

Technical advice on: Macroalga *Asparagopsis taxiformis* Lineage 2 detected in Iris Shoal, Kawau Island, and Whangārei Harbour.

Date: 4 December 2024

Purpose of document

On 18 August 2024, Biosecurity Surveillance & Incursion Investigation requested a rapid risk assessment of the macroalga *Asparagopsis taxiformis* Lineage 2 to inform response decision making and brief the Minister for Biosecurity. Given current efforts to manage exotic *Caulerpa* in New Zealand, a comparison of *A. taxiformis* Lineage 2 with *Caulerpa* was also requested to inform potential management options.

Summary of advice

Asparagopsis taxiformis Lineage 2 (L2) was recently identified at two sites in Northland. Given the distance between the two locations (~ 75 km), it cannot be assumed that this introduction is recent. *Asparagopsis taxiformis* L2 is very similar in appearance to the widespread New Zealand native *Asparagopsis armata*, and molecular techniques are often required to distinguish between the species.

Asparagopsis is generally accepted to have multiple species (including *A. armata* and *A. taxiformis*), but there is still uncertainty about how many distinct forms of *Asparagopsis* there are. Each species is currently divided into lineages based on genetic differences:

- *Asparagopsis armata* lineages L1B and L2B, and *A. taxiformis* L5 are native to New Zealand.
- *Asparagopsis armata* L1A and *A. taxiformis* L2 are native to Australia and the Indo-Pacific, respectively; both have been introduced to the Mediterranean Sea where they are considered invasive (have spread and negatively impacted local marine ecosystems).

Both *A. armata* and *A. taxiformis* demonstrate invasive behaviour in locations where *Asparagopsis* is not native, and their introduction has affected local biodiversity. It is less clear what the impacts will be for introduction of a new lineage in areas where other *Asparagopsis* species or lineages are native (such as in New Zealand waters). The farming of *A. armata* is being trialled as a methane-reducing livestock supplement. This could be impacted if *A. taxiformis* L2 establishment alters the distribution and abundance of *A. armata*. However, *A. taxiformis* L2 also has potential as a methane-reducing livestock supplement, and an aquaculture nutritional supplement for finfish (including salmon). *Asparagopsis taxiformis* L2 has the potential to establish throughout the coastline of the North Island. The alga may establish in the South Island but is unlikely to reach high densities.

National or local eradication or suppression of L2 is not feasible with currently available methods and technology. *Asparagopsis taxiformis* L2 can reproduce sexually as well as via fragmentation, making it very difficult to remove or treat effectively. Eradication and suppression of *Asparagopsis* has never been attempted in other areas of the world, probably for similar reasons.

The main pathways for domestic spread are natural dispersal via currents and entanglement in boating equipment. Using **pathway management** options (such as Controlled Area Notices, rāhui, awareness campaigns, etc.) to limit dispersal via boating equipment can slow spread over longer distances. This over-arching approach reduces the long distance spread of marine pests in general and is consistent with the fundamental biosecurity messaging of the exotic *Caulerpa* response. However, because we do not know the current distribution for *A. taxiformis* in New Zealand waters it would be difficult to effectively identify appropriate pathway management options without first undertaking a **monitoring and surveillance programme to gather more information**.

Supporting information

1. Taxonomy

Asparagopsis taxiformis (Delile) Trevisan 1845

Kingdom: Plantae

Division: Rhodophyta

Class: Florideophyceae

Order: Bonnemaisoniales

Family: Bonnemaisoniaceae

Synonym: *Asparagopsis delilei*, *Dasya delilei*, *Asparagopsis sanfordiana*, *Polysiphonia hillebrandii*, *Falkenbergia hillebrandii*, *Polysiphonia patentifurcata*.

Common name: red sea plume, limu kohu, supreme limu.

The taxonomy of *Asparagopsis* is complicated and not finalised (Zanolla et al. 2022). *Asparagopsis taxiformis* is considered a species complex with six lineages (referred to as L1–L6 hereafter), which look almost identical to each other but are genetically distinct (Zanolla et al. 2022). Taxonomic diversity is likely a result of differences in distribution (Zanolla et al. 2022). There is debate as to whether the lineages are genetic variants or independent isolated entities (Zanolla et al. 2022). Whilst the lineages are genetically distinct, there is also genetic diversity within lineages based on native and introduced ranges (Zanolla et al. 2022). For example, L2 in Japan is genetically distinct from L2 in Hawaii (Zanolla et al. 2022).

2. Geographic distribution

Asparagopsis taxiformis is a widely distributed tropical and subtropical marine red alga (Fig. 1a, 1b). The distribution of L2—the lineage detected in mainland New Zealand—encompasses the Indo-Pacific region, including South Africa, Taiwan, Japan, and the Hawaiian Islands (Dijoux et al. 2014, Zanolla et al. 2022). *Asparagopsis taxiformis* L2 is also present in Lord Howe Island, Australia (presumed a recent introduction; Andreakis et al., 2016), and the western Mediterranean Sea (Fig. 5), where it is considered invasive (Zanolla et al. 2022; Navarro-Barranco et al. 2018). In New Zealand, L5 is native and restricted to Rangitāhua/Kermadec Islands (Adams 1994, Nelson 2020).

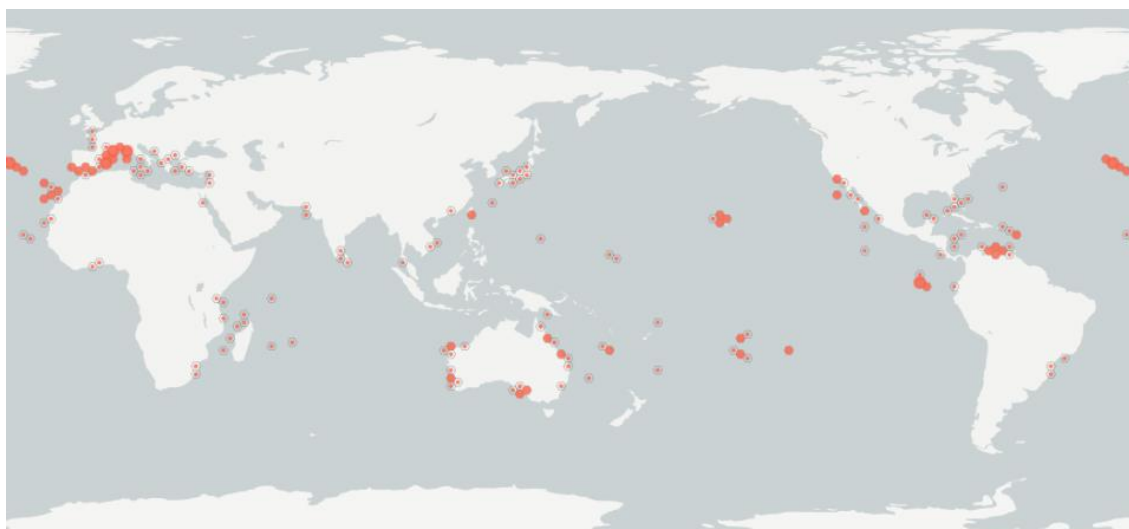


Figure 1a. Tropical and subtropical distribution of *Asparagopsis taxiformis* based on 2716 georeferenced records (observations, living specimens, occurrences). Accessed via Global Biodiversity Information Facility (GBIF Secretariat 2023).

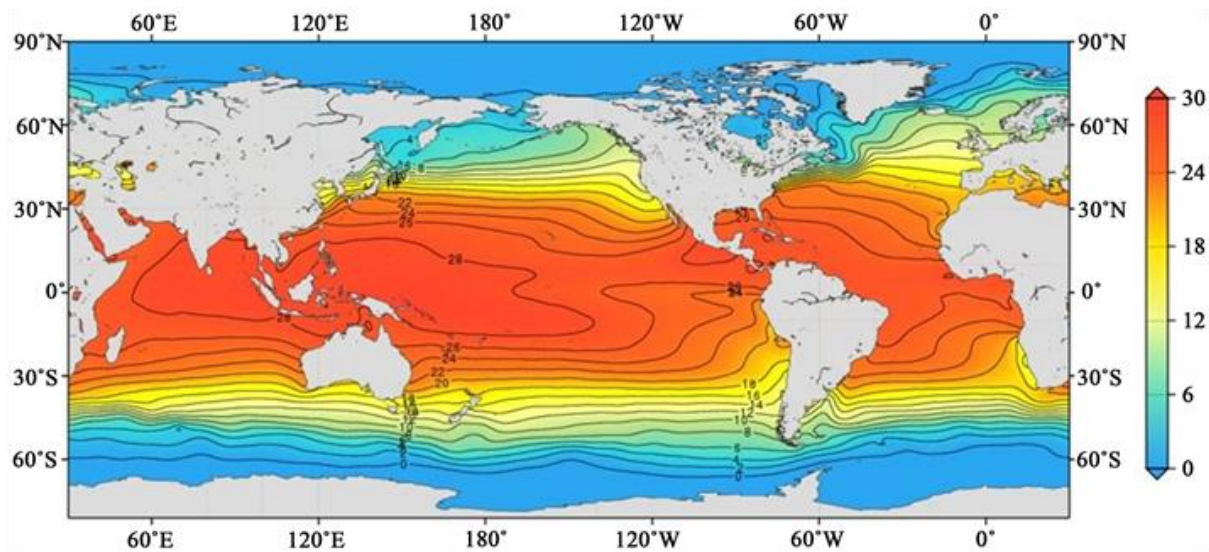


Figure 1b. Distribution of the annual sea surface temperature in °C (one-degree grid), World Ocean Atlas climatology (decadal average 1955-2017; Reagan et al. 2024).

3. Biology and ecology

3.1 Morphology, reproduction and growth

Asparagopsis taxiformis can reproduce sexually as well as vegetatively (via rhizomes and fragmentation). The life cycle involves two macroscopic forms: a stalked, branching gametophyte (fronds and rhizomes) and a filamentous, pompom-like tetrasporophyte (filaments) (Fig. 2). The haploid gametophyte can reproduce asexually via frond fragments regenerating into new individuals (Zanolla et al. 2022). The gametophyte can also reproduce vegetatively via new shoots growing from rhizomes (Zanolla et al. 2022). The diploid tetrasporophyte can reproduce vegetatively via pompom-like filaments separating from original tissue (Zanolla et al. 2022). The presence of both macroscopic life stages is likely nutrient and/or light dependant, indicated by the presence of gametophytes in the Mediterranean Sea all year, and tetrasporophytes only in spring and summer (Zanolla et al. 2018). A similar pattern was observed in New Zealand, with an absence of tetrasporophytes being sampled in winter, compared with multiple gametophyte samples (Biosecurity New Zealand 2024a).

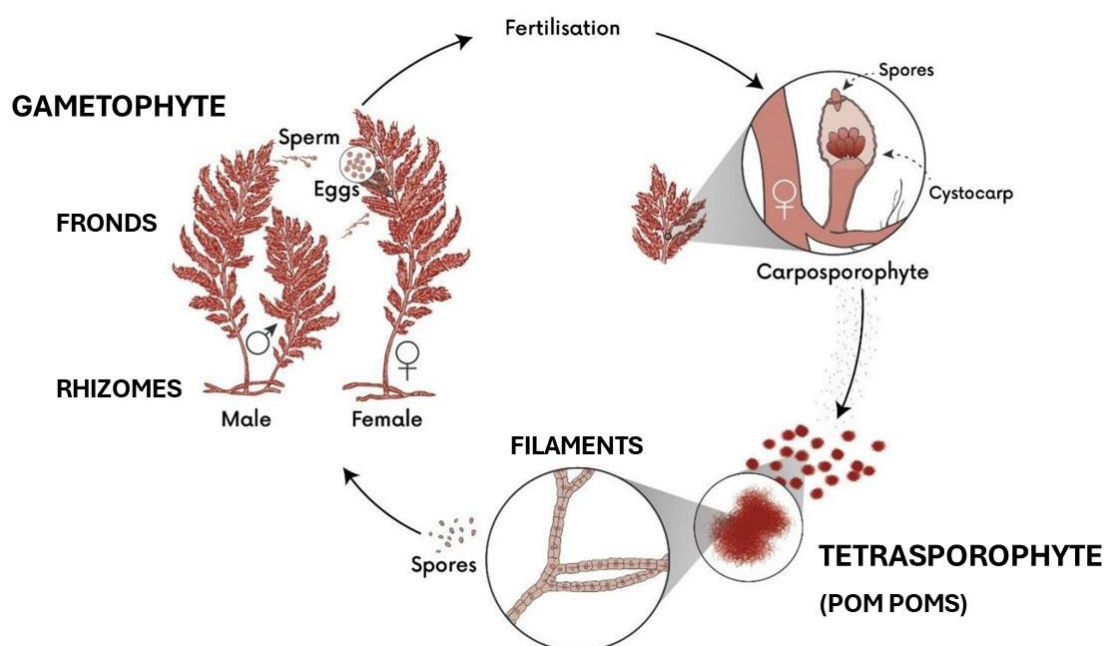


Figure 2. Life cycle of *Asparagopsis* spp. showing the two morphologically distinct life stages, the plant-like gametophyte and the pom-pom-like tetrasporophyte. Adapted from Wheeler et al. 2021.

3.2 Morphological differences between *A. taxiformis* L2 and *Asparagopsis* species native to New Zealand

The capacity to rapidly differentiate between L2 and native New Zealand *Asparagopsis* is crucial for considering whether eradication or suppression could be attempted. The gametophytes of *A. taxiformis* and *A. armata* can be somewhat differentiated visually (Appendix: Fig. S1). However, the other life stages cannot be distinguished without using microscopy or molecular techniques. The tetrasporophytes of both *Asparagopsis* species also look very similar to other native red algae.

3.2.1 Native *A. armata* – *Asparagopsis armata* is considered a species complex, with the genetically distinct L1B and L2B lineages present in New Zealand (Preuss et al. 2022). Whilst the literature typically states *A. armata* gametophytes feature characteristic harpoon-like lateral branches, which *A. taxiformis* lacks (Ní Chualáin et al. 2004, Zanolla et al. 2019, Guiry 2024), this characteristic is not always well developed in New Zealand lineages (D’Archino pers. comm.). Consequently, the harpoon-like lateral branches should not be used as the sole distinguishable characteristic for New Zealand *A. armata* lineages. Another distinguishable characteristic observed by Ní Chualáin et al. (2004) was *A. armata* gametophytes have ‘feathery branching’ compared to ‘closer spaced laterals’ of *A. taxiformis*. The tetrasporophytes of *A. armata* and *A. taxiformis* are morphologically similar but not identical at a cellular level (Zanolla et al. 2019). See Appendix Figure S1 for visual comparison of the two species.

3.2.2 Native *A. taxiformis* L5 – The six *A. taxiformis* lineages are considered morphologically cryptic but genetically distinct (Zanolla et al. 2019). However, Zanolla et al. (2019) identified ‘significant’ morphological differences between lineages which could be helpful in microscopic examination. The authors found the width of the apical cell, thickness of the cell wall, and width and length of the axial cell were diagnostic

characters to distinguish tetrasporophytes. However, the authors did not include examination of L5, thus morphological examination of L5 tetrasporophytes would need to be commissioned.

3.3 Habitat

Asparagopsis taxiformis L2 commonly occurs in coastlines on rocky substrates or as epiphytes (Zanolla et al. 2019). Introduced L2 in the Mediterranean Sea has established in temperate subtidal rocky shorelines (Fig. 5). In New Zealand, L2 was observed at 11 m depth growing on scallops, shell gravels and pebbles (Biosecurity New Zealand 2024a, NIWA 2024).

3.4 Invasiveness

Asparagopsis taxiformis L2 can form large, dense stands (Zanolla et al. 2017b), though not of the scale seen in New Zealand of exotic *Caulerpa* (Biosecurity New Zealand 2022). The L2 lineage exhibits morphological and physiological plasticity (e.g., photosynthesis occurs within a wide temperature range), which is thought to support colonisation, establishment, and fitness in introduced areas (Zanolla et al. 2014). *Asparagopsis taxiformis* L2 introduction can reduce the biomass of native macroalgal communities, as well as the abundance and richness of invertebrates that live on macroalgal surfaces (Mancuso et al. 2021, Mancuso et al. 2022, Mancuso et al. 2023; Navarro-Barranco et al. 2018; Zanolla et al. 2022).

3.5 Environmental tolerances

3.5.1 Temperature

Under laboratory conditions, the temperature tolerance of L2 ranges between 9 and 31 °C, growth occurs above 10 °C, and tetrasporophytes are produced between 21 and 27 °C (Ní Chualáin et al. 2004). In natural conditions, L2 occurs in areas of the Mediterranean where mean annual sea surface temperatures are between ~ 16–22 °C (Fig. 5; Pisano et al. 2020, GBIF Secretariat 2023).

3.5.2 Depth

Asparagopsis taxiformis L2 can grow at depths between shallow subtidal up to 30 m (Zanolla et al. 2014).

3.5.3 Latitude

In Europe, L2 established at latitudes ranging from 28° to 44 °N, and in the Southern Hemisphere at latitudes ranging from 21° to 34° S (NIWA 2024).

4. Introduction pathways

4.1 Long-distance translocation

The main pathway for long-distance translocation (100s – 1,000s of kilometres) of *A. taxiformis* is human-mediated marine transport by vessels via ballast water, hull fouling, and entanglement of fragments in equipment (e.g., anchors, anchor chains). This is the most likely introduction pathway for L2 in New Zealand.

4.1.1 Introduction and spread of invasive L2 in the Mediterranean Sea is linked to vessel movements, and the opening of the Suez Canal (Mancuso et al. 2022, Zanolla et al. 2022).

4.1.2 *Asparagopsis taxiformis* L2 could have been introduced into New Zealand via the ballast of vessels (e.g., cargo ships). Although there is no direct evidence of transport

along this pathway, *A. taxiformis* tetrasporophytes can survive two weeks in darkness, indicating the alga could survive in the ballast water of vessels (Zanolla et al. 2022).

4.1.3 *Asparagopsis taxiformis* L2 could have arrived in New Zealand as hull fouling, or as fragments entangled in marine gear or equipment (e.g., anchor or anchor chain). This is particularly likely given Whangārei Harbour and the Hauraki Gulf are popular yachting destinations.

4.1.4 International aquarium trade is unlikely to be a pathway for long-distance translocation of L2. No evidence was found of *A. taxiformis* being traded as an aquarium species nationally or internationally.

4.2 Short-distance translocation

The main pathway for short-distance translocation (10s – 100s of kilometres) of *A. taxiformis* is likely via natural dispersal and human-mediated spread by entanglement in boating equipment.

4.2.1 *Asparagopsis* species can spread naturally via fragmentation. Storms and wave action break gametophyte fronds and tetrasporophyte filaments, which can drift to new locations via currents and regenerate into new individuals.

4.2.2 *Asparagopsis taxiformis* L2 may also spread short distances attached to epifauna. The alga was observed attached to an exotic pear crab (*Pyromaia tuberculata*) in Whangārei Harbour, suggesting crabs could be a potential pathway for local spread (Biosecurity New Zealand 2024b).

4.2.3 Fragments of L2 gametophytes and tetrasporophytes can get entangled in boating equipment (e.g., anchors, anchor chains), and hitchhike to new locations.

5. Potential distribution and spread

Asparagopsis taxiformis L2 is likely to spread in New Zealand temperate waters. The information presented in section 3.5 suggests that the entirety of the North and South Island of New Zealand has coastal water temperatures within the tolerance range of L2 (Fig. 3).

However, based on *A. taxiformis* current distribution, L2 is unlikely to attain high density populations in South Island waters (Fig. 4). Based on the evidence available (section 3.5.1), southern New Zealand waters have temperatures that are suboptimal for *A. taxiformis*, and could reduce L2 photosynthesis, growth, and tetrasporophyte production.

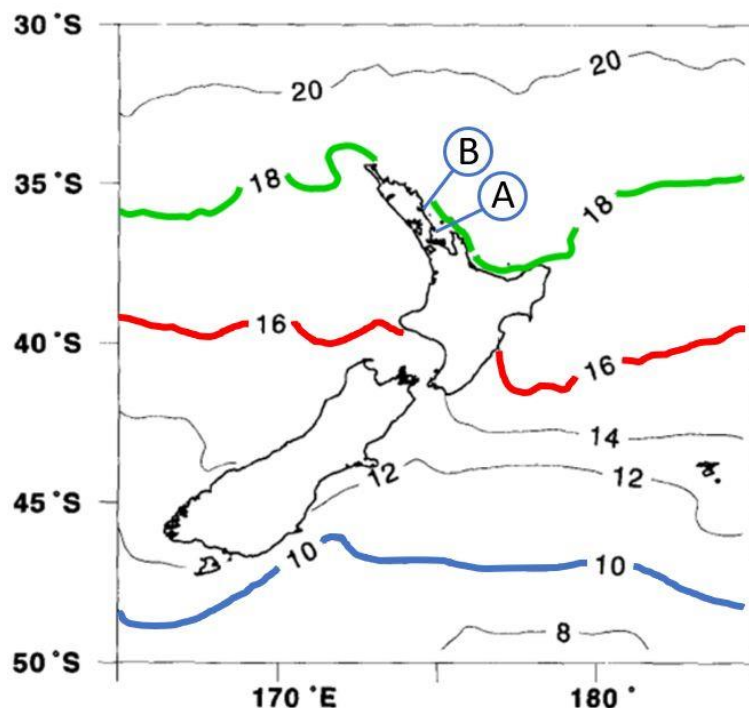


Figure 3. Locations where *Asparagopsis taxiformis* L2 was found (A: Kawau Island B: Whangārei Harbour), and New Zealand mean annual sea surface temperatures (from Chiswell, 1994). *Asparagopsis taxiformis* L2 was found between the 16 °C and 18 °C isotherms (respectively highlighted in red and green), but the literature suggests that L2 could survive as far south as the 10 °C isotherm (highlighted in blue), encompassing all New Zealand coastal waters.

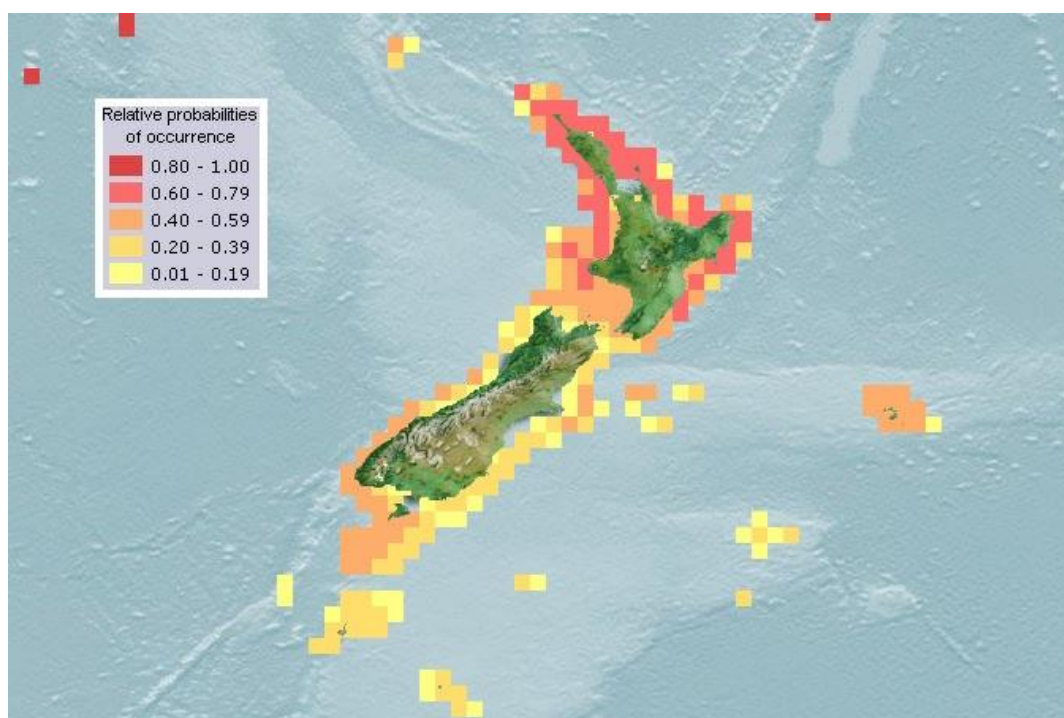


Figure 4. Computer-generated habitat suitability map for *Asparagopsis taxiformis*, based on combined occurrence data across all lineages (AquaMaps 2019). The entirety of the North and South Island has coastal water temperatures within the tolerance range of *A. taxiformis* Lineage 2, however temperatures in southern New Zealand waters are likely to be suboptimal for growth and reproduction.

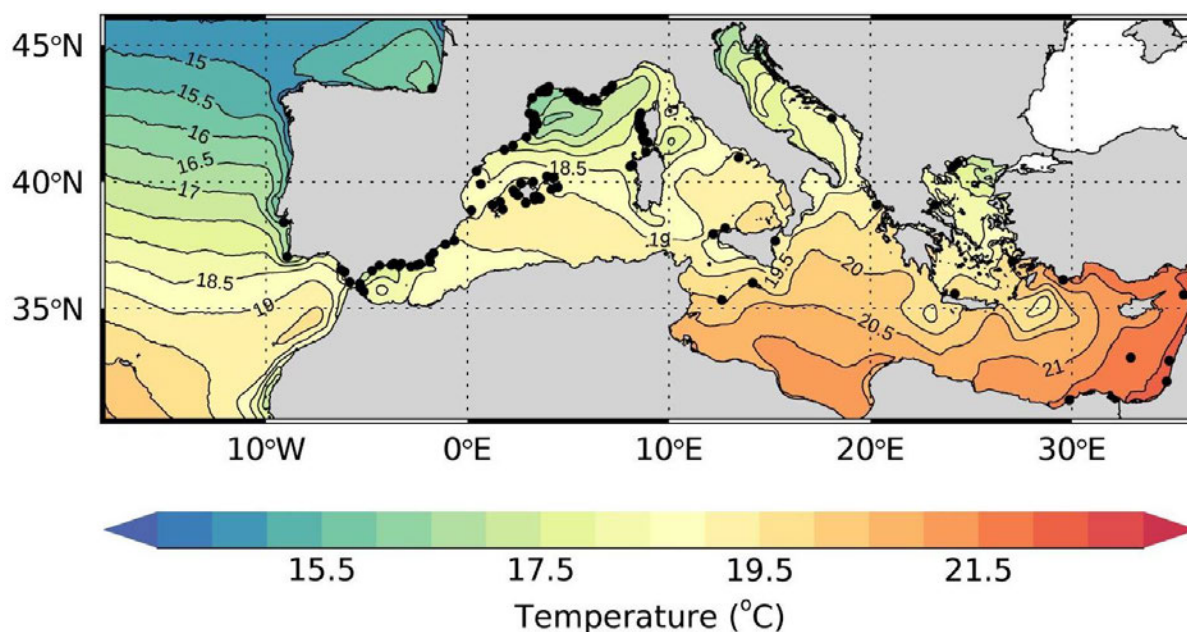


Figure 5. Mean sea surface temperatures (1982–2018) of the Mediterranean Sea and Northeastern Atlantic box (modified from Pisano et al. 2020) and invasive *Asparagopsis taxiformis* distribution. Black dots indicate georeferenced records of *A. taxiformis* (observations, living specimens, occurrences). Accessed via Global Biodiversity Information Facility (GBIF Secretariat 2023).

6. Potential negative impacts

It is unlikely that L2 can impact New Zealand as much as exotic *Caulerpa*. In well-studied regions like the Mediterranean, *A. taxiformis* has received less attention for its invasiveness compared to non-native *Caulerpa* species, despite being present for a longer time. In the Mediterranean, *A. taxiformis* was found in the early 20th century off the coast of Sicily (Verlaque 1994), while the first invasive *Caulerpa* (*C. taxifolia*) was first detected in 1984 near Monaco (Meinesz et al. 1993). *Caulerpa* has been extensively researched due to its significant impacts abroad. The smaller volume of literature on the introduction of *A. taxiformis* and its L2 likely reflects its relatively limited impacts.

Asparagopsis taxiformis L2 impacts will be higher where L2 populations will achieve higher densities. The density of L2 populations will be influenced by ecological factors such as environmental conditions (like water temperatures) and interactions with other marine organisms (particularly those with similar ecological niches, like other *Asparagopsis* seaweeds).

Impacts in the North Island will likely be greater than the South Island due to higher ocean temperatures that are more suitable to L2 (Fig. 3; Fig. 4). Similarly, within the North Island, impacts in the upper north will likely be greater than the lower north for the same reason. Climate change may also increase the magnitude of impacts, potentially promoting southward spread via increased ocean temperatures. It is less clear how L2 could interact with the New Zealand native *Asparagopsis* and to what extent L2 could have impacts. Most studies focused on *A. taxiformis* impacts took place in the Mediterranean, where no *Asparagopsis* species is native.

6.1 Environmental

Asparagopsis taxiformis L2 has the potential to cause environmental impacts in New Zealand, such as simplifying macroalgal habitat structure and reducing biodiversity of native algal forests, particularly in the northernmost New Zealand waters.

6.1.1 In the Mediterranean Sea, L2 affects the abundance and species composition of native macroalgae assemblages (Zanolla et al. 2018). For example, on the shores of Favignana Island (Egadi Islands, Sicily, Italy), stands of L2 can have 90% less plant biomass and 40% less invertebrate epibiont diversity than stands of native canopy-forming macroalgae (Mancuso et al. 2022). However, such impacts and others reported (Mancuso et al. 2021, Mancuso et al. 2023; Navarro-Barranco et al. 2018; Zanolla et al. 2022) were recorded where mean annual sea temperatures are above 18 °C (Fig. 5, Pisano et al. 2020), and warmer than New Zealand coastal waters (Fig. 3).

6.1.2 In particular, L2 has the potential to replace widely distributed native *A. armata* lineages. L2 outcompeted *A. armata* in the Mediterranean (Zanolla et al. 2018), where mean annual sea temperatures are ~ 16–22 °C (Fig. 5, Pisano et al. 2020). There is also evidence of competition between *A. armata* and *A. taxiformis* in the Azores (NE Atlantic Ocean) (Martins et al. 2019), where mean annual sea temperatures are ~ 18 °C (Fig. 1b, Reagan et al. 2024). Thus, the displacement of *A. armata* in New Zealand could occur at least above the 16 °C isotherm (Fig. 3), north of Taranaki and Napier. However, there is conflicting evidence suggesting *A. armata* has the capacity to displace *A. taxiformis* (Martins et al. 2019, including references therein). Given both species are difficult to differentiate, distribution data are potentially unreliable (Andreakis et al. 2004).

6.1.3 *Asparagopsis taxiformis* L2 is unlikely to impact the New Zealand native L5. This strain is restricted to the Rangitāhua/Kermadec Islands (Adams 1994, Nelson 2020), located about 1,000 km northeast of the North Island.

6.2 Economic

If L2 colonises large areas of seabed, this change in habitat structure could alter the distribution and abundance of commercially valuable species, particularly native seaweeds. For example, L2 could reduce the wild population of native *A. armata*. Marine and on-land farming of *A. armata* received nearly \$1.3 M from MPI between 2019 and 2023 to further investigate its potential as a methane-reducing livestock supplement (Ministry for Primary Industries 2024). Solely farming *A. armata* on land could reduce the potential economic impacts caused by L2 in the marine environment.

6.3 Socioeconomic

Large volumes of L2 beachcast, as has been observed in Whangārei Harbour (Allen pers. comms, NIWA 2024), would impact aesthetic and amenity values, including tourism. However, beachcast events of native and introduced seaweeds are commonplace in New Zealand in the absence of L2. Restrictions put in place to stop the fragmentation and spread of L2 may also negatively affect tourism (e.g., controls on swimming, boating, anchoring).

6.4 Cultural

The cultural impacts of L2 in New Zealand may be qualitatively similar to those caused by exotic *Caulerpa* (Biosecurity New Zealand 2021a), but likely at a much lesser scale:

“The Caulerpa incursion is associated with having a negative effect on the mauri (health and spirit) of the ecosystem. Mauri and mana are inextricably tied, and where mauri is negatively impacted, mana of tangata whenua is affected. Cultural values and concepts that relate to the presence and impact of C. brachypus include self-determination, environmental stewardship and community wellbeing.” (Biosecurity New Zealand 2021a)

As with exotic *Caulerpa* (Biosecurity New Zealand 2021b), impacts on mauri and mana could include, but are not limited to:

- the depletion of native epifauna, including mollusc and crustacean species due to habitat change;
- limitations in the customary and recreational gathering of molluscs and crustaceans;
- limitations on cultural practices including manaakitanga;
- potential effects on whānau ora.

7. Potential positive impacts

No evidence could be found to suggest that L2 had positive environmental, socioeconomic, or cultural impacts abroad. The literature analysed, including the *Asparagopsis* review by Zanolla et al. (2022), solely reports negative impacts. Potential negative environmental impacts associated with L2 introduction would likely outweigh any positive environmental impacts in New Zealand. However,

7.1 Economic

7.1.1 *Asparagopsis taxiformis* L2 may provide economic benefits in New Zealand as a livestock supplement. As with *A. armata*, *A. taxiformis* has shown promise as a potential livestock methane-reducing supplement. When added to cow and sheep feed, both algae reduced ruminant methane production by up to 98% (Glasson et al. 2022). A review of *Asparagopsis* use as a methane-reducing ruminant supplement suggests research in this area often focuses on *A. taxiformis* (Glasson et al. 2022), providing a larger pool of information to draw from for potential trials in New Zealand. In addition, *A. taxiformis* may be a more reliable species for commercial-scale production relative to *A. armata*, particularly in marine-based farming. This is because L2 has the capacity to tolerate wider environmental fluctuations compared with *A. armata*. The species may also produce more biomass when farmed relative to *A. armata*, as L2 doesn't self-thin like *A. armata* does (Zanolla et al. 2022).

7.1.2 *Asparagopsis taxiformis* L2 may provide economic benefits to New Zealand finfish aquaculture, notably salmon farming. There is emerging research indicating *A. taxiformis* has potential as an aquaculture nutritional supplement that enhances farmed finfish growth, resilience, and immunity (Thépot et al. 2022, Pereira et al. 2024). *Asparagopsis taxiformis* supplementation in Atlantic salmon (*Salmo salar*) farmed in Australia led to an increase of growth by 33% (Pereira et al. 2024).

8. Management options

The following assessment is not intended to replace analysis by Diagnostics, Readiness and Surveillance. Comparisons between L2 and exotic *Caulerpa* are made where appropriate.

There are six potential management options: national eradication, local eradication, suppression (reduce the population), pathway management (slow the spread), gather additional surveillance data, and no response.

8.1 Eradication

National or local eradication of L2 is not feasible. This is largely due to the distribution of L2 incursion zones in New Zealand, biological and ecological characteristics, and diagnostic challenges. Eradication attempts in areas where L2 is introduced have not been attempted.

8.1.1 The two primary incursion locations (Iris Shoal, Kawau Island, and Whangārei Harbour) are roughly 75 km apart. Given L2 reproduces vegetatively as well as sexually, it is possible the seaweed has a distribution wider than these two locations. A distribution of that scale would be difficult to eradicate. As suggested in section 8.4, gathering additional surveillance data on the current distribution of L2 is required to make an informed, practical management decision.

8.1.2 The red alga has the capacity to reproduce both asexually and sexually, as well as vegetatively, suggesting only limited propagule pressure is required to establish a population.

8.1.3 Potential distribution of L2 and the current distribution of native *A. armata* lineages will likely overlap, limiting the use of some eradication methods, such as dredging.

8.1.4 Identifying L2 in the field may be challenging, because the *A. taxiformis* complex is considered morphologically cryptic. Current methods to identify L2 in situ would require microscopic examination. In addition, the capacity to rapidly differentiate between L2 and *A. armata* is crucial for eradication efforts. However, this is difficult, as the tetrasporophyte of both species looks very similar.

8.2 Suppression

Suppression of L2 aimed at reducing the population via removal is not feasible due to the same factors mentioned in section 6.1.1. As with eradication, suppression attempts in areas where L2 is introduced have not been attempted.

8.2.3 Removal of biomass is required to reduce the current population. However, unlike exotic *Caulerpa*, L2 is difficult to differentiate from native seaweeds. Consequently, attempts to remove L2 biomass may also reduce the biomass of native seaweeds. Feasibility criteria for treatment would need to be carried out in the absence of known treatment options, or previous suppression attempts abroad.

8.3 Pathway management

Pathway management could include Unwanted Organism status, Controlled Area Notices and rāhui (prohibit human use), an awareness campaign, enhancing existing surveillance, and combining current exotic *Caulerpa* management initiatives with L2 management. However, additional surveillance data is required to ascertain the current distribution of L2 in New Zealand.

8.3.1 Currently L2 has no regulatory status. Updating the status to an Unwanted Organism under the Biosecurity Act 1993 would enable certain powers, which would aid pathway management strategies but potentially limit the ability to utilise the species in methane reduction initiatives. Unwanted Organism status would also be challenging to enforce given diagnostic limitations with L2 and other red seaweeds in New Zealand.

8.3.2 Controlled Area Notices (CAN) in conjunction with rāhui for the three incursion locations would limit L2 spread via human activities. Controlled Area Notice zones can place cleaning requirements on vessels and equipment within a defined area when leaving a notice zone. This would prevent L2 attached to vessel anchors, anchor chains, etc. being spread outside incursion zones. Notices would also place a complete ban on the removal of any sea organisms from within a zone. Rāhui would prohibit human use of incursion zones.

8.4 Gather additional surveillance data

To make an informed, practical management decision, gathering additional surveillance data on the current distribution of L2 in the North Island would be helpful. As L2 is unlikely to form high density populations around the South Island, collecting surveillance data around the North Island would be sufficient. These data will give an indication of incursion scale and inform feasibility criteria regarding management options. Such data could be collected by

existing marine surveillance programmes by NIWA, which currently conducts surveillance along the east coast of the North Island twice yearly.

8.5 No response

This option recognises that eradication is not feasible, and that localised elimination and suppression efforts will be expensive and are unlikely to succeed over the long term. This option also recognises that the impacts of L2 are unlikely to be at the scale of exotic *Caulerpa* in New Zealand. It is expected that L2 will spread mainly via entanglement with recreational vessel anchors and anchor chains. In lieu of a response, *Caulerpa* public communications and the “Protect our Paradise” campaign could be leveraged to slow the spread of L2, as the fundamental messaging—keeping vessel hulls, gear and anchors clean—is applicable to a range of marine pests, including L2.

References:

- Adams, N. M. (1994). *Seaweeds of New Zealand*. Canterbury University Press, Christchurch.
- Andreakis, N., Procaccini, G., & Kooistra, W. H. (2004). *Asparagopsis taxiformis* and *Asparagopsis armata* (Bonnemaisoniales, Rhodophyta): genetic and morphological identification of Mediterranean populations. *European journal of phycology*, 39(3), 273-283. ([link](#))
- Andreakis, N., Costello, P., Zanolla, M., Saunders, G. W., and Mata, L. (2016). Endemic or introduced? Phylogeography of *Asparagopsis* (Florideophyceae) in Australia reveals multiple introductions and a new mitochondrial lineage. *Journal of Phycology* 52(1): 141–147.
- AquaMaps (2019). Computer Generated Distribution Map for *Asparagopsis taxiformis*. Retrieved from <https://www.aquamaps.org> on 26/08/2024.
- Biosecurity New Zealand (2021a). Rapid risk assessment *Caulerpa brachypus* in Blind Bay, Great Barrier Island. ([link](#))
- Biosecurity New Zealand (2021b). Memorandum to the CTO for UO status of *Caulerpa brachypus*. ([link](#))
- Biosecurity New Zealand (2022). Memorandum to the Deputy Director-General, Biosecurity New Zealand. *Caulerpa* Response Funding Option. ([link](#))
- Biosecurity New Zealand (2024a). Investigation Report INV GR361641. ([link](#))
- Biosecurity New Zealand (2024b). Interim post-sampling report Whangārei Harbour NMHRSS Winter 2024. Agreement Number C0031763 (formerly SOW23030) (Biosecurity New Zealand project MPI21506) "National Marine High Risk Site Surveillance". ([link](#))
- Chiswell, S. M. (1994). Variability in sea surface temperature around New Zealand from AVHRR images. *New Zealand Journal of Marine and Freshwater Research* 28: 179–192.
- Creese, R. G., Davis, A. R. and Glasby, T. M. (2004). Eradicating and preventing the spread of the invasive algae *Caulerpa taxifolia* in NSW. Project No. 35593. NSW Fisheries Final Report Series. No. 64. NSW Fisheries, Australia.
- Dijoux, L., Viard, F., and Payri, C. (2014). The More We Search, the More We Find: Discovery of a New Lineage and a New Species Complex in the Genus *Asparagopsis*. *PLoS ONE* 9(7): e103826. doi:10.1371/journal.pone.0103826
- GBIF Secretariat (2023). *Asparagopsis taxiformis* (Delile) Trevis. GBIF Backbone Taxonomy. Checklist dataset. ([link](#)) Accessed 21/08/24.
- Glasson, C. R., Kinley, R. D., de Nys, R., King, N., Adams, S. L., Packer, M. A., Svenson, J., Eason, C. and Magnusson, M. (2022). Benefits and risks of including the bromoform containing seaweed *Asparagopsis* in feed for the reduction of methane production from ruminants. *Algal Research* 64: 102673.

- Guiry, M. D. (2024). In Guiry, M. D. & Guiry, G. M. 01 February 2024. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. [\(link\)](#). Accessed 04/09/2024.
- Mancuso, F. P., Chemello, R., and Mannino, A. M. (2023). The effects of non-indigenous macrophytes on native biodiversity: case studies from Sicily. *Journal of Marine Science and Engineering* 11(7): 1389. [\(link\)](#)
- Mancuso, F. P., D'Agostaro, R., Milazzo, M., and Chemello, R. (2021). The invasive *Asparagopsis taxiformis* hosts a low diverse and less trophic structured molluscan assemblage compared with the native *Ericaria brachycarpa*. *Marine Environmental Research*,166: 105279. [\(link\)](#)
- Mancuso, F. P., D'Agostaro, R., Milazzo, M., Badalamenti, F., Musco, L., Mikac, B., ... and Chemello, R. (2022). The invasive seaweed *Asparagopsis taxiformis* erodes the habitat structure and biodiversity of native algal forests in the Mediterranean Sea. *Marine Environmental Research* 173: 105515. [\(link\)](#)
- Martins, G. M., Cacabelos, E., Faria, J., Álvaro, N., Prestes, A. C., Neto, A. I. (2019). Patterns of distribution of the invasive alga *Asparagopsis armata* Harvey: a multi-scaled approach. *Aquatic Invasions* 14: 582–593. [\(link\)](#)
- Meinesz, A., De Vaugelas, J., Hesse, B., & Mari, X. (1993). Spread of the introduced tropical green alga *Caulerpa taxifolia* in northern Mediterranean waters. *Journal of applied Phycology*, 5, 141-147. [\(link\)](#)
- Ministry for Primary Industries (2024). Sustainable Food and Fibre Futures projects. [\(link\)](#). Accessed 26/08/2024.
- Navarro-Barranco, C., Florido, M., Ros, M., González-Romero, P., and Guerra-García, J. M. (2018). Impoverished mobile epifaunal assemblages associated with the invasive macroalga *Asparagopsis taxiformis* in the Mediterranean Sea. *Marine Environmental Research* 141: 44–52. [\(link\)](#)
- Nelson, W. A. (2020). New Zealand seaweeds – an illustrated guide, ed. 2. Museum of New Zealand Te Papa Tongarewa, Wellington, New Zealand.
- Ní Chualáin, F., Maggs, C. A., Saunders, G. W., and Guiry, M. D. (2004). The invasive genus *Asparagopsis* (bonnemaisoniaceae, rhodophyta): molecular systematics, morphology, and ecophysiology of falkenbergia isolates 1. *Journal of Phycology* 40(6): 1112–1126.
- NIWA (2024). Marine Exotic Species Note 138 August 2024. Notes on *Asparagopsis taxiformis* (Bonnemaisoniales, Rhodophyta) from Kawau Island and Whangārei Harbour. [\(link\)](#)
- Pereira, A., Marmelo, I., Dias, M., Silva, A. C., Grade, A. C., Barata, M., Pousao-Ferreira, P., Anacleto, P., Maulvault, A. L. (2024). *Asparagopsis taxiformis* as a Novel Antioxidant Ingredient for Climate-Smart Aquaculture: Antioxidant, Metabolic and Digestive Modulation in Juvenile White Seabream (*Diplodus sargus*) Exposed to a Marine Heatwave. *Antioxidants* 13(8): 949. [\(link\)](#)
- Pisano, A., Marullo, S., Artale, V., Falcini, F., Yang, C., Leonelli, F. E., ... and Buongiorno Nardelli, B. (2020). New evidence of Mediterranean climate change and variability from sea surface temperature observations. *Remote Sensing* 12(1): 132. <https://www.mdpi.com/2072-4292/12/1/132>
- Preuss, M., Nelson, W. A., and D'Archino, R. (2022). Cryptic diversity and phylogeographic patterns in the *Asparagopsis armata* species complex (Bonnemaisoniales, Rhodophyta) from New Zealand. *Phycologia* 61(1): 89–96.
- Reagan, J. R., Boyer, T. P., García, H. E., Locarnini, R. A., Baranova, O. K., Bouchard, C., Cross, S. L., Mishonov, A. V., Paver, C. R., Seidov, D., Wang, Z., and Dukhovskoy, D. (2024). World Ocean Atlas 2023. NOAA National Centers for Environmental Information. <https://www.ncei.noaa.gov/products/world-ocean-atlas>
- Thépot, V., Campbell, A. H., Rimmer, M. A., Jelocnik, M., Johnston, C., Evans, B., and Paul, N. A. (2022). Dietary inclusion of the red seaweed *Asparagopsis taxiformis* boosts production, stimulates immune response and modulates gut microbiota in Atlantic salmon, *Salmo salar*. *Aquaculture* 546: 737286. [\(link\)](#)
- University of Maine (2023). Climate Reanalyzer. [\(link\)](#). Accessed 23/08/2024.
- Verlaque, M. (1994). Checklist of introduced plants in the Mediterranean: origins and impact on the environment and human activities. *Oceanologica acta. Paris*, 17(1), 1-23.

- Wheeler, T., Major, R., South, P., Ogilvie, S., Romanazzi, D., and Adams, S. (2021). Stocktake and characterisation of New Zealand's seaweed sector: Species characteristics and Te Tiriti O Waitangi considerations. Report for Sustainable Seas National Science Challenge project *Building a seaweed sector: developing a seaweed sector framework for Aotearoa New Zealand*. Sustainable Seas, Ko ngā moana whakauka. 51 pp.
- Zanolla, M., Altamirano, M., Carmona, R., De La Rosa, J., Sherwood, A., and Andreakis, N. (2014). Photosynthetic plasticity of the genus *Asparagopsis* (Bonnemaisoniales, Rhodophyta) in response to temperature: implications for invasiveness. *Biological Invasions* 17(5): 1341–1353. ([link](#))
- Zanolla, M., Carmona, R., and Altamirano, M. (2017a). Reproductive ecology of an invasive lineage 2 population of *Asparagopsis taxiformis* (Bonnemaisoniales, Rhodophyta) in the Alboran Sea (western Mediterranean Sea). *Botanica marina*, 60(6), 627-638. ([link](#))
- Zanolla, M., Altamirano, M., De la Rosa, J., Niell, F. X., and Carmona, R. (2017b). Size structure and dynamics of an invasive population of lineage 2 of *Asparagopsis taxiformis* (Florideophyceae) in the Alboran Sea. *Phycological Research*, 66(1), 45-51. ([link](#))
- Zanolla, M., Altamirano, M., Carmona, R., De la Rosa, J., Souza-Egipsy, V., Sherwood, A., ... Andreakis, N. (2017c). Assessing global range expansion in a cryptic species complex: insights from the red seaweed genus *Asparagopsis* (Florideophyceae). *Journal of Phycology*, 54(1), 12–24. ([link](#))
- Zanolla, M., Carmona, R., De La Rosa, J. and Altamirano, M. (2018). Structure and temporal dynamics of a seaweed assemblage dominated by the invasive lineage 2 of *Asparagopsis taxiformis* (Bonnemaisoniaceae, Rhodophyta) in the Alboran Sea. *Mediterranean Marine Science* 19: 147-155. ([link](#))
- Zanolla, M., Carmona, R., De la Rosa, J., Salvador, N., Sherwood, A. R., Andreakis, N., and Altamirano, M. (2019). Morphological differentiation of cryptic lineages within the invasive genus *Asparagopsis* (Bonnemaisoniales, Rhodophyta). *Phycologia* 53(3): 233–242. ([link](#))
- Zanolla, M., Carmona, R., Mata, L., De la Rosa, J., Sherwood, A., Barranco, C. N., Muñoz, A.R. and Altamirano, M. (2022). Concise review of the genus *Asparagopsis* Montagne, 1840. *Journal of Applied Phycology* 34: 1–17. ([link](#))

Out of Scope

Appendix



Figure S1. Picture showing the fronds of *Asparagopsis taxiformis* (below) and *Asparagopsis armata* (above). Arrows point to harpoon-like branches that can be found in *A. armata*. While the gametophytes of the two *Asparagopsis* species can be visually distinguished, other life stages cannot be distinguished without using microscopy or molecular techniques. The picture was taken in Granada, (Southern Spain) at 5-m depth.

(Credits: J. De la Rosa – from Zanolla, M., Carmona, R., Mata, L., De la Rosa, J., Sherwood, A., Barranco, C. N., Muñoz, A.R. and Altamirano, M. (2022). Concise review of the genus *Asparagopsis* Montagne, 1840. *Journal of Applied Phycology* 34: 1–17. <https://link.springer.com/article/10.1007/s10811-021-02665-z>)