Risk assessment of Australian swamp stonecrop (*Crassula helmsii*) in Europe

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Summary

This report describes a risk assessment of the alien species Australian swamp stonecrop (*Crassula helmsii*) (hereafter: stonecrop) in Europe. The species is native to Australia and New Zealand but has been imported in many places in the world as an ornamental species for aquaria and garden ponds. It is a small perennial species of water bodies and wetlands. The species is considered invasive in several European countries.

The present risk assessment is based on a detailed risk inventory and can support national and international policy regarding management and control of stonecrop. The available information and data were analysed and the risks were classified by a team of experts using the Harmonia+ protocol.

The species invades a wide variety of artificial and natural habitats. Vegetative means of dispersal by - even minute - stem fragments being able to sprout and grow to a new plant enhances the invasion potential of the species.

Dispersion within Europe is both human-induced and natural. Main dispersion pathways are dumping of plant material from garden ponds and aquaria into nature, transportation of stem fragments during vegetation management (mowing), and transport of soils contaminated with plant fragments. Natural dispersion of vegetative fragments may occur in water bodies, but also through zoochory. In Europe, seed production has been proven possible. However, seed germination seems to be rare.

Stonecrop frequently grows in dense monospecific stands and can out-compete native plants and animals, thus changing natural ecosystems fundamentally, including the physical and chemical conditions. Both protected habitats and protected plant and animal species listed in the EU Habitat Directive may be negatively affected.

The future climate change is expected to have little effect on the risk of establishment, although high-elevation sites and northern regions may become increasingly vulnerable to stonecrop invasions, as extreme cold temperatures might become less frequent.

The risk assessment with Harmonia+ shows that the overall risk score is high for stonecrop. The risks of establishment and spread as a result of human activities are particularly high, as are the risks of negative impacts for biodiversity. Effects on human health, crops and cultivation systems are absent or less prominent.

Because the smallest stem fragments easily form a new plant, eradication is not a simple task. Not only need measures to be thorough to be effective, but also it may easily take some years of follow-up management to get rid of the species. Eradication is especially difficult because the measures taken usually create an ideal new habitat for this species. In most cases a combination of two or even more measures, applied over several years, will be required to achieve total extermination. In some instances, it may be better not to manage sites at all, to avoid dispersion of fragments and allowing the site to be overgrown by trees or other taller vegetation.

Several knowledge gaps exist, including some quite fundamental questions. Provenance and ploidy level of stonecrop throughout Europe may be different, but this is not known. Also, the

biotic and abiotic ecological effects of stonecrop may seem clear, but sound scientific research on the effects is rare or lacking. Furthermore, the impact of seeds, both in actual reproduction and in the possible building of a persistent seed bank in Europe, are largely unknown. Finally, the effectiveness of different types of eradication measures needs a thorough evaluation.

Samenvatting

Dit rapport beschrijft een risicobeoordeling van de exotische water- en oeverplant watercrassula (*Crassula helmsii*) in Europa. Deze soort is inheems in Australië en New-Zeeland maar is op veel plaatsen in de wereld ingevoerd als sierplant en zuurstofplant voor aquaria en tuinvijvers. Het is een kleine overblijvende soort van wateren en moerassen. In diverse Europese landen wordt de soort als invasief beschouwd.

Deze risicobeoordeling is gebaseerd op een uitgebreide risico-inventarisatie en kan het nationale en internationale beleid met betrekking tot beheer en bestrijding van watercrassula ondersteunen. De beschikbare data en informatie zijn door een team van experts beoordeeld met het Harmonia+ protocol.

Watercrassula kan een grote variëteit aan kunstmatige en natuurlijke habitats binnendringen. De soort is in staat zich vegetatief te verspreiden, zelfs met heel kleine stengelfragmenten die weer kunnen uitgroeien tot een nieuwe plant. Daardoor is de mogelijkheid om zich invasief te gedragen groot.

De soort heeft zich binnen Europa zowel op natuurlijke wijze als met hulp van de mens verspreid. De belangrijkste manieren van verspreiding zijn het in de natuur weggooien van planten afkomstig uit tuinvijvers en aquaria, het transporteren van stengelfragmenten door vegetatiebeheer (maaien) en transport van bodemmateriaal met plantenresten van watercrassula. Natuurlijke verspreiding van vegetatief materiaal kan passief in waterlichamen plaatsvinden, maar ook door transport door dieren. Zaadproductie lijkt zeldzaam in Europa.

Watercrassula vormt geregeld dichte massavegetaties, waardoor inheemse planten en dieren kunnen worden verdrongen. Door een besmetting kunnen natuurlijke ecosystemen fundamenteel veranderen, ook qua fysische en chemische omstandigheden. Dit kan een negatief effect hebben op volgens de EU Habitatrichtlijn beschermde habitats, planten en dieren.

De toekomstige klimaatverandering zal naar verwachting weinig effect hebben op de vestigingskansen voor de soort, hoewel noordelijke streken en hoger gelegen delen mogelijk gevoeliger worden voor invasie door watercrassula, omdat extreem lage temperaturen minder vaak kunnen voorkomen.

De risicobeoordeling met Harmonia+ laat zien dat de algemene risicoscore van watercrassula hoog is. Met name het risico op vestiging en verspreiding als gevolg van menselijke activiteiten is hoog. Dit geldt ook voor de invloed van de soort op de biodiversiteit. De effecten op de menselijke gezondheid, landbouwgewassen en andere teelten zijn afwezig of gering.

Het uitroeien van een soort waarvan zelfs de kleinste stengelfragmenten kunnen uitgroeien tot een nieuwe plant is niet eenvoudig. Maatregelen moeten niet alleen grondig zijn om effectief te kunnen zijn, het kan ook makkelijk enkele jaren nazorg vragen voordat de soort echt verdwenen is. Het uitroeien van de soort is extra moeilijk omdat veel van de maatregelen resulteren in een ideale situatie voor hergroei of nieuwe vestiging van de soort. In veel gevallen zal een combinatie van maatregelen moeten worden toegepast, gedurende een aantal jaren, voordat de soort op een locatie echt is uitgeroeid. In sommige situaties kan het beter zijn om geen beheer toe te passen, om verspreiding van fragmenten te voorkomen en om bomen of andere hoge vegetatie de groeiplaats te laten overgroeien.

Er zijn nog diverse kennishiaten, waaronder sommige vrij fundamentele. De herkomst en het ploïdie niveau van watercrassula in Europa zou verschillend kunnen zijn, maar dit is niet bekend. Hoewel de effecten op de soortensamenstelling en abiotische eigenschappen van ecosystemen duidelijk lijken, ontbreken zuiver wetenschappelijke studies naar deze effecten nagenoeg. Verder is het belang van zaden, zowel in de actuele reproductie als in de mogelijke opbouw van een langlevende zaadvoorraad in de bodem in Europa, in hoge mate onbekend. Tenslotte is er grote behoefte aan een evaluatie van de verschillende soorten maatregelen om de soort uit te roeien.

1 Introduction

1.1 Background

Australian swamp stonecrop (*Crassula helmsii*) (hereafter: stonecrop) is found in several EU Member States, including the Netherlands. The spread of this species, native to Australia and New Zealand, has increased in recent decades.
Land management organisations such as nature conservationists, municipalities, provinces, water boards and the Directorate-General for Public Works and Water Management (Rijkswaterstaat) as well as private individuals are increasingly concerned about the damage and costs entailed by stonecrop, which have even led to parliamentary questions (Proceedings of the House of Representatives of 11 March 2020 question 2020Z04814).
This prompted the Netherlands Food and Consumer Product Safety Authority (Nederlandse Voedsel- en Warenautoriteit, NVWA) to commission a risk assessment.

1.2 Advisory request

The NVWA instructed FLORON, the Radboud University Nijmegen and Stichting Bargerveen to carry out a risk assessment that meets all the criteria set out in the European Regulation on the prevention and management of the introduction and spread of invasive alien species and the corresponding Commission Delegated Regulation (EU) 2018/968. The assessment must be based on scientific substantiation of the risks associated with stonecrop. The end product must comply as much as possible with the European criteria for inclusion on the Union list and must contain, among others, the following elements:

- cultivation and trade;
- dispersal routes;
- risks to biodiversity;
- risks to the functioning of ecosystems;
- risks to ecosystem services;
- public health risks;
- socio-economic impact;
- risks of improper management;
- knowledge gaps;
- recommendations for further research.

1.3 Document structure

This report contains both background information on stonecrop and a risk assessment for this species. Chapter 2 outlines the methodical aspects of these two components. The results of the extensive literature search are then discussed in Chapters 3 to 7. The layout of the sections in this chapter has taken into account the Commission Delegated Regulation (EU) 2018/968 and the applicable risk assessment protocol (Harmonia+). Chapter 8 provides a discussion of the results of the risk assessment. The economic aspects are explained in Chapter 9, after which the options for management and control are outlined in Chapter 10.. Finally, Chapter 11 describes any knowledge gaps, as well as conclusions and recommendations.

2 Material and methods

2.1 Literature review

The online search engines Google Scholar and Web of Science (both in English) and Google.nl (in Dutch) were used to collect scientific literature (peer reviewed articles, reports and dissertations) using the digital library facilities of the Radboud University Nijmegen, ResearchGate and various Open Access facilities of journals, libraries and research institutes. Searches were carried out using various search terms for each topic covered in this risk assessment (Table 2.1). The focus of the literature review was on the topics that were insufficiently or not addressed at all in the available risk assessments, on the European context and the scale of the risks, and on the scientific substantiation required for the assessment of the relevant risk criteria. Where relevant, the (potential) distribution and risks of the species for the European Union are described for both Member States (including the Netherlands) and biogeographical regions. For each search, the first 30 hits were evaluated to select articles or reports that were relevant to the underpinning of the risk assessment. The results, the number of hits and potentially useful sources from all searches are listed in Annex 1.

Table 2.1: List of search engines used and examples of terms used.

Search engine	Search	Terms
Google.nl	Using all Key words	Watercrassula
	Combined with at least 1 of the Key words	Habitat, ecosysteem, eisen, standplaats, toleranties, negatieve, effecten, problemen, invasief, risicoanalyses
Google Scholar	Using all Key words	*Crassula helmsii*
	Combined with at least 1 of the Key words	Habitat, ecosystem, demands, stand, tolerances, negative, effects, problems, impact, invasive, risk assessments
Web of Science	Using the Key words	*Crassula helmsii* habitat, ecosystem, demands, stand, tolerances, negative, effects, problems, impact, invasive, risk assessments

The articles and reports referenced in the sources were also assessed for potentially new information on stonecrop. Additional information from publications, such as Floras of the region of origin, was used for the description of species and habitat characteristics. In addition, this risk assessment used available foreign risk assessments and factsheets on stonecrop. These were retrieved using all combinations of the scientific name (including synonyms) and the search terms ‘risk assessment’, ‘risk analysis’ and ‘risk classification’ (in multiple languages).

2.2 Distribution in the Netherlands

The data on the distribution within the Netherlands came from the Dutch National Database Flora and Fauna (Nationale Databank Flora & Fauna, NDFF; https://www.ndff.nl/). The NDFF collects distribution data provided by volunteers, provinces, municipalities, water boards, research institutes and land managers. In addition to a geographic location, some of the observations also include data relating to abundance and biotope.

2.3 Distribution across Europe

The data for distribution outside the Netherlands was gathered by combining information from various sources:
• GBIF.org (3 March 2020) GBIF Occurrence Download https://doi.org/10.15468/dl.h3py4v.
• iNaturalist: https://www.inaturalist.org/.
• EPPO
: https://gd.eppo.int/taxon/CSBHE/distribution
• CABI: https://www.cabi.org/isc/datasheet/16463

Additional distribution data was obtained by conducting searches for the various EU countries on sites containing distribution data. Furthermore, a Google search was carried out using the key words 'invasive plants' AND '*Crassula helmsii*'. The search term 'invasive plants' was translated into the official languages of the various EU Member States using Google Translate. Annex 1 contains a list of all the websites that were consulted. The publications that were found on these websites are included in the bibliography.

2.4 Risk assessment and classification using Harmonia$^+$

The risk assessment and classification of stonecrop was carried out by a team of six experts (the authors of this risk assessment) using the Harmonia$^+$ protocol. Each individual expert studied the background information of the species in advance and subsequently completed the online version of the assessment protocol (D'hondt et al. 2014) for the risk classification of the species, independently of the other experts. This involved focusing on both the current situation and a future scenario (horizon of approx. 50 years), which entailed an assessment of the impact of climate change on the risks related to stonecrop.

Following the individual risk assessment, a workshop took place with the team of assessors in which the rationale for all the risk scores and the corresponding level of confidence were outlined. The workshop also entailed a discussion on the differences between risk scores and levels of confidence. The discussions about all the Harmonia$^+$ protocol criteria resulted in consensus regarding these scores and their (scientific) substantiation.

The various risk score and levels of confidence were subsequently calculated (Box 2.1). The version of the Harmonia$^+$ protocol that was used comprises 41 questions in total, which are classified into 7 categories, which are:

1. Context (questions A1-A5);
2. Introduction of species (questions A6-A8);
3. Establishment of species (questions A9-A10);
4. Spread of species (questions A11-A12);
5. Potential environmental impact of species (questions A13-A30);
6. Potential impact of species on ecosystem services (questions A31-A33);
7. Impact of climate change on the risks of a species (questions A34-A41).

The 'Potential environmental impact of species' is divided into five subcategories, namely:

1. Impact on biodiversity and ecosystems (questions A13-A18);
2. Impact on plant cultivation (questions A19-A23);
3. Impact on livestock farming and animal welfare (questions A24-A26);

4. Impact on public health (questions A27-A28);
5. Other impact, as infrastructure degradation (questions A29-A30).

Each (sub)category contains multiple risk assessment questions, with risk score completion options and the corresponding level of confidence for each question. The risk scores allow for three to five scores (e.g. none/very low, low, moderately high, very high) or 'not applicable'. There are three possible scores for the level of confidence (low, medium or high). Every question in the risk assessment protocol is provided with an explanation, including examples that serve as a reference when determining the risk scores.

The Harmonia$^+$ protocol is a risk screening procedure. This method was solely developed for the assessment of the negative impact of alien species and does not take into account any positive effects. Any available information on the positive effects of the species assessed is included in the knowledge overview and assessed in the section on the effects on ecosystem services.

Box 2.1: Concept and definitions for risk assessment and classification of alien species using the Harmonia$^+$ protocol (D'hondt et al. 2014).

<u>Concept</u>
Invasion = f(*Introduction; Establishment; Spread; Impact$_{a\text{-}e}$*)
Risk = Exposure x Probability x Impact

<u>Invasion = risk?</u>
Exposure ≡ f_1(*Introduction;Establishment;Spread*) = ***Invasion score***
Probability x *impact* ≡ f_2(*Impact$_a$*; *Impact$_b$*; *Impact$_c$*;*Impact$_d$*; *Impact$_e$*) = ***Impact score***
with a: environment (biodiversity and ecosystems); b: cultivated plants; c: domesticated animals; d: public health; e: other

Risk = *Exposure* x *Probability* x *Impact* ≡ f_3(*Invasion score*; *Impact score*) = **Invasion**

<u>Calculation methods</u>
f_1 : (weighted) geometric mean or product
f_2 : (weighted) arithmetic mean or maximum
f_3 : product

Box 2.1 outlines the methods used to calculate the various risk scores. In the Harmonia$^+$ protocol, a biological invasion is defined as a function (f) of the introduction, establishment, spread and various types of (a-e) impact of a species (D'hondt et al. 2014). The 'risk' of an invasion is defined as the likelihood that a particular hazard of a species can actually cause harm. This risk increases (1) with the exposure to the hazardous event, (2) with the probability (likelihood) of the hazardous event actually occurring and (3) with the potential impact of that event. For that reason, the risk is defined as a product of these three factors, i.e.: exposure × probability × impact.

The protocol allows for the calculation of three scores, i.e. the invasion score, the impact score and the risk score. The invasion score is a measure of exposure and within the protocol is calculated as a function (f1) of the probability of introduction, establishment and spread. The impact score is a measure of probability × impact and within the protocol is calculated as a function (f2) of the probability of the various types of impact (a-e, i.e. impact of biodiversity and ecosystems, cultivated plants, domesticated animals and animal welfare, public health and other effects) occurring. Hence, risk can be calculated as a function (f3) of the invasion and impact score.

Various calculation functions (f1, f2 and f3 in Box 2.1 respectively) can be used to calculate the invasion score, impact score and the risk score. The protocol has also been used for weighting factors to be attributed within and between various risk categories. The default values (= 1) were used at all times for all weighting factors in the risk assessment of stonecrop. As such, the various types of impact within a given risk category are always given equal weight in the calculation of the risk scores. The maximum value is used at all times for the calculation of the impact score of a specific risk category, in order to avoid the averaging of impacts. The product of the introduction, establishment and spread score is used for the calculation of the invasion score. The maximum of the various impact scores is used at all times for the calculation of the aggregated impact score. Table 2.2 provides an overview of the threshold values and colour schemes used for the 'low', 'medium' and 'high' risk classifications.

All assessment questions allow for the level of confidence of the answer to be included. The level of confidence is consistently reported using 'low', 'medium', 'high' for 0-33%, 33-66% and 66-100% probability respectively in accordance with the principle outlined by Mastrandrea et al. (2010; 2011). In Harmonia+, the scores 0, 0.5 and 1 are allocated to 'low', medium' and 'high' respectively. For each risk category, the arithmetic mean of all confidence scores for the related criteria is calculated and subsequently converted into 'low', 'medium' or 'high' based on the threshold values (Table 2.2). The level of confidence is indicated with colour codes in shades of blue.

Table 2.2: Threshold values and colour schemes of risk and confidence classification.

Color code Risk level	Risk level	Risk score (RS)	Color code Confidence	Confidence level	Confidence score (CS)
	Low	0<RS<0,33		High	>0,66
	Medium	0,33 ≤ RS ≤ 0,66		Medium	0,33 ≤ CS ≤ 0,66
	High	>0,66		Low	<0,33

2.5 Comparison with other risk assessments

Other risk assessments for stonecrop that were drafted for other countries or regions were collected via a literature review (Section 2.1). The available risk assessments were often carried out using other protocols, which include both compact and rapid assessments for priority or warning lists for alien species and detailed risk assessments of these species for countries in Europe or for all of Europe (Table 8.1). For effective comparison of their outcomes with the current assessments, all risk scores have been harmonised into three risk classes, i.e. low, medium and high risk.
The risk classifications using the Invasive Species Environmental Impact Assessment (ISEIA) protocol (Belgian Forum on Invasive Species) were used because this protocol also distinguishes between three levels of risk, i.e. low risk (Score 4-8; Code C), medium risk (Score 9-10; Code B; watch list) and high risk (Score 11-12; Code A; black list).

Scores for the invasiveness of alien plant species using the Australian Weed Risk Assessment (WRA) system (Pheloung et al. 1999) were harmonised as low risk for WRA scores of < 11, medium risk for scores of 11-20 and high risk for scores of > 20. Scores using the Weber & Gut (2004) system, the combined WRA-WG system (Andreu & Vila 2009) and the combined WG-European and Mediterranean Plant Protection Organisation Pest Risk Assessment Scheme (EPPO) were harmonised as low risk for WG scores of < 21, medium risk for scores between 21-27 and high risk for scores of > 28. The scores of the Risk Assessment Methodology Invasive Species Ireland (Kelly et al. 2013) were harmonised as low risk for scores of < 14, medium risk for scores of 14-18 and high risk for scores of > 18.

The Great Britain Non-Native species Risk Assessment (GB-NNRA) protocol, the Methodik der naturschutzfachlichen Invasivitätsbewertung für gebietsfremde Arten (MNIGA; version 1.2) and Naturschutzfachliche Beurteilung (NFB) use three risk categories and have therefore been used unchanged. In a number of cases, no explicit risk categories were listed, however the relevant species were placed on a national or regional list of invasive alien species (e.g. blacklist, invasive species list, list of potentially invasive species or list of prohibited species). In such cases, the harmonised risk score specifies that this relates to a high score.

3 Description of species

3.1 Taxonomy

Kingdom:	Plantae
Phylum:	Tracheophyta
Class:	Magnoliopsida
Order:	Saxifragales
Family:	Crassulaceae
Genus:	Crassula

Source:
https://www.catalogueoflife.org

Figure 3.1. Growth habits of Australian swamp stonecrop (M. van de Loo)

3.2 Nomenclature

3.2.1 Scientific name

Crassula helmsii (Kirk) Cockayne

3.2.2 Synonyms

Bulliarda recurva Hook.f.
Crassula recurva (Hook.f.) Ostenf.
Tillaea helmsii Kirk
Tillaea recurva (Hook.f.) Hook.f.
Crassula helmsii (Kirk) A.Berger

3.2.3 Trade names

In the commercial trade, *Crassula helmsii* is often referred to *Crassula recurva*. There is no distinction between different cultivars in the commercial trade (Hoffman 2016).

3.2.4 Vernacular names

Danish	Newzealandsk Korsarve
German	Helms Dickblatt; Zurückgekrümmtes Dickblatt; Nadelkraut; Gekrümmtes Nadelkraut
English	Stonecrop; New Zealand stonecrop; Australian stonecrop; Australian swamp stonecrop; Swamp stonecrop; Swamp crassula; Helms crassula; Crassula; New Zealand pigmyweed; Pigmy weed

Estonian	Lõunavesikas
French	Crassule des étangs; Crassule de Helms; Orpin des marais; Orpin australien
Italian	Erba grassa di Helms
Dutch	Watercrassula, Waternaaldkruid, Naaldkruid
Polish	Grubosz Helmsa
Portuguese	Sedum dos Pântanos
Russian	Толстянка Хелмса; Тиллея отогнутая; Крассула хелмси; Буллиарда отвороченная
Spanish	Crásula de agua
Czech	Tlustice novozélandská
Welsh	Planhigyn suddlon; Corchwyn Seland Newydd
Swedish	Sydfyrling; Vattenkrassula

3.3 Description of species characteristics

Stonecrop is a perennial, evergreen, hairless, marsh and aquatic plant (Dawson & Warman 1987, Smith & Buckley 2020). The plant forms creeping stems on land and emergent as well as entirely submersed stems in the water. The stems can grow up to approximately 1 metre in length and are minimally branched; adventitious roots are formed on the lower nodes. The leaves are opposite and fused at the base, linear-lanceolate, and 4-15(-20) mm long, 0.7-1.6(-3.0) mm wide and 0.5-0.8 mm thick. The leaves are flat from above and convex from below and are somewhat thick fleshy (succulent) in plants growing on land. The uniflorous, axillary inflorescences are located at the ends of the stems and always emerge above the water. The pedicels are 2-8 mm long and curve back when the fruit is ripe. The hermaphroditic flowers are 3.0-3.5 mm across. The 4 sepals are roughly half as long as the petals and fused at the base. The freestanding calyx lobes are 1–1.5 mm long and 0.5–0.6 mm wide and triangular ovate and pointed or slightly tapered. The 4 white or pink petals are wide-elliptic ovate, 1.2-1.8 mm long and 0.8-1 mm wide and slightly tapered to a point. The 4 stamens are placed opposite the sepals and are shorter than the sepals. The filaments are thin and curved. The anthers split in a longitudinal direction. The ovary consists of 4 pistils positioned opposite the sepals; the pistils are not fused and taper to the top, at which they are truncated. The styles positioned at the top of the pistils are short, slightly curved and bear an inconspicuous stigma. The pistils carry a 0.7 mm-long nectar-producing scale at the base. Each pistil contains 8 seed buds which not all develop. The fruit consists of four smooth 2 mm-long follicles opening on the inside, each containing 2-5 seeds. The seeds are brown and smooth, 0.4-0.5 mm long and 0.25 mm wide and weigh 0.017 mg (De Lange 2014, Stace 2019, South Australian Seed Conservation Centre 2018, Smith & Buckley 2020).

Figure 3.2 Stonecrop flower (Image J. Van der Loop)

Stonecrop exhibits some degree of variation within the original area. The New Zealand plants are smaller and more delicate and diploid (2n=14). The Australian plants are bigger and hexaploid (2n=42) (De Lange et al. 2004b, 2008, De Lange 2014). The chromosome number in the United Kingdom is 2n=36 (Stace 2019). The leaves of the Australian plants are more clearly prickly and have more tapered calyx tubes and petals (Laundon 1961).

Due to these differences, the New Zealand and Australian plants were initially considered as being two distinct species, *Tillaea helmsii* Kirk and *Tillaea recurva* Hook.f. respectively. In 1907 and 1918 respectively, both species were transferred to the genus *Crassula* as *Crassula helmsii* (Kirk) Cockayne and *Crassula recurva* (Hook.f.) Ostenf. Laundon (1961) synonymised both species under the earliest valid name, i.e. *Crassula helmsii* (Kirk) Cockayne.

3.4 Similar species

Although stonecrop (*Crassula helmsii*) is similar to *Crassula aquatica*, this species is far smaller than stonecrop and barely grows to 5 cm in height; the leaves are only 3-5 mm long and the flowers in the leaf axils are sessile. By contrast, the pedicels in stonecrop are 2-8 mm long (Stace 2019, Laundon 1961). Due to the opposite leaves, submersed forms of stonecrop somewhat resemble submersed forms of *Callitriche* (Water starwort) species that lack a floating basal rosette.

A number of closely related and highly similar species can be found in New Zealand, including *C. ruamahanga* A.P.Druce (De Lange et al. 2008) and *C. moschata* G.Forst. (De Lange 2014). In total, approx. 30 species of *Crassula* can be found in New Zealand, including a number of exotic species (De Lange et al. 2011). *Crassula natans* var. *minus* (referred to as 'Floating Crassula' in Australia!), which originated from South Africa, bears a superficial resemblance to stonecrop. This species is invasive in Australia and was also recently found in New Zealand (De Lange et al. 2011). *C. peduncularis* is also closely similar to *C. helmsii*. In addition to Australia, Tasmania and New Zealand, this species can also be found in South America (Toelken 1981).

C. helmsii closely resembles *Crassula granvikii* Mildbr., a species found in the mountain regions of tropical Africa (Uganda, Kenya, Tanzania, Ethiopia, Eritrea, Rwanda, Burundi and Malawi) (Laundon 1961, Catalogueoflife.org).

3.5 Native range

The native range of stonecrop includes Australia (Victoria, New South Wales, Southern Australia, Tasmania and Western Australia) and New Zealand (coastal regions of South Island) (https://bie.ala.org.au/). In New Zealand it is a fairly rare plant that occurs naturally in small dispersed populations and is therefore likely to become locally extinct (De Lange et al. 2004a).

3.6 Invasion history of non-native range

It is unclear exactly when the plant was introduced. Reports that the species may have been introduced as early as 1890 (Nehring et al. 2013a,b) are based on confusion with *Crassula* *recurva* N.E.Br. (= *Crassula alba* Forssk.). This species was introduced to the United Kingdom from South Africa (Natal) around 1890 (Brown 1890).

In Great Britain the plant has been available in the ornamental trade since 1926, under the name *Tillaea recurva* (Laundon 1961). The nursery in question was still operating around 1980, but neither the exact origin, nor the exact import date of the material could be retrieved from the archives at the time. The plants were most likely imported from Australia before 1914. During the First World War, cultivation ponds with Nymphaea species were no longer maintained and stonecrop proliferated significantly during that period. At the time, stonecrop was not listed as a separate species, but was sold alongside other plants as an oxygen plant. Several other nurseries also obtained plant material from the nursery in question (Swale & Belcher 1982).

Plants sampled throughout the United Kingdom were found to be genetically similar and found to represent a single line to a significant degree. When comparing the various genetic lines from the original Australian region with the plant material from the United Kingdom, it was found that the British plants most likely originated from the region of the Murray river in Australia (Dawson 1994 in Smith & Buckley 2020).
See 6.1 for more information on first finds in various European countries.

3.7 Habitat and ecology

Stonecrop is not very selective in terms of its habitat; the species can be found in a broad variety of fresh water habitats, which may be slow moving or stagnant and include pools, lakes, fens, skating rinks, canals, streams and drainage canals, where the species grows both in the water and on the bank (Dawson & Warman 1987, Van Kleef et al. 2017). The species is absent in salt or brackish waters (Dawson & Warman 1987). Contrary to the former reference, more recently actual occurrence of stonecrop in brackish waters has been confirmed (Denys & Packet 2004).

The species is also not very picky about soil type, growing primarily on clay soils in England, but equally on sand, gravel and organic soils (Dawson & Warman 1987, Child & Spencer-Jones 1995, Hussner et al. 2021). In the Netherlands, stonecrop primarily can be found on sandy soils and to a lesser extent on clay (Van Kleef et al. 2017). The species grows poorly on peat soil in the Netherland (J. Van der Loop).

In Europe, lack of light and receding water levels and dry periods do not restrict stonecrop (Newman & Raven 1995, OEPP/EPPO 2007, Hussner 2009, Smith 2015, Hussner et al. 2021, Van Kleef et al. 2024). The level of rainfall required for the terrestrial growth habit of the species in its natural habitat within its native range in Australia is only 220-300 mm during the winter and 100-550 mm in the summer (Leach & Dawson 2000). In England, average rainfall in the areas where stonecrop has spread is 826 mm per year (Hill et al. 2004). In case of reduced rainfall, stonecrop remains vigorous, but growth decreases (Dawson & Warman 1987).

In its natural habitat within the native range in Australia, the average daytime temperature is between 0 and 15° during the months of May to October and between 20 and 25°C between the months of November to April (Leach and Dawson 1999). The temperature of the stands in England and Ireland together average 3.8°C in January and 15.8°C in July (Hill et al. 2004). The species can withstand frost up to -7°C (Kirby 1965, OEPP/EPPO 2007, Dawson 1994 in Smith & Buckley 2020) and even survival for three weeks in a freezer at temperatures of -18°C was observed in the Netherlands (J. Van der Loop). During winter stonecrop is thought to survive best in the fully submerged condition (Dawson & Warman 1987), although Hussner et al. (2009 & 2021) stated that the species is sensitive to air frost.

Stonecrop has the potential to be dominant in conditions that are both poor and rich in nutrients. According to Keeley (1998) and Klavsen and Maberly (2009), the invasive nature of the species is therefore not dependent on the availability of nutrients. In the Netherlands likewise stonecrop virtually only occurs as a surface-covering plant both in oligo and eutrophic waters. However, in ecosystems that are relatively poor in nutrients, such as fens, dune pools and ice rinks, the plants remain small and are not very competitive. In the absence of nutrients, stonecrop can therefore only become dominant if there is little coverage by native species (Van Kleef et al. 2017, 2024).
In England, stonecrop has been found in running waters with a current of up to 0.32 m/s (Dawson & Warman 1987) and in the Netherlands the species can be found in running water, including in the Kleine Beerze stream, along a considerable length (source: observations R. Beringen & M. Janssen in the NDFF). It is unknown what current speeds stonecrop can tolerate in the Kleine Beerze stream.

Stonecrop grows rapidly and is able to overgrow other species when nutrient availability is high (Brunet 2002, Hussner 2009, Klavsen et al. 2011, Ewald 2014, Brouwer et al. 2017, Van Kleef et al. 2017, Van der Loop et al. 2020, Hussner et al. 2021). Nitrogen, phosphorus and carbon can all stimulate the growth of stonecrop (Brouwer et al. 2017, Van Kleef et al. 2017, Van der Loop et al. 2020). The atmospheric deposition of nitrogen, the fertilisation of surface and groundwater with carbon, nitrogen and phosphorus from agricultural activities as well as manure from waterfowl may contribute to the proliferation of the species (Brouwer et al. 2017, Van der Loop et al. 2020, Van Doorn et al. 2024).

Stonecrop only uses carbon dioxide (CO_2) as a source from which to draw carbon: the plant is unable to absorb carbon from the water in the form of bicarbonate (HCO_3^-) and only uses carbon dioxide from the water layer or atmosphere. This means that stonecrop cannot grow in water with a pH higher than 8, given that only inorganic carbon is present in the form of bicarbonate (Keeley 1998) in such cases. This has been confirmed in studies showing that stonecrop only grows in waters with a pH between 4.3 and 7.8 and an alkalinity between 0 and 0.92 meq/L (Brunet 2002, Hussner 2009, Klavsen et al. 2011, Van Kleef et al. 2017, 2024). The range of water quality variables for stonecrop is probably higher in recent research by Geest and Roelofs (pers. communication E. Brouwer). Low availability of carbon dioxide underwater, despite the availability of a CAM mechanism in photosynthesis, limits the growth of stonecrop (also see 7.1.4.). In waters with prolific stonecrop growth, the average concentration of CO_2 in the summer is well above 200 µmol/L (Van Kleef et al. 2017). With regard to other aquatic plants, it has also been shown that they are no longer limited by carbon above this concentration level (Bloemendaal & Roelofs 1988).

Waters are vulnerable to invasion by stonecrop when disturbed and where open niches, such as bare soils, are present (Brouwer et al. 2017, Van Kleef et al. 2017, Smith & Buckley 2020, Van der Loop et al. 2020). This is also the case for many other invasive plant species (Hobbs 1989, 1991, Hobbs & Huenneke 1992, Rejmánek 1999). The establishment and proliferation of stonecrop is significantly inhibited in certain water types by the presence of native plant species such as shoreweed (*Littorella uniflora* Asch.), marsh St. John's-wort (*Hypericum elodes* L.), peat mosses (*Sphagnum* spec.) and pillwort (*Pilularia globulifera* L.) (Brouwer et al. 2017, Van

Kleef et al. 2017, Van der Loop et al. 2020). Competitors reduce opportunity of establishment by 70% and reduce growth by more than 95% (Van Kleef et al. 2017, Van der Loop et al. 2020).

Habitat and ecology in the region of origin

In the region of origin, Australia, stonecrop can be found in a variety of biotopes, varying from periodically drying running and standing water to the banks of lakes, with the species being both submerged by several metres and emergent on the banks several metres above the water level (Smith & Buckley 2020). Disturbances due to livestock trampling and periodic high water levels are well tolerated. The plant does not grow in fast-running water and does not tolerate flooding with salt water. In estuaries it will grow in proximity to the sea, but never in contact with seawater. The plant is able to quickly colonise bare areas, for example, after a fire, but cannot compete with tall plants such as Reed. In the south and east of the region of origin, the plant regularly grows with *Myriophyllum penduncululatum*. In the west, it is often found with the alien species *Crassula natans* Thunb. The plant can tolerate major water level fluctuations, provided the stand does not dry out. The plant is found both in weakly buffered waters with a low level of conductivity and in brackish waters (Dawson & Warman 1987, Denys & Packet 2004). Nutrient levels may also vary significantly, but the species does not grow in highly polluted waters (Dawson 1989). This differs in a number of ways from the habitat and ecology found in Europe. In Europe, for example, the species does not appear to occur in strongly saline environments and the species also appears to grow in water that is richer in nutrients than in its region of origin.

Vegetation

The National Vegetation Database (Landelijke Vegetatie Databank) (https://www.synbiosys.alterra.nl/lvd) includes 115 relevées (vegetation sampling plots) in which stonecrop is present. Stonecrop has been found in a variety of plant communities (Figure 3.3, Annex 2). Most studies were carried out in vegetations from the *Littorelletea* class, which are pioneer vegetations on mineral soils in shallow, often exposed, low-nutrient, weakly buffered, weakly acidic to neutral waters. These types of vegetation are primarily found in fens.

Many studies were also conducted in vegetations belonging to the *Nanocyperion flavescentis* alliance, which is mainly annual pioneer vegetation on moist, low-nutrient to moderately high-nutrient, weakly buffered, weakly acidic to neutral soils. This vegetation develops on heath cutting sites or along cleaned pools and fens. In more nutrient-rich habitats, stonecrop grows in the *Bidention* alliance pioneer vegetation. This type of vegetation grows on banks that dry out in the summer along nutrient-rich freshwater, such as rivers and the IJsselmeer/Markermeer. stonecrop has been found along the Krammer-Volkerak with species from brackish habitats such as Celery (*Apium graveolens* L.), Sea Aster (*Tripolium* pannonicum (Jacq.) Dobrocz.), Distant sedge (*Carex distans* Lightf.), Sea milkweed (*Glaux maritima* L.) and Blackgrass (*Juncus gerardii* Loisel.).

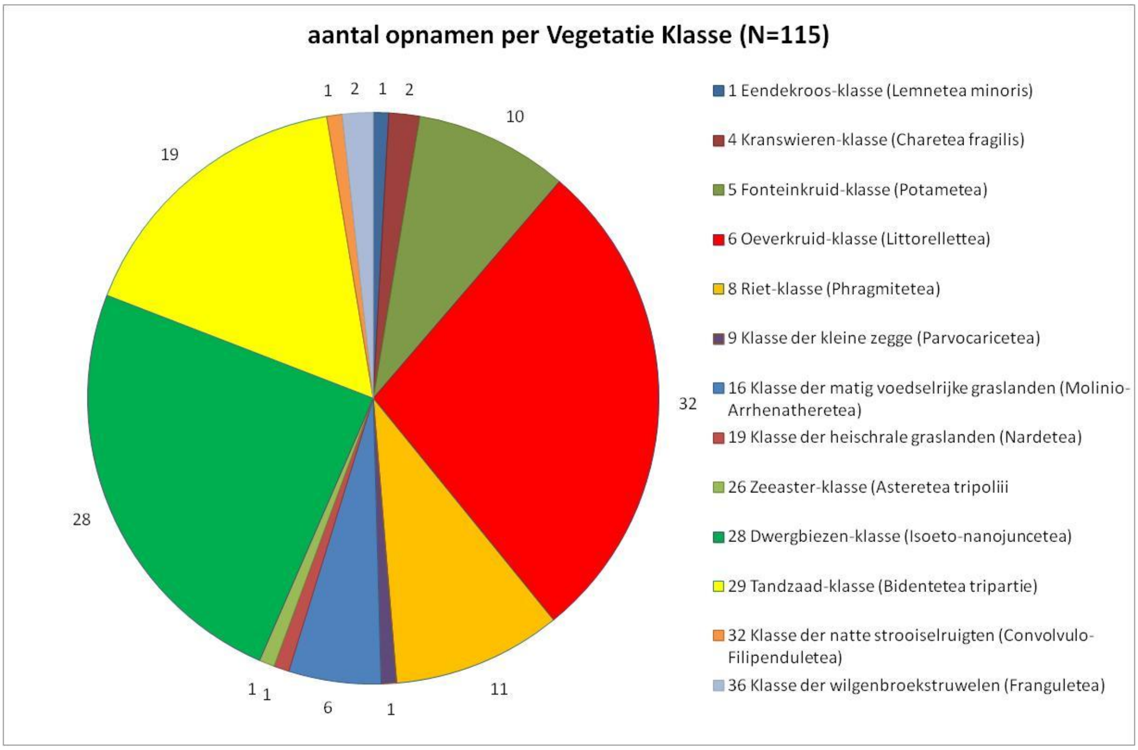

Figure 3.3. Distribution of stonecrop in the Netherlands among the various Vegetation types (Classes) based on occurrence in vegetation relevées in the Dutch National Vegetation Database (Vegetation classification according to Schaminée et al. 1995-1999).

3.8 Life cycle, reproduction and dispersal

3.8.1 Life cycle

Stonecrop is an evergreen perennial that continues to grow during winter, with an occasional decrease in biomass but with no real dormant period (Dawson & Warman 1987, Hussner 2009, Smith 2015). As a result, stonecrop has an advantage over other plants that need to produce their entire biomass at the start of the growing season, such as *Pilularia globulifera*, or that are less active during winter, such as bulbous rush (*Juncus bulbosus* L.).

In its native range, stonecrop is in bloom all year round, as long as there is sufficient water (Toelken 1981). The flowering period outside of the natural region is variable, with flowers primarily being observed from June to the end of October (Clapham et al. 1990, FLORON 2020).

3.8.2 Reproduction

The plant flowers each year with small, white or occasionally pink flowers, which produce 2 – 5 seeds that are 0.5 mm in length, both in the area of origin and in the introduced areas (Allan 1982, Dawson & Warman 1987, OEPP/EPPO 2007). No flowers form when the plant is submerged and when a plant is inundated whilst in bloom, the flowers abscisse (Diaz 2012). The flowers are hermaphroditic, tetramerous and the plant is capable of self-pollination through geitonogamy (Toelken 1981, Allan 1982), whereby the pollen of one flower is transferred to another flower on the same plant. The plants have a slightly sweet scent that attracts several species of hoverfly (*Syrphidae*) in the native range (Dawson & Warman 1987, Diaz 2012). However, these insects only transfer a very small amount of pollen and at a very short distance, which limits genetic flow (Diaz 2012). No pollinators are known outside the natural region (Dawson & Warman 1987, Smith & Buckley 2020).

The germination rate of stonecrop seed is very low in its natural habitat in the native range in Australia. Only a few plants germinated from sediment collected underneath stonecrop in South Australia within a 22-week period, which was a very low score compared to other native plants (Nicol et al. 2003). A similar test showed that stonecrop requires more than 16 weeks to germinate from seed, which again was longer than the other native plants tested, and only resulted in the germination of a few plants (Nicol & Ward 2010).

The vigour of the seeds also appears to be low outside of the native region. Seeds collected in England and the Netherlands did not germinate, most likely due to entering dormancy incorrectly for successful germination or because the seeds were difficult to separate from the surrounding tissues of the fruit (Dawson 1994) (pers. observation Van der Loop). Denys et al. (2014) and D'hondt et al. (2016) have reported successful reproduction, however, they used entire flowers due to the highly laborious nature of harvesting seeds. It cannot be ruled out that stonecrop grew out of apical meristematic tissue. In both experiments, the seeds underwent cold treatment to break dormancy. Denys et al. (2014a) applied a treatment of 56 days at 4°C and D'hondt et al. (2016) applied 60 to 105 days at 5°C. Due to the difficulty of germination, both within the native and secondary ranges, it has been concluded that seed contributes only limitedly to reproduction and thus to the spread of stonecrop. However, if a large number of flowers are present, and therefore a very large number of seeds are produced, seed may also contribute to the spread of stonecrop.

Outside of the native range, stonecrop primarily reproduces vegetatively from meristematic cell tissue (Dawson & Warman 1987, Robert et al. 2013, Crane et al. 2019). This tissue is found in every apex of sprouts and node of stems of stonecrop. Every plant fragment that contains meristematic tissue has the potential to regrow.

3.8.3 Dispersal (mechanisms, conditions for germination and establishment)

Stonecrop seeds are not glutinous and do not have structures for attachment. After they fall off, they float temporarily, allowing them to be moved by water currents and wind, after which they sink. This may contribute to the dispersal of the seeds (Dawson & Warman 1987).

In the native range, it has been observed that the species is spread through consumption and excretion (endozoochory) in the faeces of fallow deer (*Dama dama* J.L. Frish) and the Eastern grey kangaroo (*Marcopus giganteus* Shaw) (Claridge et al. 2016). In England, Belgium and the Netherlands, stonecrop has been observed to be consumed, with vital plant fragments being excreted by waterfowl (geese) and livestock (horses) (Denys et al. 2014a, Van Zuidam & Dijkhuis 2018, pers. observation Van der Loop, figure 3.4).

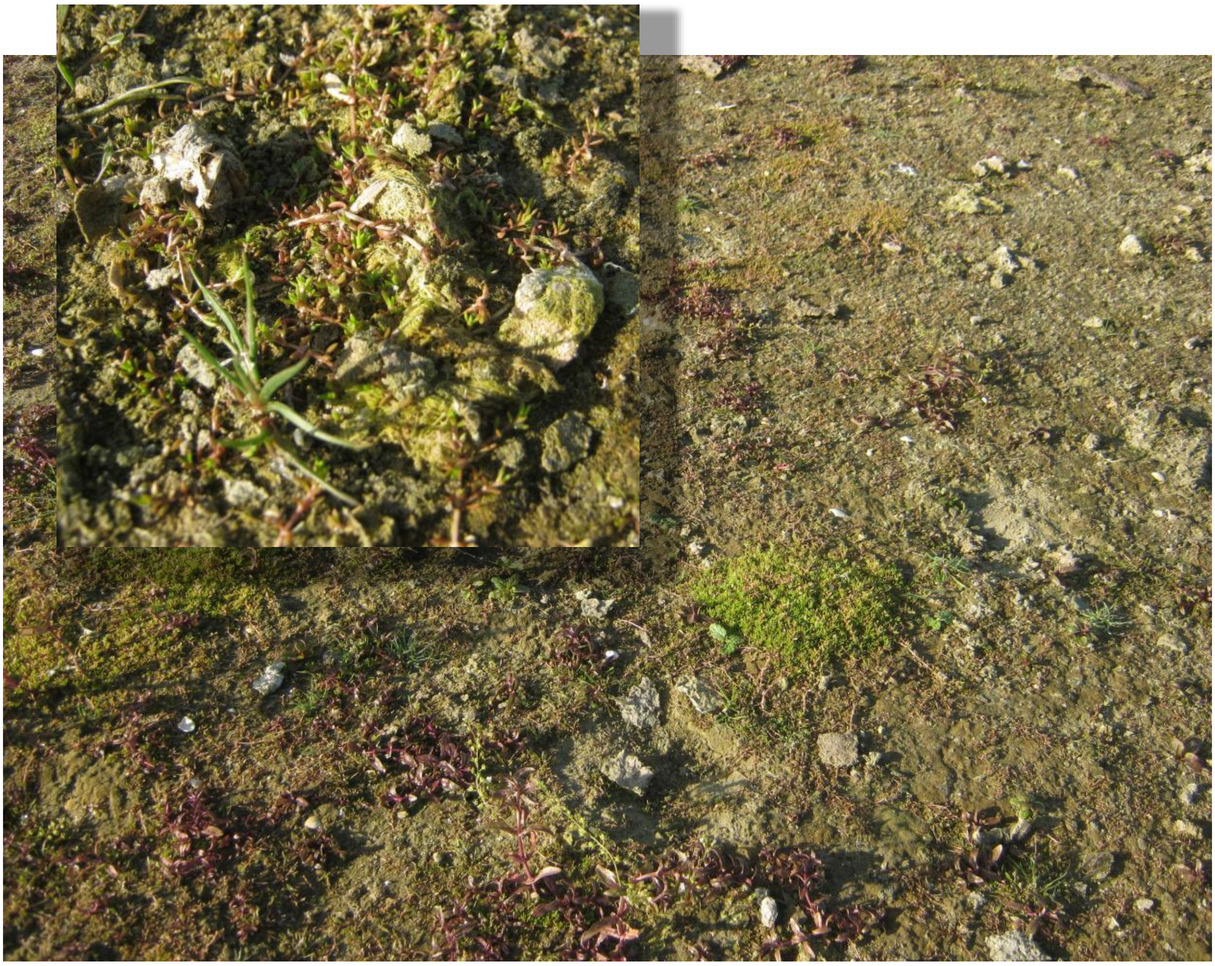

Figure 3.4. Establishment of stonecrop from goose faeces. Input: young shoots that grow from the faeces. Overview: establishment of stonecrop at sites where the faeces have since been digested and disappeared. (photos: Awie de Zwart)

Dispersal also occurs by parts of plants sticking to the feet of animals (ectozoochory) or to materials used in infected areas. (Dawson & Warman 1987, Denys et al. 2014a, Denys et al. 2014b, Ewald 2014, Dean et al. 2015, Smith 2015).

The most ideal conditions for the germination and growth of fragments of stonecrop are sites with bare soil, few native plants and that are relatively high in nutrients (Brouwer et al. 2017, Van Kleef et al. 2017, Smith & Buckley 2020, Van der Loop et al. 2020).

3.9 Ecosystem services

Stonecrop is of minor importance in terms of providing ecosystem services (Annex 5, BISE 2020).

Provisioning services
In various European countries, stonecrop is still sold as an ornamental, oxygenating aquarium and pond plant that requires little maintenance (Dawson & Warman 1987, OEPP/EPPO 2007). The total economic value of the plant, however, is estimated as low and there are a sufficient number of alternative plant species available for these services (CABI 2016).

Regulating services
In Europe, the flowering period lasts from June to the end of October, allowing stonecrop to be a source of nectar for insects (Lockton 2009). Outside of its native range, however, no pollinators have as yet been observed (Dawson & Warman 1987, Smith & Buckley 2020).

Due to its high biomass production, this species has a positive effect on carbon fixation and nutrient retention. It may be that the species could be used to tackle ecosystems polluted as a result of bioaccumulation of metals such as Cu, Zn and Al. However, no relevant literature was found on the matter.

Cultural services
Based on the available information, the species does not have any cultural relevance in Europe. In general, monocultures reduce the aesthetic value of areas and nature reserves (Sheppard et al. 2006). In that sense, stonecrop may have a negative impact on cultural services.

4 Introduction pathways (UNEP pathways and vectors)

4.1 Introduction to the EU

The pathways (UNEP 2014) through which stonecrop can be introduced into the EU and is able to spread within the EU are summarised in Table 4.1. *Crassula helmsii* is imported into Europe via the horticultural and aquarium sectors for sale to the public in garden centres and aquarium shops (Darwin & Warman 1987). Moreover, the literature shows that stonecrop arrived in Europe most likely as early as 1914 (Swale & Belcher 1982).

Table 4.1. Introduction and dispersal pathways for stonecrop based on UNEP classification of pathways of introduction and vectors (UNEP 2014). Please note: In this classification, Trade falls under 'Escape from confinement'.

Category	Subcategory	Importance	Example
Release in nature	Other intentional release	Low	- Conscious planting for the benefit of nature / area development
Escape from confinement	Botanical garden / zoo / aquaria (excluding domestic aquaria)	Medium	- Dispersal by wild birds visiting infested locations - Escape from pruning waste - Drifting with (waste) water
	Pet / aquarium / terrarium species	High	- Emptying aquariums in nature - Escape from pruning waste
	Horticulture	High	- Deliberately imported for trade - Escape from pruning waste - Unintended transport when selling other pond plants (see figure 4.1) - Unintended transport when exchanging (other) pond plants between individuals
Transport-contaminant	Transport of habitat material (soil, vegetation, wood)	High	- Unintentional transport by the transport of other plants and soil - Escape from open storage depots
	Machinery/equipment	High	- Sticking of viable plant parts to wheels / tracks - Stickting of viable plant parts to tools such as, shovels, dip-nets and wheelbarrows and footwear
	Contaminant on plants (excluding parasites, species transported by host/vector)	Medium	- Unintended presence in other transported plants - Unintended presence in pruning waste
	People and their luggage/equipment (in particular tourism)	Medium	- Viable parts of plants that stick to footwear, boats, fishing gear etc.
Corridor	Interconnected waterways/basins/seas	Medium	- Drifting plant fragments in interconnected fresh watersystems
Unaided	Natural dispersal across borders of invasive alien species that have been introduced through other pathways	High	- Dispersed by bird or other animals by lifting viable plant fragments

Figure 4.1. Horticulture poses a risk for the introduction of stonecrop due to unintentional transport as a stowaway when selling other pond plants in Dutch nurseries (Photo Martijn van de Loo)

4.2 Intentional and unintentional spread

Intentional

Within the EU, stonecrop has been widely traded as an aquarium, pond and ornamental plant and was introduced to Europe from Australia and/or New Zealand (OEPP/EPPO 2007). There are still various ways to purchase the species as an oxygenating plant; in the Netherlands, the species is inter alia available under the name Naaldkruid (*Crassula recurva*) (Pers. observation J. Van der Loop & J. van Valkenburg). New stands may be created outside gardens as a result of the dumping of excess pond/aquarium plants. In the Netherlands, and perhaps other countries, it is also sold sometimes in other retail outlets, such as supermarkets, and it is for sale on the internet (Pers. observation Van der Loop). The Ornamental Aquatic Trade Organization (OATA), the Royal Horticultural Society, and the now-defunct Dutch Covenant Waterplanten (Cooperation Agreement on Aquatic Plants) have called for an end to trade in the plant (OEPP/EPPO 2007). In the United Kingdom, Switzerland, Denmark and Spain, among others, the sale and trade are prohibited or otherwise regulated by law (Table 4.2). In Poland the species was included in the previous 2011 act on IAS, however, it is not listed under the current IAS regulations.

In the Netherlands, the deliberate introduction of the species is observed in areas of nature development. The argument for this was the rapid growth resulting in faster succession and greenery development in the area (J. Van der Loop).

Table 4.2. Links to regulations relating to the sale and trade in stonecrop.

Link
http://www.legislation.gov.uk/ssi/2019/38/schedule/made
https://www.admin.ch/opc/de/classified-compilation/20062651/index.html#app2ahref2
https://www.retsinformation.dk/eli/lta/2018/1285
http://prawo.sejm.gov.pl/isap.nsf/download.xsp/WDU20112101260/O/D20111260.pdf
https://www.mapa.gob.es/es/pesca/temas/acuicultura/RD_630_2013_Catalogo_spp_exoticas_invasoras_tcm30-77362.pdf

Unintentional

There are several ways in which the species is able to spread further through human activities. Soil containing stem fragments can be spread by soil transports or by machinery, vessels, footwear, fishing gear etc. The risk of introduction by boats and anglers arises from traveling to non-contaminated areas abroad with equipment contaminated with viable plant material. stonecrop is able to regenerate from tiny stem fragments (Dawson & Warman 1987). In England and the Netherlands, stonecrop has also been observed to be transported in trade as a stowaway with other aquatic plants (*Pontederia, Nymphaea, Nymphoides*, among others) (Laundon 1961, J. Van der Loop, see figure 4.1).

Further spread within Europe can also take place by way of more natural dispersal mechanisms (without humans playing a direct role). Detached fragments may be displaced in the presence of running water. In Australia, dispersal via running water (hydrochory) is considered to be the main dispersal mechanism of vegetative fragments within river basins (Nault & Mikulyuk 2011). Natural dispersal of stonecrop can furthermore take place through endozoochoric and exozoochoric dispersal of fragments by waterfowl and other animals (Dawson & Warman 1987, Denys et al. 2014a, Denys et al. 2014b, Ewald 2014, Dean et al. 2015, Smith 2015).

5 Climate and biogeography

5.1 Climate match, under current climate

The native range of stonecrop is within the climate regions **Cfb** and **Csb** (Table 5.1) under the Köppen-Geiger climate classification system (http://koeppen-geiger.vu-wien.ac.at/present.htm). The vast majority of the native range includes the coastal areas of New Zealand (South Island), the island of Tasmania and South East Australia (roughly the region south of the Murray River). These regions lie within the climate zone **Cfb**: warm temperate – fully humid and with warm summers. A small part of the range, the Adelaide, Kangaroo Island region and the south westernmost region of Australia, lie within climate zone **Csb**. Summers in this climate region are drier.

Table 5.1. Köppen-Geiger climate regions within the native range of stonecrop.

Code		Köppen-Geiger classification	Native region in
Cfb		Warm temperate – Fully humid – Warm summer	South East Australia, Tasmania and New Zealand
Csb		Warm temperate – Dry summer – Warm summer	Adelaide, Kangaroo Island and South West Australia

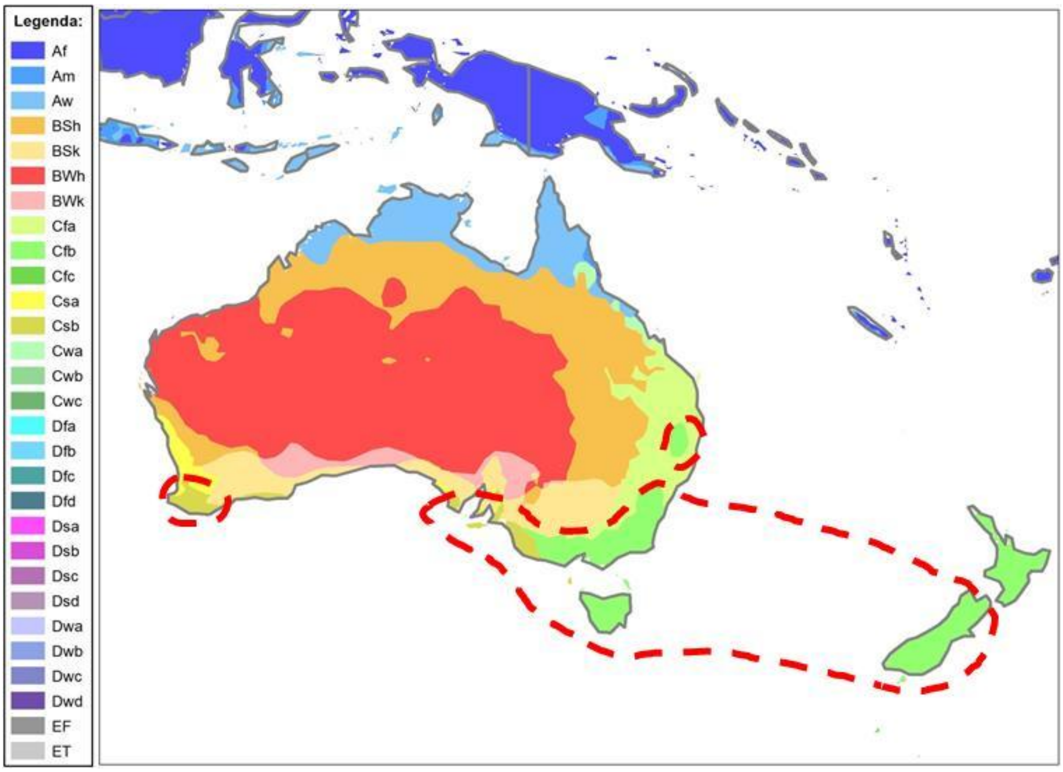

Figure 5.1. Köppen-Geiger climate regions within the native range of stonecrop (within the red dotted line).

The areas within Europe with climate regions corresponding to those of stonecrop's native range (Cfb and Csb) are shown in Figure 5.2. stonecrop's distribution in Europe (United Kingdom, Belgium, the Netherlands and the western halves of France and Germany, see Chapter 6.1) is entirely within climate region **Cfb**, the climate region in which the vast majority of the native range is located.

Regions within Europe that may potentially be suitable to stonecrop in terms of climate conditions and where the species may be expected to become established in the future, include southern France, northern Spain and Portugal, the Po Plain in Italy and parts of the Balkans. Outside of Europe, areas of Turkey, in particular coastal areas along the Black Sea, are climatologically suitable for the establishment of the species (Figure 5.2).

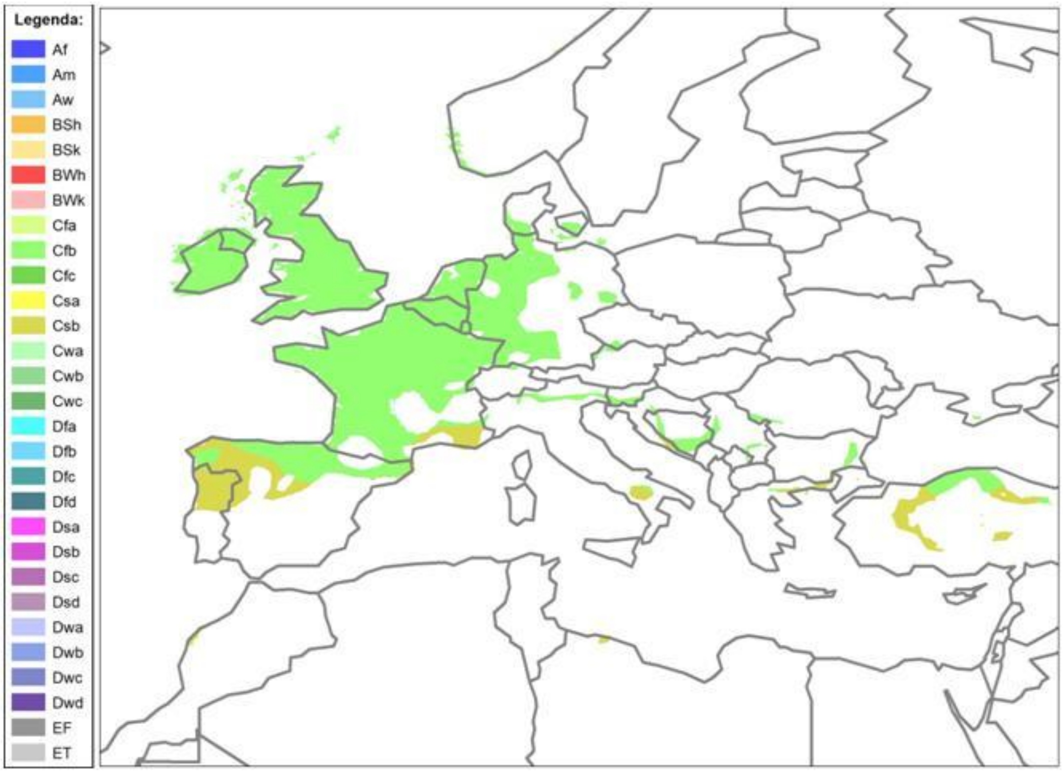

*Figure 5.2. The Köppen-Geiger climate regions **Cfb** and **Csb** within Europe.*

5.2 European biogeography

In Europe, stonecrop is primarily found in the ***Atlantic*** biogeographical region (Annex 3). The region includes the following countries: Ireland, the United Kingdom, the Netherlands, Belgium, north-western Germany, western France and Denmark. There are significantly fewer sightings of stonecrop in the ***Continental*** region: eastern France, central, eastern and southern Germany, the eastern half of Denmark and the adjacent part of Sweden. Well documented recordings from the ***Mediterranean*** region are absent until now.

5.3 Climate scenarios

Climate models predict higher winter temperatures at higher latitudes, drier summers and greater precipitation extremes in the future (Jacob et al. 2013). Although no niche modelling is available for stonecrop, it can be inferred that changing climatic conditions will increase the spread and invasiveness of stonecrop because of the following physiology of the species:

The higher average temperatures will allow stonecrop to spread to the higher parts of the Central European mountains and spread further north in Scandinavia and the United Kingdom. In addition, the species will be able to continue to grow for longer in the winter season in places where this was not possible before. Many of its native competitors do not continue to grow in winter (Bloemendaal & Roelofs 1988).

Permanent aquifer wetlands with only minor fluctuations in water levels are generally fairly resistant to stonecrop due to carbon limitation in the water layer (Klavsen & Maberly 2009, Van Kleef et al. 2017, 2024). However, due to increasing variation in periods of drought and surplus precipitation, they will develop greater water level fluctuations, after which stonecrop will be able to establish on dry banks. Unlike many competing native species, stonecrop is resistant to prolonged dry periods (Section 3.7), which gives it an advantage over a lot of native species. For stonecrop, the predicted lower rainfall and the resulting changing conditions in southern and eastern Europe and the drier summers in the rest of Europe will not limit the spread of the species (e.g. Hussner et al. 2021).

In many water bodies, stonecrop growth is limited by the lack of carbon dioxide (Van Kleef et al 2017). As carbon dioxide concentrations in the atmosphere increase, the availability of CO_2 in the water layers through diffusion also increases. This will increase the spread of submersed stonecrop and, incidentally, may also apply to native competitors that are limited by carbon.

6 Presence within the EU

6.1 Establishment status within EU countries

In Europe, the establishment of stonecrop has been confirmed with certainty in the following countries (in parentheses the year of the first observation):Ireland (1970), Germany (1981), Belgium (1982), Netherlands (1995), France (1999?), Denmark (2003), Sweden (2016), Austria (2019) Luxembourg (2020) and Spain (2023) (Figure 6.1.).

In the United Kingdom, stonecrop is mainly found in the south and east of England (Smith & Buckley 2020; Stroh et al. 2023). In the Netherlands, the species is distributed across the entire country (Verspreidingsatlas.nl). In Belgium, the species is only widespread in Flanders, with the species only found in isolated locations in Wallonia. The species is largely absent in the Ardennes (Branquart et al. 2013). In France, the species is mainly found in the west in the vicinity of the Atlantic coast, including in the regions of Brittany (Quere & Geslin 2016), Pays de la Loire (Dortel & Le Bail 2019), Normandy (Douville & Waymel 2019) and Poitou-Charentes (Fy 2015). In Germany, most stands are likewise found in the west of the country (Hussner 2008). In Sweden, the species was found in Helsingborg in 2016 but removed immediately after discovery (Artfakta 2020). In Denmark, where the species was first found in 2003, the species has spread to at least eight locations (GBIF 2022, pers. observation L. Briggs). In Austria, stonecrop has recently been discovered for the first time in the Mühlbach river (Traiskirchen, Niederösterreich) (Sauberer et al. 2020). In 2020 stonecrop was recorded for the first time at two sites (same km-square) in south-western Luxembourg (Ries & Krippel 2021). With regard to Spain, it has been reported that there is a localised presence of the species (MAGRAMA 2013). In 2024, finally documented observations have been published (Fagúndez et al. 2024). Although the species was previously reported in Italy, its presence in the Friuli Venezia Giulia region appears questionable (Galasso et al. 2018, Portale delle flora d'Italia, 2024). Reports from Portugal are currently similarly being questioned:
EPPO: https://gd.eppo.int/taxon/CSBHE/distribution
CABI: https://www.cabi.org/isc/datasheet/16463).

Although stonecrop is for sale as an oxygenating plant for aquariums or ponds in most European countries, the sources consulted (Annex 1) revealed no indications of the species having established in the wild in other EU countries.

6.2 Presence outside the EU

The only documented observation from Norway relates to the herbarium material from 2008 from a garden in Tønsberg, south of Oslo (GBIF 2020). The species does not yet appear to have established in the wild there.
Establishment in the wild has similarly not yet been documented in Switzerland (Bundesamt für Umwelt BAFU 2022); there are, however, a number of non-validated reports from Zurich and the surrounding area (Infoflora). Based on experiences from other European countries, however, the species has already been blacklisted (Buholzer et al. 2014).
The first documented observation in the United Kingdom dates back to 1956, where it has since established in the wild (Stroh et al. 2023).

In the United States, stonecrop is included in the lists of ‘noxious weeds’ in the states of Florida, Indiana, Minnesota, North Carolina and Washington. The regulations in these states anticipate the possible arrival of this invasive species. However, this does not mean that stonecrop was actually found there. The species is grown on a small scale by hobbyists, however there are no documented cases of stonecrop having established in the wild in the United States (U.S. Fish & Wildlife Service 2018). A herbarium sample collected from a pond in San Diego in 1976 came from Reading (England) (SEINet year unknown).
Reports of the species’ presence in Russia (near Lake Baikal) may be based on confusion with *Crassula aquatic* (L.) Schönland. Stonecrop has no longer been found in this area recently, but *C. aquatica* has (https://gd.eppo.int/taxon/CSBHE/distribution/RU_es)

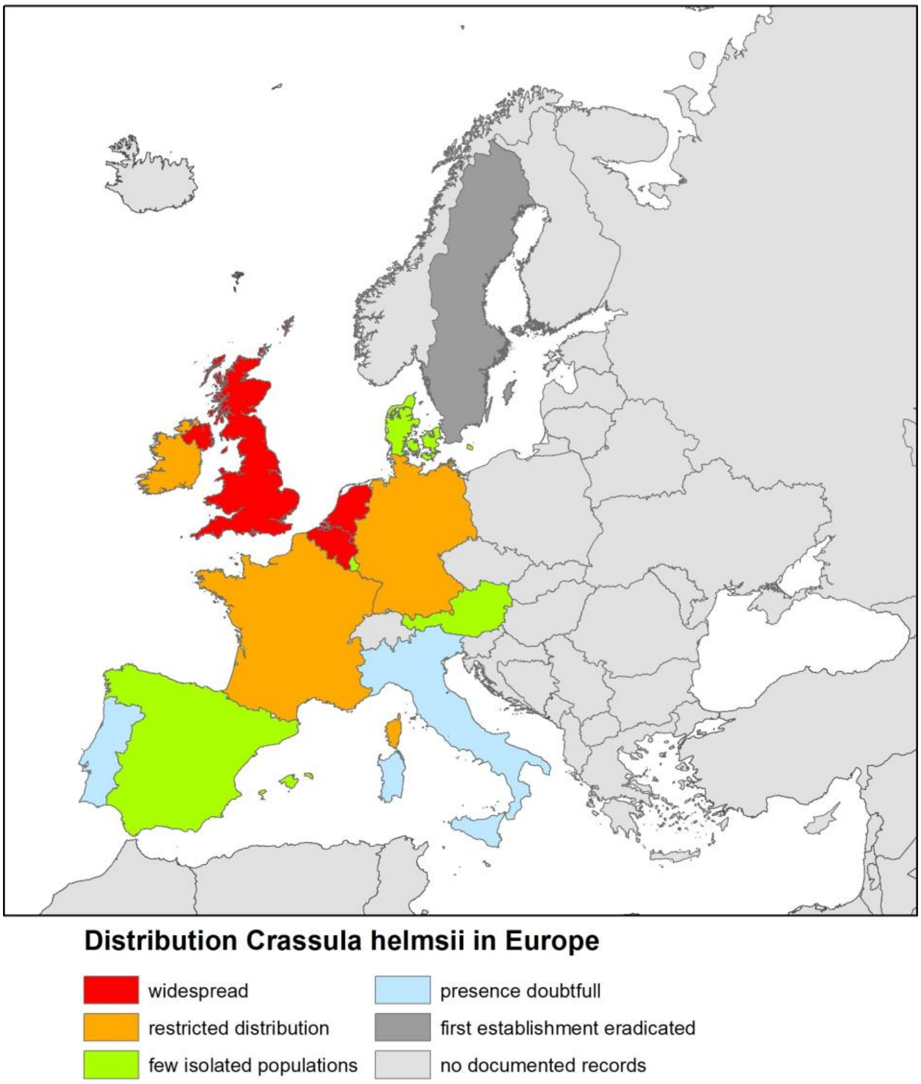

Figure 6.1 Distribution of stonecrop within the various European countries.

6.3 Distribution in the Netherlands

In the Netherlands, stonecrop can be found in the higher pleistocene regions. (Figure 6.2). The species has also been observed in a number of duneland regions, particularly on Schouwen.

Observations outside the pleistocene and the dunes are mainly from urban areas or the immediate surroundings. The presence of the species on banks along the closed estuaries, such as the Krammer-Volkerak, Hellegatsplaten and locally along the Ijsselmeer, is striking. In total, stonecrop has been observed in 1056 square kilometres ("kmhokken") in the Netherlands between 1995-2020.

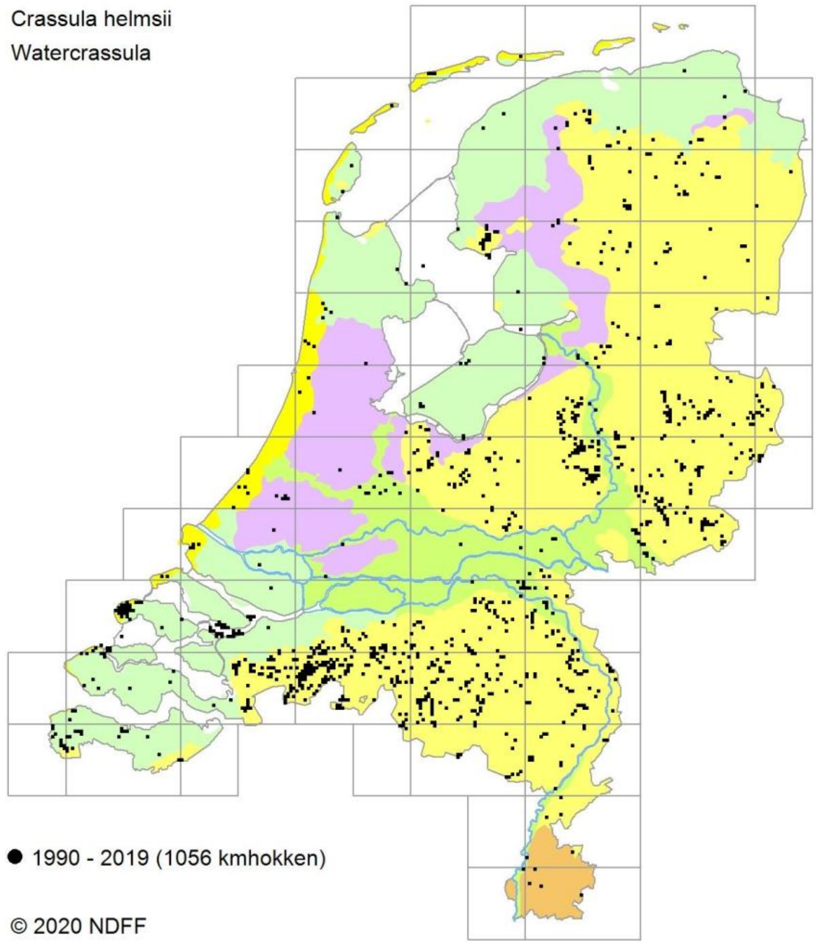

Figure 6.2 Observations of stonecrop (square kilometres) in the Netherlands.

6.4 Possible future spread in the Netherlands

As previously indicated under 5.3, a northern expansion in Europe seems likely, while the species may decline in the south.. In recent decades, the species has mainly spread further north. By contrast, in France the species seems to be spreading to the south (Dortel & Le Bail 2019). It may be that the increase in the species' range (both north and south) is primarily an indication of natural dispersal by more significant vectors, such as (migratory) birds. In the Netherlands, the advance of this species does not yet seem to have abated, as can be seen from the trend graph (Verspreidingsatlas.nl, April 2020) for this species (Figure 6.3).

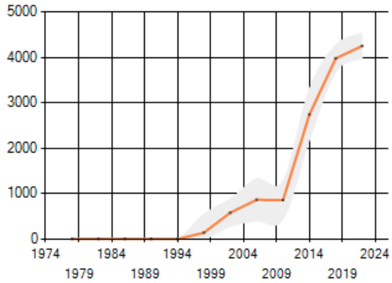

Figure 6.3 Trend graph (Index: 1990 = 100) of stonecrop in the Netherlands (1995-2018). There are no known observations in the Netherlands prior to 1995.

7 Impacts

7.1 Ecological/biodiversity

A dominant cover of stonecrop, with underwater densities of up to 1 kg dry weight/m^2 and 45 kg fresh weight/m^2 forms an impenetrable layer of vegetation on the soil, bank or water surface (Dawson & Warman 1987, OEPP/EPPO 2007, figure 7.1.). The plant establishes itself in open niches, including pioneer habitats that have been created following environmental development or on natural pioneer habitats, such as on drying banks during the summer. At these sites, stonecrop hinders the succession of native plant species and the recovery of natural vegetation (Dawson & Warman 1987, Van Kleef et al. 2017, Van der Loop et al. 2020).

Figure 7.1. Dominant cover of stonecrop in a fen in the Pannenhoef, a nature reserve in the province of North Brabant. The impact is clearly visible because the water layer has completely disappeared and the species is outcompeting other aquatic flora and fauna (Photo: J. Van der Loop).

7.1.1 Biodiversity in general

Although stonecrop is known to compete with other plants, the actual long-term effects on biodiversity are difficult to predict. Nor is it clear whether these effects would be irreversible. In a field study in England over the period 1999-2002 in stonecrop infested ponds, no significant loss in species numbers of native plants was found; in a laboratory study a thin mat (< 10 mm) of stonecrop induced a significant germination suppression of native plant species, including a 83% reduction in hairy willowherb (*Epilobium hirsutum* L.), a 69% reduction in purple loosestrife (*Lythrum salicaria* L.) and a 56% decrease in water mint (*Mentha aquatic* L.). If this suppressive effect occurs under field conditions, reproduction by seed could be greatly reduced at pond margins with minimal stonecrop presence (Langdon et al. 2004). Groups of species indicated to suffer negative effects from the presence of stonecrop include starwort species (*Callitriche* sp.), waterweeds (*Elodea* sp.), charophyte green algae (*Charophyceae*) and diatoms (*Bacillariophyta*) (CAPM 2004). In addition, effects on birds, fish, amphibians and invertebrates have been reported due to lack of space, the changing of the water flow and the changes in the chemical properties of the water, such as fluctuations in the oxygen level, a changing pH level and the availability of light (Watson 1999, Langdon et al. 2004, Branquart et al. 2013, OEPP/EPPO 2007,). A study of impacts on invertebrates (macro-invertebrates) showed no significant differences in densities and diversity between affected sites and control areas (Smith 2015). A more recent study, however, did found significantly higher diversity in macro-invertebrates, and a higher abundance of alien species within this group in situations with stonecrop. Also, a shift to detrivorous species has been observed in invaded sites (Tasker at al. 2024).

The same effects have been observed in the Netherlands, Belgium, Ireland and Germany, albeit to a more limited extent as a result of a lower number of stands or more recent introductions (Hussner 2009, Caffrey et al. 2012, Boute 2013, CAISIE 2013, Van Kleef et al. 2017, Van Veenhuisen et al. 2021, Van der Loop et al. 2023). Stonecrop cover and biomass are negatively correlated with the establishment and increase in biomass of other plants, both on land and in water (Van Kleef et al. 2017). This correlation can be interpreted in two ways. On the one hand, the spread of stonecrop may be at the expense of the space available for other species. In the event that stonecrop is the dominant competitor, each 10% stonecrop increase results in a cover decrease of 7% in the water and 9% on land for other species. On the other hand, it may be that stonecrop is not the strongest competitor, but that it is native species which limit the coverage of stonecrop in certain waters.

7.1.2 Impact on Red List, rare and/or protected species

Impact on flora

In the Netherlands, stonecrop has been observed on growth sites of European-wide protected plants (Annex IV EU Habitats Directive). These species must be protected both inside and outside Natura 2000 sites.

In the Netherlands, threats to creeping marshwort (*Helosciadium repens* (Jacq.) W.D.J.Koch) and fen orchid (*Liparis loeselii* L.) (Maas & Van Wijngaarden 2019, Wesseling 2019) have been reported. Both plant species are designated as protected species in the Nature Conservation Act (Wet natuurbescherming) in which they hold Habitats Directive species IV, Bern I status, and are also included in the Dutch Red List for vascular plants, drawn up in 2012. In North Brabant (Esschestroom) and in Zeeland (Groote Gat, Zeelandic Flanders), stonecrop has appeared near stands of creeping marshwort (*Helosciadium repens* (Jacq.) W.D.J.Koch). In both areas, the species was most likely spread by geese (Van Zuidam & Dijkhuis 2018). In Esschestroom, stonecrop coverage was rather low (<20% coverage) (pers. communication E. Brouwer).

In the Kleine Beerze river, stonecrop grows over a considerable length together with floating water-plantain (*Luronium natans* Raf.), another species with Habitats Directive species IV status (source: observations R. Beringen & M. Janssen in the NDFF). The impact of stonecrop on floating water-plantain in this scenario is unknown. In France, a negative impact on Floating water-plantain was described in Dortel & Dutartre (2018).

On the Wadden Island Terschelling the species was observed in a natural dune valley (figure 7.2). It possibly originated from a former garden pond. Within 2 years >10 ha of six moist dune valleys were overgrown by stonecrop, causing a significant loss of native flora. A study on the effects of stonecrop on this Natura 2000 site concluded that this invasive plant species not only outcompetes native vegetation but also posed a threat to the conservation objectives imposed by the European Habitat Directive (Van der Loop et al. 2022).

Figure 7.2 A moist dune valley overgrown with stonecrop in a Natura 2000 area on the Wadden island of Terschelling . An initially small infestation resulted in a high biomass production of the species outcompeting native species.

Various Red List species can also be found in the 115 vegetation studies from the National Vegetation Database in which stonecrop occurs (Table 7.1). In particular, a number of species from low-nutrient water are relatively often present in the studies which also include stonecrop. In addition to *Luronium natans* Raf., mentioned above, *Helosciadium* inundatum (L.)

W.D.J.Koch , *Baldellia ranunculoides* Parl. , *Eleogiton fluitans* (L.) Link, *Hypericum elodes* Huds., *Littorella uniflora* (L.) Asch. and *Myriophyllum alterniflorum* DC.. A number of the species of the Habitats Directive listed above do not appear in the available vegetation studies.

*Table 7.1. Red list and/or protected species in vegetation studies with stonecrop. **HD**: Annex EU Habitats Directive; **B**: protected in the Netherlands under the Nature Conservation Act; **RL**: Red List category (NT: Near Threatened, VU: Vulnerable, EN: Endangered); **Zz**: degree of rarity (a: common, z: rare, zz: very rare, zzz: extremely rare); **P**: percentage of the vegetation studies in which the species was observed (N=115). (Vegetation studies present in the Dutch National Vegetation Database March 2020, Ecological groups according to Arnolds & van der Maarel 1979). Note: author names wth species names have been omitted.*

Ecological group	Species	HD	B	RL	Zz	P.
7a-lowland peat areas	Menyanthes trifoliata (Bog bean)			NT	a	1.7
2c-pioneer vegetation moist moderate low-nutrient	Eleocharis ovata (Ovate spikerush)			NT	zzz	0.9
	Illecebrum verticillatum (Coral necklace)			VU	z	0.9
	Juncus tenageia (Sand rush)			EN	zz	4.3
	Radiola linoides (Allseed flax)			EN	zz	0.9
	Sagina nodosa (Knotted pearlwort)			VU	z	0.9
7c-Molinia meadows	Succisa pratensis (Devil's bit scabious)			NT	a	1.7
7e-dry heaths	Euphrasia stricta (Drug eyebright)			NT	a	2.6
6b-dry, neutral grasslands	Linum catharticum (Fairy flax)			VU	z	1.7
3c-high marshes	Apium graveolens (Celery)			VU	z	1.7
	Glaux maritima (Sea milkweed)			VU	z	6.1
7b-alkaline fens	Epipactis palustris (Marsh helleborine)			VU	z	0.9
	Parnassia palustris (Marsh grass of parnassus)			VU	z	1.7
7d-wet heaths	Gentiana pneumonanthe (Marsh gentian)			NT	a	1.7
	Pedicularis sylvatica (Small lousewort)			VU	z	0.9
2a-disturbed environments	Odontites vernus ssp. serotinus (Red bartsia)			NT	a	1.7
4b-oligotrophic waters	Helosciadium inundatum (Lesser marshwort)			EN	zz	4.3
	Baldellia ranunculoides ssp. ranunculoides (Upright lesser water-plantain)			EN	zz	5.2
	Eleogiton fluitans (Floating club-rush)			VU	z	9.6
	Hypericum elodes (Marsh St. John's-wort)			VU	z	14.8
	Littorella uniflora (Shoreweed)			VU	z	10.4
	Luronium natans (Floating water-plantain)	2/4	X	VU	z	2.6
	Myriophyllum alterniflorum (Alternate water-milfoil)			VU	zz	0.9
4c-eutrophic river banks	Cicuta virosa (Cowbane)			VU	z	0.9
4a-eutrophic waters	Stratiotes aloides (Water pineapple)			NT	a	1.7

Dawson & Warman (1987) reported that the dominance of stonecrop in a pond in the New Forest national park in England led to the crowding out of other plants, including Water purslane (*Ludwigia palustris* L.). In another pond, Waterweed (*Elodea* sp.) was crowded out entirely by stonecrop within 2 years. In England, water purslane (*Ludwigia palustris* L.), *Galium constrictum* Chaub. and the very rare Starfruit (*Damasonium alisma* Mill.) are threatened by the presence of stonecrop (Leach & Dawson 1999, Watson 2001).

Dortel & Dutartre (2018) identified the following endangered and/or protected species that may face competition from stonecrop, at least in part of their ecological niche in western France: *Helosciadium inundatum* (L.) W.D.J.Koch, *Ranunculus ophioglossifolius* Willd., *Cardamine parviflora* Suter, *Crypsis aculeate* (L.) Aiton, *Damasonium alisma* Mill. and *Luronium natans* Raf..

In the Fühlinger See (North Rhine-Westphalia), Hussner (2008) observed that the stonecrop growing there, at depths of up to 10 metres, exerted significant competitive pressure on the native vegetation of green algae (*Characeae*).

Figure 7.3. A drainage canal invaded by stonecrop in the Kop van Schouwen Natura 2000 area. The competition with native species can clearly be observed. (Photo: J. Van der Loop).

Impact on protected and endangered fauna

In England, there are also reports of the (potential) disruption of the breeding success of protected amphibians, including the crested newt (*Triturus cristatus* Laurenti) and palmate newt (*Triturus helveticus* Razumovsky) (Watson 1999, Langdon et al. 2004).

In Ireland and the Netherlands, a threat to the natterjack toad (*Epidalea calamita* Laurenti) has been observed (CAISIE 2013) (Van Veenhuisen et al. 2021, Van der Loop et al. 2023). This species needs shallow and open water to lay its eggs and the number of suitable egg-laying sites is decreasing as a result of the dominant growth of stonecrop. A recent study by Van der Loop et al. 2023 and Van Veenhuisen et al. 2011) showed that the spawning rate and egg survival of this toad species are negatively affected by the presence of *C. helmsii*. The negative effects of stonecrop on endangered amphibians are recognized by the IUCN. In their 'Guidelines for amphibian reintroductions and other conservation translocations' they stated that biosecurity measures must be taken to reduce the threat of invasive stonecrop (Linhoff et al. 2021).

Both the newt species referred to in the above and the natterjack toad are included in the Nature Conservation Act under the protection of the Habitats Directive (Annex IV) and/or the Berne Convention (Annex II).

A study by Tasker et al. (2024) found that stands of stonecrop can alter the assemblage of freshwater macroinvertebrates. However, even if the study shows that drastic shifts in abundance and species richness among various invertebrate orders can occur, it does not provide conclusive information regarding the impact on protected and endangered fauna and the subject warrants further study.

Figure 7.4. The stonecrop invasion in the Gijzenrooise Zegge reserve, province of North Brabant, resulting in a lower reproduction rate and survival of the Natterjack toad population. (Photo: M. van de Loo).

7.1.3 Impact on EU habitat types

Because stonecrop is not very demanding, many habitat types are vulnerable. The plant is evergreen and hardy, meaning that places where native plants that die above ground in winter are found, are taken over by stonecrop. (OEPP/EPPO 2007).

In England, the species can primarily be found on clay soils and organic soils (Dawson & Warman 1987, Dean 2015). Many freshwater systems and weak brackish water systems with standing or slow-flowing water form a suitable habitat for stonecrop both in England and the UK (Dawson & Warman 1987, Dawson 1994, Prinz et al. 2019, Smith & Buckley 2020).
In the Netherlands and Germany, the species can mainly be found on sandy soils (Hussner 2009, Van Kleef et al. 2017, Van der Loop 2017a & 2017b). stonecrop can similarly invade virtually all freshwater systems. In the Netherlands, however, the picture appears to be more nuanced. For the Netherlands, the vulnerable habitat types include the habitat types of very weakly buffered and weakly buffered fens (H3110 - Oligotrophic waters containing very few minerals of Atlantic sandy plains – *Littorelletalia uniflorae* and H3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*), Molinia meadows (H6410 - Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)), humid dune slacks (H2190), wet heaths (H4010 - Northern Atlantic wet heaths with *Erica tetralix*) and pioneer vegetation with *Rhynchosporion* (H7150 - Depressions on peat substrates of the *Rhynchosporion*). The species may also be found in other water types and humid environments, but is rarely, if ever, a threat to biodiversity.
For Belgium, weakly buffered fens (H3130), Lakes with water pineapple and pondweed (H3150 - Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation), Streams and rivers with aquatic plants (H3260 - Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation) and Rivers with muddy banks (H3270 - Rivers with muddy banks with *Chenopodion rubri* p.p. and *Bidention* p.p. vegetation) have been designated as habitat types threatened by stonecrop. However, in this regard it is also noted that all freshwater systems provide a suitable habitat for stonecrop (Robert et al. 2013).

The EU habitat types that may be impacted by the presence of stonecrop are summarised in Table 7.2.

*Table 7.2. EU Habitat types in which stonecrop is able to establish. * are priority habitat types, for which EU countries must take urgent protection measures.*

Type	Description	Source:
1150*	Coastal lagoons	Dortel & Dutartre 2018
1410	Mediterranean salt meadows (Juncetalia maritimi)	Dortel & Dutartre 2018
3110	Oligotrophic waters containing very few minerals of sandy plains (Littorelletalia uniflorae)	Dortel & Dutartre 2018
3130	Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea	Sotek et al. 2018, Dortel & Dutartre 2018, Branquart et al. 2013
3140	Hard oligo-mesotrophic waters with benthic vegetation of Chara spp.	Dortel & Dutartre 2018
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation	Sotek et al. 2018, Dortel & Dutartre 2018, Branquart et al. 2013
3170*	Mediterranean temporary ponds	Dortel & Dutartre 2018
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation	Sotek et al. 2018, Dortel & Dutartre 2018, Branquart et al. 2013
3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation	Sotek et al. 2018, Dortel & Dutartre 2018, Branquart et al. 2013
7150	Depressions on peat substrates of the Rhynchosporion	Dortel & Dutartre 2018

In the Netherlands, stonecrop was found in 40 Natura 2000 areas (Annex 4). What is striking is the relatively high number of Natura 2000 areas in the province of North Brabant and the large number of sightings in these areas. Table 7.2 shows that (EU habitats and) Natura 2000 areas also (or could be) threatened by this species.

7.1.4 Impact on physiochemical properties and structure of ecosystems

Hydrology

Thick deposits of stonecrop may impair the flow and drainage of water. The damming effect of thick deposits can even lead to local flooding and changes to the stream bed (Kelly & Maguire 2009). The disruption of the flood regime can lead to changes in the species composition and densities (Daehler 2003). In standing waters, a high dominance of stonecrop can lead to water bodies drying out faster as a result of additional evaporation, which also has a concentrating effect on substances present in the water, resulting in changes in the chemistry of the water (Casanova & Brock 2000, Birken & Cooper 2006).

Oxygen

The presence and breakdown of stonecrop leads to fluctuations in the oxygen levels of the water (Dawson & Warman 1987, Branquart et al. 2013). stonecrop may cover the water layer, reducing the degree of diffusion to deeper parts causing oxygen deprivation in those areas. This is stimulated by the accumulation of a layer of dead stonecrop residues. The degradation processes lead to greater oxygen consumption. The resulting lack of oxygen and the accumulation of organic matter in the underwater soil leads to the mobilisation of phosphate and therefore to internal eutrophication in which toxic sulphide may be released (Bloemendaal & Roelofs 1988). This has an impact on the waterbed communities, resulting in poor water quality that has a negative effect on the species in the water (CAPM 2004, OEPP/EPPO 2007,).

Inorganic carbon

Several studies claim that stonecrop has an advantage over native plants when CO_2 is present in the water layer in low quantities (Newman & Raven 1995, Keeley 1998). The plant absorbs CO_2 from the water at night through CAM photosynthesis (CAM= Crassulacean Acid Metabolism) and stores carbon inter alia in the form of malic acid. This allows the plant to use the carbon dioxide released by the respiration of plants with normal C3 photosynthesis at night, when this photosynthesis has stopped. (Newman & Raven 1995, Keeley 1998). This theoretically gives stonecrop an advantage over plants with the C3 mechanism (Keeley & Morton 1982, Madsen 1987). However, it appears that in the Netherlands, prolific stonecrop growth only occurs when the average concentration of CO_2 in the summer is well above 200 µmol/L, when the species overgrows other aquatic plants under water. In waters with a lower CO_2 concentration, stonecrop is limited in its growth and there is virtually no competition. The carbon limitation is lost as the water level drops and parts of the plant emerge above the water (Van Kleef et al. 2017).

Nitrogen

Studies from England and the Netherlands showed that high stonecrop cover and biomass is associated with low concentrations of organic nitrogen and nitrate in the surface water respectively (Smith 2015, Van Kleef et al. 2017). This shows that the species is able to efficiently extract nitrate from the water during the growing season.

Bioaccumulation

Stonecrop is a hyperaccumulator of copper, storing large quantities of this metal in its leaves, if it is present in the soil in elevated concentrations (Brooks et al. 1977). Primarily in summer, the plant is highly resistant to high concentrations of copper, 9,000 ppm/dry weight compared to 0.6 ppm in a plant control group. Stonecrop can therefore grow in locations that are contaminated with copper and where other plants do not survive (Küpper et al. 2009). At high temperatures, the plant makes more use of CAM photosynthesis (Klavsen & Maberly 2009) and more malic acid is produced at night to fix carbon. Stonecrop is better able to fix copper due to a higher malic acid concentration in the plant cells. Despite the fact that, as far as is known, stonecrop is able to accumulate the highest concentration of copper compared to other plants, the plant does not actually require additional copper, for example, for its growth or photosynthesis (Shen et al. 1997, Küpper et al. 2001, Küpper et al. 2009). In addition, stonecrop affected by copper toxicity (excess copper) is able to quickly degrade the pigments in its leaves, resulting in the death of the whole leaf. This is an additional defence mechanism against copper toxicity, as the sacrifice of leaves leads to a reduction of the internal concentration of copper within the plant (Küpper et al. 2009). In the vast majority of natural situations, copper concentrations are so low that stonecrop does not benefit from this resistance.

Presumably, stonecrop is also capable of extracting other elements from the water. This is shown by the reduced concentrations of silicon, zinc and aluminium that have been measured in plants in relation to high stonecrop cover and biomass (Van Kleef et al. 2017).

Allelopathy (secretion of growth-inhibiting substances)

A bioassay with the blue-green algae *Dolichospermum flos-aquae* (= *Anabaena flos-aquae*), in which the allelopathic potential of 33 both native and alien aquatic plants was studied, showed that stonecrop has a relatively high allelopathic potential. Of the alien aquatic plants, only *Ludwigia peploides* (Kunth) P.H. Raven and *Ludwigia grandiflora* (Michx.) Greuter & Burdet had a greater allelopathic potential (Grutters et al. 2017).

7.2 Public health and the economy

7.2.1 Diseases/allergies or other physical conditions

Based on the available information, the species does not cause any symptoms or signs of illness in humans or domestic animals.

7.2.2 Personal safety & safety of infrastructure

It may be that floating carpets of stonecrop may be mistaken for solid soil, which can pose a risk to people and animals (Sheppard et al. 2006, OEPP/EPPO 2007). There are no known reports in the EU.
In cases where stonecrop forms dense carpets, this may hinder recreational activities, such as boating, fishing, swimming and water skiing (Sheppard et al. 2006, Nault & Mikulyuk 2011). In the Netherlands, these effects have chiefly been observed in smaller running water systems, such as drainage canals and small canals (<15 m wide). Although stonecrop generally grows from the banks into the water or 'creeps' across the bed, the narrowing of larger running waterways (15 m in width or wider) due to dense growth has not been observed (J. Van der Loop). However, in isolated, highly eutrophic water, stonecrop is able to grow to completely obstruct the water body from the bed.
The drainage of water in drainage channels and structures, such as weirs and dams, may be limited when stonecrop is present (Branquart et al. 2013, Kelly & Maguire 2009). This may lead to flooding (Dawson & Warman 1987, OEPP/EPPO 2007).

7.2.3 Socio-economic impact

Monocultures reduce the aesthetic value of areas and nature reserves (Sheppard et al. 2006). In addition, recreational areas are less accessible for swimming activities and launching boats in cases of dominance of aquatic plants (Dawson & Warman 1987, Sheppard et al. 2006). In addition, affected areas are often sectioned off by site managers to limit the spread as much as possible, making them inaccessible for recreational purposes (J. Van der Loop).

See section 9.3 for information on the costs of controlling the species.

8 Risk analysis

The risk classifications of stonecrop and the corresponding levels of confidence are set out in Table 8.1. These assessments are briefly discussed in section 8.1, with reference to the numbering of the relevant assessment criteria in parentheses (A1-A41; in accordance with the online version of the Harmonia+ protocol). The results of the calculations of the risk scores and level of confidence scores are summarised in Tables 8.2 and 8.3 and are clarified in section 8.2. Section 8.3 compares these results with other risk assessments for the species.
The information used in this chapter is drawn from the previous chapters. All references used in this chapter can also be found in previous chapters.

Table 8.1: Risk assessment of stonecrop using the Harmonia+ protocol.

1. Context risk assessment		
A01. **Assesors(s)**	**Authors risk analysis NVWA (n=6)**	
A02. **Name** of the organism under assessment	**Crassula helmsii**	
A03. **Area** under assessment	**European Union**	
A04. **Status** of the organism in the area	**Alien and established in the wild**	
A05. **Risk domain**	**Environment & human health**	
Risks	Risk score	Level of confidence
2. Introduction		
A06. Probability of introduction by natural means	Low	High
A07. Probability of introduction by unintentional human actions	High	Medium
A08. Probability of introduction by intentional human actions	High	Medium
3. Establishment		
A09. Climate for establishment	Optimal	High
A10. Habitat for establishment	Optimal	High
4. Spread		
A11. Dispersal capacity within the area by natural means	High	High
A12. Dispersal capacity within the area by human actions	High	High
5a. Impacts: environmental targets		
A13. Effects on native species through predation, parasitism or herbivory	Inapplicable	High
A14. Effects on native species through competition	High	High
A15. Effects on native species through interbreeding	No/very low	High
A16. Effects on native species by hosting harmful parasites or pathogens	Very low	Medium
A17. Effects on integrity of ecosystems by affecting abiotic properties	High	Medium
A18. Effects on integrity of ecosystems by affecting biotic properties	High	Medium
5b. Impacts: plant targets		
A19. Effects on plant targets through herbivory or predation	Inapplicable	High
A20. Effects on plant targets through competition	Very low	High
A21. Effects on plant targets through interbreeding	No / very low	High
A22. Effects on integrity of cultivation systems	Very low	High
A23. Effects on plant targets by hosting harmful parasites or pathogens	Very low	Medium
5c. Impacts: animal targets		
A24. Effects on animal health or production through parasitism or predation	Inapplicable	High
A25. Effects on animal health or production by properties hazardous upon contact	Very low	High
A26. Effects on animal health or production by parasites or pathogens	Inapplicable	High
5d. Impacts: human health		
A27. Effects on human health through parasitism	Inapplicable	High
A28. Effects on human health by properties hazardous upon contact	Very low	High
A29. Effects on human health by parasites or pathogens	Inapplicable	High
5e. Impacts: other targets		
A30. Effects by causing damage to infrastructure	Medium	Medium
6. Ecosystem services		
A31. Effects on provisioning services	Neutral	Medium
A32. Effects on regulating services	Moderate negative	Medium
A33. Effects on cultural services	Moderate negative	Medium
7. Effects of climate change		
A34. Introduction	No change	High
A35. Establishment	ncrease moderatel	Medium
A36. Spread	No change	Medium
A37. Impacts: environmental targets	ncrease moderatel	Medium
A38. Impacts: plant targets	No change	Medium
A39. Impacts: animal targets	No change	High
A40. Impacts: human health	No change	High
A41. Impacts: other targets	No change	Low

8.1 Risk classification

Context

This risk assessment was carried out by six experts (A1) for the introduction of stonecrop (A2) in the EU (A3). The species is already present in various EU Member States and also has established populations in several Member States, including the Netherlands (A4). The domains of this risk assessment are 'the environment and public health' (A5). The risk assessment was carried out based on all the available information on stonecrop (Chapters 3-7). Full consensus was reached regarding all the various risk classifications and relevant levels of confidence during a workshop (Table 8.1). The results of the risk assessment are outlined in detail below.

Introduction

Outside Europe, stonecrop is likely only to be found within its original, native range (New Zealand and Australia). The probability of introduction into the EU through natural dispersal from this region of origin was determined to be low (A6). The level of confidence in this regard is high due to the significant distance from the native range and numerous (natural) barriers to dispersal of plants (and plant fragments) or seeds. The scientific literature revealed no indications for long distance dispersal through natural vectors, meaning from the regions of origin in the Southern Hemisphere, surrounded by oceans, to the European continent. There are no known distribution areas outside of Europe from which the species is able to reach EU Member States. For that reason, it can be asserted with a high level of confidence that the natural introduction frequency is less than once every 30 years, a threshold in Harmonia+.

Stonecrop was imported into many EU Member States, being a popular aquarium and pond plant. The species is still traded, although sales have already been restricted in a number of EU Member States. The plant is distributed worldwide via (internet) trade. The subsequent escape from garden ponds and parks via natural vectors (such as amphibians and birds) is very likely. The plant spreads mainly vegetatively via small stem fragments. Therefore, the absence of pollinators in the introduced areas does not hinder the spread of the species. Entire plants and plant fragments are able to piggyback as a contaminant through the sale and trade of aquatic and waterside plants, earth movement, horticultural management equipment, footwear or (sports) fishing equipment. The species is also known to be dumped into fens and ponds in the vicinity of residential areas and is regularly found alongside other aquarium and pond plants. It is unknown how often this happens within the EU. In the New Forest National Park (UK), the spread was correlated with the presence of car parks. In view of the widespread distribution in multiple EU Member States, it is very likely that the combined probability of introduction into the wild and subsequent (un)intended further spread in the EU is greater than once a year. For that reason, the probability of introduction into the wild via (un)intentional human activities (A7 and A8) has been assessed as high, with a level of confidence of medium given the absence of quantitative information on the exact relationship between unintentional and intentional by humans into the wild.

Establishment

Stonecrop has numerous established populations in multiple Member States and is widespread within the EU. Large parts of Europe are climatically suited – in particular the regions with a more Atlantic climate. Severe frost and prolonged drought hinder its growth. The species prefers standing to slow-running water as well as their banks. The plant grows in systems with both oligotrophic sandy and clay soils. The moist sections of the sandy soils and dunes in particular constitute an optimal habitat. Such habitat types are widespread within Europe. The species primarily establishes itself in pioneer conditions, which are the result of natural processes or anthropogenic interventions in many areas. The distribution data and prolific growth confirm that both the climate and habitat conditions are optimal in large parts of the EU (A9 and A10). The level of confidence regarding the suitability of these environmental factors is high. A large amount of data and numerous scientific publications is/are available on the successful establishment of the species in the EU.

Spread

The natural dispersal capacity of stonecrop for its spread within the EU has been assessed as high with a high level of confidence, due to the fact that sufficient information is available on this issue (A11). This secondary spread primarily takes place vegetatively. Very small plant fragments of stonecrop are still viable. Plants and fragments are inter alia able to spread through the water currents. In addition, dispersal (both endozoochoric and exozoochoric) via waterfowl and other animals has also been detected. Given the available data on dispersal patterns, such as for the Netherlands, a dispersal rate of 5-50 km as a result of transport by water and animals seems realistic. Moreover, this value could even be higher if the water flows over a long distance and animals migrate over long distances. The species can occasionally bridge large distances, such as from the Dutch mainland to the Wadden Islands. However, the importance of natural distribution is not easy to quantify.

The species is currently already widespread within the EU and is still commercially available in various Member States (including the Netherlands) and elsewhere. The species is still present in many ponds and is still being planted, making the likelihood of secondary spread or dumping of excess plant material in nature high. The plant can easily stowaway during earth movement, machinery for earthworks or mowing, vehicles, vessels, footwear and sports fishing gear. The probability of spread > 50 km within the EU due to human activities is higher than once per year. For that reason, the frequency of secondary spread of stonecrop through human activity is deemed to be high with a high level of confidence (A12). The relative importance of the various types of dispersal mechanisms, however, cannot be quantified.

Environmental risk

The effects of stonecrop on native species through predation, parasitism or grazing (herbivory) do not apply (A13). This can be stated with a high level of confidence. This species is an autotrophic plant that is not parasitic and has not developed any mechanisms for predation on animal species (such as carnivorous plants). Herbivory is not a plant trait and relates to the grazing of vegetation by herbivorous animals.

The impact of stonecrop on native species as a result of competition is deemed to be high (A14) with a high level of confidence. A relatively large amount of scientific literature is available on the subject. Due to its strong growth and full coverage of the soil or bed, native species are crowded out in low-nutrient, oligotrophic systems. Stonecrop also prevents the establishment of native species in pioneer vegetations, because the plant is able to quickly take up the available space in such conditions. This effect is less strong in undisturbed vegetation.

The probability of an impact on native species due to interbreeding has been classified as irrelevant/very low, with a high level of confidence (A15). Within the EU, there are no closely related species that could interbreed with stonecrop.

The probability of an impact on native species due to the transmission of parasites or pathogens carried by stonecrop has been classified as very low, with a medium level of confidence (A16). Based on the available information, these types of effects have not been identified within the EU despite the plant's long-term presence, extensive spread and the relatively high level of focus on the species. There is, however, little documentation available for the EU regarding any parasites or pathogens related to stonecrop.

The probability that stonecrop will have a significant impact on ecosystem integrity, due to changes in abiotic (A17) and biotic factors (A18), is high. Effects on physicochemical properties (such as light and oxygen content) and biodiversity are certain, due to the high productivity of this species and its frequent complete coverage of large parts of ecosystems. The species causes shifts in the species composition of vegetation of the Littorellion uniflorae alliance in and on banks of weakly buffered fens and dune valleys. These effects have been assessed as irreversible, as extensive and very expensive measures are required to completely remove the species from ecosystems. This is similarly identified in many other risk assessments and articles. However, it should be noted that quantitative information on the subject is scarce in the scientific literature and that such impact assessments rely heavily on the views of experts. That is why the assessment of these aspects relies on a medium level of confidence.

Risk to plant cultivation

The impact of stonecrop as a result of predation, parasitism or grazing (herbivory) of plant cultivation species does not apply (A19). This can be stated with a high level of confidence. The species is an autotrophic plant that is not parasitic and has not developed any mechanisms for the predation of other species. Grazing (herbivory) is a trait of herbivorous animals.

The probability of undesirable effects in plant cultivation due to competition has been assessed as very low for stonecrop (A20). No references or indications were found in the extensive literature on the environmental impact of this species in relation to Europe in this regard, which is why a high level of confidence has been assigned to these risk classifications.

The probability of an impact on cultivated plants as a result of interbreeding has been assessed to be very low (A21). Within Europe, there are no known cultivated plants or related native plant species that would allow for interbreeding. For that reason, a high level of confidence has been assigned to this risk classification.

The probability of stonecrop having an impact on the integrity of plant cultivation systems has been deemed to be very low (A22). No references or indications were found in the extensive literature on the environmental impact of this species in this regard, which is why a high level of confidence has been assigned to this risk classification.

No evidence was found in the scientific literature regarding the impact on plant cultivation as a result of the transmission of parasites or pathogens by stonecrop for the EU and elsewhere, for which reason the likelihood of this occurring was classified as being very low (A23). Due to the absence of explicit references regarding this subject in the literature, this assessment has been assigned a medium level of confidence.

Risk to domesticated animals

Health effects on (individual) domesticated animals due to parasitism or predation do not apply to alien plants and therefore a high level of confidence applies (A24).

The probability of an impact on the health of (individual) domesticated animals due to plant substances of stonecrop is very low and as such this classification has been assigned a high level of confidence (A25). No evidence was found in the scientific literature regarding the possible production of substances harmful to animals by stonecrop, while there has been a relatively large amount of research into toxic antibodies and plant toxicity.

Based on the available information, stonecrop does not affect the health of plants of domesticated animals through the transmission of parasites or pathogens either in the EU or elsewhere in the world (A26). The literature does not describe any parasites or pathogens that can be transmitted to animals by stonecrop. It can therefore be stated with a high level of confidence that this criterion does not apply.

Public health risks

The risk category 'The effect of the species on human health through parasitism (A27)' does not apply to plants, with a high level of confidence. Despite the large amount of literature on the environmental impact of stonecrop, no evidence was found regarding health effects as a result of human contact with (plant) substances. For that reason, this risk is estimated as very low (A28) with a high level of confidence. Effects on public health as a result of the transmission of parasites or pathogens do not apply (A29). A high level of confidence likewise applies in this case, given that there has been a relatively large amount of research into stonecrop and the (scientific) literature shows no evidence of such effects.

Risk of other impact

This criterion assesses the likelihood of damage occurring to infrastructure, such as buildings, roads, dykes, and water management structure (A30). Damage of this nature may limit the use of the relevant infrastructure. The likelihood-consequence matrix of the protocol was used for this aspect. Stonecrop is able to decrease water drainage when present in high densities. Water management structures (such as culverts) may become clogged. The likelihood of such effects is high, however the damage is reversible, resulting in a risk classification of medium. Due to the lack of quantitative information regarding the extent of the damage to infrastructure, the level of confidence of this risk classification is medium.

Impact on ecosystem services

Prolific growth of stonecrop in water catchment areas (such as dunes) may lead to minor negative effects on water extraction due to additional evaporation. In addition, indirect effects in multifunctional ecosystems may also lead to negative impacts on provisioning services of other species (such as the production of fish or the performance of recreational functions). The species is cultivated as an aquarium and pond plant, for which purposes plants from wild populations could be used. The harvesting and sale of plants from nature is regarded as a positive effect of the species on the provisioning services of ecosystems. The balance of the positive and negative effects on all provisioning services is deemed to be neutral (A31).
The local blockage of water drainage by stonecrop is regarded as a negative effect on the regulating service of an ecosystem. Due to its high biomass production, this species also has a positive effect on carbon fixation and nutrient retention. It may be that the species could be used to address ecosystems polluted due to the bioaccumulation of metals such as Cu, Zn and Al. The impact on regulating services (A32) has been assessed as moderately negative.
The experiential value of ecosystems similarly decreases due to the thick coverage and crowding out of native species. In systems with a (partly) recreational function, activities are therefore hindered (e.g. boating or angling). These types of effects have been assessed as moderately negative in respect of cultural services (A33).
A medium level of confidence applies to the three risk classifications (A31-A33), due to the fact that no quantitative information is available regarding the impact on ecosystems. However, sufficient knowledge is available to theoretically substantiate the impact of stonecrop on ecosystem performance. Furthermore, no methodologies exist for weighing positive and negative impacts on ecosystem services.

Impact of climate change on risks

The risk posed by stonecrop in terms of overcoming geographical barriers to its introduction and further spread in the EU will not change as a result of climate change (A34). A high level of confidence applies in respect of this assessment, given that no relevant evidence was found and there are no known mechanisms that could account for the impact of climate change on barriers

to spread. The key introduction pathways and dispersal mechanisms are well known and the risks of introduction and spread are not affected by climate factors within the expected range of temperature and precipitation changes, which assumes a time horizon of 50 to 100 years.
The chance that the species will succeed in overcoming the barriers to survival and reproduction increases slightly (A35). This is an expert opinion based on theoretical reasoning, which is why a medium level of confidence applies.
Stonecrop is already established in various climatic regions. These regions will shift slightly north as the climate changes. As a result of higher winter temperatures and reduced snow cover, the area with a suitable climate will increase slightly towards the north and in mountainous regions. In the south, this area will most likely decrease due to increasing drought. Therefore, on balance, the distribution of the species will not change substantially within the EU. Large parts of the EU will remain suitable for the establishment of the species in the near future (A36). A medium level of confidence applies in this regard, given that this is a theoretical deduction, with an absence of quantitative information or model calculations.
The likelihood of undesirable effects on the environment (A37) will increase moderately, such as in the area of the physicochemical properties of the water, such as light and oxygen content, for which a medium level of confidence applies. The causality of these types of effects can be theoretically substantiated, however there is an absence of quantitative and experimental underpinning.
The impact of stonecrop on plant cultivation through grazing or parasitism does not apply. All other effects on plant cultivation are deemed to be very low. Such impacts are unlikely to occur as a result of climate change (A38). A medium level of confidence applies to this assessment, given that there is a lack of scientific documentation.
Parasitism and transmission of pathogens and parasites by stonecrop to animals are not applicable. The probability of health risks via skin contact with plants or exposure of animals to plant substances has been assessed as very low in the foregoing. It can be stated with a high level of confidence that the risks the species poses to domesticated animals will not change as a result of climate change (A39). In addition there is no conceivable link to account for this.
Parasitism and transmission of pathogens and parasites from stonecrop to humans are not applicable. The probability of health risks through skin contact with plants or exposure to plant substances has previously been assessed as very low. It is very likely that public health risks will not change as a result of climate change (A40), which can be asserted with a high level of confidence. It its very unlikely that the plant will produce chemicals that pose a risk to humans as a result of climate change.
The probability of undesirable effects of the species on infrastructure or other socio-economic effects will not change as a result of climate change (A41). Given the lack of quantitative information on this matter, this assessment has been made with a low level of confidence.

8.2 Risk score and levels of confidence

Risk scores and levels of confidence for stonecrop were calculated based on the risk classifications using the Harmonia+ protocol (Table 8.2 and 8.3). Both the maximum and the mean scores per risk category are commonly presented. For that reason, both have been extrapolated based on the data in Table 8.1.
This species scores maximum in terms of its risks of introduction, establishment, spread and environmental impact. The risks of undesirable effects on plant cultivation, domesticated animals and public health score low. The risk of other socio-economic impact is medium. All risk scores have a high level of confidence, with the exception of a medium level of confidence

for the risk of other socio-economic effects (due to the lack of quantitative information). The aggregated invasion, impact and risk scores are high.

Table 8.2: Maximum risk (scores) and levels of confidence of stonecrop with Harmonia+.

Risk category	Risk level	Risk score	Confidence level	Confidence score
Introduction[1]	High	1,00	High	1,00
Establishment[1]	High	1,00	High	1,00
Spread[1]	High	1,00	High	1,00
Environment[1]	High	1,00	High	1,00
Plant cultivation[1]	Low	0,00	High	1,00
Domesticated animals[1]	Low	0,00	High	1,00
Public health[1]	Low	0,00	High	1,00
Other[1]	Medium	0,50	Medium	0,50
Invasion score[2]	High	1,00		
impact score[3]	High	1,00		
Risk score (Invasion x impact)	High	1,00		

1: Risk score = maximum score per risk category, confidence score = mean for all categories; 2: geometric mean; 3: maximum score.

When the mean score is used for each risk category, this species also scores high in terms of its risks of introduction, establishment and spread. The risks to the environment and other socio-economic impacts are medium. The risks of undesirable effects on plant cultivation, domesticated animals and public health remain low. All risk scores have a high level of confidence, with the exception of a medium level of confidence for the risk of other socio-economic effects (due to the lack of quantitative information). The aggregated invasion score remains high, but the impact and risk scores drop to medium.

Table 8.3: Mean risk (scores) and levels of confidence of stonecrop with Harmonia+.

Risk category	Risk level	Risk score	Confidence level	Confidence score
Introduction[1]	High	0,67	High	0,67
Establishment[1]	High	1,00	High	1,00
Spread[1]	High	0,88	High	1,00
Environment[1]	Medium	0,60	High	0,70
Plant cultivation[1]	Low	0,00	High	0,88
Domesticated animals[1]	Low	0,00	High	1,00
Public health[1]	Low	0,00	High	1,00
Other[1]	Medium	0,50	Medium	0,50
Invasion score[2]	High	0,84		
impact score[3]	Medium	0,60		
Risk score (Invasion x impact)	Medium	0,50		

1: Risk score = maximum score per risk category, confidence score = mean for all categories; 2: geometric mean; 3: maximum score.

8.3 Comparison with other risk assessments

Risk assessments of the environmental impact of stonecrop have been carried out for many countries and regions in Europe and the United States. Table 8.4 provides an overview of the protocols used, the impact examined, the risk scores and sources of these risk assessments. It also includes the harmonised risk classifications and list status of this species. The list status indicates whether the species has been included on a warning or black list for invasive species in a particular country or region. The quantitative risk scores and qualitative definitions have been harmonised into three risk classes, i.e. low, medium and high risk, by the authors of this report (see 2.7). The harmonisation of risk scores is hampered by the significant difficulties in risk assessment methods and the absence of relevant protocols (Verbrugge et al. 2012, Matthews et al. 2017). In addition, the results of risk assessments are always contextual and therefore sometimes difficult to compare for different regions or scale levels. After all, the environmental impact of alien species depends on the environmental conditions in the relevant high risk area (such as climate, environmental quality and habitat availability).

Table 8.4: Available risk assessments for stonecrop for various European countries and the United States.

Area/Country	Assessment-protocol	assessed targets: Biodiversity	Ecosystems	Plant cultivation	Infrastructure	Public health	Economy	Risk score	List	Harmonized risk score	Source
Belgium	ISEIA	1	1					12	Black List (A1)	High	Branquart et al. (2013)
Belgium	BRAS	1	1	*	*		1	N/A	ban or convenant recommended	High	Robert et al. (2013)
Germany	MNIGA	1	1	*	*	1	1	N/A	Black List - Aktionsliste	High	Nehring et al. (2013)
EPPO Region (incl. Europa)	EPPO-PRA	1	1	1	1		1	Major	prohibited - Phytosanitary Certificate recommended	High	Van der Krabben & Schrader (2006a,b)
France	PRHP	1	1		1	1	1	Moyen à élevé	Consensus list Code of Conduct invasive alien plants	High	Cambron et al. (2017)
France (Bretagne)	PRHP	1	1	1	1	1		IA1i	List proven invasive species, many localities	High	Quere & Geslin (2016)
France (Normandie)	PRHP	1	1					IA1e	List proven invasive species, expanding	High	Bousquet et al. (2016)
France (Normandie)	PRHP	1	1					IA1e	List proven invasive species, expanding	High	Douville & Waymel (2019)
France (Pays de la Loire)	PRHP	1	1					IA1e	List proven invasive species, expanding	High	Dortel & Le Bail (2019)
France (Poitou-Charentes)	N/A	1	1					N/A	List proven invasive species	High	Fy (2015)
France: Atlantic region	WRA-WG	1	1	1	1		1	31	List high priority for PRA, high risk for environment	High	Fried (2010)
United Kingdom	GB-NNRA	1	1	1	1	1	1	High	N/A	High	GB Non-Native Species Secretariat (2011)
Ireland	NAPRA	1	1	*	*	1	1	High risk	N/A	High	Millane & Caffrey (2014)
Ireland	RAMISI	1	1		1	1	1	20	List high risk species	High	Kelly et al. (2013)
Luxembourg	ISEIA	1	1					10	Alert List (B0)	Medium	Ries et al. (2013)
Luxembourg	Harmonia+	1	1	1	1	1	1	0,44		Medium	Ries et al. (2020)
Norway	NAPRA	1	1	*	*	1	1	High risk	N/A	High	Norwegian Scientific Committee for Food Safety (2016)
Poland	Harmonia+	1	1	1	1	1	1	0,38	Medium invasive	Medium	Sotek et al. (2018)
Spain	WRA	1	1	1	1		1	19	Rejected for introduction	High	Andreu & Villa (2009)
Spain	WRA-WG	1	1	1	1		1	26	List medium risk species	Medium	Andreu & Villa (2009)
Switzerland	Not mentioned	1	1					N/A	Black List	High	Buholzer et al. (2014)
United States (USA)	ERC	1				*		High	N/A	High	U.S. Fish & Wildlife Service (2018)
United States (USA)	PPQ-WRA	1	1	1	1			High (3,9)	List very invasive species	High	APHIS (2013)

1: Target extensively assessed; ***** Target mentioned; **A1**: High risk, isolated populations; **B0**: Medium risk, not yet present in 2013; **BRAS**: Belgian risk analysis scheme; **ISEIA**: Invasive Species Environmental Impact Assessment; **EPPO-PRA**: European and Mediterranean Plant Protection Organisation Pest Risk Assessment Scheme (Branquart et al., 2016); **ERC**: Ecological Risk Screening U.S. Fish & Wildlife Service; **GB-NNRA**: Great Brittain Non-Native species Risk Assessment; **N/A**: not applicable; **MMARM**: Ministerio de Medio Ambiente, Rural & Marino; **MNIGA**: Methodik der naturschutzfachlichen Invasivitätsbewertung für gebietsfremde Arten (version 1.2); **NAPRA**: Non-native species application based risk analysis; **PPQ-WRA**: Plant Protection and Quarantine WRA; **PRHP**: Protocole d'évaluation de species en vue de prescrire des restrictions d'utilisation pour les acteurs de la filière de l'horticulture ornementale et du paysage; **RAMISI**: Risk Assessment Methodology Invasive Species Ireland, version 2007; **WG**: risk assessment according to Weber & Gut (2004) for potentially invasive plant species in central Europe.; **WRA**: Australian Weed Risk Assessment system (Pheloung et al. 1999); **WRA-WG**: WRA risk assessment combined with WG-risk assesment according to Weber & Gut (2004).

The harmonised risk classifications for stonecrop provide a more or less consistent picture and closely match this classification for the EU using the Harmonia+ protocol, which uses the maximum value per risk category (section 8.2). The vast majority of the risk classifications (82.6%) indicates a high risk of undesirable effects on native biodiversity and ecosystem performance, with the exception of Luxembourg, Poland and Spain, where the risk is classified as medium. For Luxembourg, this relates to inter alia a classification from 2010, using the Belgian ISEIA protocol. At the time of that assessment, relatively little knowledge was available regarding the precise extent of the effects in Luxembourg and the surrounding countries. A classification using the Belgian Harmonia+ protocol was additionally carried out for Poland (Tokarska-Guzik et al. 2021), where the overall risk was calculated by multiplying the maximum value of impact by the mean values calculated for the invasion modules (it took into account 3 parameters: introduction, establishment and spread). As a result, the score per impact category is lower than for the maximum approach in the event that one or more subcriteria have been assessed as low or medium risks. However, the results of these assessments are consistent with the current results based on the average risks per impact category (Table 8.3).

For Spain, the results of the WRA and WRA-WG protocol were compared, with the latter protocol scoring lower. A study by Andreu & Vila (2009), based on risk assessments of 80 alien species, showed that the WRA and WRA-WG scores are significantly correlated. Naturally, individual species are able to score higher or lower with the WRA-WG than with the WRA. In the case of scores around the threshold value for a specific risk class (low, medium or high), this may occasionally result in a deviating risk classification.

9 Estimation of the potential costs (quantitative or qualitative)

9.1 Damage to biodiversity & ecosystem services

Damage to biodiversity

Based on the literature review in this report, it has been concluded that stonecrop has a significant impact on the biotic and abiotic environment (see Chapter 7 and 8). These effects are currently increasing as a result of further spread. In part, these are effects that may affect native species under certain circumstances, however, these species are generally easier to control with appropriate management. There are no known publications that express the financial damage to biodiversity.

Damage to ecosystem services

Stonecrop is sold as an aquarium and pond plant, which means that the species contributes to provisioning services (see 7.2). The total economic value of this plant species, however, is estimated to be limited, which means that any damage to producers in the event of a ban would be minor (CABI 2016). The overall costs associated with the damage to ecosystem services are unknown. This also applies to the value of regulation and maintenance services, including functioning as a potential nectar source for insects.

9.2 Damage to health, safety and the economy

The species has an impact on the safety, water infrastructure and the experiential value of nature reserves (see 7.3). Floating carpets can be confused with solid soil, for which appropriate warnings would involve certain costs. Hindering recreational activities would entail certain costs if they would have to be suspended. In practice, however, there are plenty of alternative sites available where recreational activities could take place. This may change with the further expansion of stonecrop. The drainage of canals and water management structures must be safeguarded and the removal of the plant at these locations would entail certain costs, which have not been reported. This also applies to any losses that would occur as a result of the lowering of the aesthetic value of nature reserves.

9.3 Costs of control

The costs of elimination and/or management of stonecrop are very high. In the UK the potential costs of control for 600 sites over a period of two to three years were estimated at £2-3 million (Dawson 1998 in Leach & Dawson 1999). Other sources refer to costs of €2.5 to 3.5 million for the annual control of the species in England (OEPP/EPPO 2007, Dadds & Bell 2008, Williams et al. 2010). Kelly & Maguire (2009) estimate the costs for the remediation of a small garden pond to be at €600, which may increase up to €6,000 for larger ponds and small river systems. They indicate that the efforts and funding must be continuous until the species is fully eliminated. The remediation of a lake, canal or large river system may cost between €60,000 and 115,000 in the first year.

In Ireland, the cost of monitoring, studying and rehabilitating treated areas was estimated at €350,000, with the largest expenditure twice relating to the monitoring of the species in a watercourse. (Caffrey et al. 2012).
In the Netherlands, more than €6 million have been spent on research, elimination and control of stonecrop from 2017 to dateVan der Loop. In the minister's responses to questions from the House of Representatives, an amount of approximately €10 million is even mentioned, of which more than €4 million was spent in 2018 and 2019 on control measures by the provinces of Friesland, Drenthe, Gelderland, Utrecht, North Holland, North Brabant and Limburg (Annex to the Proceedings of the House of Representatives of 18 May 2020, ah-tk-20192020-2806). The majority of the costs relate to studies aimed at determining the habitats, the ecology of the species and the formulation of cost-effective management measures, including the development of system-based management. On the Wadden Islands, approx. €4.5 million were spent on eliminating the species (Van der Loop et al. 2022 and pers. communication P. Wassenaar, stonecrop elimination Terschelling project leader, province of Friesland).
Costs were also incurred to prevent flood risks. No figures are available on this (OEPP/EPPO 2007).

10 Management

10.1 Prevention

Legal framework

European countries deal with stonecrop differently in terms of regulations. Three Member States (Denmark, Ireland and Spain) have included the species on their national lists of invasive alien species of Member State concern under EU Regulation 1143/2014. While Poland had listed the species in the past, the application has since been rejected. In the United Kingdom, Switzerland, Denmark and Spain, among others, trade of the species is prohibited or otherwise regulated by law.

Prevention of spread

Plant fragments are easily dispersed through water or adhesion to animals, people or equipment (Dawson & Warman 1987, Crane et al. 2019). The risk of spread through humans and equipment can be reduced by inspection of footwear and equipment following access to contaminated areas and removal of any plant fragments. Larger machinery, such as cranes, must be cleaned with a high-pressure cleaner at a site with a habitat that is unsuitable to stonecrop (pers. communication J. Van der Loop). The killing of small fragments could be accomplished in addition to larger-scale interventions by applying direct steam treatment. The use of steam would kill all smaller fragments of stonecrop within 10 seconds (Crane et al. 2019). The application of chemical treatment, using Virkon® Aquatic and Virasure® Aquatic, would not be sufficient for stonecrop in killing all the fragments (Crane et al. 2020). Instead of steam, hot water could be used to sterilise any footwear and equipment. However, this requires temperatures of over 50°C for a period of 15 minutes, making this method difficult to be applied in the field (Shannon et al. 2018).

Spread can also be prevented by making adjustments to the infected area. Stonecrop can be spread by recreational users who move from contaminated to uncontaminated sites. Access to contaminated areas by recreational visitors and other visitors must be minimised in order to prevent any spread. It is therefore advisable to restrict public access for recreational users to the contaminated waters by enclosing the contaminated waters. In addition, it is advisable to inform visitors and local residents about the contamination and the associated risks (Van der Loop & van Kleef 2020).

Spread can also take place via animals. Plant fragments can be moved by livestock from infected to uncontaminated areas. In order to prevent spreading to uncontaminated sites, it is advisable to also fence out infected locations for access by livestock. The risk of spreading by water fowl, i.e. ducks, ralls, waders, herons, and geese, can be reduced by constructing a net structure of ropes or other lines over the infested location. Bird-disturbing-kites can be functional for migratory birds. Between aquatic sites, smaller fences can reduce the movement between sites by walking birds (i.e. ducks and geese) (Van der Loop et al. 2020, Van der Loop et al. 2022)

Contamination

It is critical that any large machinery that is used in affected or contaminated areas, and are virtually impossible to clean effectively, such as mowers and crawler cranes, are not used in non-contaminated humid areas. Working safely with the plant requires following certain procedures. The hygiene measures aim to prevent new (cross) contamination at uncontaminated or locations where the invasive species has already been controlled, and consist of several measures such as choosing the right machines, ensuring that hired machines do not pose a risk of contamination, and afterwards the correct cleaning of equipment and machines. But the use of clean footwear and the correct disposal of contaminated material is also important for the careful handling of stonecrop (Van der Loop & van Kleef 2020). In addition, disturbances that make the soil more susceptible to contamination with stonecrop must be limited. It is therefore critical to section off the contaminated areas and make them inaccessible to humans (Van Kleef et al. 2017, Van der Loop & van Kleef 2020).

Establishment
Stonecrop quickly overgrows any open spaces in an ecosystem. At high nutrient concentrations this happens even faster (Brouwer et al. 2017, Van Kleef et al. 2017, Van der Loop et al. 2020). It is therefore vital that any disturbance of the soil in a humid system, particularly in the vicinity of known contamination (certainly up to 1 km), should be limited as much as possible. This means that any excavation work, such as for infrastructure purposes and the development of new natural resources, should be avoided where possible in the vicinity of contamination (Van Kleef et al. 2017).

Dispersal in water
Where stonecrop is located in an open water system, it is vital that the contaminated water, where possible, is isolated from the transiting water system (Van der Loop & Van Kleef 2017a,b, Van der Loop et al. 2018, Van der Loop et al. 2022). This can be achieved by disconnecting the water flow or making any culverts impenetrable for stonecrop, without hindering the water flow. If the latter is chosen, it is vital that any structures, such as culverts, should be covered with a sustainable fine-grained geotextile. Root-proof membrane fabric and other thin plastics are unsuitable for the necessary long-term use due to tearing and wear. After covering these structures, it is essential that the 'sieve' be regularly cleared to ensure that the water cannot overflow and that no dominant cover of stonecrop or other species, such as carrier algae, builds up on the sieve intake. Given that stonecrop is able to grow from meristematic cells, the full control and blocking of stonecrop cannot be guaranteed (Crane et al. 2019, pers. observation J. Van der Loop).

10.2 Management and control

In terms of taking action against an established stonecrop population, it may be possible to completely remove (eliminate) or reduce (control) the biomass.. In the latter case, this will require recurring efforts due to the regrowth of the plant.

In general, the effectiveness of elimination measures aimed at stonecrop is low but not impossible (Dawson 1996, Delbart et al. 2011, Van der Loop et al. 2018, Scheers et al. 2020, Smith & Buckley 2020, Van der Loop et al. 2022). Elimination can only be achieved where appropriate precautions concerning hygienic practices are put in place, including separated soil flows, the separation and cleaning of any equipment used and careful execution (Van der Loop et al. 2018, Van der Loop et al. 2022). In addition, the likelihood of successful elimination increases where the contaminated sites are isolated. Elimination can only be achieved if the site can be drained. If drainage cannot be achieved, the only options remaining are control or no action. When choosing the most appropriate measures, the characteristics of the contamination as well as the properties of the area and any surrounding areas must be assessed. As such, taking measures against stonecrop always requires tailored solutions. All kinds of site-specific aspects must be taken into account, such as the storage and processing of contaminated soil, the disposal of contaminated water, the presence of protected species and any relevant environmental impact, such as noise pollution (Van der Loop et al. 2018).

Early identification and rapid elimination

For new, isolated stands, the size of the population will be small and the likelihood of re-establishment will be smaller. In such cases, the probability of successful elimination as a result of small-scale controls will be greater, partly because this does not result in the creation of a new, potentially suitable biotope on a large scale (Van der Loop et al. 2018). This means that being able to respond rapidly to a new, isolated and, as yet, small stand, may be critical. Sightings must then be able to be communicated to the relevant site manager rapidly and the manager must be able to carry out a targeted elimination strategy following a quick assessment. Effective use of information and communication channels and knowledge of the various control options is crucial in such cases (Van der Loop & van Kleef 2020).

10.2.1 Mechanical

Manual removal

Manual removal, to a depth of 20 cm, is chiefly effective in the context of early identification and rapid response (Van der Loop et al. 2018). Small, new stands are best removed manually at the earliest possible stage. However, during this period, identifying a population is hampered due to the small size of the plants and the initiation of new contaminations during the control intervention (L. Denys in Robert et al. 2013). It is vital that all parts of the plant are removed in order to prevent growth into a larger population. Manual removal has previously been carried out at sites with a cover of < 1 m^2 (Dawson & Henville 1991, Adriaens et al. 2010, Boute 2013, Torensma 2017). The effectiveness of this labour-intensive measure varies, as parts are easily missed during manual removal. The method is insufficient for areas of > 1m^2 (J. Van der Loop).

Mechanical removal

The excavation of the plant is one option for the elimination or control of stonecrop at dry or drained sites (Leach & Dawson 1999, Boute 2013, Van der Loop 2023). It is crucial that very hygienic practices are followed and that all fragments of stonecrop are carefully removed. Excavation must be carried out up to a depth of >30 cm and preferably in three stages of approx. 10 cm. The success of elimination can be increased by filling the excavated profile with clean sand, thus preventing any remaining fragments from regrowing (J. Van der Loop).

On the Wadden island of Terschelling in the Netherlands, growing areas (>10 ha) dominated by stonecrop have been successfully cleaned. The eradication method has been described in detail, and can be repeated in other infested locations (Van der Loop et al. 2022). The applied method was excavation of infested locations and replenishing these areas with clean (uncontaminated by stonecrop) sand to restore boundary conditions suitable for recovery of the treated habitats in this Natura 2000 site. This method has since been successfully repeated at 10 locations in the Netherlands, where the species has completely disappeared (i.e. 4 locations in De Achterhoek, 3 locations in De Kop van Schouwen, 3 locations in Overijssel pers. communication Martijn van de Loo). The first implementation of this method in Germany has already started (De Vries & Van de Loo 2022).

Sod cutting

The same prerequisites applicable to manual removal apply to control using sod cutting. However, contaminated areas may be up to approx. 0.2 hectares (ha) in size and submersed plants can only be tackled after the water body has been drained (Adriaens et al. 2010, Boute

2013, Denys et al. 2014b, Torensma 2017, Van der Loop et al. 2018). Sod cutting involves the scraping off of the organic top layer of soil (approx. 10 cm) only. One risk of this measure, compared to mechanical excavation, is that parts of plants can easily remain in the soil, which can then regrow. The desired depth of the sod cutting depends on the soil substrate and the depth of the plant roots. Sod cutting on clay soil is much more difficult than on sandy soil (Adriaens et al. 2010). The effectiveness of sod cutting to eliminate stonecrop is low, however the species can be controlled using this method through the regular repetition of this treatment.

10.2.2 Physical

Suppression (Filling in the waterbody with soil)
The suppression of the water system is a rigorous but effective approach to eliminating stonecrop. Transforming the system from (semi-)aquatic to terrestrial causes stonecrop to lose its suitable humid habitat (Boute 2013, Sims & Sims 2016, J. Van der Loop). This method has been successfully performed several times in the Netherlands, with stonecrop being completely eliminated (i.e. 2 locations in De Achterhoek and 3 locations in De Kop van Schouwen, pers. communication Martijn van de Loo). Similar to excavation or sod cutting, the water system must be completely drained and dry. The supply of soil is crucial for suppression and the site where the soil used for suppression is stored must be situated outside of the contamination zone. Cross-contamination between the contaminant and soil extraction must be prevented, given that bare soil may be created at treated sites, which the plant can use to its advantage. Cross-contamination of the areas can be prevented by maintaining hygiene practices and keeping transport flows separate. Once an entire affected water body has been covered, the soil must then be left untouched to prevent the regrowth of stonecrop (Van der Loop et al. 2018). It takes at least two years before the covered plants are no longer viable (J. Van der Loop).

Light limitation
Light limitation can be achieved by covering the contaminated area with tarpaulin or hessian mats on the banks or by colouring the water with a dye. Both methods lead to eliminating or limiting the plant's ability to photosynthesise, which inhibits the growth of stonecrop and may lead to the plants dying off (Dawson & Warman 1987, Bridge 2005, Wilton-Jones 2005, Adriaens et al. 2010, CAISIE 2013, Robert et al. 2013, Denys et al. 2014b, Ewald 2014, Torensma 2017). In practice, these methods have proven only to be effective for controlling stonecrop – elimination cannot be achieved. Even after being covered for five years, stonecrop quickly developed into a new surface-covering contaminant, presumably from surviving fragments or by seed germination (pers. observation Van der Loop, 2017). Although covering is not effective for the complete elimination of stonecrop, control of the species is also desirable in many cases. Reducing the biomass and capturing the contamination reduces the spread of stonecrop. This method can also save time for drawing up an eradication plan, without the species spreading further in the meantime.. Finally, reducing biomass in this way makes it possible to carry out other measures, such as system-based management (Van der Loop et al. 2019, Van der Loop & van Kleef 2020). With regard to the application of dye (Dyofix®), plants will stretch towards the light and grow to emerge above the darkened water layer, making this method ineffective for both elimination and control (Boute 2013, Denys et al. 2014b, Ewald 2014).

Liquid nitrogen, scorching, foam and draining
The methods involving the application of liquid nitrogen, scorching with weed burners, covering with foam (Waipuna®) and the draining of contaminated sites are all ineffective for eliminating

or controlling stonecrop. The measures involving nitrogen, scorching and foam can only be applied to a very small area and the plants do not die completely, allowing them to recover quickly (Dawson & Henville 1991, Leach & Dawson 1999, Bridge 2005, Bogaert 2013, Boute 2013, Ewald 2014, Torensma 2017).

Draining, by contrast, is required to carry out all of the aforementioned measures. Merely draining an area, however, is insufficient for the elimination or control of stonecrop. The plants can withstand drought for a long period of time and, as a rule, the drained sites will quickly fill up again with ground or rainwater (Newman & Raven 1995, Hussner 2009, Boute 2013, CAISIE 2013, Denys et al. 2014b, Torensma 2017, Van der Loop et al. 2018).

Hot water treatment
The use of hot water treatment, where each plant is sprayed with boiling water for 30 seconds, is not effective for controlling or eliminating stonecrop (Van Kleef et al. 2019). After treatment, surviving parts of the plant will quickly grow into a new contamination. However, hot water kills a significant portion of the stonecrop plants, which makes it a method that is suitable for the management of the species, especially where regrowth and a resulting higher management frequency are not a problem. Killing the plants in this way leaves a deposit of organic matter, which hinders the recovery of the natural community, which is why this method is not suitable for nature reserves.

10.2.3 Chemical

Herbicides

Herbicides such us glyphosate, 2,4-D amine, asulam, dalapon, dichlobenil, terbutryn and diquat, both with and without the excipient Alginate®, are insufficient for elimination (Barrett 1981, Dawson & Warman 1987, Spencer-Jones 1994, Dawson 1996, Genovesi & Shine 2004, Bridge 2005, Gomes 2005, CAISIE 2013, Robert et al. 2013, Ewald 2014). The parts of the plant affected by the toxin will split off, after which new plants grow from the remaining parts.

Salt water

Salt water causes stress in stonecrop, resulting in a decrease in growth and survival. This has chiefly been demonstrated in relatively limited laboratory experiments in which the plant dies at levels as low as 4 ppm of NaCl (Charlton et al. 2010, Dean et al. 2013, Torensma 2017). In practice, however, this method is less effective, given that after control with salt water in the salt marshes in England the species had not completely disappeared (EPPO 2017). The species can then easily regrow. This is due to the salinity in the field rapidly declining as a result of groundwater or rainwater. In addition, stratification of salt and fresh water takes place, with stonecrop continuing to grow in the freshwater layer (Van der Loop & Van Kleef 2017a, J. Van der Loop 2016).

10.2.4 Biological

Grazing / control through the use of organisms

Outside of stonecrop's native range, no organisms have been found that graze on the plant or cause damage to it in any other way, such as through pathogens or due to egg laying (Dawson & Warman 1987, Dawson & Henville 1991). Efforts are being made in England to develop a biological control method. This involved identifying any natural enemies of the plant in its native range. This study identified the bile-forming mite species *Aculus crassulae* Knihinicki & Petanović (*Eriophyoidea*) which causes significant leaf damage to stonecrop in Australia (Varia et al. 2011). This species appears to specifically use stonecrop as a host and as such is a good candidate to be used as a biological agent against stonecrop (Knihinicki et al. 2018). At present, tests are being carried out in England to ascertain whether the mite species is safe to introduce to sites contaminated with stonecrop and whether the species causes sufficient damage to the plant to eliminate the species or to control it and whether the method is cost effective (Varia et al. 2017).
It has also been suggested that stonecrop may be susceptible to damage caused by leaf beetles (*Chrysomelidae*) and true weevils (*Curculionidae*) (Gassmann et al. 2006), however, there are no relevant studies available.

The grass carp (*Ctenopharyngodon idella* Valenciennes) had previously been designated as a potential biological agent due to its generalist feeding habits. 18 grass carp were released into an affected fen in the Netherlands (Denys et al. 2014b) with an area of 1.23 hectares, where the only vegetation present in the water was a dominant cover of stonecrop with a sporadically present Characeae algae species. After 6 years, the carp are still regularly observed in the fen, however stonecrop is still the dominant aquatic plant at this site (pers. observation J. van de Loop).

System-based management

System-based management focuses on reducing the available nutrients, by limiting the supply of nutrients on the one hand and increasing competition for nutrients on the other (Hobbs & Huenneke 1992, Funk et al. 2008). Laboratory experiments showed that this approach is promising for stonecrop and demonstrated that establishment and growth are significantly reduced by good coverage of native species as well as that less proliferation of the species occurs with a reduced nutrient load (Brouwer et al. 2017, Van der Loop et al. 2020, Van Kleef et al. 2024, Van Doorn et al. 2024). Also, maintaining high water tables may reduce the impact of the species, rather than risking a dry period which may stimulate the proliferation of stonecrop at the cost of other species (Van Doorn et al. 2024, Van Kleef et al. 2024). This method is currently being developed for application in management practice.

The measure consists of:
1. Identifying and tackling sources of eutrophication. These may be highly diverse and, in practice, nitrogen deposition, eutrophic soil due to former agricultural use, supply of carbon and nitrogen-rich surface and groundwater and goose faeces will often be the key sources of nutrients. It is not always easy or possible to reduce eutrophication – but every little helps. Options include disconnecting nature reserves from water supply that is high in nitrogen or reducing goose populations.
2. Breaking stonecrop's dominance. The use of hot water and cover using black foil are potential options in addition to sod cutting. In themselves, these methods are not effective for the sustainable control or elimination of stonecrop. The (dead) biomass must be disposed of to prevent nutrients from being released.
3. Encouraging native plant species in order to prevent the re-establishment and regrowth of stonecrop. This can be achieved by introducing native vegetation, ensuring that any bare soil is covered as soon as possible. Depending on the method of growth of the desired species, seeds, root fragments and entire plants can be used for introduction. The selection of species is site-specific and will change with the degree of annual inundation, soil conditions and the objectives of the area (Van Kleef et al. 2017).
Over the past two years, tests have been carried out in various practical situations to assess whether the system-oriented management of stonecrop is possible. They have shown that system-based management is a measure that can be applied in practice by making the ecosystem more resilient against the invasive species, by a reduction of stonecrop' biomass and the introduction of native species. To reduce plant biomass it is possible to apply a foil-, sod cutting- or sod cutting combined with hot water treatment. In this study, the Dutch native species *Littorella uniflora* (L.) Asch. was found most effective to suppress the increase in biomass of recolonizing stonecrop (Van der Loop et al. 2023). The system-based measures described in the foregoing are also likely to be suitable to provide unaffected areas with more resistance against stonecrop invasions.

10.2.5 Taking no action

Stonecrop benefits from disruption and eutrophication of the system (Brunet 2002, Hussner 2009, Ewald 2014, Brouwer et al. 2017, Van Kleef et al. 2017, Van der Loop et al. 2020). However, the plant can also establish when this is not the case (Keeley 1998, Klavsen & Maberly 2009). In these cases, the biomass production of stonecrop remains low and the species does not become dominant. If this is the case and spread to other vulnerable areas is unlikely, then taking no action is the appropriate advice. Implementing measures in conditions such as these would lead to disturbances in the system, which would, as a rule, lead to an increase in stonecrop (Van Kleef et al. 2017, Van der Loop et al. 2018).

10.2.6 Aftercare for treated areas

Many measures aimed at tackling stonecrop are not permanently effective due to the lack of monitoring and aftercare (Van der Loop et al. 2018). It is crucial that the relevant sites are monitored every 6 months for a period of 5 years. Areas where the plant has been subjected to control measures are disturbed and are therefore vulnerable to renewed dominance of stonecrop. The plant is able to regrow from visually dead plant residues, leftover fragments/cells or reintroductions. In the unlikely event that stonecrop is found again, small-scale measures can be put in place to subsequently eliminate the species. The key condition in this case is that the species is identified before it spreads.

10.3 Risks of improper management

Measures aimed at tackling stonecrop may contribute to the fragmentation and spread if insufficiently careful and diligent practices are not observed. This poses a risk to recolonisation and spread (Dawson & Warman 1987, OEPP/EPPO 2007, Van der Loop et al. 2018). It may, for example, be the case that biomass is temporarily significantly reduced, due to mowing and grazing, but that it may quickly increase again in the disturbed areas (Dawson & Warman 1987, Diaz 2012, Robert et al. 2013, Dean et al. 2015, Van der Loop et al. 2018).

It is vital that regular management practices are modified when stonecrop is present (see section 12.3). Activities that cause open, exposed soil on the site must be avoided when the plant is present. Regular management practices of surrounding, unaffected areas may continue to take place if there is limited disturbance of the soil (Van Kleef et al. 2017).

11 Knowledge gaps and recommendations for future (practice-based) research

Origin and chromosome number (ploidy)

There are a number of ambiguities regarding the origin of stonecrop in Europe. In England, DNA analysis revealed that stonecrop originated from a single DNA line in Australia (Smith & Buckley 2020). The origin of stonecrop in the Europe is unknown.

In addition, different types of ploidy are listed for New Zealand and Australia. Diploid plants are found in New Zealand (2n=14) and hexaploid plants (2n=42) are found in Australia (De Lange et al. 2008). It is unclear how great the variation is, because too few plants were sampled. In England a chromosome number of 2n=36 is reported (Stace 2019). This does not correspond to the data from the native range, as this is not a multiple of 7. This may be an erroneous count or it may be that the invasive stonecrop in England belongs to a different taxon (or may be a hybrid) than the species native to Australia and New Zealand.

Impact on ecosystems

It is unclear what the exact impact is of stonecrop on water chemistry and biodiversity. A comparison of chemical variables at invaded sites and reference areas is required (Smith 2015, Van Kleef et al. 2017, Van der Loop et al. 2018).

Reproduction by seed

In the past, it was thought that stonecrop had not developed a crucial seed bank in the Netherlands. Laboratory research, however, does not exclude reproduction from seed in Western Europe (Denys et al. 2014a, D'hondt et al. 2016). Most fruits do not bear seeds and the germination rate is low. However, in many contaminated areas, the number of flowers is incredibly high, potentially resulting in the number of germinating seed being significant after all. In western Europe seeds survive a normal winter in the field (Denys et al. 2014a, D'hondt et al. 2016). It is not known whether stonecrop produces a vital seed bank from which plants can still germinate after several years. This only poses a risk in cases where stonecrop is removed superficially or when buried plant parts resurface in the future.

Reproduction from buried plant parts

Some measures involve the burial of stonecrop. As in the case of seed, recolonization is theoretically possible if the buried plant parts should resurface over time, for example due to the washing away of the soil or the digging up of the soil. At the time this assessment was prepared, it was unknown whether stonecrop was able to recolonize from buried plant remains and what corresponding survival period applied..

Cost-effective control measures

It is crucial that any measures put in place to tackle stonecrop should be monitored and reported to reduce any knowledge gaps on spread, expansion, costs and impact on ecosystems. This knowledge is crucial to achieve cost-effective control measures for the species (Van der Loop et al. 2018).

Disposal of released material

Many of the applied control measures relate to the removal of the biomass of stonecrop, with or without soil material. There is no consensus regarding the processing of contaminated material. There are companies that process plant material contaminated with invasive alien species. These certified companies have professional composting facilities that operate using higher temperatures than standard composting facilities and use (certified) quality assurance systems. The websites of the industry associations for compost products (www.bvor.nl or www.biomassawerven.nl) contain an overview of the facilities for the controlled composting of invasive alien species and other organic waste flows. There is no specific research available showing that regular composting or composting at higher temperatures completely kills stonecrop.

There are limited options for the processing of contaminated soil material. The contaminated material cannot be composted alongside the soil, due to the fact that an overly high sand fraction in the composted material is undesirable (pers. communication G. van der Weerden, Radboud University Nijmegen). Sand and plant material cannot be separated due to stonecrop which is easily fragmented. In addition, a high sand fraction makes processing in an incinerator impossible. Creative solutions will have to be found for the disposal of contaminated soil material until proven effective options are available.

Other questions

In addition to the questions discussed above, there are various other practical but nevertheless relevant research questions, such as:

- What is the viability of stonecrop in the intestines of cattle and horses?
- What is the minimum depth for the burial of stonecrop to preclude regrowth?
- What is the minimum depth for the sterile excavation of stonecrop contamination, to ensure that no fragments of the species are left behind?
- What are the minimum densities for the introduction of competitors?
- What previously described control methods can be used on a supplementary basis to achieve higher effectiveness?
- What is the outlook for areas which are completely dominated by stonecrop?
- How long does this dominance prevail?
- Which species can colonize stonecrop mats?
- Will stonecrop disappear when it starts to decay in the deeper layers?

12 Discussion and conclusions

12.1 Discussion

There is a considerable amount of literature available on the ecology, risks and control of stonecrop. Nevertheless, this literature has not highlighted the risks to ecology and native biodiversity in Europe to a great extent. It may be that the impacts of this frequently highly dominant species is considered to be so significant that they have not been studied. And yet, clarifying these types of impact is critical to being able to accurately assess and describe the risk that this species entails. In this risk assessment, we have been able to demonstrate the impact of this species on ecology and biodiversity through a combination of scientific evidence and (photographic) description of the degree of dominance and ecological flexibility of stonecrop.

The Harmonia+ protocol was not necessarily developed for species that have long since been established and are widespread. Nevertheless, in conjunction with accurate documentation, it is a valuable tool for the integration of the available knowledge on the species, to highlight risks and identify ambiguities and knowledge gaps. In view of the advancing knowledge on this species, it is recommended to update the risk assessment periodically..

Stonecrop's invasive nature lies primarily in the ease with which wet or humid pioneer situations can be contaminated or can become contaminated again after control. This is associated with a generally greater ecological flexibility compared to many native aquatic and riparian plant species, for example in terms of drought tolerance. Moreover, thus far the costs of control have proven to be significantly high, with low corresponding returns. This means that the social support based for the control of such a species could decrease, as is demonstrated by the Parliamentary questions.

12.2 Conclusion

Both the invasion, impact and risk scores of stonecrop are high. The risks of significant impact on biodiversity, ecosystems and infrastructure, to a lesser extent, have been assessed as high. There is a low risk to plant cultivation, domesticated animals and public health. The level of confidence of the risk scores is high for most risk assessment categories.

The risks of stonecrop to wet nature (both in terms of ecology, biodiversity and ecosystem services) are significant in parts of North-western Europe. Combined with the impact of climate change, the species may potentially be able to establish itself in other countries or establish further north or higher in the mountains. It seems even that geese may transport it to northern countries.

Successful control or the prevention of spread – if necessary – requires a more coordinated approach, on an international scale as well as on a local scale, between managers.

12.3 Recommendations for management

An extensive and in-depth dialogue is currently ongoing between managers (water boards, municipalities, and managers of nature reserves), citizens and green entrepreneurs on methods of control and new control methods are regularly tested or promoted. As such, it is not easy to prescribe a one-size-fits-all method. The best method may vary on a case-by-case basis and will mostly require a combination of measures, which will have to be implemented for years. Table 12.1 sets out recommendations for management, which proved to be effective in practice at the time this assessment was drafted. Various measures can be taken to mitigate the adverse impact of stonecrop, which serve to eliminate or control the species. However, 'taking no action' is also a potential strategic approach. When choosing the most appropriate measures, the characteristics of the contamination as well as the properties of the area and any surrounding areas must be assessed. An assessment framework has been drawn up to assist decision making with regard to prospective action (Table 12.1). The schedule sets out the decision making process based on these factors. Measures will always have to be taken on a tailored, case-by-case basis and monitoring their effectiveness is crucial to implementing the same measures at other sites.

A key hurdle in relation to control is that parties must cooperate in order to achieve real results. At present it is all too common, for example, for a manager on one side of a water system to be their his/her best, with the manager on the other side failing to take action.

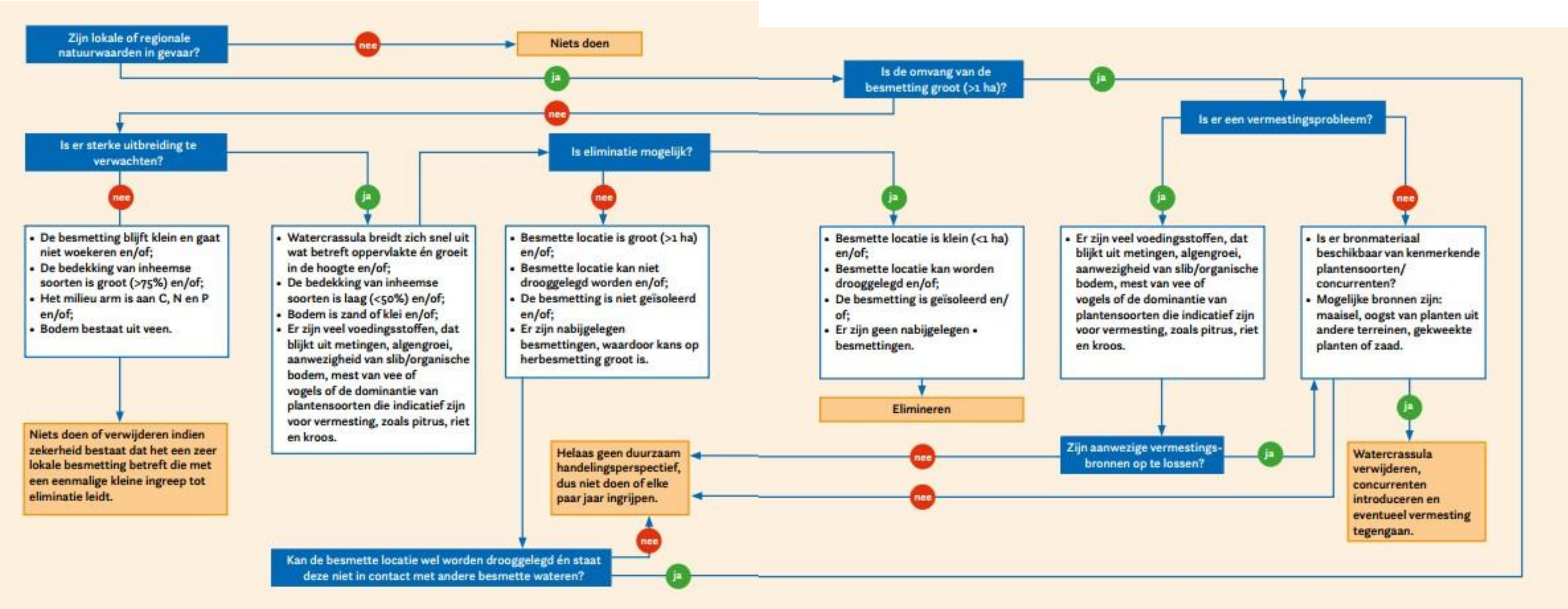

Table 12.1: Assessment framework for measures to tackle stonecrop, in Dutch (Van der Loop & Van Kleef 2020).

12.3.1 Preventing spread

Key methods to prevent the spread of stonecrop include:
1) prohibiting the import, trade, cultivation and release of the species into the wild;
2) preventing contamination through land management, earthworks and redevelopment of nature reserves;
3) preventing contamination via water systems, waterfowl and other animals such as grazers;
4) preventing contamination by recreational visitors;
5) following hygienic practices in relation to vegetation management and other activities in and around contaminated waters;
6) carrying out rapid interventions for new, small-scale establishment, including the dumping of aquarium plants and garden waste.

12.3.2 Contamination: Taking no action

Stonecrop benefits from disturbance and eutrophication of the system. However, it is able to establish in situations where this is not the case. In these cases, the biomass production of stonecrop remains low and the species does not become dominant. If this is the case and spread to other vulnerable areas is unlikely, then taking no action is the appropriate advice. Implementing measures under such circumstances would lead to disruptions in the system, which would, as a rule, lead to an increase in stonecrop.

12.3.3 Contamination: elimination

In the case of elimination, the objective is to remove the stonecrop contamination entirely. Elimination of contamination can only be achieved if (1) the contamination is isolated, (2) the site can be drained and (3) if recolonization from surrounding areas can be excluded (Van der Loop et al. 2018, Van der Loop et al. 2022).

There are several options available to eliminate stonecrop. They are predicated at all times on the site being drained in order to carry out activities in accordance with hygienic practices. Small, localised contaminations (< $1m^2$) can be removed manually, by excavating up to 20 cm in depth. For large-scale contaminations, water bodies with little natural value can be suppressed (filled with soil) in order to prevent stonecrop from spreading to valuable waters. Suppression involves the (semi-)aquatic environment being transformed into a terrestrial environment, resulting in stonecrop losing its suitable habitat. It is vital that the buried stonecrop does not resurface in the future. Another method of elimination, involving the preservation of the water body, concerns the removal of stonecrop by way of excavation. In this case, it is critical that no plant seeds or fragments are left behind from which the population can recover. Any seeds and fragments left behind unexpectedly will subsequently be defused by covering the excavated sections with clean sand, preferably of local origin. Elimination has little chance of success if hygienic practices are insufficient and if stonecrop is able to relocate from contaminated areas as a result of the activities to sections of the site that have already been treated. A specialist approach to eliminating stonecrop is therefore required.

12.3.4 Contamination: Control – traditional versus system-based

Unfortunately, conditions for elimination are often suboptimal, in which case control of stonecrop is an option. Many methods of stonecrop control, such as covering with foil, manual removal, sod cutting and hot water treatment are not suitable for elimination but are suitable for reduction of stonecrop biomass. Stonecrop almost always manages to recover to equally vigorous growth within one or several years. Such measures do temporarily reduce the risk of spread, but, as a rule, must be repeated multiple times a year. If natural values are threatened, then periodical control of stonecrop makes less sense. In such cases, it would be better to focus on stabilising the contamination at a low level using system-based control (see section 10.2.4).

12.3.5 Additional measures to tackle contamination

Exclusion from routine management
It is vital that any areas contaminated with stonecrop should be excluded from routine management. Further activities that cause exposed soil on the site must be limited as much as possible where stonecrop is present. Examples of such activities include sod cutting, remediation/reprofiling of water bodies and other forms of earthworks. Routine management practices of surrounding, unaffected areas may continue to take place if there is limited disturbance of the soil.

Isolation of known contaminations
Where stonecrop is able to spread to other waters through water, it is critical that appropriate measures are taken. Depending on the nature of the connections, locks may be diverted and structures can be made impenetrable to stonecrop.

Preventing unnecessary disturbance and spread
Where competing native species are abundant and there are no sources of eutrophication from which the species can benefit, it is vital that the disturbance of systems should be avoided as much as possible, particularly in the vicinity of a known area of contamination (up to 1 km). This means that any excavation work, such as for infrastructure purposes and the development of new natural resources, should be avoided where possible in the vicinity of a contamination. This will prevent the spread and establishment of stonecrop. If the disturbance of the existing vegetation is necessary, resulting in a large area of bare soil becoming exposed, it is essential that measures be put in place to allow the vegetation to recover rapidly.

Hygienic practices
The risk of spread by humans and their equipment can be reduced through effective inspection of footwear and equipment after accessing contaminated areas and removal of any plant fragments. Larger machinery such as cranes will have to be sprayed down with a high-pressure cleaner. It is critical that any large machinery that is used in affected or contaminated areas is not used in non-contaminated humid areas. When hiring equipment or hiring contractors with their own equipment, it is vital that parties are aware in advance of any prior contact of that machine with stonecrop. If this is the case, or in case of doubt, the machine must first be cleaned.

The material, i.e. soil and plant material, that is released when removing the biomass must be handled with care. The contaminated soil should not be used in the vicinity of water bodies, such as for the construction of dykes. Access to contaminated areas by recreational and other visitors must be minimised in order to prevent any spread. To that end, contaminated areas can be sectioned off and made inaccessible to the general public.

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Annex 1. Sources consulted to carry out the literature review and to determine the distribution of stonecrop.

Literature review search results

Search engine	Search	Terms for Chapter 3 - Species description	Date	Hits	Viewed hits	New downloads	Unavailable
Google	Using all key words	*Stonecrop*	24 March 2020	497	30	3	1
	With at least 1 of the key words	Ecologie, habitat, ecosysteem, eisen, standplaats, toleranties					
Google Scholar	Using all key words	*Crassula helmsii*	24 March 2020	1,210	30	2	0
	With at least 1 of the key words	Ecology, habitat, ecosystem, demands, stand, tolerances					
Web of Science	Using all key words	*Crassula helmsii* ecology, habitat, ecosystem, demands, stand, tolerances	24 March 2020	4	4	1	0
Total				1711	64	6	1

Search engine	Search	Terms for Chapter 7 - Impacts	Date	Hits	Viewed hits	New downloads	Unavailable
Google	Using all key words	*Stonecrop*	30 March 2020	463	30	5	0
	With at least 1 of the key words	Impact, effecten, problemen, schade, invasief, risicoanalyses, ecosysteemdiensten					
Google Scholar	Using all key words	*Crassula helmsii*	30 March 2020	707	30	8	0
	With at least 1 of the key words	Impacts, effects, problems, damage, invasive, risk assessments, ecosystem services					
Web of Science	Using all key words	*Crassula helmsii* impacts, effects, problems, damage, invasive, risk assessments, ecosystem services	30 March 2020	3	3	0	0
Total				1173	63	13	0

Search engine	Search	Terms for Chapter 10 - Management	Date	Hits	Viewed hits	New downloads	Unavailable
Google	Using all key words	*Stonecrop*	6 April 2020	382	30	5	0
	With at least 1 of the key words	management, controle, bestrijding, beheersing, elimineren, terugdringen, behandeling, methode					
Google Scholar	Using all key words	*Crassula helmsii*	6 April 2020	49	30	5	0
	With at least 1 of the key words	Management, control, combat, fighting, eradication, reducing, treatment, method					
Web of Science	Using all key words	*Crassula helmsii* management, control, combat, fighting, eradication, reducing, treatment, method	6 April 2020	5	5	0	0
Total				436	65	10	0

Search engine	Search	Terms for Chapter 11 - Useful properties	Date	Hits	Viewed hits	New downloads	Unavailable
Google	Using all key words	*Stonecrop*	4 May 2020	1,320	30	0	0
	With at least 1 of the key words	verkoop, toepassing, gebruik, baten					
Google Scholar	Using all key words	*Crassula helmsii*	4 May 2020	190	30	1	0
	With at least 1 of the key words	Sale, application, use, benefit					
Web of Science	Using all key words	*Crassula helmsii* sale, application, use, benefit	4 May 2020	1	1	0	0
Total				1511	61	1	0

Search results for stonecrop distribution

GBIF	https://www.gbif.org/occurrence/map?basis_of_record=HUMAN_OBSERVATION&basis_of_record=OBSERVATION&basis_of_record=LIVING_SPECIMEN&basis_of_record=PRESERVED_SPECIMEN&taxon_key=8035075
GISD	http://www.iucngisd.org/gisd/speciesname/Crassula+helmsii
CABI	https://www.cabi.org/isc/datasheet/16463
EPPO	https://gd.eppo.int/taxon/CSBHE
EPPO	https://pra.eppo.int/pra/e29aebca-b5f8-480d-b298-8600b9dea5b0
iNaturalist	https://www.inaturalist.org/observations?place_id=any&taxon_id=199392
Belgium	https://ias.biodiversity.be/species/show/50
Bulgaria	http://eea.government.bg/bg/bio/nsmbr/inf-system
Denmark	https://mst.dk/natur-vand/natur/artsleksikon/froeplanter/new-zealandsk-korsarve/
Denmark	https://naturstyrelsen.dk/media/nst/66891/HandlingsplanForInvasiveArter.pdf
Denmark	https://mst.dk/media/173895/revideret_liste_ikkehjemmehoerendearter_19-03-2019.xls
Germany	http://floraweb.de/webkarten/karte.html?taxnr=6731
Germany	http://www.blumeninschwaben.de/Zweikeimblaettrige/Dickblattgewaechse/crassu_wasser.htm#Helms%20Dickblatt
Germany	http://www.lanaplan.de/download/DGL2008VDWHU.pdf
Germany	http://www.ufz.de/biolflor/taxonomie/taxonomie.jsp?ID_Taxonomie=879
Germany	https://neobiota.bfn.de/handbuch/gefaesspflanzen/crassula-helmsii.html
Germany	https://neobiota.bfn.de/publikationen.html
Germany	https://www.bfn.de/fileadmin/BfN/daten_fakten/Dokumente/II_1_2_18_Natrschutzfachl_Invasivitaetsbew_Pflanzen.pdf
Germany	https://www.bfn.de/fileadmin/BfN/service/Dokumente/skripten/skript401.pdf
Germany	https://www.lv-wli.de/files/pdf/Fachbereiche/Bienenweide/skript352%20BfN.pdf
Estonia	https://ec.europa.eu/growth/tools-databases/tris/de/index.cfm/search/?trisaction=search.detail&year=2018&num=275&dLang=DE
Estonia	https://elurikkus.ee/plant-atlas/taxon
Estonia	https://www.envir.ee/et/voorliigid
Estonia	https://www.envir.ee/sites/default/files/common_alien_vasculars.pdf
Estonia	https://www.riigiteataja.ee/akt/12828512
Finland	http://koivu.luomus.fi/kasviatlas/
France	http://www.gt-ibma.eu/wp-content/uploads/2018/01/dortel_dutartre_2017_crassule_de_helms_synthese_vf.pdf
France	https://www.codeplantesenvahissantes.fr/fileadmin/user_upload/Crassula_helmssi.pdf
Greece	https://elnais.hcmr.gr/wp-content/uploads/2015/01/Arianoutsou-Bazos-Delipetrou-Kokkoris-2010.pdf
Hungary	http://mek.oszk.hu/11700/11738/11738.pdf
Hungary	http://www.termeszetvedelem.hu/invasive-alien-species
Ireland	https://invasivespeciesireland.com/species-accounts/established/freshwater/new-zealand-pigmyweed
Ireland	https://maps.biodiversityireland.ie/Species/29777
Italy	http://luirig.altervista.org/flora/taxa/index1.php?scientific-name=crassula+helmsii
Italy	https://ambiente.regione.emilia-romagna.it/it/parchi-natura2000/consultazione/dati/download/elenco-delle-specie-vegetali-dinteresse-conservazionistico-in-emilia-romagna/@@download/file/EleSpTargetRER.pdf
Italy	http://www.parcobarro.lombardia.it/_lr10/index.php?title=Lista_nera_delle_specie_alloctone_vegetali_oggetto_di_monitoraggio,_contenimento_o_eradicazione
Croatia	http://www.invazivnevrste.hr/
Latvia	http://www.videsvestis.lv/svesie-ienaceji-latvijas-flora/
Latvia	https://core.ac.uk/download/pdf/71754942.pdf
Latvia	https://lvportals.lv/skaidrojumi/250966-invazivie-augi-un-to-bistamiba-2012
Latvia	https://www.daba.gov.lv/public/lat/dabas_aizsardzibas_plani/dati1/invazivas_sugas/
Lithuania	https://am.lrv.lt/lt/veiklos-sritys-1/gamtos-apsauga/invazines-rusys/invaziniu-lietuvoje-rusiu-sarasas
Lithuania	https://am.lrv.lt/uploads/am/documents/files/Gamtos%20apsauga%20ir%20mi%C5%A1kai/Gamtos%20apsauga/Invazin%C4%97s%20r%C5%AB%C5%A1ys/invazini%C5%B3%20lietuvoje%20r%C5%AB%C5%A1i%C5%B3%20s%C4%85ra%C5%A1o%20patvirtinimo.pdf
Lithuania	https://gamtininkas.lt/2017/07/lietuvos-invaziniai-augalai/
Lithuania	https://www.glis.lt/?pid=59
Luxembourg	https://neobiota.lu/crassula-helmsii/
Luxembourg	https://neobiota.lu/crassula-helmsii/
Luxembourg	https://mdata.mnhn.lu/
Northern Ireland	http://www.habitas.org.uk/invasive/species.asp?item=4639
Norway	https://www.artsdatabanken.no/fremmedearter
Norway	https://www.bergen.kommune.no/bk/multimedia/archive/00226/Fremmede_arter_i_No_226834a.pdf
Norway	https://www.biodiversity.no/alien-species-2018
Norway	https://www.nhm.uio.no/fakta/botanikk/nyheter/invaderende-vannplanter-foreslas-satt-pa-forbudsli.html
Ukraine	http://www.ukrbin.com/index.php?id=303041&action=info
Austria	https://www.umweltbundesamt.at/fileadmin/site/publikationen/DP089.pdf
Poland	http://projekty.gdos.gov.pl/files/artykuly/127051/Crassula-helmsii_grubosz-helmsa_KG_WWW_icon.pdf
Poland	http://projekty.gdos.gov.pl/igo-crassula-helmsii

Poland	https://www.gdos.gov.pl/files/artykuly/5050/PROPOZYCJA_listy_gatunkow_obcych_ver_online.pdf
Portugal	http://invasoras.pt/en/
Portugal	http://invasoras.pt/wp-content/uploads/2013/09/Species-listed-DL.pdf
Portugal	https://flora-on.pt/#/1crassula
Romania	http://www.uaiasi.ro/CNCSIS/Plante_adventive/files/e1%20specii%20invazive%20in%20Romania.pdf
Romania	http://www.uaiasi.ro/CNCSIS/Plante_adventive/files/e2%20specii%20invazive%20in%20Romania.pdf
Romania	http://www.uaiasi.ro/CNCSIS/Plante_adventive/files/f%20specii%20adv%20noi%20in%20flora%20Romaniei.pdf
Romania	http://www.uaiasi.ro/CNCSIS/Plante_adventive/files/Sinteza_rezultatelor_2011.pdf
Romania	http://www.uaiasi.ro/CNCSIS/Plante_adventive/files/Studiu_bibliografic_asupra_plantelor_adventive_din_Moldova.pdf
Russia	http://biodat.ru/db/intro/plant_e.htm
Russia	https://www.aqvium.ru/vidy-rastenij/stvolovye-rasteniya/tolstyanka-helmsa
Serbia	http://iasv.dbe.pmf.uns.ac.rs/index.php?strana=baza
Slovenia	
Slovakia	http://maps.sopsr.sk/mapy/invazky/map.html
Slovakia	http://www.sopsr.sk/invazne-web/
Slovakia	https://pdfs.semanticscholar.org/1e51/1073b839d3c6b50311bcb17cebb6366d89d6.pdf
Spain	https://w3.ual.es/personal/edana/alienplants/checklist.pdf
Spain	https://www.aragon.es/documents/20127/674325/capdevilla.pdf/5947bd6b-f619-23d1-54a7-2d36104b5127
Spain	https://www.aragon.es/documents/20127/674325/FLORA_ACUATICA.pdf/64be8895-3842-daa1-4b2b-d99d0ae530a5
Spain	https://www.aragon.es/documents/20127/674325/LIBRO_ESPECIES_EXOTICAS_INVASORAS.pdf/8550acea-2684-21e9-f37c-b989713eac7e
Spain	https://www.mapa.gob.es/es/pesca/temas/acuicultura/RD_630_2013_Catalogo_spp_exoticas_invasoras_tcm30-77362.pdf
Spain	https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/Crassula_helmsii_2013_tcm30-69822.pdf
Spain	https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/crassulahelmsiikirkcockayne_tcm30-439570.pdf
Spain	https://www.miteco.gob.es/es/ceneam/grupos-de-trabajo-y-seminarios/red-parques-nacionales/Plan%20de%20control%20y%20eliminaci%C3%B3n%20de%20especies%20vegetales%20invasoras%20dunas_tcm30-169318.pdf
Czech Republic	http://invaznidruhy.nature.cz/caste-invazni-druhy-v-cr/
Czech Republic	http://invaznidruhy.nature.cz/caste-invazni-druhy-v-cr/invazni-rostliny/
Czech Republic	http://invaznidruhy.nature.cz/legislativa/narodni/zakon-c-326-2004-sb/
Czech Republic	http://invaznidruhy.nature.cz/res/archive/156/020384.pdf?seek=1395304558
Czech Republic	http://www.ibot.cas.cz/invasions/pdf/Pergl%20et%20al.-Black,%20Grey%20and%20Watch%20Lists%20of%20alien%20species%20in%20the%20Czech%20Republic_NeoBiota2016.pdf
Czech Republic	http://www.preslia.cz/P122Pysek.pdf
Czech Republic	https://portal.nature.cz/kartydruhu/
United Kingdom	http://www.nonnativespecies.org
United Kingdom	http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=1017
United Kingdom	https://www.brc.ac.uk/plantatlas/plant/crassula-helmsii
Sweden	https://www.artportalen.se/
Sweden	https://www.havochvatten.se/hav/fiske--fritid/arter/arter-och-naturtyper/sydfyrling-vattenkrassula.html
Switzerland	https://www.admin.ch/opc/de/classified-compilation/20062651/index.html
Switzerland	https://www.admin.ch/opc/de/classified-compilation/20062651/index.html#app2ahref2
Switzerland	https://www.efbs.admin.ch/inhalte/dokumentation/Publikationen/Broschuere_Invasive_Pflanzen.pdf
Switzerland	https://www.infoflora.ch/de/assets/content/documents/neophyten/inva_cras_hel_d.pdf
Switzerland	https://www.infoflora.ch/de/assets/content/documents/neophyten/neophyten_diverses/Schwarze%20Liste_Watch%20Liste_2014.pdf
Switzerland	https://www.infoflora.ch/de/flora/crassula-helmsii.html#info
Canada	http://www.natureconservancy.ca/en/what-we-do/resource-centre/invasive-species/
Canada	https://www.inspection.gc.ca/plant-health/plant-pests-invasive-species/invasive-plants/fact-sheets/eng/1331614724083/1331614823132
Canada	https://www.inspection.gc.ca/plant-health/plant-pests-invasive-species/invasive-plants/eng/1306601411551/1306601522570
USA	https://www.fws.gov/fisheries/ANS/erss/highrisk/ERSS-Crassula-helmsii-FINAL.pdf
South Africa	https://www.inaturalist.org/observations/11287010

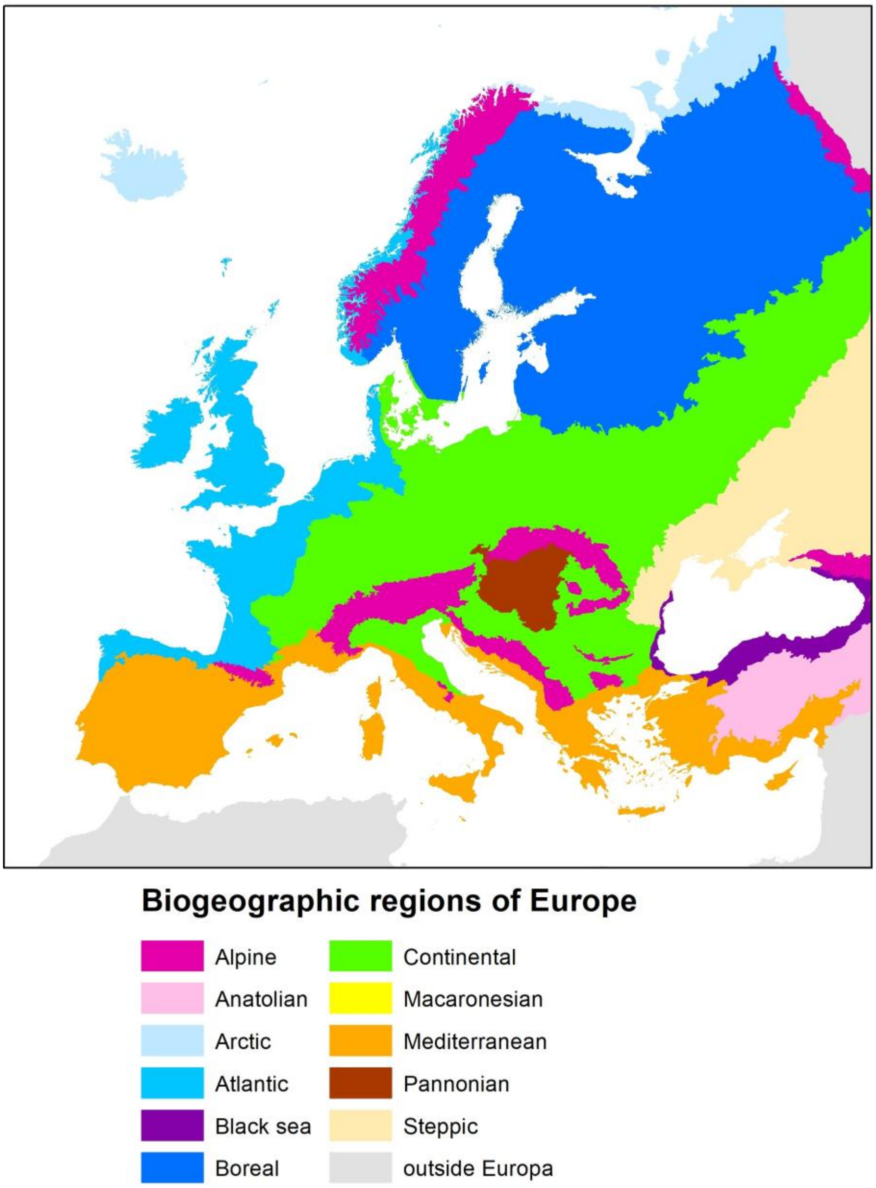
Australia	https://bie.ala.org.au/species/https://id.biodiversity.org.au/node/apni/2902057
New Zealand	http://www.nzflora.info/factsheet/Taxon/Crassula-helmsii.html
New Zealand	http://www.nzpcn.org.nz/flora_details.aspx?ID=248
New Zealand	http://www.nzpcn.org.nz/plant_distribution_results.aspx?Species_Name=Crassula+helmsii

Annex 2. Plant communities in which stonecrop was found in the Netherlands.

syntaxon	number of studies
1 Lemnetea minoris class	
1RG02 Basal community Lemna trisulca-[Lemnion trisulcae]	1
4 Charetea fragilis class	
4BB CHARION VULGARIS	
4BB01 Charetum vulgaris	1
4CA CHARION CANESCENTIS	
4CA01 Charetum canescentis	1
5 Potametea class	
5BA NYMPHAEION	
5BA04 Potameto-Nymphoidetum	1
5BB HYDROCHARITION MORSUS_RANAE	
5BB01 Stratiotetum	2
5BC PARVOPOTAMION	
5BC01 Potametum berchtoldii	1
5CA RANUNCULION PELTATI	
5CA03 Callitricho-Myriophylletum alterniflori	1
5CA04 Callitricho hamulatae-Ranunculetum fluitantis	1
5RG01 Basal community Myriophyllum spicatum-[Potametea]	*2*
5RG04 Basal community Ceratophyllum demersum-[Nupharo-Potametalia]	*1*
5RG08 Basal community Callitriche platycarpa-[Callitricho-Potametalia]	*1*
6 Littorellettea class	
6AA LITTORELLION UNIFLORAE	
6AA01A Isoeto-Lobelietum isoetetosum	3
6AC HYDROCOTYLO-BALDELLION	
6AC01 Pilularietum globuliferae	8
6AC02 Scirpetum fluitantis	4
6AC03 Eleocharitetum multicaulis	3
6AD ELEOCHARITION ACICULARIS	
6AD01 Littorello-Eleocharitetum acicularis	14
8 Phragmitetea class	
8AA SPARGANIO-GLYCERION	
8AA01 Eleocharito palustris-Hippuridetum	1
8AB OENANTHION AQUATCAE	
8AB02 Sagittario-Sparganietum	3
8BB PHRAGMITION AUSTRALIS	
8BB01B Scirpetum lacustris rumicetosum	1
8BB04A Typho-Phragmitetum typhetosum angustifoliae	2
8BB04B Typho-Phragmitetum calthetosum	1
8BB04C Typho-Phragmitetum typicum	3
9 Parvocaricetea class	
9RG02 Basal community Carex nigra-Agrostis canina-[Caricion nigrae]	1
16 Molinio-Arrhenatheretea class	
16AB CALTHION PALUSTRIS	
16AB01 Crepido-Juncetum acutiflori	2
16RG04 Basal community Juncus effusus-[Molinietalia/Lolio-Potentillion]	*4*
19 Nardetea class	
19AA NARDO-GALION SAXATILIS	
19AA02 Gentiano pneumonanthes-Nardetum	1
26 Asteretea tripolii class	
26RG02 Basal community Agrostis stolonifera-Glaux maritima-[Asteretea tripolii]	1
28 Isoëto-nanojuncetea class	
28AA NANOCYPERION FLAVESCENTIS	
28AA01A Cicendietum filiformis centunculetosum	3
28AA01B Cicendietum filiformis juncetosum	20
28AA02B Isolepido-Stellarietum cardaminetosum	1
28AA04A Digitario-Illecebretum digitarietosum	2

28AA04B Digitario-Illecebretum peplidetosum	2
29 Bidentetea tripartie class	
29AA BIDENTION TRIPARTITAE	
29AA01 Polygono-Bidentetum	4
29AA02A Rumicetum maritimi typicum	1
29AA02B Rumicetum maritimi chenopodietosum	1
29AA03A Chenopodietum rubri spergularietosum	1
29AA04 Eleocharito acicularis-Limoselletum	12
32 Concolculo-Filipenduletea class	
32RG07 Basal community Pulicaria dysenterica	1
36 Franguletea class	
36AA SALICION CINEREAE	
36AA02A Salicetum cinereae calamagrostietosum canescentis	1
36AA02B Salicetum cinereae typicum	1

Annex 3a. Biogeographic regions of Europe (map).



Annex 3b. Biogeographic regions of Europe (table).

Distribution of stonecrop within Europe. xxx: widespread; xx: localised spread; x: few isolated stands; ?: species may be able to establish in (parts of) the country in future. The area (%) of a specific region has been listed for each country.

Europe EU		Alpine	Anatolian	Arctic	Atlantic	BlackSea	Boreal	Continental	Macaronesia	Mediterranean	Pannonian	Steppic	Outside
Belgium	xxx				61			39					
Bulgaria	?	16				7		78		0		0	
Cyprus										100			
Denmark	x				31			69					
Germany	xx	1			20			79					
Estonia							100						
Finland		5					95						
France	xx	6			49			34		12			
Greece		0						0		100			
Hungary		0						0			100		
Ireland	xx				100								
Italy	?	17						29		54			
Croatia		15						55		30	0		
Latvia							100						
Lithuania							100	0					
Luxembourg	x							100					
Malta										100			
Netherlands	xxx				100			0					
Austria	x	63						37			0		
Poland		3					0	97					
Portugal	?				5				3	91			
Romania		21				2		56			6	16	
Slovenia	?	38						62		0	0		
Slovakia		71						0			29		
Spain	x	2			11				1	86			0
Czech Republic		0						96			4		
Sweden	?	19					77	4					
Europe non-EU													
Norway	?	59		1	23		17						
Russia		2		4		0	18	7				8	62
Serbia	?	5						70			25		
Switzerland		59						41					
North Macedonia		47						53		0			
Ukraine		4				0		54			0	41	
United Kingdom	xxx				100								
Liechtenstein		100											

Annex 4: Natura 2000 sites in the Netherlands in which stonecrop has been found, with the number of infections, based upon data in the National Database Flora and Fauna (NDFF).

Province	Natura 2000 area	Number of sites in NDFF
Drenthe	Dwingelderveld	1
Friesland	Duinen Ameland	1
	Duinen Terschelling	6
	IJsselmeer	26
Gelderland	De Bruuk	1
	Korenburgerveen	180
	Landgoederen Brummen	256
	Veluwe	51
Groningen	Leekstermeergebied	1
Limburg	Geuldal	6
	Groote Peel	1
	Maasduinen	26
	Sarsven en De Banen	3
	Weerter- en Budelerbergen & Ringselven	1
North Brabant	Brabantse Wal	63
	Kampina & Oisterwijkse Vennen	3
	Kempenland-West	192
	Krammer-Volkerak	76
	Langstraat	19
	Leenderbos, Groote Heide & De Plateaux	407
	Loonse en Drunense Duinen & Leemkuilen	64
	Regte Heide & Riels Laag	1
	Vlijmens Ven, Moerputten & Bossche Broek	10
North Holland	IJsselmeer	5
	Kennemerland-Zuid	1
	Naardermeer	6
	Noordhollands Duinreservaat	7
Overijssel	Aamsveen	1
	Achter de Voort, Agelerbroek & Voltherbroek	6
	Landgoederen Oldenzaal	6
	Rijntakken	4
Utrecht	Oostelijke Vechtplassen	2
Zeeland	Grevelingen	2
	Groote Gat	1
	Kop van Schouwen	175
	Krammer-Volkerak	27
	Manteling van Walcheren	11
	Oosterschelde	2
South Holland	Duinen Goeree & Kwade Hoek	7
	Krammer-Volkerak	74
	Meijendel & Berkheide	4
	Nieuwkoopse Plassen & De Haeck	1
	Voornes Duin	17

Annex 5. Overview of Ecosystem Services (BISE 2020).

Section	Division	Group	Class
Provisioning	Nutrition	Biomass	Cultivated crops
			Reared animals and their outputs
			Wild plants, algae and their outputs
			Wild animals and their outputs
			Plants and algae from *in-situ* aquaculture
			Animals from *in-situ* aquaculture
		Water	Surface water for drinking
			Ground water for drinking
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing
			Materials from plants, algae and animals for agricultural use
			Genetic materials from all biota
		Water	Surface water for non-drinking purposes
			Ground water for non-drinking purposes
	Energy	Biomass-based energy sources	Plant-based resources
		Mechanical energy	Animal-based resources
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals
			Bio-chemical detoxification / decomposition / mineralisation in land / soil, freshwater and marine systems including sediments; decomposition / detoxification of waste and toxic materials (phyto)degradation, (rhizo)degradation.
		Mediation by ecosystems	Filtration/
			sequestration/
			storage/accumulation by ecosystems
			Dilution by atmosphere, freshwater and marine ecosystems
			Mediation of smell/noise/visual impacts
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates
			Buffering and attenuation of mass flows
		Liquid flows	Hydrological cycle and water flow maintenance
			Flood protection
		Gaseous / air flows	Storm protection
			Ventilation and transpiration
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance,	Pollination and seed dispersal
			Maintaining nursery populations and habitats
		Pest and disease control	Pest control
			Disease control
		Soil formation and composition	Weathering processes
			Decomposition and fixing processes
		Water conditions	Chemical condition of freshwaters
			Chemical condition of salt waters
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations
			Micro and regional climate regulation
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings
			Physical use of land-/seascapes in different environmental settings
		Intellectual and representational interactions	Scientific
			Educational
			Heritage, cultural
			Entertainment
			Aesthetic
	Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic
			Sacred and/or religious
		Other cultural outputs	Existence
			Bequest

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