood of snakes being transported to new locations, no inspection program can be 100% effective, as all control tools experience occasional failures and some shippers even actively evade the voluntary inspection program. Nevertheless, some specific methods proved to be very effective: for example, the use of **temporary barriers** was 93% to 99% effective at restricting snake movement at cargo staging areas (Clark *et al.*, 2018; Perry *et al.*, 1998). Fumigation methods based on other chemical repellents (i.e. chloroform, naphthalene, carbon dioxide) have also been tested but appeared not to be effective for eliciting the exit of brown tree snakes from cargo (Kraus *et al.,* 2015b). Other, more effective gasses (for example, methyl bromide) or compounds might face legal barriers for application.

According to Engeman and Vice (2001b), the efficacy of **detector dogs** for locating stowed brown tree snakes in cargo depends on the capability of the team, composed of the dog and handler. This was tested in a controlled situation and showed that up to 70–80% of snakes were located in optimal situations (Engeman *et al.,* 1998), though much less before the test became a routine procedure. Detection rates averaged 62% for brown tree snakes in escape-proof containers planted in cargo without the knowledge of the dog handlers (Engeman *et al.,* 2002). This was likely due to insufficient search patterns by the handler, or the handler not detecting an indication from the dog that a snake was present, showing the complexity of the interaction between a dog and a handler.

In general, the main impediment to effective snake control has been the lack of clear **jurisdictional responsibility** and a reluctance to commit the necessary **funds and time** (Campbell *et al.,* 1999). In any case, it would be economically unsustainable to maintain permanent interdiction measures at all potential cargo destinations on a given island (Stanford & Rodda, 2007). Another limit is due to the fact that some searchers are more effective than others, and **inexperienced searchers** are less effective than trained searchers, especially in islands where there are no native snakes on which to practise searching (Stanford & Rodda, 2007). Nevertheless, the extensive concerted program implemented by the USA authorities since 1993 to reduce the potential for brown tree snakes to accidentally enter Guam's transportation system is considered highly cost-effective (Stanford & Rodda, 2007).

As part of the EU Regulation on IAS, pathway management plans for invasive alien species in general (hence not exclusively on invasive alien snakes) are being adopted and implemented in all EU Member States. However, no information is available yet on the effectiveness of such plans.

EFFORT REQUIRED

To be effective, biosecurity should be supported by a system enforced as part of a sound legislation framework, to be applied consistently at all levels of organisation, with relevant authorities checking effectively and systematically all transports and consignments.

In order to guarantee the effectiveness of the pathway management plans, this measure would need to be implemented on a permanent basis.

RESOURCES REQUIRED

The resources needed for these preventive measures include staff costs, costs for cars and materials to check the consignments, equipment to implement the various techniques (traps, detection dogs, chemical or physical barriers, material for fumigation, etc.), as well as budgets for the training of personnel at inspection points and raising awareness.

The costs for developing pathway action plans should also be considered as a pre-condition for the relevant pathways to be managed accordingly.

However, no published information is available about the required resources for these measures in Europe.

According to an assessment of the costs of prevention and control related to the potential arrival of the brown tree snake in Hawaii made by Burnett *et al.* (2006), "Under current prevention expenditures of $2.6 million, Hawaii faces an approximate 90 percent probability that a single snake will arrive over a ten-year time horizon. If expenditures were increased to $4.7 million, the probability of a single arrival decreases twofold, to about 45 percent. Finally, if we increase preventative spending to $9 million per year, the probability of an arrival decreases another twofold, to about 20 percent". And also: "To maintain a zero population of snakes, we would need to spend $1 million to eradicate any potential entrant".

ADDITIONAL COST INFORMATION

No data are available for Europe, but it is possible to get a general idea of the resources at stake by looking at the USA, where every year some $4.6 million are spent to manage one species only, the brown tree snake, hence showing that the cost of inaction may be quite high (Pimentel *et al.*, 2000; Stanford & Rodda, 2007; Simberloff, 2002). Although control tools for brown tree snakes are better developed than for almost any other reptile (Stanford & Rodda, 2007), eradication of established populations is expensive and difficult (Rodda *et al.,* 2002; Rödder & Lotters, 2010) and the ecological and economic costs of inaction are great. Indeed, confining the snakes to Guam is considered intrinsically more cost-effective than eradicating them on a new island (Campbell *et al.,* 1999).

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Positive
Social effects: Positive
Economic effects: Negative

A positive environmental effect could be the possible detection of other, non-desired invasive alien species that are known to be introduced through the same pathways. Also, the social effects would be positive, because the implementation of biosecurity measures is aimed at preventing further societal impacts, including on human health.

A negative economic effect could occur for the goods dealer, when an infested consignment is found. The effect could become larger if the infestation is detected at the level of an entire cargo.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

This measure should be generally acceptable, but traders of goods might not be so happy with it, so perhaps mixed. To increase the level of acceptability, pathway action plans should be developed in collaboration with the key stakeholders, for example by engaging with and involving representatives from relevant associations and organisations acting at the national level.

LEVEL OF CONFIDENCE*

Established but incomplete.

The lack of information on the actual implementation and impact of biosecurity measures for invasive alien snakes in the EU and relevant Member States does not allow to consider such measure well established.

* See Appendix

Measures to prevent the species spreading once they have been introduced.

Physical and electrical barriers (exclosure fencing)

MEASURE DESCRIPTION

Prevention of (unaided) secondary spread can be achieved by installing physical or electrical barriers, for example through different types of fencing (Engeman & Vice, 2001b; Clark *et al.*, 2018). The aim of fencing is to prevent further dispersal of invasive alien snakes from already existing populations into new suitable reproduction habitats. This measure can be especially useful to support biosecurity measures (see *Biosecurity measures and pathway action plans* section), to restrict the dispersal of newly introduced populations, and also to limit movement in sites undergoing control or eradications (Rodda *et al.*, 2002; Rodda & Savidge, 2007; Hegan, 2014). For this purpose, fences may be combined with **trapping**, such as terrestrial drift fences with funnel and pitfall traps, in which case the method is also suitable for management, as well as for surveillance and monitoring, as experienced with *L. getula* in its native range in South Carolina (Winne, 2007). Additionally, fences need to be buried below ground level to prevent snakes from escaping, and may be complemented with **electrified wire or poly tape** to increase overall effectiveness (particularly if mortality of the animals is not a concern, see Weisser *et al.* (2017), although animal welfare aspects need to be taken into account). Hayashi *et al.* (1983) describe an electrified (480 mA, estimated peak of 8 to 10 kV), 60cm high fence to prevent the invasion of habitats (by *Trimeresurus flavoviridis*) around three villages in southern Japan. The snakes were effectively prevented from entering the area and were observed to aggregate outside the fence.

Besides preventing snakes from spreading further from already invaded areas, fencing can also be applied to protect vulnerable sites from alien snake invasion and preserve specific conservation assets by creating **snake-free sanctuaries** for native wildlife. This strategy of "creating insularity" (cf. Rodda *et al.,* 2002) could be useful to consider in the case of naivety of endemic prey that is heavily impacted by alien snakes. We could however not find any documented cases where this strategy was applied. For such pest-free areas to remain free of snakes this would equally require an investment in early detection, ensuring barrier integrity etc.

Fencing designs and materials may be varied as reported by Weisser *et al.* (2017), who were testing the effectiveness of the method. For *E. obsoleta* the recommended height of a fence should be in the range of about 1–2 meters, while the materials may include textured cloth/erosion fencing, weather shade, wire mesh, netting, vinyl, masonry, concrete, fly ash applied to a foundation wall, and various combinations of electrified fencing as reported above (but see the original work for technical details). Other technical details for the design of temporary barriers, particularly those being used for excluding snakes at cargo staging areas, are provided by Clark *et al.* (2018), although the focus of this publication is on brown tree snakes. Infrastructure such as roads or runways may also represent barriers to the dispersal of brown tree snakes, at least partially, depending on traffic volume, gap width, and surface type (Clark & Savarie, 2012). For other snake species that are more fossorial or are able to use underground refuges for movement or resting, barriers should be buried, typically at a depth of at least 15 cm but potentially this should be much deeper, for instance for *L. getula*. When engaging in snake-proof fencing, herpetologists, local wildlife authorities or snake control experts should be consulted to seek advice on the most appropriate barrier for the specific species (material and mesh size, height and burial depth, angle), location and needs, and/or consult various sources of best practices in fencing[19] (for example Perry *et al.*, 2001; OMNR, 2013).

Other types of barriers aimed at protecting homes and infrastructures, as well as children from bites or wildlife from predation (such as nesting birds) are also available, see details in Campbell *et al.* (1999). However, this represents a barrier for species spread only very locally, for example risk areas/sites.

SCALE OF APPLICATION

There is little information on the scale of application of this measure, but is likely to be effective only locally and for relatively small areas (but see Hayashi *et al.,* 1983, who successfully fenced 6.75 ha with 1000 m fence, 13.7 ha with 2100 m and 23.8 ha with 2500 m) as often the detection threshold for snakes is low and therefore they will

[19] https://www.ontario.ca/page/reptile-and-amphibian-exclusion-fencing

Pictures of a double funnel trap. © Jorge Saavedra Bolaños.

be detected only when numbers are already fairly high. In Guam, for example, where four successful barrier designs for the brown tree snake have been developed and tested for management purposes (hence not specifically to prevent spread), a 23 ha site has been largely trapped out following the erection of a fence around the perimeter, although not all snakes had been captured from inside (Rodda *et al.,* 2002).

EFFECTIVENESS OF THE MEASURE

Effective.

A specific fence designed by Weisser *et al.* (2017) that aimed at preventing the escape of rat snakes (*E. obsoleta*) was not sufficient to confine mature rat snakes, despite the use of electric wires and a repellent. In Guam, the use of **temporary barriers** was 93% to 99% effective at restricting brown tree snake movement in laboratory tests (Perry *et al.,* 1998). Nevertheless, a number of practical problems were encountered in the design of snake barriers in Guam, like the extraordinary climbing abilities of brown tree snakes, high levels of rat damage to chewable barrier surfaces in snake-reduced areas, high maintenance requirements of low-cost barriers, and frequent and destructive cyclonic storms (Rodda *et al.,* 2002).

Barrier effectiveness and durability to create a snake-free habitat in Guam were studied by Rodda *et al.* (2002), who identified four classes of successful designs: temporary, bulge, masonry, and vinyl. The pre-stressed molded concrete design was 100% successful in repelling snakes, and impervious to rat and typhoon damage. Rodda *et al.* (2007a) also tested the feasibility of a fly-ash covered wall design, and concluded that this may provide a cost-effective barrier for brown tree snake, provided specific criteria are met (with the only main challenge being large snake size).

Drift fences were successfully applied in association with funnel traps on a wildlife refuge in Nebraska to control bullsnakes (*Pituophis catenifer*), which are actually native to the area, but did represent a threat to waterfowl nests (Imler, 1945). However, the aim of this measure here was to manage the species, rather than to prevent its spread.

Overall, the effectiveness of this measure will depend on the actual species targeted, and the specific environmental context.

EFFORT REQUIRED

The fence or dispersal barrier should be installed for as long as there is a risk for invasive alien snakes dispersing out of the invaded habitat.

The integrity of the fence should be regularly checked (for vandalism, falling branches, storms, etc.). If a fence is kept for several consecutive years, appropriate materials should be chosen that resist UV degradation (for example permanent exclusion panels made from UV-stable recycled plastic). Failures in material and installation represent the most important factor impairing the effectiveness of exclosure fences for reptiles (Baxter-Gilbert *et al.,* 2015).

RESOURCES REQUIRED

There are significant differences in the cost associated with the type of barrier used and the expected duration. Fencing is relatively cheap in terms of the required materials and work effort for the setup, but when combined with electric wires, and/or trapping, costs may rise. For example, checking the traps for captured snakes would require high effort of time investment.

Maintenance costs may also be important, for example Weisser *et al.* (2017) noted that while concrete or masonry structures are reported to be effective, they would likely be cost prohibitive under a number of scenarios, so an inexpensive, short-term fence designed to keep snakes within an enclosure as a component of a repellent study may be a preferred option.

A reptile protection fence to prevent whip snakes from migrating outside of their range. The fence stands 1 m high and is buried in the ground. It is a stable film that is UV-resistant. © Hubert Laufer.

Barrier durability to create a snake-free habitat in Guam was studied by Rodda *et al.* (2002), who reported a fairly high initial cost (c. $300/m), despite a conservative life expectancy of fifty years.

ADDITIONAL COST INFORMATION

Information on cost approximation could be retrieved by exploring the many commercially available snake fences, although it should be acknowledged that many are designed for household applications and invasive alien species management programs are probably often run at other spatial scales. In an attempt to eradicate the green whip snake (*Hierophis viridiflavus*) from a landfill site in Rhineland-Palatinate (Germany), a UV-resistant, smooth film was attached to an existing chain-link fence around the landfill. The fence was buried at least 30 cm into the ground, was 1 m high and approximately 3.5 km long (information: Büro für Landschaftsökologie LAUFER, pers. comm. Hubert Laufer, 2023). The materials and construction cost around €60,000. The fence is damaged by bigger wildlife (such as wild boars, deer), but also by small mammals. Therefore, it must be checked and repaired regularly, which incurs additional costs.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Negative
Social effects: None
Economic effects: None

The non-target environmental effects of fencing may also be negative, as the presence of a fence also prevents dispersal of native species both to and from a site. This effect will vary depending on the timing of application and the period during which the area in focus is fenced, so it can be minimised. No social or economic effects of fencing are documented.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

The prevention of dispersal of native animals to and from a fenced site might be somewhat unacceptable to conservationists. However, this effect can be mitigated depending on the timing and duration of keeping the barriers installed and so, if explained accordingly to stakeholders (including the general public), acceptability might increase.

LEVEL OF CONFIDENCE*

Established but incomplete.

Fencing is a well-established method that has been widely used to prevent snake dispersal, but information on its effectiveness is still scanty (and mostly focusing on experiences for the species management rather than preventing spread).

* See Appendix

Public awareness

MEASURE DESCRIPTION

Raising public awareness of the risks posed by invasive alien species in general is undoubtedly an important management tool to deal with invasive alien snakes (see measures described under the *Rapid eradication* and *Management* sections below), and to prevent their introduction and spread (see also the measures described under the *Surveillance for early detection* section). Examples of educational material to raise awareness on the risk of spread of invasive alien snakes is available for Europe in relation to the management of the California kingsnake (*L. getula californiae*) in Gran Canaria. In particular, identification and publicity material have been produced as part of the LIFE10 NAT/ES/000565 project[20] and are still being produced as part of the STOPCULEBRAREAL project[21]. This campaign also includes a smartphone application[22] for citizens to report on snake occurrences. According to Gallo Barneto *et al.* (2023) the dissemination campaign has been essential to promote citizen participation in the management of the alien snake. Having a communication strategy, based on social media and updated related content hosted in a project website, has become an essential outreach element promoting the call for action through volunteering activities and informative workshops.

Similar results were stressed by Montes *et al.* (2021, 2022) in relation to the management of the invasive alien horseshoe whip snake *(H. hippocrepis*) on the island of Ibiza (Balearic Islands, Spain) where this species is threatening the only endemic vertebrate, the Ibiza Wall Lizard (*Podarcis pityusensis*) with extinction. In this context, public-education programs were developed to improve the reporting of snake sightings and increase the likelihood of snake removal. Immediate reporting of snakes in fact is considered essential to their successful capture by management personnel, and improved public engagement is very much needed for this. It should be noted that dealing with citizens (communication, provision of information, collection of snakes that have been caught) can also require considerable time and effort from field operators that cannot be otherwise spent on actively searching for snakes in other, more poorly inhabited areas, as was noted in the California kingsnake program on Gran Canaria (pers. comm. Julien Piquet, 2023). Public awareness campaigns and citizenship involvement should be carefully planned and citizen groups should be implicated in control programs in an organized fashion (for example using trusted “champions” that have direct communication with management staff, creating local nodes that can filter data, information and collect trapped animals). The need of raising awareness to ensure the correct involvement of citizens, including for reporting and trapping snakes themselves (as well as helping on the management/maintenance of traps) is fundamental. For example, the improvement of an effective information network in Ibiza (through the establishment of an information protocol for public services, the creation of a network of informants between public services, through talks given between these groups, the preparation of an informative leaflet, and an information campaign among the Ibizan population with the help of the leaflet) were key objectives of a project in Ibiza for the management of the horseshoe whip snake (Montes *et al.,* 2015). Similarly, an information campaign was undertaken to assist the first campaign for the control of the Montpellier snake (*M. monspessulanus*) in Mallorca (Rubio *et al.,* 2023). In relation to the use of net-traps to catch Habu snakes (*T. flavoviridis*) on Okinawa, Japan, Nishimura (2011) noted that nets were mainly set around residential properties to be checked and maintained by the residents. The same was reported for the removal of snakes in Ibiza (Balearic islands, Spain) where a volunteer group was structured to maintain snake traps (with relevant live baits, hence which needed to be visited regularly) scattered throughout the island of Ibiza to overcome the scarcity of governmental human resources available to tackle invasive alien snakes (Costa & Martínez, 2023).

In relation to snake management, a risk assessment was done for the asp viper (*V. aspis*) in the Netherlands (Van de Koppel *et al.,* 2012a), where the species is not present anymore (and had been in suboptimal climatic conditions) after being eradicated in 2006 (pers. comm. Walter Getreuer, 2023). The risk assessment identified public education as an important preventive measure against introduction of asp vipers in the Netherlands. Public awareness and stakeholder engagement are also fundamental elements for a successful implementation of the codes of conduct or the pathway action plans described under the *Prevention* section. For example, according to the result of the risk assessment of asp vipers (*V. aspis*) in the Netherlands (Van de Koppel *et al.,* 2012a), releases from captivity were considered an important introduction pathway (though still with an overall low likelihood). Education is a key measure for preventing the deliberate and accidental release of asp vipers, but this consideration can be extended to all invasive alien snakes. As stated in the asp viper risk assessment, information should be clearly directed at snake keepers,

[20] http://www.lifelampropeltis.com/
[21] https://www.stopculebrareal.com/
[22] https://play.google.com/store/apps/details?id=com.inventiaplus.lampropeltis&hl=nl&gl=US

focusing on the consequences and impacts of introductions, as well as on appropriate measures to prevent escapes of snakes from captive facilities. Public education campaigns, in which traders and retailers can play an important role (possibly with the support of the zoo community as well), are essential to reach potential releasers. Public education could also help prevent asp vipers (or any other alien snakes) from ending up in the luggage or cars of travellers, although chances of introduction of asp vipers through transport are very low (Van de Koppel *et al.,* 2012a).

SCALE OF APPLICATION

In order to guarantee the effectiveness of the awareness-raising campaigns, this measure would need to be implemented on a permanent basis.

EFFECTIVENESS OF THE MEASURE

Unknown or not yet applied.

Information on the actual effectiveness of awareness information campaigns in relation to the prevention of alien snake introductions is not available in Europe.

To prevent the brown tree snake from being introduced in a number of Pacific islands with transportation links to Guam, public education programs have been used by both American and Japanese officials in a wide variety of communications (mass media, public seminars, workshops, individual contacts, etc.). This resulted in the support of large numbers of volunteers who facilitated the detection of alien snakes and the implementation of relevant control measures, in a highly cost-effective way (Campbell *et al.,* 1999).

According to Van de Koppel *et al.* (2012a), in relation to the need to prevent the introduction of the asp viper (*V. aspis*) in the Netherlands, a disadvantage of public education is the need of ongoing active maintenance and accompanying costs. This makes it hard to sustain an adequate campaign for a long time-span, with relevant effects rapidly fading.

EFFORT REQUIRED

No information was found on the issue.

RESOURCES REQUIRED

No information was found on the issue.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Positive
Social effects: Positive
Economic effects: None

Environmental side effects of this measure should be generally considered positive, as it may contribute to create awareness on other invasive alien species, hence contributing to prevention, sightings and potential management. The same is applied to the social effects, because it educates people and makes them aware of the issue. Economic effect would be positive as long as this would help prevent impact of invasive alien snakes on biodiversity and ecosystem services (that otherwise would need to be managed and restored).

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

This measure should be generally acceptable to all stakeholders.

LEVEL OF CONFIDENCE*

Inconclusive.

No information was found on the issue.

* See Appendix

Measures to run an effective surveillance system for achieving an early detection of a new occurrence.

Use of passive trapping methods (in high risk areas)

MEASURE DESCRIPTION

This measure aims at setting up a monitoring system at sites that are considered at high risk of introductions within Member States that are known to be vulnerable. The use of traps may be more suited to perform surveys at priority sites (for example, of conservation value) or in small islands, in response to the risk of secondary spread of a species, especially once it has established in nearby areas. The measure can also be used to confirm possible sightings of the species, for example, in association with citizen-science or other methods. For details on the various techniques and tools, please see *Trapping methods and devices* section, below.

A specific trap system usually adopted for snakes in both terrestrial and aquatic environments are **Artificial Cover Objects (ACOs)**, also known as **artificial coverboard arrays**. These may be constructed of metal, wood, or roofing material, such as asphalt shingles boards or cardboards, and placed in both upland and aquatic habitats used by snakes as artificial refugia or to thermoregulate (Matthias *et al.* 2021; Winne, 2007).

Lampropeltis getula is a readily identifiable species often found in association with human activity (Fisher *et al.,* 2021). Encouraging rapid reporting of new incursions increases the likely success of rapid response before the species can become established. In its native range in South Carolina, both artificial coverboard arrays and aquatic funnel traps were successfully used to monitor the population of this species, suggesting that the method may in fact be suitable for surveillance and monitoring in the EU as well (Winne, 2007). However, Winne (2007), in a long-term (1975–2007) study comparing ACOs with drift fences, aquatic funnel traps and opportunistic hand captures in South Carolina, report that the number of snake captures with ACOs (including but not restricted to *L. getula*) was about three times lower compared to the numbers of captured snakes caught in drift fences and funnel traps. Considering this, ACOs do not seem very cost-effective for *L. getula* and need to be combined with active trapping methods (for example using traps with lures). It is also known that time of day, temperature, and sky cover can significantly influence capture rates with ACOs (Joppa *et al.,* 2009).

An artificial cover object (ACO) optimally positioned to provide shelter for snakes. © R. Gallo Barneto.

Reviewing an artificial cover object (ACO) placed between plants. © Jorge Saavedra Bolaños.

SCALE OF APPLICATION

The method may not be cost effective when applied to large scales (especially with live lures and if traps are not selective in their targets). Hence, this method can only be used locally, i.e. at high risk sites or islands.

EFFECTIVENESS OF THE MEASURE

Neutral.

For an objective of early detection within a Member State, the measure is not really feasible to be applied across a large geographic scale, however it could be applied to high risk sites, especially islands, and in any case in areas somehow connected to locations in the same Member States or others that have populations of the species from where individuals may spread to new areas. On the other hand, this technique requires less labour than visual surveys while still providing good results in terms of actual snake occurrence (Yackel Adams *et al.,* 2021).

Artificial Cover Objects (ACOs) are not necessarily very effective for all species. In fact, for many species, capture rates with ACOs are rather small. Although these might work in some species, ACOs mostly show low capture rates (Cox *et al.*, 2009; Welbourne *et al.*, 2020; Lemm & Tobler, 2021) and are therefore not very well suited for early detections at low densities. Nevertheless, ACOs have been suggested to work for other species of snakes in grassland contexts (Olson & Warner, 2003). They could, therefore, as a low-intensity monitoring tool, be combined with other methods such as eDNA or camera traps (Welbourne *et al.,* 2020). For example, active-infrared triggered cameras are described by Welbourne (2013), along with a system referred to as the "Camera Overhead Augmented Temperature" or "COAT" method, which may help targeting multiple species. The Adapted-Hunt Drift Fence Technique (AHDriFT), which combines commercially available game cameras and traditional drift fences to survey reptiles, is another promising combination, as documented by Martin *et al.* (2017) for a number of snake species. This technique allowed to reduce field time by 95% compared to the use of pitfall or funnel traps.

In a 2023 eradication program for an introduced green whip snake (*Hierophis viridiflavus*) population (of the southern subspecies *H. v. carbonarius*) from a 60 ha landfill site in Rhineland-Palatinate (Germany), catching by hand in combination with artificial cover objects places proved to be the most effective method (information: Büro für Landschaftsökologie LAUFER, pers. comm. Hubert Laufer, 2023). Various artificial hiding places were tested (such as foil, hard plastic, corrugated plastic, corrugated sheet metal, smooth sheet metal, roofing felt, wooden panels, stone plates, waste). The best options were foil, hard plastic and roofing of 1 m² in size.

EFFORT REQUIRED

The effort can be considered quite large as the cost for placement of baits and lures, and controlling traps is high. Traps have to be checked at least once a day (potentially more often) depending on several factors, including presence of (other) predators, heat, etc. which may kill the bycatch.

RESOURCES REQUIRED

As active trapping is possible through a number of different methods and, in practice, is mostly integrated with other methods, it is difficult to provide information on costs. It can be assumed that human resources (trapping hours) would represent a relatively bigger cost than many of the trapping materials. There is potentially also the cost of lures for the traps.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental effects: Mixed
Social effects: Mixed
Economic effects: Mixed
Using nets and traps humanely requires regular (daily) checking, to release bycatch of native snakes or other species alive and in good conditions. However, because of the risk of bycatch, the use of traps may have negative effects on other species. Artificial cover objects should not have any negative impact if used appropriately, yet their effectiveness is relatively low (see above). There are no major socio-economic side effects reported in literature, but the use of traps may be seen negatively by citizens and stakeholders, especially those that may cause the death of the animals.

The cost is high and vandalism can be an issue. It may be prevented by providing good on-site (information panels) and on-device (for example on traps and wildlife cameras) information about the control program, although this may also be counterproductive.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.
The use of traps and especially nets may lead to negative perceptions from fishermen, hunters and general public.

As bycatch is released in good condition and traps must be checked daily, animal welfare objections are probably not so much of an issue.

LEVEL OF CONFIDENCE*

Well established.
The methods to catch the species are well described.

* See Appendix

Environmental DNA (eDNA)

MEASURE DESCRIPTION

Environmental DNA (eDNA) sampling is a monitoring technique especially useful for the detection of secretive or elusive, as well as cryptic or rare species, hence potentially very valuable for finding snakes because other methods may be challenging and time-consuming (see Nordstrom *et al.*, 2022). Environmental samples are collected from water or soil and tested for the presence of DNA left by organisms. This fairly new tool has been used mainly to detect aquatic species from water samples (Piaggio *et al.,* 2013), and also for semi aquatic snakes or terrestrial species that occasionally reside in pools (Rose *et al.,* 2019; Mousavi-Derazmahalleh *et al.,* 2023). However there are also examples for terrestrial species of snakes and other reptiles (Nordstrom *et al.*, 2022). In the case of terrestrial environments, for collecting eDNA data of terrestrial species of snakes, surveys are usually done using **Artificial Cover Objects** (ACOs) (Matthias *et al.,* 2021). Regarding ACOs see also *Use of passive trapping methods* section.

In the case of the invasive alien California kingsnake (*L. getula californiae*) introduced in Gran Canaria (Canary Islands) López-González and López-Darías (2023) considered the use of techniques based on eDNA very useful to confirm their presence, as it allowed them to overcome the inherent difficulties that characterise the visual detection and monitoring of this fossorial species. The first step for the use of this technique required the identification of a specific primer for this species. This was achieved using DNA samples isolated from cotton swabs rubbed on the body surface of *L. getula californiae*, and on three different types of artificial surfaces that some snakes had previously rubbed on. According to López-González and López-Darías (2023) in a next phase the optimisation of this technique will allow, given sufficient eDNA is found in the environmental samples soil under ACOs, to reliably and efficiently detect *L. getula californiae* presence in the natural environment of Gran Canaria, as well as in any other place where it is required, solving the difficulty presented by detection through traditional means. Preliminary results showed that soil is not the best but the cotton swabs from directly under the ACOs were sufficient enough (pers. comm. Marta Lopez Darias, 2023). The plan is to look at water samples in the future (pers. comm. Marta López Darias, 2023).

Red cornsnake. © Northganaturalist r (CC BY-NC-3.5) via iNaturalist.

SCALE OF APPLICATION

Sensitivity of the technique depends on the spatial scale at which the survey is applied.

EFFECTIVENESS OF MEASURE

Effective.

It is often reported that eDNA methods may be more accurate than traditional methods, such as trapping or visual surveys. However, uncovering snake DNA from environmental samples using either species-specific or metabarcoding assays has shown varying efficiency, as reviewed by Nordstrom *et al.* (2022), and Mousavi-Derazmahalleh *et al.* (2023). For example, a study on the eDNA of the Burmese python (*P. bivittatus*), a semi-aquatic invasive alien species in Florida, showed that it can be successfully isolated from water samples (Piaggio *et al.,* 2013). Yet, it has also been shown to work in terrestrial soil samples for Burmese python under field conditions, and for red corn snake *Pantherophis guttatus* in the lab with eDNA detected 3.5 h after the snakes had contact with soil and for up to 6 days after their removal (Kucherenko *et al.*, 2018). In contrast, other studies showed that this technique may prove technically and biologically challenging in some cases, including in both terrestrial and semi-aquatic environments (Matthias *et al.,* 2021), and may require a very targeted approach to environmental sampling for successful detection. For example, with the Kirtland's snake (*Clonophis kirtlandii*), eDNA did not seem to offer an advantage over traditional survey methods, possibly because of the low rate of tissue shedding and the rapid degradation of eDNA (Ratsch *et al.*, 2020). Eastern massasauga rattlesnake (*Sistrurus catenatus*) was only detected in two of 100 environmental samples despite their known presence (Baker *et al.*, 2020). Also the study of Rose *et al.* (2019) aimed at detecting two species of watersnake (*Nerodia fasciata* and *N. sipedon*) introduced to California, USA, showed that despite the many successes of eDNA surveys, traditional sampling methods can have higher detection probability for some species, even in aquatic environments. On the other hand, it is recognised that DNA fragments can persist decades or even centuries in soil (depending on circumstances) and may be contaminated by humic substances, hence may not reflect adequately current situations (Nordstrom *et al.,* 2022). For this reason, Rose *et* *al.* (2019) recommend that those tasked with managing species invasions explicitly compare eDNA and traditional survey methods in an occupancy framework to inform their choice of the best method for detecting nascent populations.

EFFORT REQUIRED

No information was found on the issue but presumably sampling for eDNA is well established. Water subsamples can be pooled on the same biofilter to more rapidly obtain presence data at landscape level, before sampling more in depth when positive signals are encountered, such as described for invasive amphibians (van Doorn *et al.,* 2022). Sampling schemes for eDNA generally need to be adapted to the species ecology and activity period to maximise the probability of detection and ideally have an adaptive design.

RESOURCES REQUIRED

Sampling and analysis are best performed with two staff members. Personnel cost can be reduced by sending the samples to dedicated labs.

ADDITIONAL COST INFORMATION

The price per eDNA sample depends on the method used for analysis, providing primers are already developed for the species to be detected. For example, the unitary cost for an eDNA sample for detection of invasive African clawed frog (*Xenopus laevis*) in Belgium was around €190 per sample with very sensitive ddPCR analysis and including quality control via positive and negative samples, testing for potential inhibition via a positive internal control and, in case samples were affected by inhibitory compounds, cleaning of the DNA extract prior to detection. However, this did not include the costs for taking the samples in the field which depends on the number of samples and locations of the study area. The unitary cost can go down considerably with higher numbers of samples analysed in batch, and, likewise, the more samples are taken on a certain location, the cheaper per sample/waterbody. No information was found on the cost for (terrestrial) eDNA sampling for snakes specifically.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Mixed

No negative side effects are expected from this method from an environmental and societal point of view. In fact, the method is non-invasive; it has nearly no side effects or very little impact, as at most, slight disturbance of the surveyed sites can be caused, mostly because of the placement of ACOs. The economic effects are considered mixed, because the method can be relatively costly, hence may have some financial impact.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

In comparison to traditional monitoring methods, eDNA approaches are less expensive and do not have any negative impact on the environment, if applied appropriately.

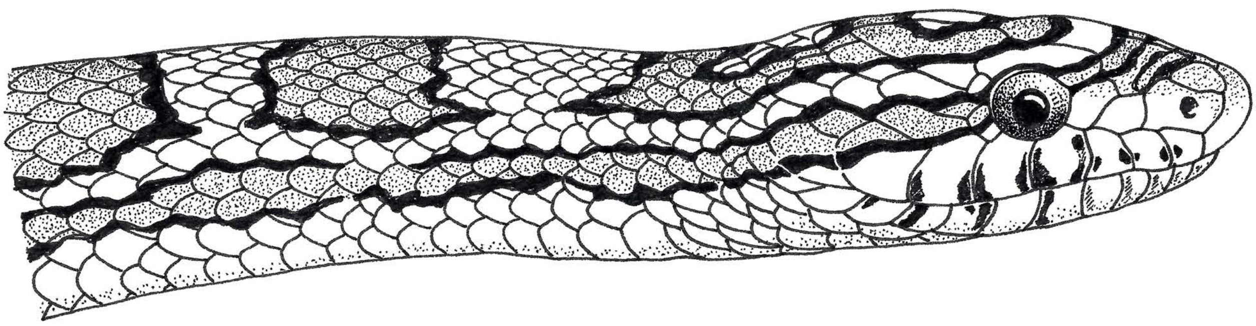
LEVEL OF CONFIDENCE*

Established but incomplete.

The method of eDNA is already extensively tested under controlled and natural conditions in a number of taxa and can thus be assumed to be a well-developed method that is proven to be very reliable and cost-effective for species detection, although this is mostly true only for aquatic environments. Concerning snakes, this method is a new and promising technique for the management of invasive alien species, but in terrestrial and semi-aquatic environments the technique needs to be still fine-tuned, as its effectiveness may largely depend on the species and its ecology and environment.

* See Appendix

Pantherophis guttatus. © Massimiliano Lipperi, Studio Wildart.



Sniffer dogs

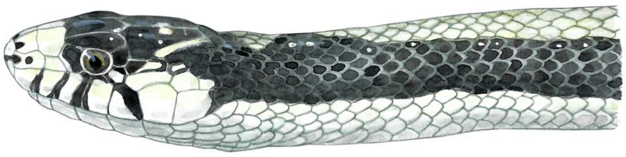
MEASURE DESCRIPTION

Sniffer/detection dogs can be used to locate snakes or areas where snakes are active. For example, in the EU, according to Gallo Barneto *et al.* (2023) since August 2022, a canine unit has been working as part of the management of the California kingsnake (*L. getula californiae*) in Gran Canaria, in an area of interest, Mercalaspalmas (logistics centre for food product distribution). A specific protocol to prevent the entry of snakes into its facilities was developed. In the future, these biosecurity actions may be extended to other places of interest, such as ports and airports of the island.

In Gran Canaria dogs have also been trialled to detect free-living brown tree snakes. Studies based on marked snakes suggest dogs located 26–44% of snakes within 5 m, but that other methods were then needed to help humans find and extract snakes from their refuges (Savidge *et al.*, 2011). Trained dogs have also been used to identify holes used by snakes of other species (Stevenson *et al.*, 2010). Dogs are likely to increase the effectiveness of searches, particularly when snakes may only be present at a low density. They show success in complementing with visual searches and snake traps, to improve the likelihood of removal from areas where other methods have been used to reduce snake numbers (Rodda & Savidge, 2007). However, other methods are likely to be needed to capture snakes once dogs have identified the general area of interest. The current control of the California kingsnake *(L. getula californiae)* on Gran Canaria is considering the use of dogs to supplement their other activities. For sniffer dogs to be used as a method for control of snakes in the wild, the LIFE Lampropeltis project experience has shown that care must be taken to train dogs under normal field conditions[23]. For example, if dogs are used to detect snakes in stressful environments, with snakes producing offensive odours to deter predators, they will systematically fail to detect snakes in any other setup. Also, fossorial kingsnakes detected in the environment by a sniffer dog could be hiding 2 m below ground and therefore still need to be found and removed after detection (pers. comm. Julien Piquet, 2023).

SCALE OF APPLICATION

As with other surveillance methods, this is not a measure that is suited to be used for early detection at a large scale (such as a national scale), but could be applied for detection within high risk sites of conservation concern, or as part of an eradication or management program, as well



Lampropeltis getula californiae. © Massimiliano Lipperi, Studio Wildart.

as in survey at inspection points (see *Biosecurity measures and pathway action plans* section). Advantages of cost and scale can potentially be gained by training sniffer dogs on multiple alien species in certain surveillance areas, making the instalment of a detection dog division a much more attractive prospect.

EFFECTIVENESS OF MEASURE

Effective.

As a measure for early detection at a national level, the measure will not be effective due to the scale of potential application, but at a site scale level the measure can be used to detect the species and confirm possible sightings, especially in areas where the species is difficult to detect visually. For example, Montes *et al.* (2021) in relation to the horseshoe whip snake (*H. hippocrepis*) in Ibiza (Balearic Islands, Spain), noted that the canine teams have demonstrated high detectability of individual snakes although other methods (such as thermal fumigation; Kraus *et al.,* 2015a) were also necessary to capture the snakes hiding inside rock walls used as shelter once detected. Dogs can be used to improve search efficiency but have yet to be used effectively as part of a snake eradication program.

EFFORT REQUIRED

There is no detailed information given on this in literature.

RESOURCES REQUIRED

There is a need for a trained dog and a dog handler. Training such dogs requires investment in time and money (training a sniffer dog usually requires a training program of a minimum of 6–8 months), at least for training and maintenance (including feeding, housing, transport, as well as regular veterinary checks). However, some authors (Yackel Adams *et al.,* 2021) stressed that while this technique is very attractive, it is actually cost prohibitive, and this would discourage its wider use.

ADDITIONAL COST INFORMATION

There is no information available on the costs in literature. Although training a sniffer dog requires time and resources

[23] http://www.lifelampropeltis.com/images/pdf/C3_perros_final.pdf

(see above), dogs can be trained for detection of other species at the same time, which increases the efficiency of the measure for surveillance.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Mixed
Social: Mixed
Economic: Mixed
There are no side effects mentioned in literature. Dogs in the natural environment may act as a form of disturbance for some wildlife.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
Since the dog is specifically trained to find the alien snakes and does not harm native species, the measure can be considered acceptable.

LEVEL OF CONFIDENCE*

Established but incomplete.
Not many details for the EU are available, therefore the method can be considered established but incomplete.

* See Appendix

The U.S. Department of Agriculture (USDA) Animal Plant Health and Inspection Service (APHIS) Wildlife Services (WS) scientists and partners estimate the current population of invasive brown tree snakes in Guam is approximately 1–2 million. The snakes have caused the extinction of most of the island's native wildlife; thousands of power outages; widespread loss of domestic birds and pets; and considerable emotional trauma to residents and visitors. © USDAgo (CC BY-3.0) via Encyclopedia of Life.

Citizen science

MEASURE DESCRIPTION

Monitoring with citizen science can offer great support to both general and risk oriented-surveillance and is crucial for early detection. In general, the accuracy of the data volunteers collect compares favourably to that of professionals (Crall *et al.*, 2010, 2011, 2015). Using on-line recording and smartphone apps, along with the development of social media, allows for fast dissemination of new records, reduces mistakes and data loss, and improves the speed of record submission, uptake by databases and early warning alerts (Adriaens *et al.*, 2015; August *et al.*, 2015).

Citizen-science species occurrence datasets are increasingly recognised as a valid tool for monitoring the occurrence and spread of invasive alien species across large spatial and temporal scales (Roy *et al.*, 2015). They are dependent on citizen-scientists who collect and upload data, typically from 'opportunistic sampling' with no underlying scientific survey design (Boakes *et al.*, 2010) which can limit the conclusions that can be drawn from these data (Isaac *et al.*, 2014) and may lead to a delay in detecting a new presence of the species. Smartphone applications can be a helpful tool to support recording and speed up record submission (Adriaens *et al.*, 2015), such as the dedicated app for reporting *Lampropeltis* occurrences on Gran Canaria (Lampropeltis, Gobierno de Canarias). Unstructured citizen-science data do not reliably allow to estimate species abundance or population trends (Kamp *et al.*, 2016; Probert *et al.,* 2022), yet in an early-warning scenario it is likely sufficient to know where a species is establishing, and these data limitations are thus of a lesser concern.

For Union list species such as *L. getula*, a number of general reporting portals (for example iNaturalist, Natusfera, Observation.org, Artsdatabanken, Faune de France etc.) and specific applications (see overview on https://easin.jrc.ec.europa.eu/easin/CitizenScience/Projects) are available to report occurrences (Price-Jones *et al.,* 2022). *Lampropeltis getula* is a readily identifiable species often found in association with human activity. The discovery of new snakes in an area is likely to attract public attention, hence *L. getula* may be particularly suitable for being the object of being detected through citizen science. Encouraging rapid reporting of new incursions increases the likely success of rapid response before the species can become established. Motivations of various target groups might differ, therefore citizen science programs should be targeted towards the audience at hand (Anđelković *et al.,* 2022). For *L. getula*, naturalists, herptile enthusiasts, orchard and garden owners, hunters, anglers and also the general public are relevant target groups. In addition, monitoring with citizen science can play a significant role in public engagement, improved education and public awareness about invasive alien species, and is recognised as fundamental to the attainment of the objectives of invasive alien species policies (Roy *et al.*, 2018). Volunteers focus mainly on visual observations yet can also be implicated in management. According to Gallo Barneto *et al.* (2023), a significant amount of captures were obtained through citizen's warnings, highlighting the importance of public help in the management of the California kingsnake (*L. getula californiae*) in Gran Canaria.

The first records of the asp viper (*V. aspis*) in the Netherlands were reported by the visitors of the park area where the species was introduced (pers. comm. Walter Getreuer, 2023). However, many false reports followed the first records and relevant coverage of this introduction by the media (pers. comm. Walter Getreuer, 2023).

On the other hand, misidentifications can lead to unnecessary responses and therefore a waste of resources, so data validation is key (Adriaens *et al.,* 2015, 2021). Around existing populations of species of Union concern occurring in the EU, dedicated citizen science surveys can be organised, where people are trained to recognise and detect the species, for example by learning to identify *L. getula* and other confusing species present in the area (as this may have important implications for management and implementation of the EU IAS Regulation). Volunteers can then adopt a certain area assigned to them, perform door-to-door interviews with private citizens and perform inspections of their gardens and properties. Also, interviews with anglers and hunters can be an effective method to learn about *L. getula* presence. As snakes are popular with the press, media attention can be used to increase awareness and involve the general public in early detection.

SCALE OF APPLICATION

Surveillance using citizen scientists can be applied at any desired geographic scale. It is useful to implement general, large scale surveillance to train volunteers in identifying the species and to intercept any solitary escaped or translocated individuals in uninvaded areas. Citizen involvement in trapping can be considered a good option, yet requires careful planning and organisation to prevent the management team losing time in specimen collection (see *Public awareness* section). Otherwise, any citizen-science program might die from its own success (pers.

comm. Julien Piquet, 2023). Around existing populations, more dedicated (risk-oriented or aimed at containing or managing the species) citizen science surveys can be organised.

EFFECTIVENESS OF MEASURE

Effective.

In general, online citizen-science platforms can be used to set-up an early warning system to detect alien species (Gallo and Waitt, 2011). However, unless no native snakes are present like in the case of *L. getula californiae* in the Canary islands (Spain), alien species may be confused with a number of native species. Therefore, the stakeholders engaged will need to be informed or trained on the observation and identification of the species. This may lead to problems of misidentification and misreporting. It is therefore important to have observations submitted to a quality control/validation process (for example based on pictures checked by experts). Also, it should be noted that, although citizen science offers the advantage of organising passive detection at large spatial scales, there are differences in detection probability between different snake species. In general, snakes are notoriously hard to detect by inexperienced observers, and there will be a serious effect of behaviour on the chances of detection by the public. For example, fossorial (such as *E. taeniura*, *I. braminus*), (semi-)arboreal and aquatic species may go undetected whereas more conspicuous terrestrial species (*L. getula*, *P. molurus*) could be more effectively detected by citizens. Similarly, active predatory snakes are more prone to be detected by citizen science, compared to snakes acting as ambush predators, juvenile snakes or smaller species which in fact are more likely to be missed (Yue *et al.,* 2019).

The potential of the method may be highlighted by examples from beyond the EU, although they are aimed at species removal rather than its simple detection, as well as at species identification. A major initiative in this context is the “Burmese Python Challenge” which took place in Florida in 2013 (Hegan, 2014). The event resulted in about 1,600 people involved, mostly inexperienced hunters and not particularly well-trained in identifying the Burmese python (*P. bivittatus*) from native snakes, from 38 states (Dell’Amore & Andries, 2013). They managed to remove 68 pythons from the wild in the Everglades, showing that public attitudes clearly may play a role in the management of invasive alien species. Similarly, in Martinique (in the Lesser Antilles), an eradication program was initiated in 1970 against the lancehead (*Bothrops lanceolatus*), a venomous yet endemic snake (unfortunately perceived as a fatal threat due to the mortality risk for the human population, rather than as a conservation concern). In Martinique the local authorities offered a 20 US dollars’ reward for any individual lancehead killed, resulting in a dramatic decrease of the number of snakes killed yearly between 1970 and 2002 by 97%: from 12,000 snakes in 1970 down to 386 in 2002 (Gros-Désormeaux *et al.,* 2017). Another event worth reporting here is the week-long online citizen science challenge launched by Durso *et al.* (2021b), which attracted over 1,000 participants from around the world and showed a large online active community of professional herpetologists and skilled avocational snake enthusiasts with the potential to quickly and accurately identify snakes. This initiative provided evidence that innovative citizen science initiatives based on snake identification platform, such as HerpMapper[24] and iNaturalist[25], can play significant roles in training and building capacity (Durso *et al.,* 2021a).

EFFORT REQUIRED

Different aspects need to be considered when implementing this measure (AlienCSI, 2023): 1) provide an online platform where actual observations can be posted (which may already exist for other alien species) and ensure that if more platforms exist they are duly interconnected to avoid scattered information (data management); 2) educate/train people in order to reduce misidentifications, 3) have a quality check by local experts on the data posted and 4) make it easily accessible and easy to retrieve data.

RESOURCES REQUIRED

The cost incurred when running citizen science projects includes human resources for coordination, communication and for providing training and feedback to volunteers, set-up and updates of e-infrastructure, equipment for observation/captures, and production of identification sheets, leaflets etc. The costs can be reduced by making use of existing platforms for citizen science surveys (for example iNaturalist). The cost of setting up a smartphone app, for instance, can greatly vary depending on the target species (groups) and its functionalities (Adriaens *et al.*, 2015). However, one should be aware that running a proper citizen science survey is more than launching an app, website or tool, and does incur costs for keeping the volunteer network running (including the educational aspect) and maintaining the data (data management). Guidance is available on setting up citizen science programs for alien and invasive alien species and on how to plan and deal with data collection and management, volunteer engagement and feedback, the use of technologies such as smartphone apps, and communications (Roy *et al.*, 2012; AlienCSI, 2023).

ADDITIONAL COST INFORMATION

A general COST action implemented between 2018 and 2023 provides specific details on the costs for this method: Increasing understanding of alien species through citizen science (Alien-CSI)[26].

[24] www.herpmapper.org
[25] www.inaturalist.org
[26] https://www.cost.eu/actions/CA17122/ and https://www.ceh.ac.uk/our-science/projects/alien-csi

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Positive
Social: Positive
Economic: Mixed

The involvement of citizens in the observations of alien species can have a positive environmental effect as they increase awareness about the problems related to alien species and their impacts and may even contribute to the management of the species in general. However, Teillac-Deschamps *et al.* (2009) found that the concern about general environmental questions is often limited, even if there is a public awareness campaign organised. In addition, setting up such an online platform can also be useful for getting data and thus information on other (alien) species (Roy *et al.*, 2018).

It is thought that field staff could act as potential vectors of transmission of snake diseases (i.e. Snake Fungal Disease is an infectious disease confirmed in numerous species of snakes caused by the fungus *Ophidiomyces ophidiicola*) into new sites and to native species. The risk of this mode of transmission is not fully understood compared to vectors such as other wildlife. However, as a precaution, it is essential that field workers follow hygiene protocols to prevent further spread of snake diseases such as Ophidiomycosis.

Being outdoors is also known to be a prime motivator for people to engage in citizen science programs (Anđelković *et al.* 2022), hence a positive social effect.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

The measure will be generally accepted by most stakeholders and is already being used for several species worldwide. As the method is based on visual/auditory observations, it is generally non-invasive. There might be issues with access to private land or inaccessible nature reserves by volunteers. Reporting through citizen science can potentially result in management actions being undertaken on private lands, which owners do not always agree with.

LEVEL OF CONFIDENCE*

Established but incomplete.

The use of volunteers for snake surveillance (and citizen science for IAS reporting in general) is well established, but information on its effectiveness, as compared to other methods, is not definitive. The method will have different effectiveness according to the species and its behaviour, and the involvement of citizens in actual management requires specific considerations.

* See Appendix

Visual surveys (incl. radio-tagged scout snakes)

MEASURE DESCRIPTION

Monitoring reptiles, whether by specialist herpetologists or volunteers, has a long tradition and several good protocols are available outlining potential methods (see for example McDiarmid *et al.,* 2012). Visual surveys are a useful management component in relation to the application of several methods, for example for biosecurity measures (see *Biosecurity measures and pathway action plans* section) as well as for citizen-science (see *Citizen science* section) and hand captures (see *Active searching and hand capture* section). To prevent the spread of brown tree snakes to other islands, including Hawaii, wildlife managers have had success with control measures in Guam airports and seaports, usually supported by visual searches, along with other methods, i.e. dog searches, and snake traps (Mullin & Seigel, 2009; Hegan, 2014). Visual surveys of brown tree snakes in Guam have been complemented by spotlight searches, for example with the use of torches along fence lines (Engeman & Vice, 2001a). Clark *et al.* (2018) emphasised that light can be applied and interpreted in such a way as to increase the probability of detection for a snake that is within the field of vision of an observer. Night-time visual searches were conducted by local wildlife personnel to support a small number of snake traps placed in the vicinity of encounters in recipient island (Stanford & Rodda, 2007). Nocturnal visual surveys are actually known to detect brown tree snakes of all sizes and are the primary detection tool used by the Brown Treesnake Rapid Response Team (Amburgey *et al.*, 2021; Yackel Adams *et al.*, 2021).

Lures can also be used to increase visual encounter probabilities for invasive alien snakes. For example, in the case of the search for brown tree snakes, according to some tests trialled on Guam where prey populations are reduced, visual surveys conducted on transects with live mouse lures resulted in detection probabilities that were 1.3 times higher than on transects without live mouse lures (Amburgey *et al.,* 2021).

Guzy *et al.* (2023) also describe the method of using **scout snakes** (or Judas animals) for Burmese python detection (see also Smith *et al.,* 2016). The species forms breeding aggregations from December to March that have been observed to include up to eight individuals. Researchers and managers have capitalised on this behaviour and used radio telemetry to track **radio-tagged scout snakes** that reveal the location of other pythons during the breeding season, thereby allowing removal of additional snakes from the population (Smith *et al.,* 2016). Although scout snake programs are more costly per python removed than road cruising, scout snakes are a tool targeting the removal of large, reproductive pythons that are far from roads and that might not be captured otherwise. Whether the use of radio-tagged scout snakes is a good method for detection will depend on the phenology and breeding behaviour of the target species.

SCALE OF APPLICATION

According to Clark *et al.* (2018) visual detection of individual snakes can be influenced by multiple factors such as snake size, sex and body condition, as well as observer impact and environmental conditions. It is usually made along transects, hence the scale of application is dependent on the number of staff or volunteers available.

According to Rodda *et al.* (2002) visual searches were pivotal to ensure that snakes of all sizes had been eliminated from a 1 ha enclosure in Guam, although they were considered relatively "tedious and time consuming".

EFFECTIVENESS OF MEASURE

Neutral.

To evaluate the efficiency of traps, artificial cover objects (ACOs) and active surveys in the California kingsnake (*L. getula californiae*) in Gran Canaria, Piquet *et al.* (2023) identified three sampling zones, distributed over 17 ha, and deployed 18 traps and 15 ACOs (separated 20 m from each other) in each of them. Moreover, for two months, while checking for traps and ACOs, a team of 2–6 people performed visual surveys and line transects, and compared the efficiency of these methods. Visual encounter surveys and line transects had a similar number of captures per unit of effort (CPUE) (4.10 ± 10.38 y 3.55 ± 10.13 capture/100 observers-hours, respectively), definitely higher than that for traps (0.02 ± 0.05 captures/100 trap hours) and ACOs (which produced no captures). Such results indicate that for the California kingsnake active surveys are much more efficient than traps, even though this is a fossorial species. **Active trapping methods** such as **visual searches with hand capture** are often considered insufficient to control snakes (Christy *et al.,* 2010). However, they offer fairly good results for certain species, e.g. *P. molurus* (Guzy *et al.,* 2023), *B. irregularis* (Christy *et al.,* 2010) and *L. getula californiae* (Piquet *et al.*, 2023). They should therefore not be ruled out and can represent an important part of an integrated control strategy (see *Integrated management strategies* section).

Potential biases of visual surveys used for the brown tree snake (*B. irregularis*) were also examined to assess the efficacy of this method (Boback *et al.,* 2020). The result showed that visual surveys can predict the presence of the target snakes even at low densities (0.4 animals/ha) but perform poorly at predicting areas of high use

Searching for snakes using radiotrack and dog guide. © Ramón Gallo Barneto.

(due to the influence of vertical position and refuge type used by snakes), showing that microhabitats are likely to disproportionately affect visual surveys, which must be taken into consideration for management purposes. Furthermore, visual searcher abilities and motivation are known to be highly variable and affect the efficiency of results, as opposed to trapping methods, and are relatively tedious and time-consuming, as revealed through research activities on Guam (Rodda *et al.,* 2002; Campbell *et al.,* 1999; Stanford & Rodda, 2007). To evaluate visual searching as a control tool for populations of the brown tree snake, Christy *et al.* (2010) designed a capture-mark-recapture study to evaluate detection probability as a function of time, gender, size, body condition, recent detection history, residency status, searcher team and environmental covariates. Under average conditions on Guam, detection probability (the likelihood that an average snake present in a survey area will be detected at least once during a survey period) was about 0.07 per mid-sized snake (ca. 900 mm snout-vent length) per search occasion along forested transects (Christy *et al.,* 2010).

This shows the importance of properly evaluating the efficiency of the control methods available to capture snakes on a species-by-species basis, so to design effective management strategies (Piquet *et al.,* 2023).

EFFORT REQUIRED

Search efforts for the brown tree snake (*B. irregularis*) in Guam carried out through nocturnal visual surveys along transects, one to four times per week, using headlamps and working in teams of two, was considered sufficient (Boback *et al.,* 2020) despite some limits showing that applying visual surveys for cryptic species can be effective but requires knowledge of how to minimise perception and availability bias.

RESOURCES REQUIRED

No information was found on the issue.

ADDITIONAL COST INFORMATION

Guzy *et al.* (2023) present cost estimates and limitations for a variety of techniques used to detect (and capture) Burmese pythons across southern Florida. The method that accounts for most python observations is visual surveys on foot or in vehicles along roads, trails etc. Over the course of two years for 4,731 surveys and 2,107 removed Burmese pythons, the cost of these surveys was approximately $628,471, which includes FWC staff salaries, contractor wages, and material costs, resulting in a cost of $298 per python and 0.09 pythons per survey hour (McCaffrey *et al.,* 2022).

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: None
Social: None
Economic: None
Visual surveys are in principle selective and should not have considerable side effects apart perhaps from some potential disturbance of the habitat and/or other biota.

No specific social and economic effects are reported or anticipated.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
No special impact is expected for the implementation of this method, hence it should be generally acceptable to stakeholders.

LEVEL OF CONFIDENCE*

Established but incomplete.
The method has been used already, but results are not always satisfactory and need to be assessed species by species.

* See Appendix

Surveillance at points of introduction

MEASURE DESCRIPTION

See measures described under the *Prevention* section above.

Remote sensing and near-infrared cameras

MEASURE DESCRIPTION

Surveying invasive alien snakes may require specialised field observers, a challenge that prevents authorities and wildlife managers from efficient management of these groups of species. For example, Maestresalas *et al.* (2023) noted that due to visual surveys being extremely time- and resource-consuming for secretive snakes like the California kingsnake (*L. getula californiae*) in Gran Canaria, increasing the detection on surface still requires further technological advances e.g., **remote sensing techniques**. **GPS-based techniques** for the study of animal movement have greatly advanced in recent years, including for invasive alien snakes (Smith *et al.,* 2018). Nevertheless, this technology is still difficult to apply to cases like the California kingsnake in Gran Canaria that involve a fossorial, less mobile, and small-bodied species (Maestresalas *et al.,* 2023).

A **novel system** for the acquisition of information, based on remote sensing technologies, has been developed in Japan (Aota *et al.,* 2021). The system, which adopts the use of drone images coupled to a type of machine learning called deep neural network, has been used in Japan to detect an invasive alien lizard species, *Anolis carolinensis*, an organism that is difficult even for a trained human to identify (Aota *et al.,* 2021).

Since human eyesight can detect light with wavelengths from 400–700 nanometers, Guzy *et al.* (2023) suggested drones or vehicles mounted with **near-infrared cameras implementing artificial intelligence** could increase the number of Burmese pythons removed from roads during visual surveys by possibly detecting additional pythons at an 850 nm wavelength that visual searchers may have otherwise overlooked.

Otherwise, the use of simple trail **cameras** (using live lures) has increased in recent years (Yackel Adams *et al.,* 2021).

SCALE OF APPLICATION

The machine learning system was successfully applied in a very small island, Ani-jima in the Ogasawara Islands (Aota *et al.,* 2021).

EFFECTIVENESS OF MEASURE

Unknown or not yet applied.

Remote sensing and GPS-based techniques (Maestresalas *et al.,* 2023) are well established and are now routinely used to study movement ecology. Their effectiveness as a technology for the detection of snakes is however not known. The machine learning system tested on lizards in Japan resulted in approximately 70% precision of automatically detecting the invasive alien lizard, as part of a control strategy of the species on the Ogasawara Islands, hence showing the potential to contribute to an efficient and effective approach also for invasive alien snakes (Aota *et al.,* 2021). The use of drones and neural networks may be effective tools for reducing the human costs of monitoring invasive alien species that are difficult to detect even by a trained human (although the network often failed to detect the lizard in images wherein the whole body of the individual was not visible) improving the efficiency of management initiatives (Aota *et al.,* 2021).

EFFORT REQUIRED

No specific information is available in relation to the use of remote sensing techniques on alien snakes.

Regarding the machine learning system tested on lizards in Japan, in terms of time spent, human detection took 228 seconds more than detection by a neural network, which took approximately 1.2 seconds per image on average and two images per second (Aota *et al.,* 2021).

RESOURCES REQUIRED

No specific information is available in relation to resources needed for remote sensing techniques on alien snakes.

ADDITIONAL COST INFORMATION

As opposed to an efficient machine learning-based system, in the study made by Aota *et al.* (2021) monitoring lizards using field surveyors required not only personnel expenses but also training costs, which may result in making effective conservation and ecosystem management difficult.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Positive
Social: Positive
Economic: Positive
Remote sensing techniques are potentially relatively free of side effects.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Normally technological measures are well accepted by most stakeholders.

LEVEL OF CONFIDENCE*

Inconclusive.

Remote sensing and GPS-based techniques have not been applied to snakes for surveillance or detection so their effectiveness as a technology for the detection of snakes is unknown.

* See Appendix

Measures to achieve rapid eradication after an early detection of a new occurrence.

Contingency planning and emergency measures

MEASURE DESCRIPTION

The rapid eradication of new introductions can be achieved thanks to a sound implementation of surveillance measures for early detection. Some examples of successful eradications of new introductions of invasive alien snakes in Europe or beyond exist, although they are very rare. The most prominent is probably the one of *L. getula* which, following the adoption of the EU Regulation on IAS, was detected twice and removed from the environment in both 2022 and 2023[27]. Other examples are the case of the asp viper (*V. aspis*) in the Netherlands, where in 2006 eight specimens were found and successfully removed from Bos Valckesteyn near Poortugaal, Rotterdam (Van de Koppel *et al.,* 2012a; pers. comm. Walter Getreuer, 2023). Similarly, in Switzerland, between 2016 and 2020, three populations of green whip snakes (*Hierophis viridiflavus*) introduced outside their natural range (in the canton of Vaud) were removed (Mondino *et al.,* 2022). That was possible because of a rapid response action. However, incipient populations are always difficult to detect, so it may be easier to act once the details of an introduced population are sufficiently known, particularly in terms of actual distribution and population size. Yet, this is not always sufficient either. In fact, in Belgium, following the introduction of the beauty rat snake, *E. taeniura* occurred in 2006, van Doorn *et al.* (2021) advocate a rapid response as the most appropriate risk management strategy. Key factors considered important for a successful control campaign by van Doorn *et al.* (2021) include clear lines of responsibility, dedicated budgets and perseverance, political and stakeholder support, clear risk communication, as well as thorough scientific follow-up. However, apart from a few animals occasionally being removed, no substantial measures are implemented so far (Tim Adriaens, 2023 unpublished).

In the case of the asp viper, the Netherlands has developed a risk assessment (Van de Koppel *et al.,* 2012a) including a protocol to provide a concise overview of all necessary and/or possible steps for reacting adequately should the species occur somewhere in the country again in the future.

Snake traps used in the Balearic Islands. The mouse is used as bait and the no return hole where the snake enters the trap can be seen. © COFIB-Ibiza.

A Ladder snake caught in a snake trap in the Balearic Islands. The mouse, used as bait, can be seen in a separate compartment. © COFIB-Ibiza.

A rapid response would appear even more urgent in the case of the required management of the horseshoe whip snake (*H. hippocrepis*) on Ibiza (Balearic Islands, Spain), where this species was introduced and is threatening the endemic wall lizard (*P. pityusensis*) with extinction (Montes *et al.,* 2022). Here, a rapid intervention team was established, along with a detailed action protocol agreed between the various concerned administrations (Montes *et al.,* 2015).

[27] See EASIN Notification System here https://easin.jrc.ec.europa.eu/notsys (the NOTSYS platform is the official tool for EU Member States to notify the Commission and other Member States about any new detections of IAS of Union concern and related eradication measures)

According to Montes *et al.* (2021) it is fundamental to develop a rapid-response protocol for snake sightings in new satellite localities across the southwestern part of Ibiza (where the invasive snake is not yet widespread) and on the islets, because the snakes can disperse discontinuously in transported nursery materials and construction materials, or by swimming (Montes *et al.,* 2022). Picó *et al.* (2017) report that the ladder snake (*Z. scalaris*) most probably invaded Formentera from Ibiza. They applied experimental, mouse-baited live traps in the introduction area (La Mola) as part of a rapid intervention plan. Rapid intervention protocols could follow methods developed for other snake species, such as in the case of the establishment of the Brown Treesnake Rapid Response Team (Stanford & Rodda, 2007).

This clearly means having a contingency plan at hand along with the necessary financial (and humane) resources. Nevertheless, as noted by Campbell *et al.* (1999) in relation to the case of the introduced brown tree snake in Guam, the difficulties in mobilising the necessary resources for incipient snake colonies that are fundamentally an invisible and largely unknown threat until it become apparent, are a clear obstacle for the establishment of sound contingency plans and relevant resources. One example of systematic contingency to preventing invasive alien species from establishing and rapidly responding to incursions is provided by the work of the GB Non-Native Species Secretariat[28] and the Guidelines for invasive species planning and management on islands (IUCN, 2018). The necessary steps in drafting such plans include considering how to generate support and build capacity, analysis of the legislative and policy framework, gathering baseline information, setting priorities, biosecurity, management and post management restoration measures among others.

However, the reality is that the mobilisation of the necessary funding is usually slow, provided that a mechanism for nature conservation exist at all, and full of bureaucratic caveats and obstacles. An example in the EU is the LIFE funding (see Scalera *et al.,* 2017). The LIFE program is suitable for financing action to deal with the management of alien species (see for example LIFE Lampropeltis LIFE10 NAT/ES/000565)[29], yet from the time a proposal is prepared and submitted to its actual start, provided that is successfully selected, it may take many months.

On the other hand, the techniques for monitoring, capturing and removing the snakes are the same as discussed under the other sections on prevention, early detection and management. But they can be established only once the nature of the new invasion is known. Awareness campaigns for the general public (and tools for promptly reporting any sightings, including for example an app), and training courses for staff in charge of the operations (i.e. covering visual searches, snake capture and handling, response logistics, search area and trapping methods) should also be foreseen, as discussed by Stanford and Rodda (2007) in relation to the Rapid Response Team established to assist in detection and capture of brown tree snake on recipient islands after being accidentally transported from Guam.

In the Balearic Islands (Spain) a team has worked regularly in the same areas for 10 years, developing an understanding of the territory (pers. comm. Víctor Colomar, 2023). The highly versatile field team, normally working in alien wildlife control, can be activated in less than 24 hours to attend emergencies. Local society knows the fieldworkers, the organisation and their purpose, which facilitates the transversal information exchange in a rapid and effective way (pers. comm. Víctor Colomar, 2023).

SCALE OF APPLICATION

The rapid eradication of the asp viper (*V. aspis*) in The Netherlands was carried out in a small area including the Valckesteyn Forest near Poortugaal (Rotterdam), on both sides of the Old Meuse (pers. comm. Walter Getreuer, 2023).

EFFECTIVENESS OF MEASURE

Effective.

According to the available information, contingency plans are effective for snakes despite still limited evidence.

EFFORT REQUIRED

No information was found on the issue.

RESOURCES REQUIRED

According to an assessment of the costs of prevention and control related to the potential arrival of the brown tree snake (*B. irregularis*) in Hawaii made by Burnett *et al.* (2006) "catching a single snake out of roughly 15 will be at least $76,000, and catching one out of a population of one will cost just under $1,000,000. Catching a single snake from a population at capacity costs about $31 based on the cost of night traps and a study investigating the use of dogs in detecting planted snakes".

The costs for the rapid eradication of the asp viper (*V. aspis*) in the Netherlands were estimated at about 4,000 euro, mostly exclusively for personnel (pers. comm. Walter Getreuer, 2023).

ADDITIONAL COST INFORMATION

No information was found on the issue.

[28] https://www.nonnativespecies.org/non-native-species/contingency-plans/
[29] https://www.lifelampropeltis.com/

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Unknown
Social: Unknown
Economic: Unknown
No information was found on the issue.

ACCEPTABILITY TO STAKEHOLDERS

Unknown.
No information was found on the issue.

LEVEL OF CONFIDENCE*

Inconclusive.
No information was found on the issue.

* See Appendix

Lampropeltis getula californiae. © Massimiliano Lipperi, Studio Wildart.

Active searching and hand capture (Active capture)

MEASURE DESCRIPTION

One of the most popular and effective methods to capture snakes for management purposes is through manual captures, which include the use of tools such as snake bags, snake hooks, and snake tongs to grab snakes safely and assist capture e.g. from vegetation. This method can be equally implemented for any management purpose, from eradication to control, to containment. Significant numbers of snakes can be captured using this method after visual searching, especially if using experienced personnel, although it is labour intensive (Robertson *et al.,* 2017a). As reported by Gallo Barneto *et al.* (2023) in the case of the California kingsnake (*L. getula californiae*) in Gran Canaria, by adapting human resources of the project to the phenology of the species, the control actions carried out in the last 25 years through manual captures, supported by visual searches (Cabrera-Pérez *et al.*, 2012) along with the use of traps, have been characterised by some important improvement in the method. A better knowledge of *Lampropeltis* ecology and behaviour was considered key to improving efficiency by identifying productive times of day, season, habitats and microhabitats to target (Hubbs, 2009; Cabrera-Pérez *et al.,* 2012; Maestresalas *et al.,* 2023). Maestresalas *et al.* (2023) state that active searches should be conducted during daylight, from February to mid-November, before the breeding season starts until the end of the activity period. However, juvenile snakes are not caught through active searches, so it seems they might have a very different daily activity or activity patterns and might hide very well (pers. comm. Marta López Darias, 2023).

Capturing a California kingsnake (*Lampropeltis californiae*) by hand in Gran Canaria. © Ramón Gallo Barneto.

Search team STOPCULEBRAREAL searching for kingsnakes. © Ramón Gallo Barneto.

In Switzerland, all 94 individuals of the three introduced populations of green whip snake (*H. viridiflavus*) removed were captured by hand during the reptiles' activity periods, ranging from April to July, i.e. as soon as they came out of hibernation and until temperatures became too high to allow their captures (Mondino *et al.,* 2022). The same was reported for Belgium, where several individuals of the introduced rat snake (*E. taeniura*) were caught by hand and removed, following observations collected from an online citizen science platform and validated by experts through *ad hoc* field surveys (van Doorn *et al.,* 2021). The removal of the asp viper (*V. aspis*) in the Netherlands was made through hand captures too (pers. comm. Walter Getreuer, 2023).

While this is an effective method to capture individuals, it may not be an effective method to completely remove snakes from an area if used in isolation. Studies of *Lampropeltis* in its native range suggest animals spend over 70% of their time inactive in holes and crevices (Richardson *et al.,* 2006; Wund *et al.*, 2007), while studies of search efficiency to detect brown tree snakes suggest only 7% of the snakes present in an area are located per search (Christy *et al.*, 2010). Multiple repeated searches will be required to give confidence that an area has been cleared if eradication is the objective.

In the Everglades ecosystem (USA) a dedicated event with money prizes was launched to remove invasive Burmese pythons. It is the Florida Python Challenge®[30] which required participants to be trained for capturing snakes safely, and made many prizes available, including a $10,000 Ultimate Grand Prize.

SCALE OF APPLICATION

Snake control for eradication poses particular problems. Brown tree snakes have been successfully eradicated from small fenced plots (1 ha) on Guam using a variety of methods including hand-capture. However, attempts to eradicate snakes from larger areas have not proved successful (Rodda *et al.,* 2002). The eradication of well-established snake populations remains challenging.

EFFECTIVENESS OF MEASURE

Effective.

Hand capture has been documented as an effective method to capture significant numbers of snakes, although other methods may be needed to ensure complete removal, including artificial cover objects or specific traps (van Doorn *et al.,* 2021). In the Canary Islands, for example, some preliminary results of trapping vs active search showed that active searches are more effective than trapping in terms of labour hours only, hence without considering the price of building and getting mice for traps (pers. comm. Julien Piquet, 2023). Not surprisingly, there is a strong link between eradication feasibility and invasion extent (Booy *et al.,* 2020; Robertson *et al.,* 2017b).

However, hand capture is limited by the captor's willingness to handle potentially dangerous snakes and the ability to find snakes in situations where the snakes are not obvious (Campbell *et al.,* 1999). Hence, this method may be not adequate for all species.

Moreover, the efficiency of this method will decline as a population is reduced, and more targeted approaches are likely to be required to ensure the removal of all animals in an area.

For example, according to Rodda *et al.* (2002) there are no control or eradication methodologies available for species like the Asian wolf snake (*L. capucinus*) introduced in the 1980s in Christmas Island (Australia), in the Indian Ocean, where it is threatening native species with extinction. Furthermore, the attempts aimed at the eradication of *L. capucinus* from the small Île aux Aigrettes in the Indian Ocean have been unsuccessful (O'Shea *et al.,* 2018).

EFFORT REQUIRED

This method requires minimal equipment costs, but is time-consuming.

RESOURCES REQUIRED

No information was found.

ADDITIONAL COST INFORMATION

No information was found.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Positive
Social: Positive
Economic: Positive

[30] https://flpythonchallenge.org/

Using a fiberscope to detect snakes in their lair. © Jorge Saavedra Bolaños.

This method poses few risks to health and safety beyond those associated with handling snakes, and is unlikely to raise significant environmental, social or environmental concerns. In general, it does not cause non-target impacts aside from minimal disturbance.

Any control of a vertebrate is likely to attract some opposition, but hand capture has been widely used in *L. getula* and other snake species control programs (Cabrera-Pérez *et al.*, 2012; Vice & Pitzler, 2000).

ACCEPTABILITY TO STAKEHOLDERS

Mixed.
No information was found.

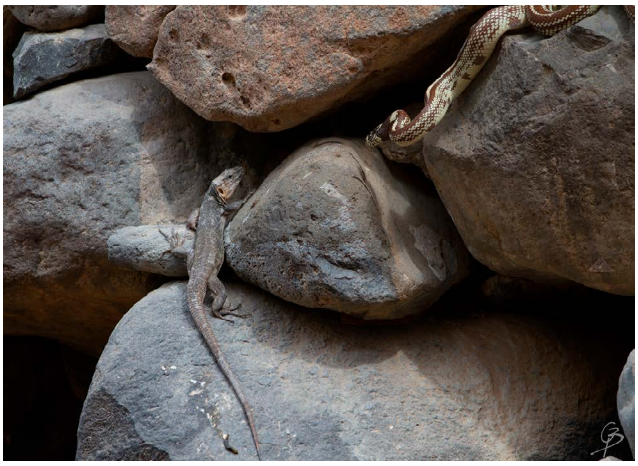
LEVEL OF CONFIDENCE*

Well established.
Hand capture has been documented as an effective method to capture significant numbers of snakes, although other methods may be needed to ensure the complete removal of snakes from an area.

* See Appendix

Lampropeltis getula getula. © Massimiliano Lipperi, Studio Wildart.

Trapping methods and devices (passive capture)



A kingsnake chasing a Gallot's lizard. © Ramón Gallo Barneto.

MEASURE DESCRIPTION

A variety of trap designs have been successfully used to capture snakes and several methods are used to trap snakes (Fitch, 1987; Bennett, 1999; Das, 2012; Fitzgerald & Yantis, 2012; Picó *et al.,* 2017). Traps can be equally implemented for any management purpose, from eradication to control, to containment (and for surveillance and prevention as well).

Cabrera-Pérez *et al.* (2012) provide photographs of trap designs trialled on Gran Canaria, against the California kingsnake (*L. getula californiae*), based on those used to capture brown tree snakes on Guam. A wide variety of snake traps are available commercially and designs are freely available on-line. The materials are usually cheap and likely to be locally available. For example, the design of the traps developed for the captures of the Montpellier snake (*M. monspessulanus*) introduced to Mallorca (Balearic islands, Spain), are described by Febrer-Serra *et al.* (2021) together with other methodological details. A detailed protocol is also described by Montes *et al.* (2021) in relation to the horseshoe whip snake (*H. hippocrepis*) in Ibiza (Balearic Islands, Spain). Also, a modified **minnow** trap known as the Wildlife Service Standard Trap (WSST) used by the USDA Wildlife Services program to capture brown tree snakes on Guam, was described in detail by Clark *et al.* (2018). Trapping was also carried out on an uninhabited islet in Mallorca (i.e. Illa dels Conills) where the horseshoe whip snake (*H. hippocrepis*) was recently introduced (Picó, 2023). In total, 6 horseshoe whip snakes with 10 traps and 1330 days of trapping from May to November.

Traps can be **baited** with food items or used with **lures** to increase their attractiveness to snakes. Some programs have used live bait to attract snakes. The use of live bait may be restricted by welfare and wildlife regulations and advice from local authorities should be sought before considering this approach. A variety of lures to attract snakes are commercially available (web search 'snake lure'), although the advantages of these products remain largely untested. For example, the use of a live mouse lure, contained within a separate wire mesh chamber, within the Wildlife Service Standard Trap used for brown tree snakes on Guam, is described by Clark *et al.* (2018). Also in California (USA), southern watersnakes (*Nerodia fasciata*) were captured through a combination of hand captures and aquatic trapping, using a mix of buckets and minnow traps, baited with mosquitofish and other preys (Reed *et al.,* 2016).

In the Balearic Islands (Spain), in an effort to protect the Ibiza wall lizard (*P. pityusensis*) from the concrete risk of extinction by predation from the ladder snake (*Z. scalaris*) and the horseshoe whip snake (*H. hippocrepis*), mass trapping exercises are being carried out in two protected areas (Ses Feixes de Talamanca and Ses Salines natural park) where invasive alien snakes are thriving[31]. In total 100 prototype "smart" traps were produced. Live mice are used as a bait, but are placed in a separate compartment (so that snakes cannot access them) and need to be fed and watered regularly. To measure the effectiveness of this method there are volunteers involved, with the task to set and maintain the traps and take care of the snakes once they are caught.

The use of pheromone traps may be considered if future developments will show the efficacy and efficiency of this method over other types of attractants (Parker & Mason, 2012).

The efficiency of trapping can be increased by the establishment of a specific trapping scheme tailored to the biology of the target species (see Clark *et al.,* 2018 in relation to the trapping of brown tree snakes in Guam). This includes consideration of the habitat and the best places to set traps, as well as optimal spacing between traps for instance (Engeman & Linnell, 1998, 2004). The assessment of the spatial ecology of the California kingsnake (*L. getula californiae*) on Gran Canaria (particularly home range, activity patterns, or habitat use) was important to inform and enhance control actions (e.g. best period in the day to catch snakes or open traps) and is in general crucial to the management of snakes, which show extremely low detectability, secretive behaviour, cryptic

[31] https://ibizapreservation.org/en/project/lizards/

colouration, sporadic activity patterns, or use inaccessible habitat (Maestresalas *et al.,* 2023). However, it is worth noting that juvenile snakes do not enter the traps and it seems that they might have very different daily activities or activity patterns because they are not caught through active searches either (pers. comm. Marta López Darias, 2023). So, it seems they might hide very well and in general with the traps and active searches are not caught (pers. comm. Marta López Darias, 2023).

Several types of traps are available.

Traps may include funnel entrance designs such as **minnow** traps and pitfalls. In the case of the brown tree snake in Guam the favoured model is a **winnow** trap made of mesh cylinders about 50 cm long X 20–30 cm diameter with inward-pointing funnel ends, with live prey (i.e. mice) as attractants, protected by metal cages (additional technical details of design and placement are available in Rodda *et al.,* 1999b). Funnel traps were also used successfully (in association with drift fences) on a wildlife refuge in Nebraska to control bullsnakes (*P. catenifer*), which are actually native to the area, but did represent a threat to waterfowl nests (Imler, 1945). Other similar variants were also tested (Vice *et al.,* 2005).

Multi-capture traps and trap-drift fence combinations were designed and tested for capturing pythons (Engeman *et al.*, 2011).

Net traps are also used for snakes, i.e. fine nylon netting held upright on a frame will lead snakes moving through

Pictures of a box trap. © Jorge Saavedra Bolaños.

the netting to become entangled. **Electrical netting** can also be used. For example, the use of net-traps and other variants to catch Habu snakes (*Trimeresurus flavoviridis*) on Okinawa is described by Nishimura (2011), and Hayashi *et al.* (1983, 1984).

Funnel traps appeared very effective, like reported for the brown tree snakes in Guam (Campbell *et al.,* 1999).

Glue traps are another example, although they are not selective, and their use may be regulated/restricted in the EU. Various boxes, tunnels or tubes coated with a sticky resin where snakes are caught on the sticky surface are available commercially and on-line, together with instructions for their manufacture (web search 'snake glue trap'). These are primarily used to remove small numbers of snakes from in or around dwellings (Knight, 1986). This author describes the release of captured animals by the use of cooking oil to break down the glue. Released animals appeared to suffer no long-term effects if released quickly after capture, although in many applications snakes are left to die in the trap.

Very few studies have empirically compared passive (e.g. traps) and active methods (e.g. visual searches and hand capture) for snakes (Guzy *et al.,* 2023) and some sources indicate that active methods can be more effective than traps in capturing a high number of snakes depending on the species (e.g. Mullin & Seigel, 2009). The advantage of traps compared to hand captures and visual searches is that they reduce the need for people to be present to capture snakes, can work well in less practical situations like with adverse weather, late night hours, remote areas, etc. as experience in Guam with the brown tree snake shows (Campbell *et al.,* 1999). Moreover, traps are particularly suitable for being used by apprehensive personnel who can participate with little risk (Campbell *et al.,* 1999). However, traps often require live lures to yield high capture rates (Boyarski *et al.,* 2008; Fritts *et al.,* 1989) which leads to higher costs for trap revision, and the capture of non-target species. Traps also incur a preparation and instalment costs and may completely fail if alternative preys are present (Clark *et al.,* 2018) whereas hand capture methods have none of these problems - yet face other issues like observer biases (Mullin & Seigel, 2009).

Traps alone may not be sufficient to successfully control a species, hence their efficiency can be improved by other accompanying measures, including manual captures supported by **visual searches** and **dog searches**, use of **chemicals** spread through aerial broadcast and **bait** stations (see Hegan, 2014 and Savarie *et al.*, 2001, in relation to the control of brown tree snakes in Guam). Artificial **barriers** to guide moving snakes towards the trap, or prevent immigration to the eradication site, may also be fundamental complimentary tools. The use

Ladder snake (*Zamenis scalaris*) on Formentera cliff, Balearic Islands. © COFIB-Ibiza.

of a **bounty system**, or other kind of cash payments to individuals upon evidence of the collection of an organism, has been used to support the implementation of control measures in some cases. For example, in Japan the measures to survey and control the established populations of the Taiwan beauty snake (*E. taeniura friesi*), and the Taiwanese Habu (*Protobothrops mucrosquamatus*), entailed the trapping of snake along with the purchase of *E. t. friesi* individuals from local people (Asato *et al.,* 2022). The experience with the use of a bounty system also showed that mostly adult specimens were removed because they were easier to capture, as documented with a native population of American watersnakes (*N. sipedon*) which had to be removed from a fish hatchery in Missouri, USA (Bauman & Metter, 1975). Otherwise the system may lead to create a "perverse incentive" to "cheat," for example, through captive rearing, surreptitious importations and even the further introduction of the target snakes to other location (including neighbouring islands in the case of the brown tree snake in Guam) to maintain or replicate this source of income (Clark *et al.,* 2018). Involvement of the public in reporting and trapping snakes can be an effective tool to overcome the scarcity of governmental human resources available to tackle invasive alien snakes (Costa & Martínez, 2023), as demonstrated by control programs on horseshoe whip snake (Montes *et al.,* 2015), Montpellier snake (*M. monspessulanus*) (Rubio *et al.,* 2023), Habu (*T. flavoviridis*) (Nishimura, 2011) and *L. getula* on Gran Canaria, yet requires careful planning (see *Public awareness* section).

SCALE OF APPLICATION

Trapping can be applied at various spatial scales, but the success will depend on species and context. For brown tree snake, trapping over moderately sized areas (~17 ha) allowed to reduce snake populations significantly (Clark *et al.*, 2018) and severe suppression or elimination of brown tree snakes in small plots was feasible (Campbell *et al.*, 1999; Rodda *et al.*, 1999a).

EFFECTIVENESS OF MEASURE

Neutral.

Although widely applied in control operations, very few trapping programs for open populations (as opposed to closed populations that were fenced or are in a secluded environment) have effectively been able to eradicate invasive alien snakes. Spatz *et al.* (2022), in their review of island eradication, do not mention any snake eradication. Reed *et al.* (2016) mention that although the overall capture per unit effort (CPUE) in traps declined with time during an intensive 76-day trapping campaign to control introduced southern watersnakes (*Nerodia fasciata*) in Southern California, it was unlikely that this represented a decrease in the snake population size. Despite this, a sizeable amount of literature is available on the use of traps to capture snakes and on the efficiency of different trap designs. Both trap and hand captures are biased by varying detection and capture probabilities among size classes, ages, and sexes (Reed *et al.,* 2016). Many studies however mention mixed success of traps to reduce snake numbers or poor trapping effectiveness for specific species. Based on the literature, traps are seemingly effective in capturing active-searching predators, particularly medium-to-small snake species with rupicolous or arboreal habits (Clark *et al.*, 2018; Picó *et al.*, 2019), yet their effectiveness drops for large sit-and-wait predators inhabiting semi-aquatic environments (Guzy *et al.*, 2023). Engeman and Vice (2001a) found that brown tree snake trapping success rates (on fences and forest edges) were four to seven times more successful than visually directed hand removal efforts using spotlights. However, studies on the effectiveness of trapping showed an exponential decline in trapping success as local populations of snakes were depleted while the removal rate for spotlighting and hand capture remained constant over time (Engeman & Linnell, 1998; Engeman & Vice, 2001a).

Due to the lack of baseline data on initial densities, it is not always clear if described trapping operations actually effectively reduce snake numbers. Some studies however do suggest that for some species, and in some situations, trapping does control snake numbers. For example, Montes *et al.* (2021) in relation to the horseshoe whip snake (*H. hippocrepis*) on Ibiza (Balearic Islands, Spain), noted that the use of traps was effective, as long as the numbers of snakes were high (although they are still insufficient to protect the endemic Ibizan lizard). The choice of the type of trap, bait and placement determines the results obtained. More specifically, regarding the management of brown tree snakes in Guam, about 1% to 25% of the snakes present per night were removed, with a long-term average of about 12.5%, suggesting that if barrier leakage was not a problem, eradication should be completed in a few weeks (Rodda *et al.,* 2002). On Formentera, over an area of 321 ha, baited live traps for ladder snake (*Z. scalaris*) had an efficiency of up to 0.167 captures per trap and per night, and 0.040 captures per unit effort on average but with seasonal changes in trapping success (Picó *et al.,* 2017). Interestingly, studies also show that trapping rates are higher if trapping areas are left undisturbed (Rodda *et al.,* 1999b; Picó *et al.,* 2017) i.e. if entrance rates to the areas by trappers are reduced, for instance by prolonging the checking intervals (e.g. 12 days in autumn, weekly in summer, Picó *et al.,* 2017). Of course, when live trapping, this needs to be balanced against welfare impacts on caught snakes.

In any case, although trapping over moderately sized areas (~17 ha) allowed the significant reduction of snake populations, from a logistic perspective it seems time-consuming, costly, and not practical for large areas or rugged terrain, where aerial application of toxic baits may result more effective (Clark *et al.,* 2018) although their use in the EU may be regulated/restricted. However, in relation to the control bullsnakes (*Pituophis catenifer*) in Nebraska, experiments showed that one person hunting snakes on foot for 6 hours daily was the equivalent of 2 to 3 traps for capturing bullsnakes operated concurrently (Imler, 1945). Also, Gallo Barneto *et al.* (2023) noted that the control measures carried out in the last 25 years with the California kingsnake (*L. getula californiae*) in Gran Canaria allowed to make important improvements in the use of traps, usually in association with manual capture methods.

A number of weaknesses regarding the use of traps were reported, particularly from the experience with the brown tree snakes in Guam (Campbell *et al.,* 1999; Stanford & Rodda, 2007; Rodda *et al.,* 2002, 2007b), but not exclusively (see also the cases reported by Bauman & Metter, 1975; Febrer-Serra *et al.,* 2021; Cabrera-Pérez *et al.,* 2012):

- snake traps are most effective for adult snakes, while usually fail to catch smaller snakes
- snake traps (particularly with live baits) are less effective in environments with high prey abundance (which can be expected where snakes are systematically removed), at the end of the feeding season, or if different feeding habits exist between different life stages (in the case of brown tree snakes Clark *et al.* (2018) noted a strong ontogenetic prey preference for small lizards and non-responsiveness to rodent-based lures)
- snake traps may not be effective at low density of the target snake population
- snake traps may produce bycatch, leading to unintended

impacts on non-target species
- snake traps may be not effective in low numbers
- snake traps may lead to the genetic selection of animals that are reluctant to entering traps, especially an issue with long-term lethal control

Trapping, as a measure by itself, is unlikely to eradicate a population entirely (see above). For this reason, an integrated response protocol including rodent control is suggested, e.g. which considers the application of rodenticide to reduce the density of this prey (Stanford & Rodda, 2007). Also, new trap designs to capture small snakes are required (Rodda *et al.,* 2002) as well as new types of bait/lures, and effective systems to ensure the site of eradication is not experiencing any immigration/recruitment of the target species (i.e. through the use of effective snake-proof **fences** and **barriers**).

Hawks have been used on Gran Canaria to detect and remove kingsnakes, showing some potential of **falconry** for managing invasive California kingsnakes. However, only 29 snakes have been captured thanks to Harris's hawks, therefore, the effectiveness of this measure may be limited compared to other methods (Gallo-Barneto & Gesplan, 2015). Considering the California kingsnake is nocturnal and fossorial, the use of hawks for kingsnake detection/control is probably not very effective for this species.

EFFORT REQUIRED

The effort required depends on the size of the area that is targeted, the density of occurrence of the species, and the accessibility, therefore it is difficult to give an overall estimate of the effort that is required.

RESOURCES REQUIRED

The minnow traps used for the management of the brown tree snake in Guam were reported to cost about US$6–12 each for the trap and mouse chamber, but additional costs were to be calculated for other necessary devices, and staff time for maintenance of live baits, setting and monitoring the traps, etc. (Rodda *et al.*, 1999b).

According to an assessment of the costs of prevention and control related to the potential arrival of the brown tree snake (*B. irregularis*) in Hawaii made by Burnett *et al.* (2006) "In the case of the brown tree snake, our results suggest that maintenance of a very low population is the optimal policy choice. If in fact a small number of snakes are already present, the mix of prevention and control must focus on both intercepting arrivals and catching existing snakes and maintaining a low population in perpetuity. At low populations, perpetuity damages and first-period removal costs become relatively unimportant, and the optimal number of snakes occurs where the marginal benefit of population reduction (due to lower costs of population maintenance) equals the marginal cost due to increased prevention expenditures".

SIDE EFFECTS

Environmental: Mixed
Social: Unknown
Economic: Mixed

Traps are a relatively safe and benign method of capture if used correctly. They do not pose particular health and safety, environmental, economic or social risks.

The environmental side effects can be negative, as the traps and nets will also capture non-target native species (bycatch). For example, in relation to the control of bullsnakes (*P. catenifer*) in Nebraska, the funnel traps used in association with drift fences resulted to be quite indiscriminate, capturing all sorts of reptiles and amphibians, as well as small mammals and birds (Imler, 1945). Among them, also some other non-target snake species, such as the garter snake (*Thamnophis radix* and *T. sirtalis parietalis*), eastern yellow-bellied racer (*Coluber constrictor flaviventris*), and hog-nosed snake (*Heterodon nasicus*) (see details in Imler, 1945). Especially when traps are placed in areas with high abundance of native or endemic species this can lead to substantial mortality if non-target species are not rapidly released, which needs to be considered when designing trapping campaigns. For instance, Piquet *et al.* (2023), over a period of two months, captured a total of 229 *Gallotia stehlini*, 331 *Chalcides sexlineatus* and 15 *Tarentola boettgeri*. Regular checking and the release of non-target species, as well as strategic placement of traps, can reduce the risks posed. In relation to the use of net-traps to catch Habu snakes (*Trimeresurus flavoviridis*) on Okinawa, Japan, Nishimura (2011) describes the non-target capture of other snake species, crabs and giant land snails. This method preferentially captured larger animals, those carrying a recent meal or gravid females. Nishimura (2011) describes checking nets infrequently and most animals were found dead in the nets. The welfare of the captured animals was not recorded, and snakes may be injured during capture as well as dying in the nets. Daily checking would be required to use this method for live capture. Social side effects are not reported in the literature. Negative side effects on economic activities can exist if the nets/traps are destroyed/stolen.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

Given the many different types of traps and relevant implications in terms of impacts and perceptions by the public, including in relation to animal welfare consideration, acceptability of stakeholders is not clearly identifiable, and is likely to be highly context dependent.

LEVEL OF CONFIDENCE*

Well established.

There is a lot of information available on which trapping method yields the best results, how they should be placed and when and what is the effectiveness.

* See Appendix

Chemical control (toxins, fumigant, repellents, attractants)

MEASURE DESCRIPTION

There are a number of chemical control methods for invasive alien snakes (Brock & Howard, 1962; Brooks *et al.*, 1998; Campbell *et al.*, 1999), ranging from toxicants, attractants and repellents, and irritants (Engeman & Vice, 2001b).

The most popular method is likely the one based on the use of acetaminophen (otherwise better known as paracetamol) in baits - usually dead (possibly neonatal) mice - to be delivered through bait stations (e.g. or "bait tube") or traps (to administer the bait to the target snake as selective as possible and reduce non-target impacts), including in association to barriers, or spread by hand, or through aerial broadcast (Clark *et al.*, 2012, 2018; Friebohle *et al.*, 2020; Hegan, 2014; Rodda & Savidge, 2007; Savarie *et al.*, 2001).

The toxic effect of acetaminophen in snakes is similar to CO (carbon monoxide) poisoning, as it causes death through methemoglobinemia and probable respiratory failure due to severe hypoxia (Mathies & Mauldin, 2020), which in simple words is by depriving cells of oxygen, hence resulting in anoxia, a kind of euthanasia considered relatively humane and effective (Clark *et al.,* 2018; Savarie *et al.,* 2001).

Field tests carried out to verify the suitability of acetaminophen to reduce population levels of brown tree snakes on Guam (Savarie *et al.,* 2001; Johnston *et al.,* 2002; Clark *et al.,* 2012) and California kingsnakes on Gran Canaria (Friebohle *et al.,* 2020) confirmed the effectiveness of acetaminophen baits at very low dosage (100% death occurring with an 80 mg/ bait, below the standards for safe humane exposure) (Savarie *et al.,* 2001; Clark *et al.,* 2018) to drastically reduce snake populations quickly and to bring survival to near zero (Savarie *et al.,* 2001). The tests also showed that intake of poisoned baits by non-target species such as rats or crabs was rare (Clark *et al.,* 2018), and that regurgitation of poisoned bait, although frequent in California kingsnakes, did not increase probability of surviving (Friebohle *et al.,* 2020).

Acetaminophen was also being considered for use in the Everglades (Florida, USA) with the Burmese python (*P. molurus bivittatus*), a species otherwise difficult to locate, given the effective camouflage in the marshy and often inaccessible habitat (Engeman *et al.,* 2011; Hegan, 2014).

Other chemicals were also tested. For example, dermal and oral toxicity tests were conducted on brown tree snakes, which showed that rotenone, propoxur, natural pyrethrins, allethrin, resmethrin were effective when delivered either orally or dermally, while diphacinone, warfarin, and aspirin were effective only when delivered orally and nicotine only once applied dermally (Brooks *et al.,* 1998; Savarie *et al.,* 2000). Nicotine in water has been used also for the control of garter snakes in arid areas (e.g. in Manitoba, USA), where it apparently worked well, but only during drought conditions (Stickel, 1953).

SCALE OF APPLICATION

The method can be used at either the local or regional scale. For example, an aerial delivery system (ADS) was developed to support landscape-scale control through the use of toxicants (Clark *et al.,* 2012; Siers, 2019).

EFFECTIVENESS OF MEASURE

Effective.

The use of acetaminophen seems very effective (Clark & Savarie, 2012), but unless snakes are prevented from reinvading cleared areas, the effects of small-scale population reduction efforts are expected to be short term (Savarie *et al.,* 2001).

Although acetaminophen has been evaluated as a humane and effective toxicant for other invasive reptiles, any recommendations for application in a management scenario should be preceded by confirmation of its efficacy for the target species (Savarie *et al.,* 2001).

EFFORT REQUIRED

No information was found on the issue.

RESOURCES REQUIRED

No detailed information was found on costs, but snake removal using poisoned baits was found to be about 1.67 times more cost-effective than trapping, i.e., $2.45 per snake killed vs. $4.08 per snake trapped (Clark *et al.,* 2012). Clarks and Savarie (2012) consider that the aerial broadcast of acetaminophen may be economically promising as a large scale control method.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Mixed
Social: Unknown
Economic: Unknown

Side effects may be important in areas with the presence of a very diverse fauna potentially susceptible to non-target poisoning (like in the Canary Islands), which may require increased caution when considering acetaminophen field use

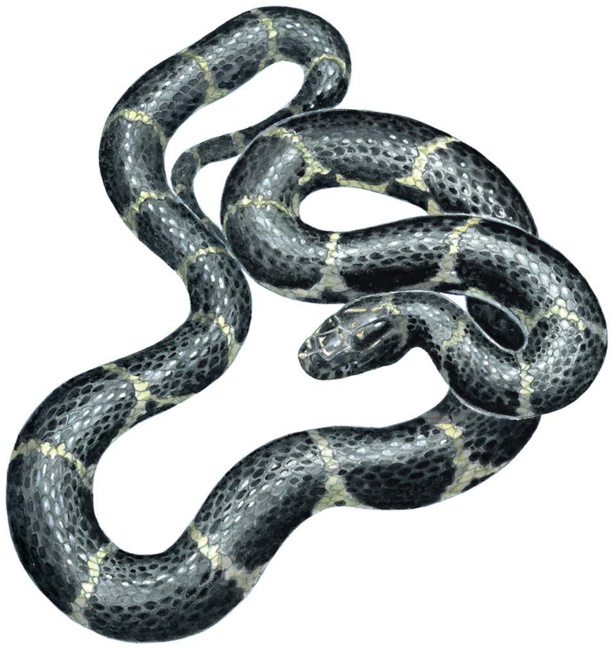
(Friebohle *et al.,* 2020). However, test made with brown tree snakes in Guam showed very limited non-target bait-take - only by a toad (*Bufo marinus*), and a monitor lizard (*Varanus indicus*) - with no evidence of ill effects after ingestion (Clark & Savarie, 2012). Similar results were also found within a dedicated risk assessment made by Johnston *et al.* (2002) who checked the effect of acetaminophen baits on a number of non-target domesticated and wild species of mammals, birds, and invertebrates (including other alien species, like rats and mice).

No information was found on the possible social and economic effects.

ACCEPTABILITY TO STAKEHOLDERS

Unknown.

No information was found on the issue; however the use of acetaminophen is considered relatively humane and effective (Clark *et al.,* 2018), which may help the acceptability for what concerns welfare considerations and public perceptions.



Lampropeltis getula getula. © Massimiliano Lipperi, Studio Wildart.

LEVEL OF CONFIDENCE*

Established but incomplete.

The method is established but was not extensively used, and experience is limited to few species only (see description above).

* See Appendix

Biological control (pathogens, parasites)

MEASURE DESCRIPTION

Biological control entails the use as a management tool of a species' natural enemy (i.e. predators or pathogens such as fungi and viruses) into the new range of the target species (see for example Engeman & Vice, 2001b). Given the history and high risks associated with biological control methods, this should be viewed as a last option (Hegan, 2014). In the case of the brown tree snake in Guam it was noted that this introduced species is able to reproduce and spread more easily since there are no natural predators, parasites, pathogens and competitors in the new ecosystems (Hegan, 2014). Some tests were conducted with the brown tree snake using either acarine parasites and viral contagions, haemogregarine parasites and predator snakes, and similar tests were also done with the Habu snake, but without practical results for the time being (Campbell *et al.*, 1999; Clark *et al.*, 2018; Wittenberg & Cock, 2001). Surveys within the brown tree snake's native range were also undertaken to look for candidate pathogens or parasites, but this did not lead to any practical result either (Clark *et al.,* 2018). For example, haemogregarine-like parasite infections were tested on brown tree snakes, but apparently had no significant effect on their health, showing that these parasites may not be a good candidate to control the species (Caudell *et al.,* 2002). Further experimental studies on biocontrol efficacy showed that the introduced brown tree snake population on Guam had been released of its native parasites, and paved the way to identify a candidate biological agent out of a list of helminth or haemoprotozoan parasites (Richmond *et al.,* 2012).

SCALE OF APPLICATION

No information was found on the issue.

EFFECTIVENESS OF MEASURE

Unknown or not yet applied.

Tested methods, although promising, were not considered definitive. On the other hand, because of the inherent risks of this method, biological control would require long-term extensive testing (including the possibility of genetic engineering) before development, plus the establishment of safeguard measures in case of application (Engeman & Vice, 2001b).

EFFORT REQUIRED

No information was found on the issue.

RESOURCES REQUIRED

No information was found on the issue.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Mixed
Social: Unknown
Economic: Unknown

Some biological control methods (for example those entailing the release of predators) may have negative effects on many other species, including native and protected or endangered ones. Others, for example those which involve the release of parasites or pathogens, are not always applicable, for example in places where there are species phylogenetically close to those being controlled, because the similar physiology of the individuals may lead to them sharing the negative effects alongside other non-target species. In the Balearic Islands (Spain), for example, there is an endemic lizard *Podarcis pityusensis* susceptible to negative impacts via the implementation of biological control methods (pers. comm. Víctor Colomar, 2023).

No information was found on the possible social and economic effects, although they are expected to be minimal.

ACCEPTABILITY TO STAKEHOLDERS

Unknown.
No information was found on the issue.

LEVEL OF CONFIDENCE*

Inconclusive.
No information was found on the issue.

* See Appendix

Habitat restoration vs. habitat alteration

MEASURE DESCRIPTION

Habitat management is a method to mitigate damage (but in some cases will merely relocate problems and impacts). Considering the limited success of managing invasive snake populations in general, **strategies that limit the impacts of established snake** populations on biodiversity probably deserve more attention as part of integrated control strategies. Methods to control the populations of invasive alien snakes and mitigate their impact on biodiversity include some kind of habitat management aimed at making target areas less attractive to snakes, from the design of **structural alterations** to the supply of **refugia** and the **reduction of prey abundance** (see reviews in Campbell *et al.*, 1999; Engeman & Vice, 2001b). For example, on Gran Canaria, *L. getula californiae* profits from feeding on invasive rats and other small human commensal mammals that are pest species themselves (Monzón-Argüello *et al.,* 2015). Rodent control programs in such areas could lead to a reduction of invasive alien snakes and the concomitant reduction of pest species which could boost public support. This however needs to be balanced against the predation on endemic reptiles as these disappear entirely in areas that are invaded by the snakes (Piquet & López-Darias, 2021).

Some of the methods cannot be of any use for the eradication of the target snake population, but at least can contribute to improving the conservation status of the threatened native species, like in the case of the planting of **trees and shrubs** for roosting and nesting which, along with the placement of **nest boxes**, is recommended as a measure for the conservation of birds threatened by the brown tree snake (Hegan, 2014; Wiles *et al.*, 2003).

Also, the use of **bright lights** to discourage nocturnal animal like the brown tree snake from visiting certain facilities seem a potential option, despite the risk of habituation and of attracting some of the preys favoured by the snake such as geckos (Campbell *et al.,* 1999).

Maintaining artificial **snake-free areas** (or snake reduced habitats) may also be an option, for example by creating isolated predator-free nature reserves using a combination of snake barrier and eradication methodologies, as explored in Guam with the brown tree snake, and in Japan with the Habu snake (Engeman & Vice, 2001b; Rodda *et al.*, 1999a, 2002). Areas of high conservation value may be targeted for intensive snake control to reduce their impacts. The coordinated use of a combination of methods among those described in the other sections, together with fencing to reduce rates of recolonisation may reduce levels of damage. Urban habitats may also act as predator-free areas. Vez Garzón *et al.* (2023) showed that urban areas act as refuges for an endemic lizard species in areas where otherwise invasive alien snakes thrive. Outside these urban "refuges", the

Natrix tessellata. © Massimiliano Lipperi, Studio Wildart.

abundance of lizards is severely affected by the presence of the horseshoe whip snake.

Other mitigation measures may also be considered, such as prey training (see Rowell *et al.,* 2020) to minimise snake predation on endangered species. However, this method has not been fully developed as yet, and mostly tested on captive animals. For example Burunat-Perez *et al.* (2018) present the results of experiments regarding antipredator training of the endangered lizard, *Gallotia simonyi*, in the Canary Islands, but the focus of the work was not on snakes (it was on raptors and domestic felids) and involved only lizards kept in captivity.

In the Balearic Islands (Spain) a "Gardening Manual" is being developed. (pers. comm. Víctor Colomar, 2023). It will be published with the aim of teaching the community how to create private gardens at home that may work as refuges for endemic lizards, *Podarcis pityusensis*, and avoid, as much as possible, the presence of snakes. This project is under the national Recovery, Transformation and Resilience Plan (PRTR) financed by NextGenerationEU, exactly "Project for the control and, where appropriate, the eradication of different invasive alien species in different habitats and geographical locations" (pers. comm. Víctor Colomar, 2023).

SCALE OF APPLICATION

So far habitat restoration and habitat alteration measures were tested/applied only locally.

EFFECTIVENESS OF MEASURE

Unknown or not yet applied.

Snake removal along with wildlife restoration measures are possible but sometimes not very practical because of high costs and other factors, e.g. size of area to be managed/protected and types of equipment, e.g. barriers and fences, however cost-effectiveness is not well known yet (Rodda *et al.,* 2002).

Regarding measures for habitat alterations, this requires the habitat structure to be a limiting factor for the target species, which sometime seems not the case, for example habitat structure is not considered a primary limiting factor for brown tree snakes (Rodda *et al.,* 1999c).

The effectiveness of reducing prey abundance is not well known. However, this option may be costly and as such not always feasible. For example, in Japan the high recurring costs of rat control to reduce Habu populations have discouraged the implementation of this potentially important strategy (Campbell *et al.,* 1999). Moreover, invasive alien snakes may have many different (alien) alternative preys, which would make them to continue having abundant populations even if the endangered or protected native species decline.

EFFORT REQUIRED

No information was found on the issue.

RESOURCES REQUIRED

No information was found on the issue.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Unknown
Social: Unknown
Economic: Unknown
No information was found on the issue.

ACCEPTABILITY TO STAKEHOLDERS

Unknown.
No information was found on the issue.

LEVEL OF CONFIDENCE*

Well established.
Refugia have been documented as an effective method to capture significant numbers of snakes, although other methods may be needed to ensure the complete removal of snakes from an area.

* See Appendix

Shooting

MEASURE DESCRIPTION

Shooting was used to eliminate watersnakes (*N. sipedon*) in a goldfish hatchery in Missouri, USA (Bauman & Metter, 1975). Actually, the species is native in that area, but due to the economic damage caused to the fishery plant, a bounty system was established for every watersnake killed (15 cents per snake). According to a study made in 1973, a total of 6,328 snakes were killed in a year (throughout the non-hibernating season), of which 1,370 were shot with a 22 calibre pistol (Bauman & Metter, 1975). The same authors noted that the number of snakes bountied and observed at the hatchery did not vary from year to year, suggesting that the control of the watersnake population prevented its expansion but did not significantly affect its size.

The method is not sufficiently popular to allow a clear assessment of the scale of application. Furthermore, no information was found on the effort and resources required, side effects, acceptability to stakeholders, and level of confidence for this measure.

Integrated management strategies

MEASURE DESCRIPTION

The use of a combination of the measures described for the management of invasive alien snakes (see the *Management* section for details on the separate measures), to be identified depending on the specific circumstances, can be the best approach. The choice of the management options may depend on the overall objectives (eradication, control or containment), which in turn would be affected by the actual size of the target site, the number of individuals or density of the target species, the connectivity of the relevant habitat with other suitable sites, the non-target species present in the area and the risk of non-target effects on them, but also the natural history and biology of the target species is pivotal. For example, López-Darías *et al.* (2023) summarised the accumulated knowledge on the phenology and movement ecology of the species, their habitat selection and prey preference, showing how this information can guide management. Similarly, they reviewed the most relevant results of a set of objectives addressed to directly inform the management of this invasion (eDNA use, biosecurity, trap selectivity, assessment of control method effectiveness, etc.).

The control of small populations within a specified area trapping with the assistance of detection dogs and the associated use of toxic baits seems to be the most appropriate approach (see relevant sections above).

There are several options to deal with the individuals captured and removed from the wild. Using the trapped animals for research on their condition and reproductive status should generally be the first option to consider. This can give insight in the demography of the population in relation to the effectiveness of the applied measures (e.g. is the method targeting all life stages? What is the reproductive status of the population? Is it going through any bottlenecks genetically?). Generally, when managing invasive populations in an adaptive management context, performing autopsies or X-raying gravid animals to collect data on their reproductive status is a good idea. One of the methods is to euthanise the animals, for example with pentobarbital at 0.1 ml per 100 g (Picó *et al.,* 2017) or any other approved method (cf. AVMA Guidelines for the Euthanasia of Animals). Another option is to place the animals within rescue centres or zoos, as in the case of *E. taenura* in Belgium (Adriaens T., 2023 unpublished). There is also the case of the asp viper (*V. aspis*) in the Netherlands, where one of the individuals removed was kept in captivity by Staatsbosbeheer where it also gave birth to youngsters before dying (pers. comm. Walter Getreuer, 2023) In some cases private pet owners can also take care of the specimens if an official agreement with them is made and if the proper measures are taken to avoid secondary dispersal.

SCALE OF APPLICATION

The scale of application depends on the resources available, and the management aims across the sites identified for management. Some sites may be suitable for eradication, and others for control or containment. In terms of effectiveness, measures with the aim of control will be more likely to be applied across a larger area than eradication.

EFFECTIVENESS OF MEASURE

Neutral.

As regards population control, there is evidence that physical removal measures can be effective at individual sites. However, the effectiveness across a large geographic scale is currently unknown, and is likely to be much harder to achieve, and potentially impossible. The same can be said also for eradication and containment. The local environmental conditions and the size of the population determine the effectiveness of the measure.

In a 2023 eradication program for an introduced green whip snake (*Hierophis viridiflavus*) population (of the southern subspecies *H. v. carbonarius*) from a 60 ha landfill site in Rhineland-Palatinate (Germany), catching by hand in combination with artificial cover objects has proven to be the most effective method (information: Büro für Landschaftsökologie LAUFER, pers. comm. Hubert Laufer, 2023). As a side note, about 230 specimens were removed from the wild and given to private holders as a strategy to prevent the killing of the snakes, which is not permitted (pers. comm. Hubert Laufer, 2023).

Examples of effectiveness described for different methods applied within different projects can be found in the other sections above.

EFFORT REQUIRED

The effort required depends again on the management objective that is set, on the area (e.g. size of the waterbody), and the density of number of the individuals that are targeted. It is expected that the effort required to manage established populations (such as population control, eradication, or containment across many sites) will be relatively high due to the human resources needed (for example, for setting and checking traps) and the fact that the measures will need to be in place permanently (or repeated on a regular basis).

RESOURCES REQUIRED

No information was found on the issue.

ADDITIONAL COST INFORMATION

No information was found on the issue.

SIDE EFFECTS (INCL. POTENTIAL) – BOTH POSITIVE AND NEGATIVE

Environmental: Mixed
Social: Mixed
Economic: Mixed

Several side effects can occur depending on the management action that was chosen. For details please see previous measures under the *Management* section.

ACCEPTABILITY TO STAKEHOLDERS

Mixed.

The acceptability will depend on the stakeholder group. Nature conservationists could be more in favour of control measures especially if the species threatens native species. Non-lethal despatch of animals, for example through rehoming, can be considered a viable option if this is needed for keeping up public support for management. It should be noted, however, that this mostly comes at higher cost for housing and sterilisation, involves a risk of reinvasion and also is not without welfare impacts.

LEVEL OF CONFIDENCE*

Established but incomplete.

Specific studies comparing the effectiveness of integrated management strategies with single-strategy control are lacking, yet many of the eradication and control campaigns described have taken an adaptive approach towards managing snake populations and are combining various methods.

* See Appendix

Hierophis viridiflavus. © Massimiliano Lipperi, Studio Wildart.

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Appendix

Level of confidence provides an overall assessment of the confidence that can be applied to the information provided for the measure.

- **Well established:** comprehensive meta-analysis or other synthesis or multiple independent studies that agree.
- **Established but incomplete:** general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps.

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