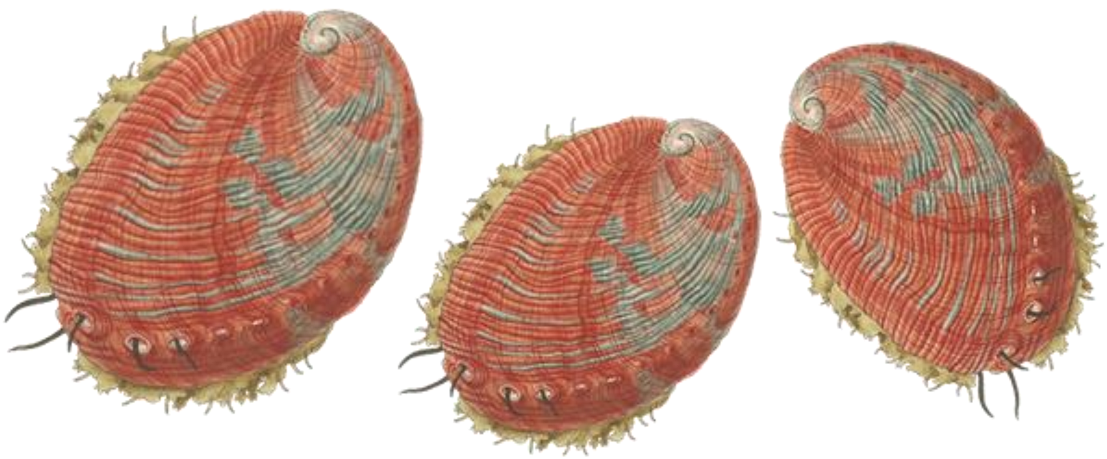
Abalone

Haliotis spp.



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Worldwide

All production systems, including enclosed and sea ranching

Aquaculture Standard Version A3.1

Report ID 27815

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Seafood Watch Consulting Researcher

Disclaimer

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About Seafood Watch®

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from www.seafoodwatch.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives" or "Avoid". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch®'s sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

Guiding Principles

Seafood Watch® defines "sustainable seafood" as seafood from sources, whether fished or farmed, that can maintain or increase production without jeopardizing the structure and function of affected ecosystems.

Sustainable aquaculture farms and collective industries, by design, management and/or regulation, address the impacts of individual farms and the cumulative impacts of multiple farms at the local or regional scale by:

1. **Having robust and up-to-date information on production practices and their impacts publicly available;**
   Poor data quality or availability limits the ability to understand and assess the environmental impacts of aquaculture production and subsequently for seafood purchasers to make informed choices. Robust and up-to-date information on production practices and their impacts should be publicly available.
2. **Not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level;**
   Aquaculture farms minimize or avoid the production and discharge of wastes at the farm level in combination with an effective management or regulatory system to control the location, scale and cumulative impacts of the industry's waste discharges.
3. **Being located at sites, scales and intensities that maintain the functionality of ecologically valuable habitats;**
   The siting of aquaculture farms does not result in the loss of critical ecosystem services at the local, regional, or ecosystem level.
4. **Limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to non-target organisms;**
   Aquaculture farms avoid the discharge of chemicals toxic to aquatic life or limit the type, frequency or total volume of use to ensure a low risk of impact to non-target organisms.
5. **Sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains;**
   Producing feeds and their constituent ingredients has complex global ecological impacts, and the efficiency of conversion can result in net food gains or dramatic net losses of nutrients. Aquaculture operations source only sustainable feed ingredients or those of low value for human consumption (e.g., by-products of other food production), and convert them efficiently and responsibly.
6. **Preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes;**
   Aquaculture farms, by limiting escapes or the nature of escapees, prevent competition, reductions in genetic fitness, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems that may result from the escape of native, non-native and/or genetically distinct farmed species.

7. **Preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites;**
   Aquaculture farms pose no substantial risk of deleterious effects to wild populations through the amplification and retransmission of pathogens or parasites, or the increased virulence of naturally occurring pathogens.
8. **Using eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture;**
   Aquaculture farms use eggs, larvae, or juvenile fish produced from farm-raised broodstocks thereby avoiding the need for wild capture, or where farm-raised broodstocks are not yet available, ensure that the harvest of wild broodstock does not have population-level impacts on affected species. Wild-caught juveniles may be used from passive inflow, or natural settlement.
9. **Preventing population-level impacts to predators or other species of wildlife attracted to farm sites.**
   Aquaculture operations use non-lethal exclusion devices or deterrents, prevent accidental mortality of wildlife, and use lethal control only as a last resort, thereby ensuring any mortalities do not have population-level impacts on affected species.
10. **Avoiding the potential for the accidental introduction of non-native species or pathogens during the shipment of live animals;**
    Aquaculture farms avoid the international or trans-waterbody movements of live animals, or ensure that either the source or destination of movements is biosecure in order to avoid the introduction of unintended pathogens, parasites and invasive species to the natural environment.

Once a score and rating has been assigned to each criterion, an overall seafood recommendation is developed on additional evaluation guidelines. Criteria ratings and the overall recommendation are color-coded to correspond to the categories on the Seafood Watch pocket guide:

Best Choices/Green: Are well managed and caught or farmed in environmentally friendly ways.
Good Alternatives/Yellow: Buy, but be aware there are concerns with how they're caught or farmed.
Avoid/Red: Take a pass on these. These items are overfished or caught or farmed in ways that harm other marine life or the environment

Final Seafood Recommendation

Enclosed Abalone Aquaculture

Criterion	Score	Rating	Critical?
C1 Data	7.73	GREEN	
C2 Effluent	9.00	GREEN	NO
C3 Habitat	6.93	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	–1.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	**48.66**		
Final score (0–10)	**6.95**		

OVERALL RATING

Final Score	6.95
Initial rating	GREEN
Red criteria	0
Interim rating	GREEN
Critical Criteria?	NO

FINAL RATING

GREEN

Scoring note—scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of –10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

The final score for enclosed abalone aquaculture worldwide is 6.95 out of 10. In addition to a numerical Green score, there are no Red criteria. The final rating is Green and a recommendation of "Best Choice."

Sea-Ranched Abalone Aquaculture—*Updated Please See Appendix 2 for Justification*

Criterion	Score	Rating	Critical?
C1 Data	7.27	GREEN	
C2 Effluent	9.00	GREEN	NO
C3 Habitat	8.67	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	–1.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	**49.94**		
Final score (0–10)	**7.13**		

OVERALL RATING

Final Score	7.13
Initial rating	GREEN
Red criteria	0
Interim rating	GREEN
Critical Criteria?	NO

FINAL RATING
GREEN

Scoring note—scores range from 0 to 10, where 0 indicates very poor performance and 10 indicates the aquaculture operations have no significant impact. Criteria 8X, 9X, and 10X are exceptional criteria, where 0 indicates no impact and a deduction of –10 reflects a very significant impact. Two or more Red criteria result in a Red final result.

Summary

The final score for sea-ranched abalone aquaculture is 7.13 out of 10. The final rating is Green and a recommendation of "Best Choice."

Executive Summary

This assessment was originally published in January 2017 and reviewed for any significant changes in March 2022. No changes were made to the body of the report. Please see Appendix 2 for details of review.

Abalone is a single-shelled mollusk native to temperate and tropical oceans around the world. With up to 100 species worldwide, only about 15 are grown in aquaculture for human consumption. Abalone available to U.S. consumers is grown domestically and imported from Australia (34%), China (33%), Mexico (17%), and Chile (10%), among other countries. Data availability is considered excellent due to the wide availability, comprehensive coverage, and multiple peer-reviewed sources.

Production systems may use any combination of single-pass, flow-through tanks on land, and tethered cages or other enclosures in the sea. There are also some forms of sea ranching that still take place, but sea ranching is not as common as it once was and new, more sustainable methods for sea ranching are being developed. Enclosed (land- and sea-based) and sea-ranched methods will have separate assessments for some criteria, resulting in separate final scores and recommendations.

Data. Although the availability of reliable data varies between countries, this assessment applies to the global abalone farming industry as a whole, including both enclosed and sea-ranching methods of aquaculture. Because the industry is still developing, a large amount of data sharing is taking place among commercial operations and research institutions. In particular, efforts by the World Wildlife Fund (WWF) and the Aquaculture Stewardship Council (ASC) have led to global dialogues and the development of guidelines for best industry practices. It should be noted that the availability of data for farming operations in China and other parts of Asia is somewhat limited and the assessment for the sustainability of abalone farmed in these areas may be less robust. But farming techniques being used are similar worldwide and thus can be assessed together. The combination of published research, publicly available information, increasing commercial efficiency, government regulation, and the development of industry standards has resulted in the free flow of information and a high level of industry transparency. The final score for Criterion 1—Data is 7.73 out of 10 for enclosed farms and 7.27 out of 10 for sea ranches.

Effluent. The effluent produced through abalone farms is discharged into the ocean; however, it is low in nitrogen. There are regulations that control the actions of abalone farms, and even though the level of enforcement for regulations may not be clear in all cases, effluent from abalone farms is not considered to have adverse effects on the natural environment. The criterion for effluent score is 9 out of 10 for both production methods.

Habitat. Sea-based enclosures used for abalone farming may allow for the deposition of organic matter beneath arrays, but these impacts are minor and do not significantly alter the functionality of the ecosystem. Similarly, land-based facilities are typically sited on coastal lands, but do not result in large-scale or ecologically destructive conversion. Traditional sea ranching can be highly destructive and result in a great loss of habitat functionality due to the clearing of ranching sites. Although this practice is still occurring, more modern forms of ranching (i.e., artificial reef farming) are being developed to enhance and restore otherwise unproductive areas on the seafloor. Because of the differences in habitat conversion and impact, Factor 3.1 is scored 9 out of 10 for enclosed farming and 2 out of 10 for sea ranching. The content of management measures is largely similar and robust, though the potential for clearance of benthic habitats for sea ranching cannot be considered to be entirely based on ecological principles. Management effectiveness is typically strong, though some concern exists in some regions. Ultimately, the score for Criterion 3—Habitat is 6.93 for enclosed farms and 2.4 for sea ranches.

Chemical Use. There is minor concern about chemical use in abalone aquaculture. Because antibiotics are largely ineffective for treatment of disease in abalone, their use in the industry is largely absent. Some antifoulants and disinfectants may be used on abalone farm infrastructure and equipment, although these chemicals generally pose less risk of ecological impact than those used in other types of aquaculture. There is no evidence suggesting that chemical use in abalone aquaculture is harming the environment, but there is some risk that applied chemicals could accumulate in poorly flushed or intensively farmed areas. The final score for Criterion 4—Chemicals is 8 out of 10 for both methods.

Feed. In the wild, abalone is an herbivore, consuming only micro- and macroalgae over the course of its life. Some aquaculture operations supplement algal feed with feeds that contain quite small amounts of fishmeal protein, but this practice is relatively rare. In general, cultured abalone does not consume any wild fish, has a small feed footprint, and produces a net gain in edible protein. Algae harvest is generally regulated, and harvested biomass regrows quickly. Abalone feed is therefore considered to be quite sustainable, and Criterion 5—Feed scored 10 out of 10 for both methods.

Escapes. As a benthic- and substrate-oriented organism, farmed juvenile or adult abalone has only a minor risk of escaping from the farming infrastructure and moving away from the farming location. There is a greater risk that spawning events occur during growout, potentially releasing large numbers of eggs to receiving ecosystems. Ultimately, the escape risk for all abalone aquaculture is moderate. Considering the historically poor success of intentional stocking efforts, it is not likely that escapees would establish outside of farms, and competition for resources is likely low. The majority of abalone farms raise locally native species, reducing the risk of ecological harm from nonnative escapees, although selective breeding for multiple generations has generally rendered farm-origin abalone genetically distinct from its wild counterparts. Where nonnative species are produced, they may or may not already be present in surrounding habitats. In some locations, the potential exists for nonnative species to escape and establish themselves in local marine habitats. Overall, there is a moderate risk of escape and, although competitive impacts are likely low, there is a potential for genetic hybridization between farm-origin and wild abalone. For both methods, the final score for Criterion 6—Escapes is 4 out of 10.

Disease. Historically, the primary disease concern for abalone has been bacterial withering foot syndrome. More recently, a variant of the herpes virus has infected abalone populations in Australia, China, and Taiwan. Disease transmission between farmed and wild abalone has occurred in the past, and because of untreated effluent discharge and flow-through sea enclosures, there is a risk of further transmission. But the global industry is well regulated, with constant monitoring for outbreaks and with practices in place to reduce the transfer of disease. The final score for Criterion 7—Disease is 4 out of 10 for both methods.

Source of Stock. Source of stock for abalone farms generally comes from facilities that produce abalone seed stock. The broodstock for these facilities may be from the natural, native population or a nonnative population, or it may be a hybrid that is used specifically for aquaculture. Collection of broodstock or larvae is not considered to have a negative effect on the natural population. There are no significant impacts on wild populations from the collection of abalone broodstock or larvae for aquaculture. Criterion 8X for Source of stock scored 0 for both methods.

Wildlife and Predator Mortalities. Enclosed sea-based growouts and sea ranches could attract predators or other animals to the abalone farm. There is no evidence that there is significant mortality of predators or wildlife due to removal from farms. For both methods, Criterion 9X for wildlife and predator mortality scored –1.

Unintentional Species Introductions. Because there is no reliance on international or trans-waterbody movement for the purpose of abalone farming or trade, there is essentially no significant concern for the escape of unintentionally introduced species. Criterion 10X for escape of unintentionally introduced species scored 0 for both methods.

Summary. Overall, abalone farmed in land and sea-based enclosures receives a score of 6.95 out of 10, making this a Green or “Best Choice” recommendation. Abalone farmed in sea ranches scores slightly lower at 6.24 out of 10, with one Red criterion (Habitat), making it an overall Yellow or “Good Alternative” recommendation.

Introduction

Scope of the analysis and ensuing recommendation

Species

Seven species of abalone (genus *Haliotis*) are cultured in significant numbers:
Red abalone (*Haliotis rufescens*)—Mexico, Chile, United States
Japanese abalone (*Haliotis discus hannai*)—Japan
Paua or black abalone (*Haliotis iris*)—New Zealand
Tokobushi or small abalone (*Haliotis diversicolor supertexta*)—China, Japan
Perlemoen abalone (*Haliotis midae*)—South Africa
Blacklip abalone (*Haliotis rubra*)—Australia
Greenlip abalone (*Haliotis laevigta*)—Australia

Geographic Coverage

This report assesses worldwide abalone production. Methods for culturing abalone include enclosed farming and sea ranching, and these methods are similar in all geographic areas.

Production Method(s)

Hatchery, nursery, land-based farms, sea-based growout, and sea ranching. Enclosed (land-based and sea-based) production methods and sea-ranching methods will have separate scores for some criteria, resulting in separate final scores and recommendations.

Species Overview

Brief overview of the species

Abalone is a sessile mollusk found in temperate and tropical intertidal marine waters around the world. It is exclusively an herbivore, consuming microalgal films as larva and macroalgae as a juvenile and adult. It is characterized by its single large shell, which has a series of holes along one edge and an iridescent interior. Like most marine snails, the meat of the abalone is a single large foot that it uses for locomotion. Abalone has a fairly simple life history that includes a larval stage, settlement, and benthic life (Figure 1).

The number of species of abalone worldwide ranges (depending on the source) from approximately 56 to 100, but aquaculture operations tend to focus on approximately 15 species, subspecies, and hybrids (Geiger 2000) (Allsopp et al. 2011), with only about 6 species being produced in notably large quantities (Farming Week 2012). Red abalone (*Haliotis rufescens*) dominates U.S. production and markets because it grows quickly in the temperate waters of the North American West Coast and reaches the largest size of any abalone species. The native habitat of red abalone stretches from Oregon to Baja California, from low intertidal waters to a depth of 40 m (130 ft) (Braje et al. 2009).

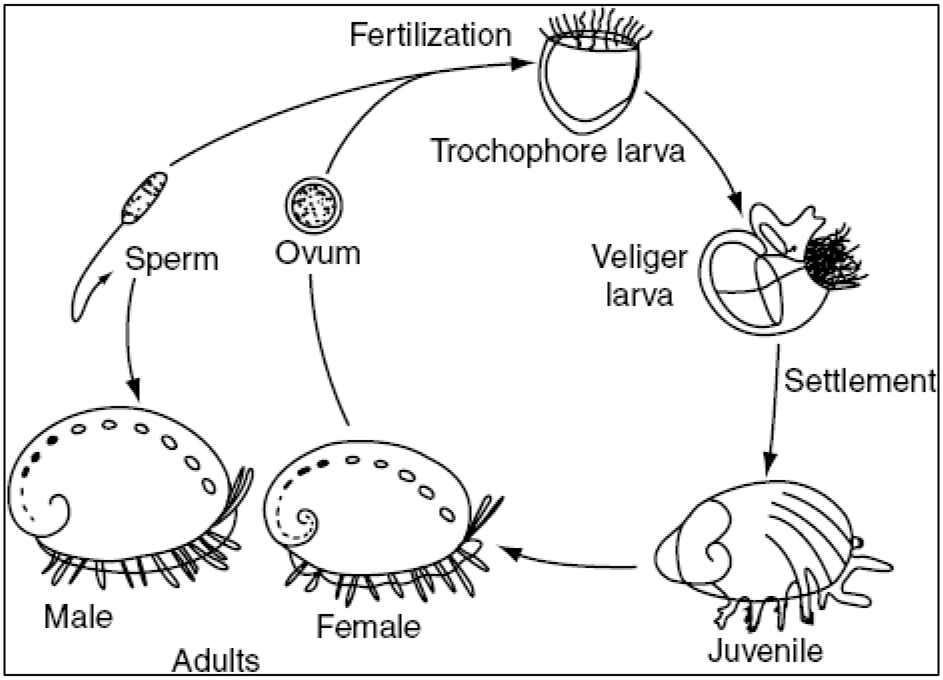

Figure 1. Abalone life cycle (Farming Week, 2012)

Production system

Abalone farming consists of three phases: hatchery, juvenile, and growout. In the hatchery and juvenile phases, young abalone are grown in land-based raceway tanks and holding tanks. During the growout phase, abalone may be raised using a variety of production systems, including raceway tanks on land, tethered cages or other enclosures at sea, and unenclosed sea ranches.

For sea ranching, abalone are allowed to live freely on the ocean floor during growout. In the past, destructive methods have been used to clear and prepare the ocean floor for abalone ranches; however, more modern techniques are now being used. Most notably, artificial reef farming is becoming popular and aims to actually enhance and restore marine ecosystems while acting as an abalone ranch, which is commonly referred to as an "abitat."

This assessment will focus on the two growout methods: enclosed (land-based and at sea in cages/enclosures) and sea ranching, with most production coming from enclosed methods of aquaculture (pers. comm., Australian Abalone Growers Association 2016).

Production Statistics

All species under this assessment are *Haliotis* spp. About 1% of all abalone production occurs in the Americas. Japanese abalone (*H. discus hannai*) makes up about 97% of worldwide production, which takes place primarily in Asia. A large portion of United States abalone imports are from Australia, which produces blacklip (*H. rubra*) and greenlip (*H. laevigata*) abalone (Table 1).

Data on the percent of industry represented by enclosed and sea-ranching production methods are not readily available. But most abalone production occurs in Asia (China and Korea), and most production there (95%) uses in-water multi-tier baskets or suspended cages of some kind (Cook 2014) (Wu, Liu, and Wang 2009) (Wu and Zhang 2013) (Park and Kim 2013). On a website about abalone aquaculture in Korea, there was no mention of sea ranching being done in Korea—only in on-land and enclosed sea cages (Korea-US Aquaculture n.d.). Therefore, it appears that sea ranching does not contribute significantly to worldwide production. Sea ranching for this assessment will include any traditional sea ranching that may still occur and new forms of sea ranching that are using artificial reefs.

Australia's production is of interest to this report because the United States is now importing a large amount of abalone from Australia (34% of imports). Australia's production systems include a relatively small amount of farming on artificial reefs, in cages suspended off the bottom, and in land-based farms. Land-based systems are by far the most popular system used (MESA 2014) (Government of South Australia 2015), with over 880 metric tons (MT) out of 945 MT of production coming from land-based farms in 2014/2015 (pers. comm., Australia Abalone Growers Association).

Mexico's production occurs mostly at sea, using suspended cages (Abulones Cultivados, S. DE R. L. DE C V. 2008).

Table 1. Worldwide production statistics in 2013 (FAO 2016).

Land Area	Species	Scientific name	2013 (MT)
Africa	Perlemoen abalone	*Haliotis midae*	1,115
Americas	Abalones	*Haliotis* spp.	209
	Japanese abalone	*Haliotis discus*	23
	Red abalone	*Haliotis rufescens*	1,171
Total Americas			1,403
Asia	Abalones	*Haliotis* spp.	118,006
Europe	Abalones	*Haliotis* spp.	2
	Tuberculate abalone	*Haliotis tuberculata*	10
Total Europe			12
Oceania	Abalones	*Haliotis* spp.	801
Grand total			121,337

Import and Export Sources and Statistics

The U.S. produced about 201 MT of abalone (*Haliotis* spp.) in 2013 and produces an average of about 220 MT each year (range is 175–262 MT over 10 years). Interestingly, the United States imports a large percentage (about 34% in 2015) of abalone products from Australia rather than

Asian countries, where most production takes place (Figure 2). U.S. imports of abalone products from Australia have increased significantly, from 57,528 kg in 2010 to 262,874 kg in 2015 (NOAA 2016).

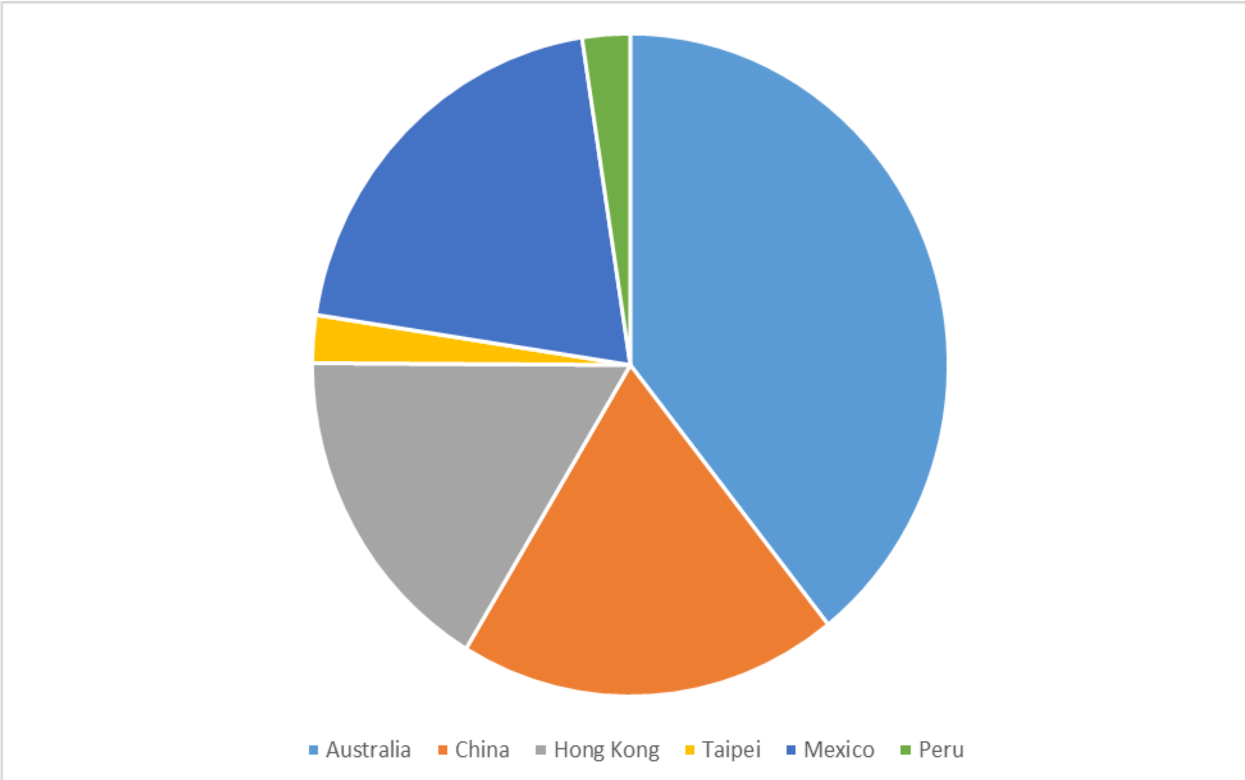

Figure 2. Sources of United States abalone imports in 2015. All countries that accounted for less than 10,000 kg of United States imports were omitted (NOAA 2016).

The following equation was used to determine the total abalone left in the U.S. for consumption:

(production + imports) – (exports + re-exports) = total left in the U.S. for consumption.

This was the finding:

(250,000 [estimated from Cook 2014] + 775,625) – (593,732 + 411,085) = 1,025,625 – 1,004,817 = 20,808 kg.

It shows a balance of 20,808 kg (20.8 MT) of abalone remaining in the U.S. in 2015 for consumption, although an estimate was used for the production in the U.S. Also, the U.S. export value is greater than the production value, which is confusing because exports should include only domestic products. Therefore, although the data for imports and exports are available, they are somewhat inconsistent. Industry contacts in the U.S. suggested that the amount of abalone consumed in the U.S. is undoubtedly larger than 20.8 MT. The Monterey Abalone Co., a farm in California, produces approximately 7–10 tons per year, none of which is exported. There are five other farms in California, most of which produce much more than the Monterey Abalone Co., and they export little, if any, product (pers. comm., Monterey Abalone Co. 2016).

Common and Market Names

Scientific Name	*Haliotis* spp.
Common Name	Abalone

Product forms

The U.S. imports and exports the following abalone products:

- Abalone frozen/dried/salted/brine
- Abalone live/fresh
- Abalone prepared/preserved
- Abalone products prepared dinners

Analysis

Scoring guide

- With the exception of the exceptional criteria (8X, 9X and 10X), all scores result in a zero to ten final score for the criterion and the overall final rating. A zero score indicates poor performance, while a score of ten indicates high performance. In contrast, the three exceptional criteria result in negative scores from zero to minus ten, and in these cases, zero indicates no negative impact.
- The full Seafood Watch Aquaculture Standard that the following scores relate to are available on the Seafood Watch here and by navigating through our website, www.seafoodwatch.org.

Criterion 1: Data Quality and Availability

Impact, unit of sustainability and principle

- Impact: poor data quality and availability limits the ability to assess and understand the impacts of aquaculture production. It also does not enable informed choices for seafood purchasers, nor enable businesses to be held accountable for their impacts.
- Sustainability unit: the ability to make a robust sustainability assessment
- Principle: having robust and up-to-date information on production practices and their impacts publicly available.

Criterion 1 Summary

Enclosed Farms (on land and at sea)

Data Category	Data Quality	Score (0–10)
Industry or production statistics	7.5	7.5
Management	10	10
Effluent	10	10
Habitat	7.5	7.5
Chemical use	5	5
Feed	7.5	7.5
Escapes	7.5	7.5
Disease	7.5	7.5
Source of stock	10	10
Predators and wildlife	5	5
Introduced species	7.5	7.5
Other (e.g., GHG emissions)	Not Applicable	n/a
Total		**85**

C1 Data Final Score (0–10)	**7.73**	**GREEN**

Sea Ranches

Data Category	Data Quality	Score (0–10)
Industry or production statistics	5	5
Management	7.5	7.5
Effluent	10	10
Habitat	7.5	7.5

Chemical use	5	5
Feed	7.5	7.5
Escapes	7.5	7.5
Disease	7.5	7.5
Source of stock	10	10
Predators and wildlife	5	5
Introduced species	7.5	7.5
Other (e.g., GHG emissions)	Not Applicable	n/a
Total		**80**

C1 Data Final Score (0–10)	**7.27**	**GREEN**

Brief Summary

An update of this assessment was conducted in March 2022. This criterion was updated with new information. The update can be found in Appendix 2 at the end of this document.

Although the availability of reliable data varies between countries, this assessment applies to the global abalone farming industry as a whole, including both enclosed and sea-ranching methods of aquaculture. Because the industry is still developing, a large amount of data sharing is taking place among commercial operations and research institutions. In particular, efforts by the World Wildlife Fund (WWF) and the Aquaculture Stewardship Council (ASC) have led to global dialogues and the development of guidelines for best industry practices. It should be noted that the availability of data for farming operations in China and other parts of Asia is somewhat limited, and the assessment for the sustainability of abalone farmed in these areas may be less robust. But the farming techniques being used are similar worldwide and thus can be assessed together. The combination of published research, publicly available information, increasing commercial efficiency, government regulation, and the development of industry standards has resulted in the free flow of information and a high level of industry transparency. The final score for Criterion 1—Data is 7.73 out of 10 for enclosed farms and 7.27 out of 10 for sea ranches.

Justification of Rating

Industry or Production Statistics:

Industry and production statistics are available through national reporting services (e.g., NOAA) and international organizations (e.g., FAO) as well as industry participants. Although information is generally readily available, it is unclear how accurate the numbers are, particularly from countries that are known for inaccurate reporting. In some cases, projections or estimates are used to fill in information gaps. In many cases, it is unclear whether abalone is coming from enclosed or sea-ranch aquaculture methods. Most abalone is produced through enclosed systems, and information for this type of farming is generally readily available. Sea ranching is less common, and information on its production and methods are less available.

Enclosed farms score 7.5 out of 10 for industry or production statistics, while sea ranching scores 5 out of 10 for industry or production statistics.

Management:

The abalone industry appears to be well managed, with international cooperation on the development of industry practices and regional implementation bodies (government departments and industry organizations). Though management measures for enclosed methods are in place and still being developed, management measures for sea ranching are still in their infancy, especially for new methods involving the use of "abitats." Because of collapsed wild stocks and three species of abalone being endangered, additional research has evaluated the potential to use aquaculture as a means of seeding and supplementing wild stocks. Enclosed aquaculture scores 10 in management data and sea ranching scores 7.5 out of 10.

Effluent:

Data on the effects of abalone farm effluent are available from peer-reviewed resources. Even though there is not an abundance of material on this subject, it is acceptable because the body of literature generally concludes that effluent from abalone farms is not considered to negatively affect the surrounding environment. Both enclosed and sea-ranched abalone score 10 out of 10 for effluent data.

Habitat:

Data on the effect of abalone farming on surrounding habitat are available to some extent from peer-reviewed sources. Scoring was based somewhat on information available about abalone farming in general, which did not directly mention the impact on surrounding habitat but described farming methods. Enclosed farms can be considered minimally destructive to natural habitat, but some gaps in data include the effects to which sea-based cages might shade or scour the seafloor and the effects of farm siting on coastal lands. Sea ranches have an obvious impact on marine benthic habitat, in particular the use of "abitats," which involve placing large structures on the seafloor. The effects of sea ranching are not well described. In most cases, sea-ranching methods hope to actually improve habitat for naturally occurring organisms, but little data are available on this. Enclosed farms and sea ranches both score 7.5 out of 10 for habitat data.

Chemical Use:

Little data are available about the use of chemicals in abalone farming, namely because of the general lack of chemical use in the industry. Chemical use is limited to the use of a small amount of gamma-aminobutyric acid (GABA), which is used only for larval settlement, cleaning products, and potentially for anti-fouling chemicals on sea-based cages. There is little chemical use in abalone farming, especially compared to many other types of aquaculture; however, because of the lack of data on the subject, it is hard to determine to what extent some chemicals are used (primarily anti-foulants). Both enclosed farms and sea ranches score 5 out of 10 for chemical use data.

Feed:
There are data available on feeding needs and methods for abalone aquaculture. Abalone is an herbivore and is often fed its natural diet of algae and seaweed. But there may be some use of pelletized feeds that contain small amounts of fishmeal or oils. It is unknown to what extent feeding may be supplemented by pelletized feed. Feeds are still being developed to meet the needs of the industry, and it seems that most food for abalone comes from natural and sustainable sources. Both enclosed farming and sea ranches score 7.5 out of 10 for data on feed.

Escapes:
There is a fair amount of literature available on the potential for "seeding" of abalone in areas where natural populations have diminished. There is also information on the farming of native and nonnative species. In areas where nonnative species are farmed, there may be more of a risk that escapes could harm the natural ecosystem. The data on escapes do not effectively indicate the potential for escapes to harm the environment. Enclosed farms and sea ranches both score 7.5 out of 10.

Disease:
There is a large amount of data and information available on diseases that have affected the abalone aquaculture industry as well as natural populations. Peer-reviewed articles are available, as are public reports and government documents. Enclosed farms and sea ranches both score 7.5 out of 10 for data on disease.

Source of Stock:
Information is available on the source of stock for abalone aquaculture. There is little concern over this topic, because most stock comes from local hatchery-reared seed. Both enclosed farms and sea ranches score 10 out of 10 for data on source of stock.

Predators and Wildlife:
There is not an abundance of information on wildlife and predators on abalone farms. Most information on this is anecdotal and simply states that predators are removed from farms, without indicating mortality. Enclosed farms and sea ranches both score 5 out of 10.

Introduced Species:
There is not much information available on introduced species resulting from abalone farming. This is somewhat acceptable: there is little concern about this topic because there is no international or transbody shipment of animals. Both enclosed farms and sea ranches score 7.5 out of 10.

Conclusions and final score
Overall data quality and availability for abalone aquaculture are good. Many of the gaps in data can likely be attributed to the relative newness and sustainability of the industry compared to many other forms of aquaculture.

The final numerical score for Criterion 1—Data is 7.73 out of 10 for enclosed abalone aquaculture and 7.27 out of 10 for sea ranched abalone.

Criterion 2: Effluent

Impact, unit of sustainability, and principle

- Impact: aquaculture species, production systems, and management methods vary in the amount of waste produced and discharged per unit of production. The combined discharge of farms, groups of farms, or industries contributes to local and regional nutrient loads.
- Sustainability unit: the carrying or assimilative capacity of the local and regional receiving waters beyond the farm or its allowable zone of effect.
- Principle: not allowing effluent discharges to exceed, or contribute to exceeding, the carrying capacity of receiving waters at the local or regional level.

Criterion 2 Summary

Enclosed and Sea-Ranched

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**9**	**GREEN**

Brief Summary

The effluent produced through abalone farms is discharged into the ocean, but it is low in nitrogen. There are regulations that control the actions of abalone farms, and even though the level of enforcement for regulations may not be clear in all cases, effluent from abalone farms is not considered to have adverse effects on the natural environment. The criterion for effluent score is 9 out of 10.

Justification of Rating

Because effluent data quality and availability are good (i.e., the Criterion 1 score was 10 out of 10 for the effluent category), the evidence-based assessment was utilized.

In its post-larval form, abalone consumes algal films that form naturally on surfaces inside the holding tanks. As a larger juvenile and adult, abalone consumes locally cultured or harvested macroalgae, or naturally growing algae (Flores-Aguilar et al. 2007) (Allsopp et al. 2011) (del Vino Viera Toledo 2014). There may also be some use of low-nutrient-content feed in intensive aquaculture (Gavine and McKinnon 2002). Brown algae (*Macrocystis* spp. and *Laminaria* spp.) are most commonly used as feed for juvenile and adult abalone (Allsopp et al. 2011) (FAO 2010) (Flores-Aguilar et al. 2007) (Munoz et al. 2011) (Perez-Estrada et al. 2011) (Wu 2007). No additional fertilizer is used for the culture of abalone or its feed (Hernandez et al. 2009). Biological waste in abalone farm discharge tends to be low in nitrogen; approximately 7.2 kg N is produced per ton of abalone raised to market size (Probyn et al. 2015), and outflows measure well below the standards set out by the Abalone Aquaculture Dialogue Standards (43 umol N l^{-1}) (ASC 2012). Additionally, when comparing abalone farm effluent to ambient seawater, the effluent is not considered to pose a significant risk to the environment (Probyn et al. 2015). Whether abalone is grown in tanks on land, in cages at sea, or on a sea ranch, 100% of its waste is discharged into the ocean (Allsopp et al. 2011) (Godoy and Jerez 1998). Because of the low nutrient content of abalone feeds (seaweeds, or pelletized feed), low feeding rates, and the relatively low stocking densities, growth rate, and production, adverse effects on water and sediment quality are unlikely (Gavine and McKinnon 2002). Abalone requires good water quality for survival, and the health of the farmed abalone would likely decline long before any serious impacts on the water or sediment quality could be seen (Gavine and McKinnon 2002).

Abalone culture operations are subject to local and national environmental regulations. For example, in Chile, federal regulations require suspended solids, oxygen, ammonia, and temperature (among other factors) to be monitored continuously (Allsopp et al. 2011). Exact monitoring requirements vary depending on the size of the farm, its location, and the feed used (Allsopp et al. 2011). In Australia and New Zealand, trigger values have been established for a range of local physical and chemical stressors, as well as toxicants, in aquatic ecosystems. Therefore, these parameters are monitored on farms; if levels become unacceptable, then further investigation will begin (Probyn et al. 2015). But the information available about some areas is unclear as to whether these laws are adequately enforced.

The final score for Criterion 2—Effluent is 9 out of 10 for both enclosed farms and sea ranches.

Criterion 3: Habitat

Impact, unit of sustainability, and principle

- Impact: Aquaculture farms can be located in a wide variety of aquatic and terrestrial habitat types and have greatly varying levels of impact to both pristine and previously modified habitats and to the critical "ecosystem services" they provide.
- Sustainability unit: The ability to maintain the critical ecosystem services relevant to the habitat type.
- Principle: being located at sites, scales, and intensities that maintain the functionality of ecologically valuable habitats.

Criterion 3 Summary

Enclosed Farms

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		8
F3.2a Content of habitat regulations	3	
F3.2b Enforcement of habitat regulations	4	
F3.2 Regulatory or management effectiveness score		4.8
C3 Habitat Final Score (0–10)		**6.93**
Critical?	NO	**GREEN**

Sea-Ranching: *This method was updated with new information in March 2022. The update can be found in Appendix 2 at the end of this document. Resulting scores of the update are shown here.*

Habitat parameters	Value	Score
F3.1 Habitat conversion and function		9
F3.2a Content of habitat regulations	5	
F3.2b Enforcement of habitat regulations	4	
F3.2 Regulatory or management effectiveness score		8
C3 Habitat Final Score (0–10)		**8.67**
Critical?	NO	**GREEN**

Brief Summary

An update of this assessment was conducted in March 2022. This criterion was updated with new information. The update can be found in Appendix 2 at the end of this document.

Sea-based enclosures used for abalone farming may allow for the deposition of organic matter beneath arrays, but these impacts are minor and do not significantly alter the functionality of the ecosystem. Similarly, land-based facilities are typically sited on coastal lands, but do not result in large-scale or ecologically destructive conversion. Traditional sea ranching can be highly destructive and result in a great loss of habitat functionality from the clearing of ranching sites. Although this practice is still occurring, more modern forms of ranching (i.e., artificial reef farming) are being developed to enhance and restore otherwise unproductive areas on the seafloor. Because of the differences in habitat conversion and impact, Factor 3.1 is scored 8 out of 10 for enclosed farming and 2 out of 10 for sea ranching. The contents of management measures are largely similar and robust, though the potential for clearance of benthic habitats for sea ranching cannot be considered to be entirely based on ecological principles. Management effectiveness is typically strong, but some concern exists in some regions. Ultimately, the score for Criterion 3—Habitat is 6.93 for enclosed farms and 2.4 for sea ranches.

Justification of Rating

Factor 3.1. Habitat conversion and function

All larval production occurs in tanks at land-based facilities. The degree of habitat conversion and impact depends almost exclusively on the producer's choice of abalone growout method.

<u>Enclosed Growout</u>

Enclosed growout typically occurs in enclosures at sea or in land-based raceway tanks, which direct the flow of water around the tank to ensure adequate aeration.

Asia is the world's largest producer of abalone (Jia and Chen 2001), farming in raft, pen, tunnel, and cage enclosures; in indoor, land-based tanks; and via open water sea ranching (del Vino Viera Toledo 2014) (Hishamunda and Subasinghe 2003) (Jia and Chen 2001). It has recently been reported that traditional sea-ranching operations no longer represent much of the industry in Asia, with almost all farming (95%) being done in multi-tier growout baskets (Cook 2014) (Wu, Liu, Zhang and Wang 2009) (Wu and Zhang 2013). Enclosed growout methods are also the most common forms of abalone farming in all the countries under consideration (Abulones Cultivados, S. DE R. L. DE C V. 2008) (Allsopp et al. 2011).

Sea-based enclosures used to farm abalone include cages of various designs tethered to wharves, barges, or buoys, thus minimizing an operation's footprint above the seafloor (Godoy and Jerez 1998). For those enclosure arrays using moorings to maintain their position in the water, their contact with the seabed is only at those mooring points (Figure 3). Some Korean research has shown that, although sediments directly beneath highly intensive cage farming of abalone have had an accumulation of organic matter, a decrease in pH, and reductive conditions, the sediments on the industry's perimeter remained oxic (Kang et al. 2015). In addition, other research in the same intensively farmed region has shown the benthic impacts directly beneath abalone cages to be not significant (Oh et al. 2015). Though the direct impact of these enclosures on the benthic habitat is typically minor, there is some additional concern that they shade and scour the seabed, particularly in areas with seagrass beds or reefs (DOF WA 2010) (EPA South Australia 2007). The proposed guidelines for certification by the Aquaculture Stewardship Council (ASC), for example, recommend that tethered cages be located over sandy or muddy seafloors to minimize the risk of environmental impact and stock escapes. Many abalone farming regions have guidelines in place for farm siting and will strongly oppose any operations that may negatively affect sensitive habitats, such as seagrass beds, marine reefs, and coastal dunes (EPA South Australia 2007). Ultimately, sea-based enclosures used for abalone farming have little, if any, direct contact with the benthos, and the impact of metabolic and other waste deposition is typically minor and localized. There is some concern that enclosure arrays will shade benthic habitats, but impacts to the ecology of those habitats is considered "unlikely" (DOF WA 2010).

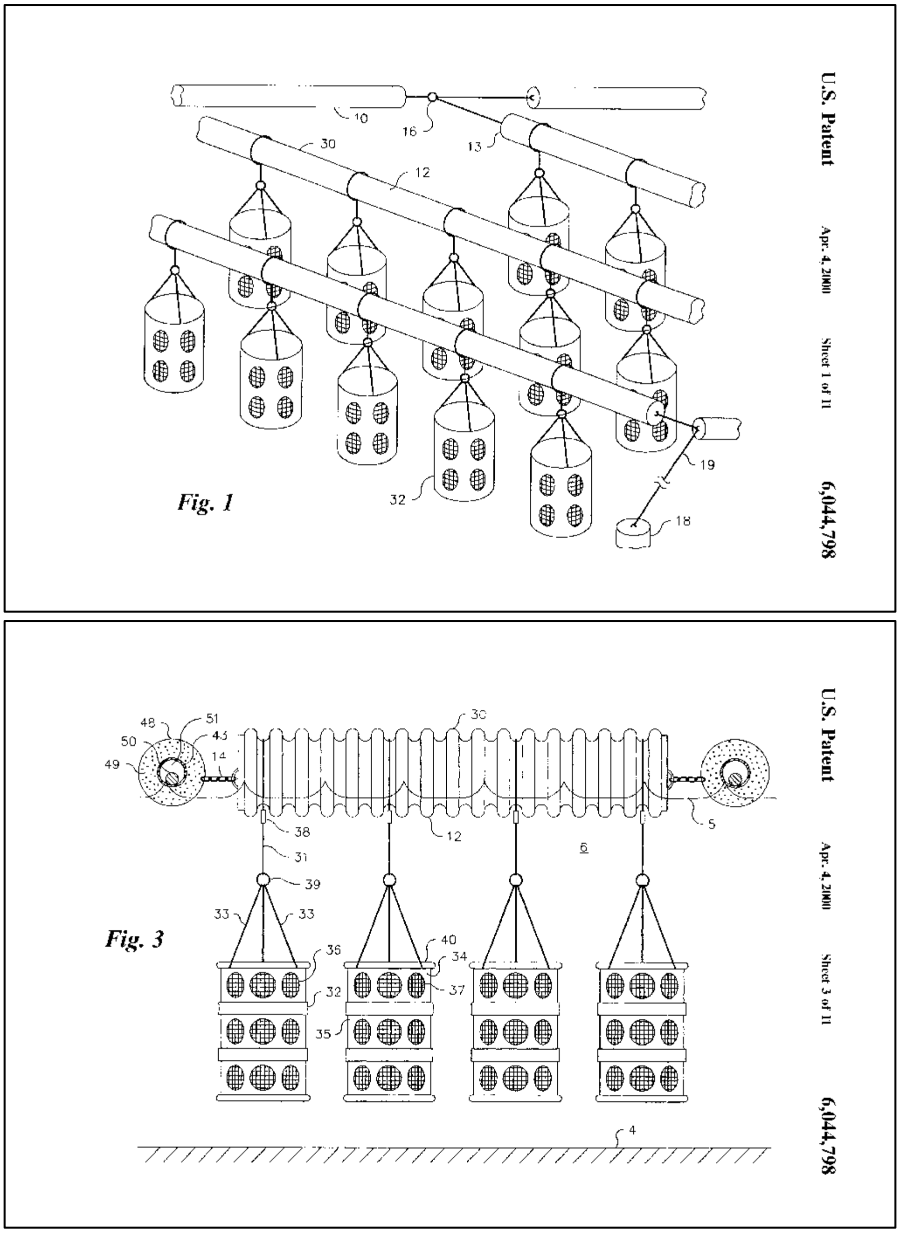

Figure 3. Examples of sea-based cages (https://www.google.com/patents/US6044798).

For land-based operations, siting of farms must consider the volume of water required to be pumped to the facility, and in that respect, farms are often located on the coast, near the water (e.g., Figure 4). The Abalone Aquaculture Dialogue (WWF 2010) discusses concerns with land-based abalone farms, which included farm siting and infrastructure that could cause destruction of coastal habitats and, for human users, could limit access to public land or be aesthetically unappealing. Coastal aquaculture activities have received negative attention, mostly because of coastal shrimp farming, which has destroyed huge areas of mangrove forest (Primavera 2006), though the scale of habitat conversion for shrimp farming and other agriculture activities is considerably more than that for land-based abalone farming. Indeed, there is little evidence in the literature that land-based abalone activities negatively affect the functionality of coastal environments and habitats. Nonetheless, it is important to consider the potential cumulative impacts on coastal habitats that the expansion of abalone farming may have in the future.

Figure 4. A land-based abalone farm (http://www.mesa.edu.au/aquaculture/aquaculture17.asp).

Sea-based and land-based enclosed farming systems used for abalone growout have typically minor impacts to the habitats in which they are sited. But localized impacts to sediments directly beneath intensive enclosure arrays or to coastal habitats may occur. Overall, the score for Factor 3.1 for enclosed abalone farms is 8 out of 10.

<u>Sea ranching</u>

Sea ranching is assessed here to include traditional sea ranching on the seafloor and sea ranching using artificial reefs. Traditional sea ranching involves "seeding" small juvenile abalone onto areas of the shallow subtidal seafloor, where they grow until large enough to harvest. When used, artificial reefs are situated on the seafloor and serve as a surface for abalone to attach to. In either form of sea ranching, the seafloor may be left in its natural state or it may be heavily modified, with complete removal of undesirable native species and structures or the addition of artificial reefs ("abitats"). Some have reported that newer methods using artificial reefs are in fact improving biodiversity in the vicinity if the farm, where otherwise there was low diversity (Murphy 2016).

Notable to this assessment is the fact that the United States now imports most of its abalone from Australia. Land-based growout facilities dominate the industry in Australia; however, there is some sea ranching being done through the use of artificial reefs in Western Australia (Figure 5). Impacts from abalone ranching may include those associated with artificial habitat construction (including the settlement of introduced organisms) and scouring of the sediments surrounding structures. Abalone ranching activities would be restricted to designated aquaculture zones, as is the case for all marine aquaculture in Crown waters, so related impacts would be expected to be contained within these zones (Gavine and McKinnon 2002).

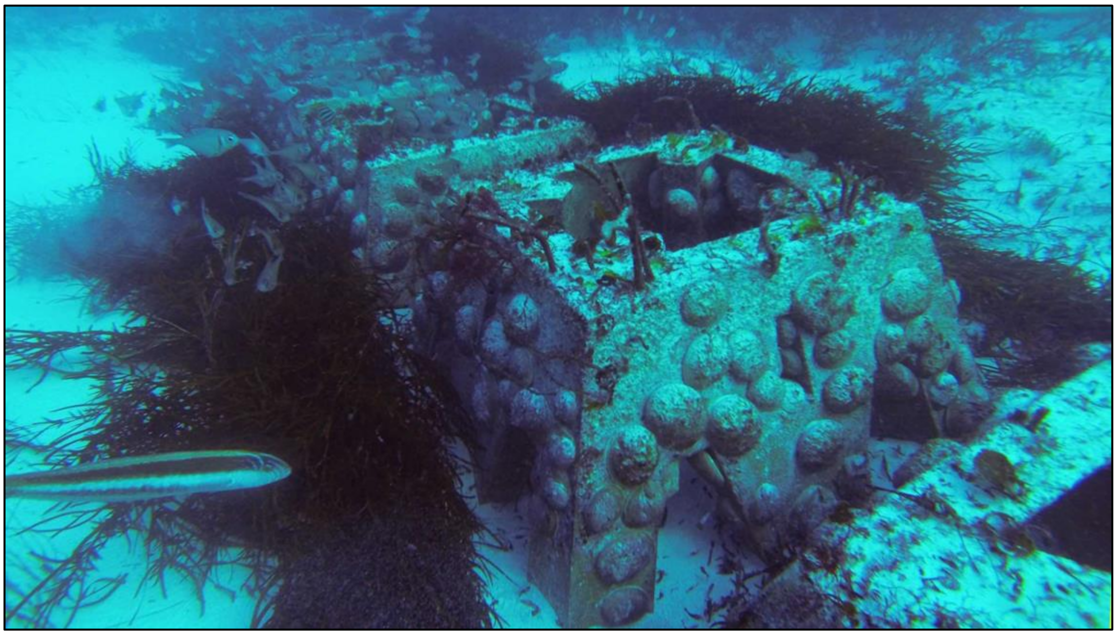

Figure 5. Artificial reef structure in Flinders Bay, Western Australia (http://haejoo.com/ocean-grown-abalones-greenlip-abalone-ranching-research-project/).

As a result of the employment of clearing practices of inshore subtidal benthic habitats for abalone sea ranching, the score for Factor 3.1 for sea ranching is 2 out of 10.

The score for Factor 3.1 is 8 out of 10 for enclosed farms and 2 out of 10 for sea ranches.

Factor 3.2. Farm siting regulation and management

<u>Factor 3.2a: Content of habitat management measures</u>
In all regions, the siting and operation of growout facilities are subject to legal restrictions. Though countries vary in the extent of regulations, most major suppliers of abalone to U.S. markets have robust legal systems in place to protect surrounding habitats.

<u>United States</u>
American abalone farms are located in California, Oregon, and Hawaii, where they are subject to state and federal conservation laws (Elston and Ford 2011) (USDA 1995) (USDA 2007).

Chile

Chilean abalone farming is restricted on both a regional and a federal basis (Flores-Aguilar et al. 2007) (Godoy and Jerez 1998). Environmental assessment and government agency review are required before the introduction of new stock species and growout locations, and consideration is given to the presence of aquaculture operations for other species (Flores-Aguilar et al. 2007) (Godoy and Jerez 1998). In some regions, the harvest of kelp for feed is also restricted by permits (Allsopp et al. 2011) (Flores-Aguilar et al. 2007).

Australia

Australian aquaculture is overseen by state and federal agencies, under the Department of Agriculture, Fisheries and Forestry, with a strong legal framework for environmental management, protection, and enforcement (Tailby and Gant 2002). Relevant legal documents include the Environmental Protection Act (1993) and the Aquaculture Act (2001), along with many others on waste management and disease control (EPA South Australia 2007).

Japan and China

Chinese aquaculture operations are managed by the Bureau of Fisheries, while Japanese aquaculture is managed by the Fisheries Agency under the Ministry of Agriculture, Forestry and Fisheries. Both Chinese and Japanese governments subsidize abalone aquaculture, including sea ranching operations (James et al. 2007). Ranch and enclosure farming locations are assigned by permit, but it is unclear how much weight environmental considerations are given in permit decisions (FAO China) (FAO Japan).

Generally, the content of management measures governing abalone aquaculture is moderately strong, but expansion control and area-based siting management is uncertain on a global scale. But because sea-ranching abalone farms can completely clear benthic habitats, the management systems that govern them cannot be considered to be entirely based on ecological principles. Thus, the score for Factor 3.2a is 3 out of 5 for enclosed farms and 2 out of 5 for sea ranches.

Factor 3.2b: Enforcement of habitat management measures

Enforcement of habitat management measures varies between countries that export to the United States. Most countries assessed here have adequate legal structures in place for management and enforcement.

United States

Federal enforcement is carried out by a number of agencies, including the Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the U.S. Fish and Wildlife Service (FWS), and the National Marine Fisheries Service (NMFS) (Elston and Ford 2011) (USDA 1995) (USDA 2007). In California, the Department of Fish and Wildlife (CDFW) is considered the “lead agency” for aquaculture. CDFW regulates abalone farm siting and management. The California Coastal Commission also restrictively regulates farm siting and management (pers. comm., Monterey Abalone Co. 2016).

Chile

Enforcement of regulations is considered robust in Chile (Allsopp et al. 2011) (Flores-Aguilar et al. 2007) (Godoy and Jerez 1998).

Australia

Australia has a strong legal framework for environmental management, protection, and enforcement (Government of Western Australia 2013) (Tailby and Gant 2002). State and territory governments have the primary legal responsibility for land and waters within the 3 nautical mile limit, and the Australian Government has responsibility to the 200 nautical mile limit (FAO 2010).

Japan and China

There are serious concerns about the effectiveness of environmental law enforcement by Chinese and Japanese agencies (FAO China) (FAO Japan). Both Chinese and Japanese governments subsidize abalone aquaculture, including sea-ranching operations (James et al. 2007).

The enforcement of management measures is generally effective for both enclosed farms and sea ranches, because organizations are identifiable and contactable, and permitting is often transparent, though there are uncertainties for efficacy in some countries. Ultimately, the score for Factor 3.2b is 4 out of 5 for both enclosed farms and sea ranches.

When combined with the Factor 3.2a score, the final Factor 3.2 score is 4.8 out of 10 for enclosed farms and 3.2 out of 10 for sea ranches.

Conclusions and final score

Although it is clear that variation exists in the content and enforcement of regulations in different production countries, there is a low risk of habitat damage from enclosed production systems. There are still some unknown effects such as shading and scouring that may occur in enclosed, sea-based systems. Sea ranches alter marine habitat extensively and although improved methods are being developed, there may still be serious effects on marine habitat.

Factors 3.1 and 3.2 combine to give a final Criterion 3—Habitat score of 6.93 out of 10 for enclosed farms and 2.40 out of 10 for sea ranches.

Criterion 4: Evidence or Risk of Chemical Use

Impact, unit of sustainability, and principle

- Impact: Improper use of chemical treatments impacts nontarget organisms and leads to production losses and human health concerns due to the development of chemical-resistant organisms.
- Sustainability unit: nontarget organisms in the local or regional environment, presence of pathogens or parasites resistant to important treatments
- Principle: limiting the type, frequency of use, total use, or discharge of chemicals to levels representing a low risk of impact to nontarget organisms.

Criterion 4 Summary

Enclosed and Sea-Ranched

Chemical Use parameters	Score	
C4 Chemical Use Score (0–10)	**8**	
Critical?	NO	**GREEN**

Brief Summary

There is minor concern about chemical use in abalone aquaculture. Because antibiotics are largely ineffective for treatment of disease in abalone, their use in the industry is largely absent. Antifoulants and disinfectants generally pose less risk of ecological impact than chemicals used in other types of aquaculture, but some antifoulants and disinfectants may be used on abalone farm infrastructure and equipment. There is no evidence suggesting that chemical use in abalone aquaculture is harming the environment, but there is some risk that applied chemicals could accumulate in poorly flushed or intensively farmed areas. The final score for Criterion 4—Chemicals is 8 out of 10.

Justification of Rating

Abalone culture is largely free of the chemicals, particularly antibiotics, found in other forms of intensive aquaculture. Antibiotic use is common in the farming of other species, particularly finfish, but available evidence suggests that antibiotic use in abalone farming is either minimal or, more commonly, nonexistent (Henton 2010) (Bailey 2015) (The Cultured Abalone Farm 2015). Importantly, a volume of research has shown that the use of antibiotics for treatment of disease in abalone is largely ineffective, citing issues with administration, absorption, prolonged residue presence, insufficient efficacy, impaired growth, and reduced survival (Hadlinger et al. 2001) (Hadlinger et al. 2002) (Hadlinger et al. 2005) (Hadlinger et al. 2006) (Anguiano-Beltrán and Searcy-Bernal 2007).

Larval settlement during the hatchery phase is induced with a synthesized, concentrated form of gamma-aminobutyric acid (GABA), which is naturally found in the red coralline algae preferred by larval abalone in the wild. Some operations may treat ocean-based cages and enclosures with antifouling chemicals, and land-based aquaculture requires the use of general disinfectants to maintain sanitary conditions. Hatchery and growout facilities ultimately discharge their wastewater into the environment, potentially introducing these chemicals into the marine environment (BCSGA 2012). Although many areas have wastewater treatment regulations in place to decrease the chance of any chemicals from abalone aquaculture entering the marine environment (EPA South Australia 2007), there is some potential for the accumulation of chemicals in poorly flushed receiving waterbodies or where the industry is concentrated.

Conclusions and final score

There is only minor concern for the use of chemicals in abalone aquaculture.

The final numerical score for Criterion 4—Chemical Use is 8 out of 10 for both enclosed farms and sea ranches.

Criterion 5: Feed

Impact, unit of sustainability, and principle

- Impact: feed consumption, feed type, ingredients used, and the net nutritional gains or losses vary dramatically between farmed species and production systems. Producing feeds and their ingredients has complex global ecological impacts, and their efficiency of conversion can result in net food gains, or dramatic net losses of nutrients. Feed use is considered to be one of the defining factors of aquaculture sustainability.
- Sustainability unit: the amount and sustainability of wild fish caught for feeding to farmed fish, the global impacts of harvesting or cultivating feed ingredients, and the net nutritional gains or losses from the farming operation.
- Principle: sourcing sustainable feed ingredients and converting them efficiently with net edible nutrition gains.

Criterion 5 Summary

Enclosed and Sea-Ranched

Feed parameters	Value	Score
F5.1a Feed Fish Efficiency Ratio (FFER)	0.00	10.00
F5.1b Source fishery sustainability score	0.00	
F5.1: Wild fish use score		10.00
F5.2a Protein IN (kg/100 kg fish harvested)	20.53	
F5.2b Protein OUT (kg/100 kg fish harvested)	22.01	
F5.2: Net Protein Gain or Loss (%)	7.24	10
F5.3: Feed Footprint (hectares)	0.00	10
C5 Feed Final Score (0–10)		**10.00**
Critical?	NO	**GREEN**

Brief Summary

In the wild, abalone is an herbivore, consuming only micro- and macroalgae over the course of its life. Some aquaculture operations supplement algal feed with feeds that contain quite small amounts of fishmeal protein, but this practice is relatively rare. In general, cultured abalone does not consume any wild fish, has a small feed footprint, and produces a net gain in edible protein. Algae harvest is generally regulated, and harvested biomass regrows quickly. Abalone feed is therefore considered to be quite sustainable, and this criterion scored 10 out of 10.

Justification of Rating

Factor 5.1. Wild Fish Use

Factor 5.1a—Feed Fish Efficiency Ratio (FFER)
No wild fish is used for feed. Macroalgae are harvested by hand or by mower from wild or cultured stocks. In nearly all cases, these algae are not used for human consumption.

The score for Factor 5.1a—Feed Fish Efficiency Ratio is 10 out of 10.

Factor 5.1b—Sustainability of the Source of Wild Fish
No wild fish is used for feed. Macroalgae are harvested by hand or by mower from wild or cultured stocks. In nearly all cases, these algae are not used for human consumption.

When combined, the Factor 5.1a and Factor 5.1b scores result in a final Factor 5.1 score of 10 out of 10.

Factor 5.2. Net Protein Gain or Loss
The FFER ratio for abalone is zero because abalone is an herbivore. Abalone is primarily fed with kelp and other macroalgae, which are rapidly renewable resources. Abalone and macroalgae share many of the same growing conditions, facilitating the use of locally harvested feed. Kelp and other algae are harvested from wild or cultured sources by third-party suppliers or the aquaculture operations themselves using mowers or hand collection (Allsopp et al. 2011) (Munoz et al. 2011), frequently under permit or other regulatory oversight (Flores-Aguilar et al. 2007) (McBride 1998) (Perez-Estrada et al. 2011).

Some abalone aquaculturists supplement algal feed with proteins from fishmeal and soy, particularly in Australia, Korea, and some regions of Chile (FitzGerald 2008) (Korea-US Aquaculture n.d.). Feeds are still under development because abalone is a slow grazer and pellets need to stay intact for an extended period of time underwater in order to be consumed. Also, new feeds are being developed that contain plant proteins, with little use of fishmeal or oils (MISA 2012). Because kelp is an adequate and typically inexpensive food source, the use of artificial feed appears to be rare in the countries included in this assessment, and sustainable feed sources for aquaculture are now highly sought after by consumers, encouraging the industry to stick with sustainable feed sources (WWF 2010) (del Pino Viera Toledo 2014).

Macroalgae used as abalone feed have a protein content of approximately 11.7%–27.4% (dry weight), depending on species (Hernandez et al. 2009). At harvest, approximately 35%–40% of the abalone is edible; the rest of the animal consists of shell and viscera (American Abalone Farms). Harvested and processed abalone meat has a protein content of approximately 17.1% wet weight (Hernandez et al. 2009). But the most significant factor in this calculation is that macroalgae used as abalone feed are not used for human consumption.

Protein in feeds used for abalone species globally are sourced from 100% marine ingredients, 0% crop ingredients, and 0% land animal ingredients. One hundred percent of the protein provided is considered to come from sources not suitable for human consumption. There is an overall net edible protein gain of 7.24%, leading to a Factor 5.2 score of 10 out of 10.

Factor 5.3. Feed Footprint

To produce the most conservative sustainability evaluations, data for the most intensive grazing scenarios were used. Abalone grazing rates depend on water temperature, abalone species and size, and type of algae being consumed. An adult red abalone (*Haliotis rufescens*) of average pre-market size (shell length 9 cm/3.5 in, live weight 100 g/0.2 lbs) consuming a typical diet of brown algae (*Macrocystis* spp.) in temperate waters (14 °C/57 °F) will eat 1%–2% of its body weight per day (Winter and Estes 1998). An average-sized abalone farm holds 2 million abalone, of which approximately 500,000 will be adults in the growout phase (Big Island Abalone 2012). If each abalone were to consume 2% of its body weight every day, the farm would go through 1,000 kg/2,200 lbs of wet kelp per day. For purposes of these calculations, that total kelp weight was converted to the amount of carbon contained in the kelp, so these 500,000 abalone consume 44 kg/97 lbs of carbon daily (Zimmerman and Kremer 1986). The weight of 500,000 live abalone in the growout phase is approximately 50 MT, of which 35% is salable meat after harvest. Thus, 500,000 live abalone will produce 17.5 MT of marketable product. Therefore, 1 MT of salable meat requires 2.51 kg of carbon in kelp per day, or 0.918 MT of carbon per year.

Kelp species grow in shallow shelf seas, which have an average annual productivity of 2.68 MT of carbon per hectare per year (Talberth et al 2006). Thus, 1 MT of salable abalone meat requires 0.342 hectare’s worth of ocean productivity per year. Kelp are a rapidly renewable resource, and studies have shown that properly executed harvests have no significant effect on the kelp forest canopy (Donnellan and Foster 1999). In short, macroalgae provide a sustainable, low-impact source of aquaculture feed.

The area necessary for production of marine ingredients required for 1 ton of abalone species is 0.342 ha. The combination of these two values results in an overall feed footprint of 0.342 ha/ton of farmed fish. This results in a final Factor 5.3 score of 10 out of 10.

Conclusions and final score

Abalone feed can be considered extremely sustainable, especially compared to other forms of aquaculture. Seaweeds used for feed are harvested sustainably and regrow quickly. If feeds are used, they are typically made up of plant-based proteins, with little use of fishmeal or oils, but this practice is not considered representative of the global aquaculture industry.

For both enclosed and sea-ranched abalone, Factors 5.1, 5.2, and 5.3 combine to give a final Criterion 5—Feed numerical score of 10 out of 10.

Criterion 6: Escapes

Impact, unit of sustainability, and principle

- Impact: competition, genetic loss, predation, habitat damage, spawning disruption, and other impacts on wild fish and ecosystems resulting from the escape of native, non-native and/or genetically distinct fish or other unintended species from aquaculture operations
- Sustainability unit: affected ecosystems and/or associated wild populations.
- Principle: preventing population-level impacts to wild species or other ecosystem-level impacts from farm escapes.

Criterion 6 Summary

Enclosed and Sea-Ranched

Escape parameters	Value	Score
F6.1 System escape risk	4	
F6.1 Recapture adjustment	0	
F6.1 Final escape risk score		4
F6.2 Invasiveness		5
C6 Escape Final Score (0–10)		**4**
Critical?	NO	**YELLOW**

Brief Summary

An update of this assessment was conducted in March 2022. This criterion was updated with new information. The update can be found in Appendix 2 at the end of this document.

Because abalone is a benthic- and substrate-oriented organism, there is only a minor risk that farmed juvenile or adult abalone will escape from their farming infrastructure and move away from the farming location. There is a greater risk that spawning events occur during growout, potentially releasing large numbers of eggs to receiving ecosystems. Ultimately, the escape risk for all abalone aquaculture is moderate. Considering the historically poor success of intentional stocking efforts, it is not likely that escapees would establish outside of farms, and competition for resources is likely low. The majority of abalone farms raise locally native species, reducing the risk of ecological harm from non-native escapees, though selective breeding for multiple generations has generally rendered farm-origin abalone genetically distinct from their wild counterparts. Where non-native species are produced, they may or may not already be present in surrounding habitats. In some locations, the potential exists for non-native species to escape and establish themselves in local marine habitats. Overall, there is a moderate risk of escape; although competitive impacts are likely low, there is a potential for genetic hybridization between farm-origin and wild abalone. The final score for Criterion 6—Escapes is 4 out of 10.

Justification of Rating

Factor 6.1. Escape risk

Sea-based enclosures, raceways, and flow-through tanks all carry an inherent risk of escape by juvenile or adult individuals because of failure of enclosures or effluent screens, or by larvae because of adult spawning. This potential is frequently addressed in environmental impact reviews for growout enclosure siting (Allsopp 2011) (Hawkins and Jones 2010). Escape risk particularly becomes a concern when there is translocation of animals for aquaculture. For example, in Western Australia, juvenile abalone were brought in from South Australia for aquaculture purposes (Hawkins and Jones 2010), though current practices for sea farming do not include translocations (pers. comm., Australia Abalone Growers Association 2016). There is potential for the genotype of wild native stocks to be compromised if the imported abalone escape or spawn (Hawkins and Jones 2010). There are translocation protocols in place to minimize the risk of escapes (Victoria State Government 2007) (EPA 2007). Because abalone are raised in habitats suitable for their survival, there is estimated to be no mortality of juvenile or adult escapees.

The score for Factor 6.1 is 4 out of 10.

Factor 6.2. Invasiveness

Approximately 55 to 100 species of abalone can be found worldwide. Of these, approximately 15 are farmed in aquaculture, about half of which can be found in U.S. markets. Some of these species are grown in regions to which they are native, while others are not. In order to produce a single score for internationally farmed abalone, the most conservative numbers have been used.

<u>United States</u>

Aquaculture operations in California farm red abalone (*Haliotis rufescens*), green abalone (*H. fulgens*), and pink abalone (*H. corrugata*), and all three are native to the U.S. West Coast (Allsopp 2011). Big Island Abalone, a newer aquaculture operation in Hawaii, farms Japanese abalone (*H. discus hannai*), which is not native to the Hawaiian Islands (Big Island Abalone 2012).

<u>Australia</u>

Australian farms grow greenlip abalone (*H. laevigata*), blacklip abalone (*H. rubra*), and a hybrid of the two species known as the “tiger” abalone (*H. laevigata* x *H. rubra*). Though the greenlip and blacklip are native to the Australian coast, the tiger hybrid is exclusive to aquaculture (Allsopp 2011) (Guo 2009).

<u>Mexico</u>

A small number of Mexican abalone farms are located along the Baja Peninsula, where they grow the native red abalone (*H. rufescens*), green abalone (*H. fulgens*), and pink abalone (*H. corrugata*) (Allsopp 2011) (McBride 1998).

Chile
Chilean farms grow red abalone (*H. rufescens*) and Japanese abalone (*H. discus hannai*), neither of which is native to South America. Red abalone was introduced to Chilean waters in 1987 for enclosure farming, and today it accounts for 97.5% of Chilean-grown abalone because it is well adapted to the region's environment (Allsopp 2011) (Flores-Aguilar et al. 2007) (Godoy and Jerez 1998).

China
The native Japanese abalone (*H. discus hannai*) accounts for the majority of Chinese-grown abalone, farmed primarily for domestic consumption. Most exports are a hybridized species (*H. discus hannai* x *H. discus discus*) exclusive to aquaculture (Allsopp 2011) (Cook and Gordon 2010) (Guo 2009).

Where abalone species are farmed in or near their native habitats, larval stock is produced from captive abalone selected for favorable traits. These stocks are likely to have some genetic differentiation relative to their wild counterparts, because they are more than one generation domesticated. Chilean and Hawaiian farms, along with Chinese and Australian farms using hybridized stock, are the only major sources of abalone produced in areas to which they are not native. In Hawaii and Australia, there is no evidence that non-native species have escaped and established into surrounding habitats. In Chile, non-native red abalone have been released into the wild, but this colonization appears to be localized and well monitored (Flores-Aguilar et al. 2007). In California, out-planting of hatchery-reared native red abalone, in an effort to enhance the wild population, was largely unsuccessful (Burton and Tegner 2000). Similarly, research conducted by Hawkins and Jones (2002) concluded that the likelihood of establishing an abalone population as a result of a spawning event of farm-origin abalone was "very small." It can therefore be determined that escapement of either native or non-native abalone has not resulted in their presence or ecological establishment in the wild, and that such establishment is highly unlikely.

The second part of the invasiveness evaluation addresses the potential competitive and genetic impact of escapees on surrounding ecosystems. Because abalone populations around the world have been significantly affected by fishing pressure, and because of the demonstrated low success of the establishment of planted, hatchery-reared, or escaped farm stock, there is low risk that escaped abalone will compete with native populations for food or habitat, or increase the risk of predation (Cook and Gordon 2010) (USDA 1995). There is a greater risk that abalone selectively bred in captivity may affect native wild populations through hybridization (Allsopp 2011) (Elston and Ford 2011).

The score for Factor 6.2 is 5 out of 10.

Conclusions and final score
There is a moderate risk of escapes from both enclosed farms and sea ranches. There is also a moderate risk that the escaped animals would have a genetic and/or competitive impact on the ecosystem.

For both enclosed and sea-ranched abalone, Factors 6.1 and 6.2 combine to give a final numerical score of 4 out of 10 for Criterion 6—Escapes.

Criterion 7: Disease—pathogen and parasite interactions

Impact, unit of sustainability, and principle

- Impact: amplification of local pathogens and parasites on fish farms and their retransmission to local wild species that share the same water body
- Sustainability unit: wild populations susceptible to elevated levels of pathogens and parasites.
- Principle: preventing population-level impacts to wild species through the amplification and retransmission, or increased virulence of pathogens or parasites.

Criterion 7 Summary

Enclosed Farms and Sea-Ranched

Pathogen and parasite parameters	Score	
C7 Disease Score (0–10)	4	
Critical?	NO	YELLOW

Brief Summary

An update of this assessment was conducted in March 2022. This criterion was updated with new information. The update can be found in Appendix 2 at the end of this document.

Historically, the primary disease concern for abalone has been bacterial withering foot syndrome. More recently, a variant of the herpes virus has infected abalone populations in Australia, China, and Taiwan. Disease transmission between farmed and wild abalone has occurred in the past, and because of untreated effluent discharge and flow-through sea enclosures, there is a risk of further transmission. But the global industry is well regulated, with constant monitoring for outbreaks and with practices in place to reduce the transfer of disease. The final score for Criterion 7—Disease is 4 out of 10.

Justification of Rating

Because disease data quality and availability are good (i.e., Criterion 1 score of 7.5 or 10 for the disease category), the Seafood Watch evidence-based assessment was utilized.

There is a moderate concern of pathogen and parasite transmission between wild and cultured populations, particularly in abalone grown in sea-based cages.

Of greatest concern for both wild and cultured abalone is withering syndrome, a disease caused by infection with the bacterium *Candidatus* Xenohaliotis californiensis (Elston and Ford 2011) (Moore et al. 2002). Abalone may harbor the bacteria in their gastrointestinal tract with no ill effect; it is only in waters warmer than 18 °C/64 °F that the infection becomes lethal (Elston and Ford 2011) (Moore et al. 2000). Withering syndrome causes the abalone's muscular foot to atrophy and shrink, eventually killing the animal and destroying salable meat. Transmission of *Ca.* X. californiensis occurs only between abalone, though every species of *Haliotis* tested thus far has been susceptible (Moore et al. 2002). Research has demonstrated that the pathogen can be transmitted between organisms through the water column, and does not require direct contact (Moore et al. 2001) (Friedman et al. 2002) (Bower 2009).

In more temperate waters off the southwest coast of North America, outbreaks of withering foot syndrome occur regularly in both wild and cultured populations of red and black abalone. These outbreaks are generally triggered during summer and fall warming periods and have been especially severe under El Niño conditions. The 1997–1998 El Niño event caused high mortality in farmed red abalone from central California to Baja California (Moore et al. 2002). In the late 1980s, a similar warming trend in Southern California collapsed the short-lived black abalone industry altogether, underscoring the danger that disease transmission poses to aquaculture (Braje et al. 2009). It has also been confirmed that the discharge water from abalone farms in California has a higher concentration of the bacteria that causes withering foot syndrome than the surrounding ocean waters, demonstrating the potential for on-farm disease to affect natural populations (Lafferty and Ben-Horin 2013).

Additional pathogens occasionally affect farmed and wild abalone stocks, some of which are still new to science and the abalone industry (Gavine et al. 2009). In December 2005, a herpes-like virus appeared in three land-based aquaculture farms in southern Australia. The infection causes abalone viral ganglioneuritis (AVG), which results in inflammation and decay of nervous tissues, with a 60%–95% mortality rate within 14 days (Corbeil et al. 2012) (Dang et al. 2011) (Hooper et al. 2007) (Lafferty and Ben-Horin 2013). Australian outbreaks have led to high mortality events in surrounding wild populations when the virus was introduced to seawater through the placement of infected abalone in sea cages and discharge of water from land-based operations (Corbeil et al. 2012) (Hooper et al. 2007) (Lafferty and Ben-Horin 2013). So far, AVG has only been observed in southern Australia, Taiwan, and China, but the disease's high virulence makes it a growing concern for the industry (Corbeil et al. 2012) (Hooper et al. 2007) (Jones and Fletcher 2012).

Concentrated populations of cultured abalone present a high risk of novel pathogen development and a vector for transmission to wild populations. To prevent outbreaks and loss of stock, abalone health is closely monitored throughout the industry. The World Organization for Animal Health (OIE), the governing body for live animal transport under the World Trade Organization, recommends regular testing of all farmed abalone and notification of any "*Ca.* X. californiensis" infection. These protocols have been adopted as basic standards by a number of countries (Elston and Ford 2011). Some countries may have additional requirements to prevent the spread of disease:

<u>Chile</u>
Laws require monitoring of cultured abalone every 6 months. So far, this monitoring has shown the presence of parasites in farmed stocks but no full-blown outbreaks (Flores-Aguilar et al. 2007).

China

Chinese stocks of cultured abalone have also been affected by disease and parasites over the years. In 1994, disease killed more than 90% of abalone in the fledgling industry, prompting aquaculturists to hybridize *H. discus hannai* native to China with *H. discus hannai* native to Japan. Today, the intraspecific hybrids show high disease resistance and account for 95% of farmed Chinese abalone (Guo 2009).

Australia

In response to the threat posed by abalone viral ganglioneuritis (AVG), Australian government entities are tightening their biosecurity protocols and may be changing the way abalone is farmed in the future. Currently, Australian aquaculture operations require constant monitoring for AVG, and their seawater supply is immediately shut down if any infection is suspected. But a report in 2012 from the Department of Fisheries of Western Australia declared that the risk posed to wild populations by transmission from farmed abalone in sea pens is “unacceptable,” and proposed changes to current industry practices (Jones and Fletcher 2012). A 2016 report by Murphy (2016) suggests that hatchery juveniles are now put in a biosecure area for 2 weeks and then must be cleared by the Department of Fisheries before being put out to sea ranches. Abalone juveniles are tested for multiple diseases and general health before being released for ranching (FISH December 2012).

Conclusions and final score

There is a high risk of bacterial and viral pathogen transmission between wild and cultured stocks, and there is evidence that such transmissions have occurred in the past. This risk is somewhat mitigated by the development of stronger, industry-wide biosecurity regulations. For both enclosed and sea-ranched abalone, the final numerical score for Criterion 7—Disease is 4 out of 10.

Criterion 8X: Source of Stock—independence from wild fisheries

Impact, unit of sustainability, and principle

- Impact: the removal of fish from wild populations for on-growing to harvest size in farms
- Sustainability unit: wild fish populations
- Principle: using eggs, larvae, or juvenile fish produced from farm-raised broodstocks, thereby avoiding the need for wild capture.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 8X Summary

Enclosed Farms and Sea-Ranched

Source of stock parameters	Score	
C8 Independence from unsustainable wild fisheries (0–10)	0	
Critical?	NO	GREEN

Brief Summary

Stock for abalone farms generally comes from facilities that produce abalone seed stock. The broodstock for these facilities may be from the natural native population or a non-native population, or it may be a hybrid that is used specifically for aquaculture. Collection of broodstock or larvae is not considered to have a negative effect on the natural population. There are no significant impacts on wild populations from the collection of abalone broodstock or larvae for aquaculture. The criterion for source of stock is scored 0.

Justification of Rating

Most broodstock used by U.S. aquaculture operations and primary exporters to the U.S. are produced in captivity to select for ideal traits. Collection of wild broodstock in these countries occurs infrequently and in small enough numbers to not be a significant threat to wild populations (Allsopp 2011) (Elston and Ford 2011). It should be noted that the new Aquaculture Stewardship Council abalone standards used to determine ASC sustainability certification recommend that aquaculture operations use native wild broodstock in areas where native populations are threatened or endangered. This recommendation is intended to minimize the risk of impact or hybridization with introduced species by escaped larvae or adults. Nevertheless, the policy could increase pressure on these threatened populations from human collection, but there is no evidence of increased pressure to date (ASC 2011).

Conclusions and final score

Nearly all farmed abalone stocks are produced in hatcheries by domesticated broodstock. In addition, those dependent on wild broodstock/wild fisheries are not considered to threaten the population status, and no farmed stock is dependent on sourcing endangered species. For both enclosed and sea-ranched abalone, the final numerical score for Criterion 8X—Source of Stock is a deduction of 0 out of –10.

Criterion 9X: Wildlife and Predator Mortalities

Impact, unit of sustainability, and principle

- Impact: mortality of predators or other wildlife caused or contributed to by farming operations
- Sustainability unit: wildlife or predator populations
- Principle: aquaculture populations pose no substantial risk of deleterious effects to wildlife or predator populations that may interact with farm sites.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score. A score of zero means there is no impact.

Criterion 9X Summary

Enclosed Farms and Sea-Ranched

Wildlife and predator mortality parameters	Score	
C9X Wildlife and predator mortality Final Score (0–10)	**–1**	
Critical?	NO	**GREEN**

Brief Summary

Enclosed sea-based growouts and sea ranches could attract predators or other animals to the abalone farm. But there is no evidence that there is significant mortality of predators or wildlife due to removal from farms. The criterion for wildlife and predator mortality is scored –1.

Justification of Rating

Growout cages and other enclosures are intended to isolate captive abalone from predators and other wild animals. Sea ranches are open to surrounding predators and wildlife. But because sea pens and ranches are concentrated areas of prey, they become enticing opportunities for sea otters, crabs, sea stars, and other marine carnivores. Abalone farmers aim to minimize losses by preventing breaches of farming enclosures, though they do occasionally occur. Farmers may remove predators when they enter a cage or sea-ranch area in order to protect the abalone (MESA 2008) (Monterey Abalone Company n.d.), but most predators are simply relocated away from the aquaculture site (Monterey Abalone Company n.d.). Ultimately, though isolated mortalities may occur, there is no evidence that interactions with abalone growout facilities result in significant predator and wildlife mortalities.

Conclusions and final score

There is no evidence to suggest that abalone farms contribute to significant predator or wildlife mortalities. For both enclosed and sea-ranched abalone, the final numerical score for Criterion 9X—Wildlife Mortalities is –1 out of –10.

Criterion 10X: Escape of Unintentionally Introduced Species

Impact, unit of sustainability and principle

- Impact: movement of live animals resulting in introduction of unintended species
- Sustainability unit: wild native populations
- Impact: aquaculture operations by design, management, or regulation avoid reliance on the movement of live animals, therefore reducing the risk of introduction of unintended species.

This is an "exceptional" criterion that may not apply in many circumstances. It generates a negative score that is deducted from the overall final score.

Criterion 10X Summary

Enclosed Farms and Sea-Ranched

Escape of unintentionally introduced species parameters		Score	
F10Xa International or trans-waterbody live animal shipments (%)		10	
F10Xb Biosecurity of source/destination		N/A	
C10X Escape of unintentionally introduced species Final Score		**0.00**	**GREEN**

Brief Summary

Because there is no reliance on international or trans-waterbody movement for the purpose of abalone farming or trade, there is no significant concern with regard to the escape of unintentionally introduced species. The final score for Criterion 10X—Escape of Unintentionally Introduced Species is 0 out of –10.

Justification of Rating

Larval and juvenile abalone are generally produced locally, with no international/trans-waterbody movement of stock and with minimal risk of the unintentional introduction of alien species (pers. comm., The Abalone Farm 2016). Seed imports in other countries tend to be limited to new companies in the process of establishing themselves; once a reliable stock can be maintained, imports drop significantly or entirely (BC Shellfish Grower's Association 2012). Records of abalone being introduced to areas where they are not native indicate that imports occurred more than 20 years ago, and no indications of new introductions are apparent (FAO 2016). Additionally, the introductions are not reported to have had negative impacts on the ecosystem (FAO 2016).

According to U.S. National Marine Fisheries Service statistics (2016), the United States does import live/fresh abalone from Australia, Mexico, Chile, and South Korea, but it is unclear how much is actually live versus fresh product. Most of the live/fresh imported products go to land-locked states and the East Coast, where there are no native abalone, but most of the fresh farmed abalone in the U.S. market are domestically grown (pers. comm., The Abalone Farm

2016). Abalone produced in Asia for Asian markets is typically canned or frozen; sale of live abalone is relatively rare (Allsopp 2011).

Factor 10Xa International or trans-waterbody live animal shipments

Because 0% of production relies on international/trans-waterbody animal movements, the score for Factor 10Xa is 10 out of 10.

Factor 10Xb Biosecurity of source/destination

This factor is not applicable because there is no international or trans-waterbody movement.

Conclusions and final score

There is currently no significant concern with regard to the escape of unintentionally introduced species for abalone aquaculture. For both enclosed and sea-ranched abalone, the final numerical score for Criterion 10X—Escape of Unintentionally Introduced Species is 0 out of –10.

Overall Recommendation

The overall recommendation is as follows:

The overall final score is the average of the individual criterion scores (after the two exceptional scores have been deducted from the total). The overall rating is decided according to the final score, the number of red criteria, and the number of critical scores as follows:

– **Best Choice** = Final Score ≥6.661 **and** ≤10, and no Red Criteria, **and** no Critical scores
– **Good Alternative** = Final score ≥3.331 and ≤6.66, **and** no more than one Red Criterion, **and** no Critical scores.
– **Red** = Final Score ≥0 and ≤3.33, **or** two or more Red Criteria, **or** one or more Critical scores.

Enclosed Farms

Criterion	Score	Rating	Critical?
C1 Data	7.73	GREEN	
C2 Effluent	9.00	GREEN	NO
C3 Habitat	6.93	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	–1.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	**48.66**		
Final score (0–10)	**6.95**		

OVERALL RATINGING

Final Score	6.95
Initial rating	GREEN
Red criteria	0
Interim rating	GREEN
Critical Criteria?	NO

FINAL RATING
GREEN

Sea Ranches

Criterion	Score	Rating	Critical?
C1 Data	7.27	GREEN	
C2 Effluent	9.00	GREEN	NO
C3 Habitat	8.67	GREEN	NO
C4 Chemicals	8.00	GREEN	NO
C5 Feed	10.00	GREEN	NO
C6 Escapes	4.00	YELLOW	NO
C7 Disease	4.00	YELLOW	NO
C8X Source	0.00	GREEN	NO
C9X Wildlife mortalities	–1.00	GREEN	NO
C10X Introduced species escape	0.00	GREEN	
Total	**49.94**		
Final score (0–10)	**7.13**		

OVERALL RATINGING

Final Score	7.13
Initial rating	GREEN
Red criteria	0
Interim rating	GREEN
Critical Criteria?	NO

FINAL RATING
GREEN

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Appendix 1—Data Points and all Scoring Calculations

Enclosed Culture

Criterion 1: Data Quality and Availability

Data Category	Data Quality (0–10)
Industry or production statistics	7.5
Management	10
Effluent	10
Habitats	7.5
Chemical use	5
Feed	7.5
Escapes	7.5
Disease	7.5
Source of stock	10
Predators and wildlife	5
Unintentional introduction	7.5
Other—(e.g., GHG emissions)	n/a
Total	**85**

C1 Data Final Score (0–10)	**7.73**	**GREEN**

Criterion 2: Effluents

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**9**	**GREEN**
Critical?	NO	

Criterion 2: Effluents

Factor 2.1—Biological waste production and discharge

Factor 2.1a—Biological waste production

Protein content of feed (%)	11.73
eFCR	1.2
Fertilizer N input (kg N/ton fish)	7.2
Protein content of harvested fish (%)	18

N content factor (fixed)	0.16
N input per ton of fish produced (kg)	55.2
N in each ton of fish harvested (kg)	28.8
Waste N produced per ton of fish (kg)	**26.4**

Factor 2.1b—Production system discharge

Basic production system score	0.34
Adjustment 1 (if applicable)	0
Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0
Discharge (Factor 2.1b) score (0–1)	**0.34**

% of the waste produced by the fish is discharged from the farm

Factor 2.1 Score—Waste discharge score

Waste discharged per ton of production (kg N ton-1)	8.98
Waste discharge score (0–10)	**9**

Factor 2.2—Management of farm-level and cumulative effluent impacts

2.2a Content of effluent management measure	2
2.2b Enforcement of effluent management measures	3
2.2 Effluent management effectiveness	**2.4**

C2 Effluent Final Score (0–10)	**9.00**	**GREEN**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0–10)	8

Factor 3.2—Management of farm-level and cumulative habitat impacts

3.2a Content of habitat management measure	3
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	**4.8**

C3 Habitat Final Score (0–10)	**6.93**	**YELLOW**
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	**Score**	
C4 Chemical Use Score (0–10)	**8**	
C4 Chemical Use Final Score (0–10)	**8**	**GREEN**
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	**Score**
5.1a Fish In:Fish Out (FIFO)	
Fishmeal inclusion level (%)	0
Fishmeal from by-products (%)	0
% FM	0
Fish oil inclusion level (%)	0
Fish oil from by-products (%)	0
% FO	0
Fishmeal yield (%)	22.5
Fish oil yield (%)	5
eFCR	1.75
FIFO fishmeal	0.00
FIFO fish oil	0.00

FIFO Score (0–10)	**10.00**
Critical?	NO
5.1b Sustainability of Source fisheries	
Sustainability score	0
Calculated sustainability adjustment	0.00
Critical?	NO
F5.1 Wild Fish Use Score (0–10)	**10.00**
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	11.73
eFCR	1.75
Feed protein from fishmeal (%)	0.00
Feed protein from EDIBLE sources (%)	100.00
Feed protein from NON-EDIBLE sources (%)	0.00
Protein OUTPUTS	
Protein content of whole harvested fish (%)	17.1
Edible yield of harvested fish (%)	35
Use of non-edible by-products from harvested fish (%)	100
Total protein input kg/100kg fish	20.5275
Edible protein IN kg/100kg fish	20.53
Utilized protein OUT kg/100kg fish	22.01
Net protein gain or loss (%)	7.24
Critical?	NO
F5.2 Net Protein Score (0–10)	**10**

5.3. Feed Footprint

5.3a Ocean area appropriated per ton of seafood		
Inclusion level of aquatic feed ingredients (%)		0
eFCR		1.75
Carbon required for aquatic feed ingredients (ton C/ton fish)		*69.7*
Ocean productivity (C) for continental shelf areas (ton C/ha)		*2.68*
Ocean area appropriated (ha/ton fish)		0.00
5.3b Land area appropriated per ton of seafood		
Inclusion level of crop feed ingredients (%)		0
Inclusion level of land animal products (%)		0
Conversion ratio of crop ingredients to land animal products		*2.88*
eFCR		1.75
Average yield of major feed ingredient crops (t/ha)		*2.64*
Land area appropriated (ha per ton of fish)		0.00
Total area (Ocean + Land Area) (ha)		0.00
F5.3 Feed Footprint Score (0–10)		10

Feed Final Score

C5 Feed Final Score (0–10)	**10.00**	**GREEN**
Critical?	**NO**	

Criterion 6: Escapes

6.1a System escape Risk (0–10)	4	
6.1a Adjustment for recaptures (0-10)	0	
6.1a Escape Risk Score (0–10)	**4**	
6.2 Invasiveness Score (0–10)	**5**	
C6 Escapes Final Score (0–10)	**4**	**YELLOW**
Critical?	**NO**	

Criterion 7: Diseases

Disease Evidence-based assessment (0–10)		
Disease Risk-based assessment (0–10)	0	
C7 Disease Final Score (0–10)	**4**	**YELLOW**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0–10)	0	
C8 Source of Stock Final Score (0–10)	**0**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and Predator Mortalities

C9X Wildlife and Predator Score (0–10)	**−1**	
C9X Wildlife and Predator Final Score (0–10)	**−1**	**GREEN**
Critical?	NO	

Criterion 10X: Escape of Unintentionally Introduced Species

F10Xa live animal shipments score (0–10)	10.00	
F10Xb Biosecurity of source/destination score (0–10)	5.00	
C10X Escape of unintentionally introduced species Final Score (0–10)	**0.00**	**GREEN**
Critical?	n/a	

Sea Ranching Culture

Criterion 1: Data Quality and Availability

Data Category	Data Quality (0–10)
Industry or production statistics	5
Management	7.5
Effluent	10
Habitats	7.5
Chemical use	5
Feed	7.5
Escapes	7.5
Disease	7.5
Source of stock	10
Predators and wildlife	5
Unintentional introduction	7.5
Other—(e.g., GHG emissions)	n/a
Total	**80**

C1 Data Final Score (0–10)	**7.27**	**GREEN**

Criterion 2: Effluents

Effluent Evidence-Based Assessment

C2 Effluent Final Score (0–10)	**9**	**GREEN**
Critical?	NO	

Criterion 2: Effluents

Factor 2.1—Biological waste production and discharge

Factor 2.1a—Biological waste production

Protein content of feed (%)	11.73
eFCR	1.2
Fertilizer N input (kg N/ton fish)	0
Protein content of harvested fish (%)	18
N content factor (fixed)	0.16

N input per ton of fish produced (kg)	48
N in each ton of fish harvested (kg)	28.8
Waste N produced per ton of fish (kg)	**19.2**

Factor 2.1b—Production system discharge

Basic production system score	0.34
Adjustment 1 (if applicable)	0
Adjustment 2 (if applicable)	0
Adjustment 3 (if applicable)	0
Discharge (Factor 2.1b) score (0–1)	**0.34**

\# % of the waste produced by the fish is discharged from the farm

Factor 2.1 Score—Waste discharge score

Waste discharged per ton of production (kg N ton-1)	6.53
Waste discharge score (0–10)	**9**

Factor 2.2—Management of farm-level and cumulative effluent impacts

2.2a Content of effluent management measures	2
2.2b Enforcement of effluent management measures	3
2.2 Effluent management effectiveness	**2.4**

C2 Effluent Final Score (0–10)	**9.00**	**GREEN**
Critical?	NO	

Criterion 3: Habitat

Factor 3.1. Habitat conversion and function

F3.1 Score (0–10)	2

Factor 3.2—Management of farm-level and cumulative habitat impacts

3.2a Content of habitat management measure	2
3.2b Enforcement of habitat management measures	4
3.2 Habitat management effectiveness	**3.2**

C3 Habitat Final Score (0–10)	**2.40**	**RED**
Critical?	NO	

Criterion 4: Evidence or Risk of Chemical Use

Chemical Use parameters	**Score**	
C4 Chemical Use Score (0–10)	**8**	
C4 Chemical Use Final Score (0–10)	**8**	**GREEN**
Critical?	NO	

Criterion 5: Feed

5.1. Wild Fish Use

Feed parameters	**Score**
5.1a Fish In:Fish Out (FIFO)	
Fishmeal inclusion level (%)	0
Fishmeal from by-products (%)	0
% FM	0
Fish oil inclusion level (%)	0
Fish oil from by-products (%)	0
% FO	0
Fishmeal yield (%)	22.5
Fish oil yield (%)	5

eFCR	1.75
FIFO fishmeal	0.00
FIFO fish oil	0.00
FIFO Score (0–10)	**10.00**
Critical?	NO
5.1b Sustainability of Source fisheries	
Sustainability score	0
Calculated sustainability adjustment	0.00
Critical?	NO
F5.1 Wild Fish Use Score (0–10)	**10.00**
Critical?	NO

5.2 Net protein Gain or Loss

Protein INPUTS	
Protein content of feed (%)	11.73
eFCR	1.75
Feed protein from fishmeal (%)	0.00
Feed protein from EDIBLE sources (%)	100.00
Feed protein from NON-EDIBLE sources (%)	0.00
Protein OUTPUTS	
Protein content of whole harvested fish (%)	17.1
Edible yield of harvested fish (%)	35
Use of non-edible by-products from harvested fish (%)	100
Total protein input kg/100kg fish	20.5275
Edible protein IN kg/100kg fish	20.53
Utilized protein OUT kg/100kg fish	22.01
Net protein gain or loss (%)	7.24
Critical?	NO
F5.2 Net Protein Score (0–10)	**10**

5.3. Feed Footprint

5.3a Ocean area appropriated per ton of seafood		
Inclusion level of aquatic feed ingredients (%)		0
eFCR		1.75
Carbon required for aquatic feed ingredients (ton C/ton fish)		*69.7*
Ocean productivity (C) for continental shelf areas (ton C/ha)		*2.68*
Ocean area appropriated (ha/ton fish)		0.00
5.3b Land area appropriated per ton of seafood		
Inclusion level of crop feed ingredients (%)		0
Inclusion level of land animal products (%)		0
Conversion ratio of crop ingredients to land animal products		*2.88*
eFCR		1.75
Average yield of major feed ingredient crops (t/ha)		*2.64*
Land area appropriated (ha per ton of fish)		0.00
Total area (Ocean + Land Area) (ha)		0.00
F5.3 Feed Footprint Score (0–10)		10

Feed Final Score

C5 Feed Final Score (0–10)	**10.00**	**GREEN**
Critical?	**NO**	

Criterion 6: Escapes

6.1a System escape Risk (0–10)	4	
6.1a Adjustment for recaptures (0–10)	2	
6.1a Escape Risk Score (0–10)	**6**	
6.2 Invasiveness Score (0–10)	**5**	
C6 Escapes Final Score (0–10)	**4**	**YELLOW**
Critical?	**NO**	

Criterion 7: Diseases

Disease Evidence-based assessment (0–10)		
Disease Risk-based assessment (0–10)	0	
C7 Disease Final Score (0–10)	**4**	**YELLOW**
Critical?	NO	

Criterion 8X: Source of Stock

C8X Source of stock score (0–10)	0	
C8 Source of Stock Final Score (0–10)	**0**	**GREEN**
Critical?	NO	

Criterion 9X: Wildlife and predator mortalities

C9X Wildlife and Predator Score (0–10)	**-1**	
C9X Wildlife and Predator Final Score (0–10)	**-1**	**GREEN**
Critical?	NO	

Criterion 10X: Escape of unintentionally introduced species

F10Xa live animal shipments score (0–10)	10.00	
F10Xb Biosecurity of source/destination score (0–10)	5.00	
C10X Escape of unintentionally introduced species Final Score (0–10)	**0.00**	**GREEN**
Critical?	n/a	

Appendix 2—Update

An update of this assessment was conducted in March 2022 in the most-up-to-date Seafood Watch Aquaculture Standard Version 4.0. Updates focus on an assessment's limiting criteria (i.e., Critical, Red, or lowest scoring) (inclusive of a review of the availability and quality of data relevant to those criteria), so this review evaluates the C3—Habitat, C6—Escapes, and C7—Disease criteria for production-system types that are more open (sea ranching). Information regarding the impacts of sea-ranching production systems to habitat was found and is summarized here in Appendix 2, and results in a change in the rating/recommendation from a Yellow/Good Alternative to a Green/Best Choice.

For enclosed systems (e.g., enclosed bottom culture, indoor flow-through tank, outdoor flow-through tank, and off-bottom culture), the C6—Escapes and C7—Disease criteria were evaluated. No information was found or received that would suggest that the final ratings are no longer accurate. No edits were made to the text of the report (except an update note in the Executive Summary and all updated criteria).

The following text summarizes the findings of the review.

Update Scoring Summary

There are two recommendations from this update, consistent with the scope of the 2017 assessment:

For abalone grown in enclosed production systems (e.g., enclosed bottom culture, indoor flow-through tank, outdoor flow-through tank, and off-bottom culture), results of the update support the findings of the previous assessment, and the Overall Recommendation remains Best Choice with a Green rating. The recommendation and rating were updated after evaluating the two low-scoring criteria: Criterion 6—Escapes and Criterion 7—Disease; both criteria remain moderate, due primarily to the open nature of the production system with the environment.

For abalone grown in sea-ranching production methods, there is a change in the Overall Recommendation from a Good Alternative to a Best Choice. The rating and recommendation were updated after evaluating the three low-scoring criteria: Criterion 3—Habitat, Criterion 6—Escapes, and Criterion 7—Disease. There was no change to Criterion 6—Escapes and Criterion 7—Disease; both criteria remain moderate concerns, due primarily to the open nature of the production system with the environment. But, new details regarding the impact of sea ranching to habitat resulted in a change in final score and rating for Criterion 3—Habitat from 2.40 out of 10 and a Red rating to 8.67 out of 10 and a Green rating. The change in score is driven by the availability of detailed information demonstrating that the conversion of habitat for extant sea ranching operations results in minimal impacts to marine coastal inshore ecosystem functionality.

As a result, the Final Score for abalone grown in sea ranching production systems is 7.13 out of 10 and, with zero red criteria, the Overall Recommendation is considered a Green Best Choice.

Criterion 1—Data

This section seeks to update the Habitat criterion data availability score for more open production systems (e.g., sea ranching) from the 2017 assessment. Due to the significant changes in the justification of habitat-related data and the resulting final rating change, the text here summarizes the Data score for

Criterion—3 Habitat for sea-ranching production.

Data for Criterion 3—Habitat for sea ranching production systems were obtained from company websites, government literature and websites, and peer-reviewed literature. Given the small size and number of active sea-ranching operations, there is reliable information of the industry's siting, habitat type, regulatory content, and enforcement. Comprehensive nationally and/or regionally aggregated analysis and reviews at the industry level are limited, so the incompleteness of data describing habitat impacts and management effectiveness of sea-ranching production results in some uncertainties. As a result, the data quality is considered moderate–high and scores 7.5 out of 10.

Criterion 1—Data

This section seeks to summarize the quality and confidence of the available data for Criterion 6—Escapes and Criterion 7—Disease. There were not significant changes to the justification of either criterion, so the text here briefly summarizes the quality and confidence of the available data.

For all production systems, there remains uncertainty about the impacts of on-farm disease and escapes (e.g., spawning activities) on wild species and ecosystems. As a result, the availability of information for each criterion (e.g., Habitat, Escapes, and Disease) in this update is moderate.

Criterion 3—Habitat

This section seeks to update the Habitat criterion for more open production systems (e.g., sea ranching) from the 2017 assessment, which had resulted in a C3—Habitat score of 2.40 out of 10 and a Red rating.

Factor 3.1—Habitat conversion and function

Sea-ranching operations allow abalone to live freely on the ocean floor during growout as opposed to other, more controlled production systems described in this assessment (e.g., enclosed bottom culture, indoor flow-through tank, outdoor flow-through tank, and off-bottom culture). Sea-ranching production methods include the use of "abitats" and seeding of temperate rocky reefs. Abitats are manufactured structures that are designed to mimic rocky reefs and are constructed from concrete.

According to the FAO, global abalone production (inclusive of all species) in 2017 was 168,329.46 metric tons (MT, live weight). China is the largest producer by volume, accounting for nearly 90% of production in 2017, followed by South Korea at nearly 10%. All remaining production accounted for less than 1% of global production in 2017, and came from South Africa, Chile, Australia, the United States, Taiwan, New Zealand, Mexico, and France (see Table 2).

Table 2: Abalone production by volume in live weight metric tons in 2017 by country. Data FAO, 2019

Country	Species	Production (mt, live weight)	Percentage of Production	Year
China	Abalones nei	148,539.00	88.24%	2017
South Korea	Abalones nei	16,027.00	9.52%	2017
South Africa	Perlemoen abalone	1,121.58	0.67%	2017
Chile	Red abalone, Japanese abalone	1,030.86	0.61%	2017
Australia	Abalones nei	873.13	0.52%	2017
United States	Abalones nei	341.00	0.20%	2017
Taiwan	Abalones nei	276.38	0.16%	2017
New Zealand	Rainbow abalone	90.00	0.05%	2017
Mexico	Red abalone	23.51	0.01%	2017
France	Tuberculate abalone	7.00	0.00%	2017

Nearly all abalone farming across the globe uses ocean-based sea cages or land-based flow-through/raceway production methods. A country-by-country summary of production methods for the top 10 abalone-producing countries is provided in Table 2. Results indicate that all sea ranching production originates from three farms in South Africa and one farm in Australia, combining to represent roughly 0.064%[1] of global abalone aquaculture production. The remaining 99.94% is produced from sea cages and land-based production methods.

China

According to Wu and Zhang (2016), there do not appear to be any sea-ranching operations in China, with the dominant growout system types being land-based flow-through/raceway methods, and floating sea cages (Ke, C. et al. 2018). Production in 2016 was roughly 140,000 tons, with 80% of production from Fujian Province, 6% from Guangdong, 11% from Shandong, 2% from Liaoning, and approximately 1% of production from other, unknown areas of China (Ke, C. et al. 2018). In 2016, approximately 9,000 tons or 6% of abalone production was transported between the south and north; in the winter, abalone are grown in Fujian, and in the summer are transported up to the northern provinces of Shandong and Liaoning to help improve survival rates (avoiding typhoon and high temperatures) and increase growth rates (Ke, C. et al. 2018). This transportation method, "South-North relay," is reportedly an increasingly common practice (Ke, C. et al. 2018).

South Korea

In South Korea in 2016, there were 2,215 abalone farms licensed to operate, with about 80% of the farms located around Wando Island and producing a total of 8,533 tons or 63% of the national abalone landings (Kwang-Sik Choi and Han-Kyu Lim 2017). Farms are located on the southern and western coasts and utilize sea-cage production methods while co-culturing with seaweed. There is some production

[1] This is a rough estimate using the best data available. South African sea ranching production is 28 MT (2016), while Australia sea ranching production is ≈80 MT (2021) for a total production of ≈108 MT, while not controlling for year of production and weighting methods. The total FAO aquacultured abalone production in 2017 was 168,329.46 MT.

around Jeju Island that uses raceway/flow-through production methods (World Health Organization 2021) (Sim et al. 2021). In the southern and western coasts, *Haliotis discus hannai* is grown due to colder winter water temperatures, while farther south on Jeju Island, warmer-water abalone species (e.g., *Haliotis discus*, *Haliotis discus hannai*, *and Haliotis diversicolor*) are grown (World Health Organization 2021). There are no sea-ranching operations in South Korea.

South Africa

As of 2016, there are 17 operational abalone farms in South Africa—12 are land-based facilities, 2 are sea-cage operations, and 3 are sea-ranching farms (Urban-Econ Development Economists 2018). In addition to the three operating sea ranching farms, there are seven companies that have been permitted for abalone sea-ranching production, although forecasts for production estimates indicate no "significant quantities" until 2023 due to the timeline of abalone production and logistics (Urban-Econ Development Economists 2018). Estimated abalone volume from the three sea-ranching operations in South Africa is roughly 28 MT annually (Urban-Econ Development Economists 2018).

Chile

In Chile, there are 25 active companies with growout operations on land with raceway/flow-through methods or sea cages. Raceway and flow-through production methods are practiced in the central/northern provinces of Copiapó and Coquimbo, and sea-cage methods are used in Puerto Montt and Chiloé. There are no sea-ranching operations in Chile (Aqua Chile 2017).

Australia

In Australia, there are 12 abalone farms, 11 of which cultivate abalone with land-based flow-through techniques, while 1 farm is a sea-ranching operation (pers. comm., Nick Savva 2022). In 2021, 1,400 MT of abalone were produced by the flow-through farms. The single sea-ranching farm in Western Australia, Ocean Grown Abalone, harvested roughly 80 MT in 2021 (pers. comm., Nick Savva 2022) (Ocean Grown Abalone 2020) (Adams, B. 2020).

United States

According to Dr. Laura Rogers-Bennett from the University of California Davis, Wildlife Health Center, there are six abalone farming operations in the United States (Rogers-Bennet, L. 2018). The United States Department of Agriculture, in its 2018 census of aquaculture, identified four abalone farms. But, marine aquaculture statistics in the United States can be misleading (Froehlich et al. 2022). For the purposes of this assessment, five farms were identified—four in California and one in Hawaii—and all but one utilize land-based flow-through production methods; the other uses sea cages. There are no abalone sea-ranching operations in the United States.

Taiwan

Intertidal-pool-culture production systems produce the most abalone in Taiwan and consist of constructed cement ponds along the shoreline (Huang et al. 2019). Expansion of intertidal culture has not occurred since 2000 due to: a) environmental protections in the New Taipei City Government, and b) economic and disease-related issues that caused a production decline from the high of 2,500 MT in 2000 to about 275 MT in 2017 (Huang et al. 2019). There is also some land-based flow-through/raceway production (Te-Hua HSU & Jin-Chywan GWO 2018), though data attributing the number of farms and the production methods were not found in the literature. There is no abalone sea-ranching production in Taiwan.

New Zealand

There are two abalone farms in New Zealand, both utilizing flow-through production methods (Stenton-Dozey et al. 2020) The two farms are the Moana and the New Zealand Abalone company. There is no abalone sea-ranching production in New Zealand.

Mexico

There are two privately owned abalone farms in Mexico using raceways or sea-cage methods (Searcy-Bernal, R. 2018) (Rieve, K. 2021) (Woolford, J. 2019). There are no abalone sea-ranching farms in Mexico.

Europe

In Europe, there are two abalone farms in France and two abalone farms in Ireland (pers. comm., Sylvain Huchette 2022). Total production from France is estimated to be about 10 MT annually, with unknown production amounts from the farms in Ireland. (Courtois de Viçose, G. 2018) (pers. comm., Sylvain Huchette 2022). The two farms in France are located in Brittany, with one producing abalone from land-based semi-RAS and flow-through production methods and the other growing out abalone in enclosed bottom-culture production systems integrated with seaweed cultivation (pers. comm., Sylvain Huchette 2022). There is no abalone production in France from sea-ranching production methods.

Therefore, the evaluation of Factor 3.1—Habitat conversion and function for sea ranching is exclusive to the production from farms in Australia and South Africa, because these are the only farms and countries where sea ranching appears to be occurring in any significant quantity.

In Australia, one farm, Ocean Grown Abalone, cultivates abalone using sea-ranching methods. The farm is located near Augusta, Western Australia in Flinders Bay at depths between 15 and 19 meters and "1.4 km from the nearest coast and 4.7 km at its most distant point" (Ocean Grown Abalone 2020). The site lease is for 413 hectares, though less than 1% of the lease footprint consists of abalone production modules (abitats); each abitat's footprint is 1.4 m^2 and there are about 10,000 modules (Ocean Grown Abalone 2020). "The general substrate in the bay is of Quaternary sands overlying Cretaceous sediments, with sparse seagrass beds and macroalgae on low relief limestone or granite reefs" (from Ocean Grown Abalone, 2020 *citing* Western Australian Planning Commission 2003) (Department of Environment and Conservation 2006). No abitats were placed on top of seagrass (Ocean Grown Abalone 2020). Monitoring was conducted before leasing the site, and it identified the need for sediment and nutrient monitoring to insure that aquaculture operations would not adversely contribute to nutrient enrichment of the sediment area. From 2014 to 2019, bi-annual sediment monitoring concluded that there was "no impact of OGA [Ocean Grown Abalone] aquaculture activities on surrounding sediments." Sediment sampling and monitoring are now required every 5 years (Ocean Grown Abalone 2020).

Because the site of Ocean Grown Abalone is within 3 nautical miles of the coastline at depths of 15 to 19 m, the farm site is characterized as coastal inshore habitat, which is considered to have moderate value by the SFW Aquaculture Standard. The available information indicates that the operation does not have more than a minimal impact on the surrounding ecosystem.

In South Africa, sea-ranching operations stock hatchery-reared abalone (typically by hand) into kelp beds (considered a high habitat value) within designated boundaries determined by the Department of Agriculture Forestry and Fisheries (Japp, D. & Wilkinson, S. 2016) (Hutchings, K., Massie, V., & Clark, B. 2019). All permitted ranching operations undergo an environmental review (see Factor 3.2a—Content of Management Measures), which includes a review of the carrying capacity of the proposed ranching area and an analysis of potential trophic and ecological impacts. Ongoing ecological monitoring of sea-ranching operations in Kleinzee, South Africa concluded that there is no significant difference between sea-ranching operations and control sites (Hutchings, K., Massie, V., & Clark, B. 2019). Therefore, as with the farm in Australia, the available information indicates that the operation does not have more than a minimal impact on the surrounding ecosystem.

As a result, evidence indicates that sea-ranching operations occur only in South Africa and Australia. The primary habitat type is coastal inshore subtidal and rocky reef, and the documented environmental impact to the coastal ecosystems is minimal. The resulting score for Factor 3.1—Habitat conversion and function for sea ranching is 9 out of 10.

Factor 3.2. Farm siting regulation and management

<u>Factor 3.2a—Content of Habitat Management Measures</u>

The evaluation of Factor 3.2a for sea ranching is exclusive to the production from the Australia and South Africa farms, because these are the only farms and countries where sea ranching appears to be occurring with any significant production.

In South Africa, several legislative and regulatory frameworks are relevant for abalone sea ranching and habitat protections, as follows.

Marine Aquaculture Rights is an initial application to participate in marine aquaculture production which, upon approval, results in a license. The license is valid for 15 years with the option to renew on an annual basis (Urban-Econ Development Economists 2018).

According to the *Guidelines and Potential Areas for Marine Ranching and Stock Enhancement of Abalone in South Africa* (Government Notice 2010, No. 729), an initial application for Ranching Rights must also be submitted to the Department of Environmental Affairs (DEA) and include the proposed location as well as an assessment of potential ecological impacts (e.g., trophic impacts, genetic impacts, and disease) while identifying the habitat, present species (including threatened or endangered species), and carrying capacity of the proposed location (Hutchings, K., Massie, V., & Clark, B. 2019). This initial application, upon further evaluation, develops into an Environmental Impact Assessment for Environmental Authorization and, if approved, the aquaculture activities are permitted (Urban-Econ Development Economists 2018).

The *Abalone Traceability Protocol* was developed in 2018 to help better trace abalone products in the value chain. This protocol also helps to prevent black market/illegal harvests (poaching) and improve food safety (Urban-Econ Development Economists 2018).

The *Standard Marine Aquaculture* outlines conditions for aquaculture production and adherence for a number of aquaculture activities, and provides Specific Conditions for Abalone, Harvesting Ranched Abalone, and Seeding Abalone for Ranching. Among the specific conditions are a timely process for reporting potential disease issues/mortalities, sourcing of broodstock from local genetic zones, conditions for animal movement, defined density/carrying capacity of growout locations, and coordination with local fisheries managers during harvesting.

Other important legislation that aims to protect and conserve marine resources and that all abalone sea-ranching environmental reviews are subject to include: *Marine Living Resources Act*, *National Environmental Management Act*, *National Environmental Management Biodiversity Act*, and the *National Environmental Management Protected Areas Act*. These intertwining legislations provide a basic framework to limit marine ecosystem impacts by any industry.

Therefore, sea ranching of abalone in South Africa is considered area-based because select areas have been identified as opportunity areas for abalone sea ranching production by the Department of Forestry, Fisheries and the Environment (DFFE)[2] (Japp, D. & Wilkinson, S. 2016) (Hutchings, K., Massie, V., & Clark, B. 2019). Based on other environmental review applications, cumulative impacts of ranching operations appear to be considered and contextualized with other activities and industries in the area, while maintaining kelp forest and rocky reef functionality (Japp, D. & Wilkinson, S. 2016) (Hutchings, K., Massie, V., & Clark, B. 2019). As a result, the score for Factor 3.2a—Content of habitat management measures appears comprehensive and scores 5 out of 5 for South African sea-ranching operations.

In Australia, the single sea-ranching operation is managed by state authorities and legislation in Western Australia, consistent with national legislation and underlying national policies and guidelines. All marine aquaculture operations are zoned within an Aquaculture Development Zone in Western Australia to help develop a sustainable marine aquaculture industry (Department of Primary Industries and Regional Development *accessed March 2022*). But, the sea-ranching operation under review falls outside of the development zones identified in Western Australia (the Albany Aquaculture Development Zone, Kimberley Aquaculture Development Zone, and Mid-West Aquaculture Development Zone), likely because the sea-ranching operation was developed before these aquaculture zones. The main management tool regulating aquaculture in Western Australia is the Aquatic Resources Management Act (Department of Primary Industries and Regional Development *accessed March 2022*). To operate, an Aquaculture License must be applied for and is issued by the Department of Primary Industry and Regional Development of Western Australia (*accessed March 2022*). The application for license includes an outline of Management and Environmental Monitoring Plans (MEMPs) to be submitted annually; these include baseline environmental studies, monitoring parameters and programs, monitoring for marine fauna, evaluation of protected species, biosecurity plans, and internal auditing plans. Plans are reviewed by the Department of Water and Environmental Regulation and the Department of Primary Industries and Regional Development of Western Australia.

Besides the Management of Environmental Monitoring Plans, the other major environmental legislation including marine habitat and species protection appears to be the Environment Protection and

[2] Fisheries was included under the Department of Agriculture, Forestry and Fisheries but was restructured into the DFFE in 2019.

Biodiversity Conservation Act (Department of Agriculture Water and the Environment *accessed March 2022*). If a proposed aquaculture operation has the "potential to have a significant impact on a matter of national environmental significance," then the proposed aquaculture operation must be reviewed by the public to collect comments and by the Department of Sustainability, Environment, Water, Population and Communities to determine the likely impact and its significance.

These regulatory tools are identified and documented in the sea-ranching operations Aquaculture Management and Environmental Monitoring Plan (2020). In this plan, a review of the marine and terrestrial environments interacting with the farm region was documented by the Department of Parks and Wildlife: an environmental baseline was established for the nutrient budget and flux, oceanographic characteristics, type and economic significance of fisheries, and the marine fauna. A monitoring plan is also detailed along with mitigation/management of specific environmental issues, including risks and response protocols to potential habitat impacts (e.g., interactions with marine mammals, seagrass communities, and sediments).

Altogether, the content of habitat management measures includes important habitat protections through the licensing and review of aquaculture proposals and management and environmental monitoring plans. Area-based cumulative management of marine aquaculture in each Australian state is addressed through defined and constrained aquaculture zones, which undergo similar environmental reviews. Although the sea-ranching operation currently operates outside the three approved aquaculture management zones, any expansion of the current sea-ranching footprint must undergo licensing review. The environmental review process is contextualized with other industries and is therefore considered integrated. As a result, Australia's and Western Australia's content of habitat management is considered comprehensive and the resulting score for Factor 3.2a is 5 out of 5.

Overall, Factor 3.2a—Content of habitat management measures for sea-ranching operations is considered comprehensive and scores 5 out of 5. This is entirely reflective of the habitat protections and regulatory management structure of the only known abalone sea-ranching operations globally, in South Africa and Australia.

F3.2b—Enforcement of Habitat Management Measures

In South Africa, the initial environmental permitting process is evaluated, vetted, permitted, and enforced by the Department of Environmental Affairs and the Department of Forestry, Fisheries and the Environment (DFFE) (Urban-Econ Development Economists 2018). There are other agencies involved but are all coordinated within the lead agency, DFFE (Department of Agriculture, Land Reform and Rural Development *accessed March 2022*). Enforcement of habitat protections during farming operations is also handled by DFFE (Department of Agriculture, Land Reform and Rural Development *accessed March 2022*), but the frequency of monitoring and inspection of sea-ranching growout is unknown.

In Australia, audits are conducted by "Fisheries and Marine Officers and independent external auditors" (Department of Fisheries 2013) to measure environmental performance and compliance with the Aquaculture Management and Environmental Monitoring Plan (MEMP). For sea-ranching operations in Australia, environmental monitoring must be conducted and submitted to the Department of Fisheries of Western Australia once every 5 years, which was determined based on MEMP results of a pilot study suggesting low environmental risk (Aquaculture Management and Environmental Monitoring Plan (2020).

Given the challenge of monitoring and enforcing risk areas of sea-ranching production (such as density), enforcement measures are considered effective but with clear limitations. There is little evidence of any environmental impacts from sea ranching exceeding the allowed impacts under environmental impact assessments and, given the nature of the production method and species, monitoring has its challenges for enforcement bodies. Nevertheless, with the size and structure of the agencies, the clear guidelines and protections of habitat measures evaluated before and during operations, and the mitigations outlined in the environmental review, enforcement appears effective but with limitations, such as knowledge gaps (e.g., frequency of inspections). As a result, Factor 3.2b—Enforcement of habitat management measures scores 4 out of 5 for South Africa and Australia.

Criterion 3—Habitat Conclusion

Evidence indicates that sea-ranching operations occur only in South Africa and Australia. The primary habitat type is coastal inshore sub-tidal and rocky reef, and the documented environmental impact to the coastal ecosystems is minimal. The resulting score for Factor 3.1—Habitat conversion and function for sea ranching is 9 out of 10.

The farm siting regulation and management of sea-ranching operations is considered comprehensive and effective. Management of abalone sea ranching in South Africa and Australia is considered area-based, with farm siting guidance based on preserving ecosystem functionality with holistic environmental reviews, and contextualized with other activities and industries in the area. As a result, Factor 3.2a—Content of habitat management measures appears comprehensive and scores 5 out of 5 for South Africa and Australia sea-ranching operations. Given the challenge of monitoring and enforcing risk areas of sea-ranching production, enforcement measures are considered effective but with clear limitations. There is little evidence of any environmental impacts from sea ranching exceeding the allowed impacts under environmental impact assessments. As a result, Factor 3.2b—Enforcement of habitat management measures scores 4 out of 5 for South Africa and Australia. Combined, Factor 3.2—Farm siting regulation and management of sea-ranching operations scores 8 out of 10.

Altogether, Factor 3.1—Habitat conversion and function scores 9 out of 10, and Factor 3.2—Farm siting regulation and management scores 8 out of 10, which combine for a final score for Criterion 3—Habitat of 8.67 out of 10.

Criterion 6 – Escapes

This section includes all production method types for this assessment.

<u>Factor 6.1—Escape risk score</u>

The escape risk considers the characteristics of the production systems, the potential and/or evidence of escapes, and the practices taken to mitigate escape risk. This assessment includes a wide variety of production methods and practices.

Generally, all production practices have separate life-cycle operation stages for seedling, juvenile, and growout. The nursery and juvenile stages are outside the scope of this assessment and are not included.

Spawning during the growout stage is possible and is the primary risk. During the growout life stage, a variety of production methods are implemented, and all are considered to have a degree of open exchange with marine environments.

In general, literature, management plans, and documentation of mitigation practices and/or strategies to limit abalone escapes are limited. There may be some escape risk mitigation efforts for land-based aquaculture that provide additional barriers to escapes, such as screens, filters, and settling ponds (Eyre Peninsula n.d.). Other growout production systems (e.g., enclosed bottom culture, indoor flowthrough tank, outdoor flowthrough tank, and off-bottom culture) have physical barriers limiting the ability of abalone to escape from the production system. But, the open exchange of seawater leaves the production system open for the possibility of abalone spawning, to lead to escape into the surrounding environment, which is typically adjacent to or within preferred wild habitat. Sea-ranching systems have an open exchange with marine waters (Wu and Zhang 2016), with no physical barriers to filter any potential spawning escapes or expansion of its boundaries. In Australia, the production system (the "abitat" sea-ranching method) is surrounded by sandy benthic bottoms, so escapes and larval dispersal are limited through this siting and biological constraint (Aquaculture Management and Environmental Monitoring Plan 2020).

Primary studies monitoring abalone escapes or spawning frequency and the risk of establishment from abalone aquaculture are limited. Production practices described by Wu and Zhang (2016) in China did not cover escape risks. Environmental Impact Reviews for abalone aquaculture identify a low risk for abalone escapes due to the barriers to establishing in the wild from larvae (Theil et al. 2003 citing Hawkins and Jones 2002 and Burton and Tegner 2000). Furthermore, data may be lacking due to the challenges of identifying farmed escapes versus wild abalone specimens (Theil et al. 2003).

As a result, the concern for Factor 6.1—Escape risk remains moderate. This is due primarily to the nature of the production systems being open to the environment, while documentation, although limited, identifies escapes as having a low risk for establishing.

Factor 6.2—Competitive and genetic interactions

No new evidence of genetic and/or ecological disturbance from abalone escapees affecting wild abalone populations was found in the literature during this review.

Criterion 6—Escapes Conclusion
Overall, no new information or insight was readily available regarding the risk of escapes from abalone farms or their potential impacts to wild populations. As a result, the concern for escapes remains moderate.

Criterion 7 – Disease

This section includes all production method types for this assessment.

New literature since the 2017 report largely documents abalone viral ganglioneuritis (AVG), the monitoring and adaptive management of AVG outbreaks, and the physiology of abalone in response to stress in the context of global climate change.

In general, abalone farms are open systems and do not control abiotic environmental factors, leaving the farms susceptible to coastal water quality conditions (Morash and Alter 2015). Fluctuations in abiotic conditions such as temperature, dissolved oxygen, salinity, CO_2, and pH may affect abalone stress and immunity (Morash and Alter 2015). The predicted effects of climate change—increases in sea surface temperature, increases in CO_2, increased severity of El Niño and La Niña events—as well as the potential synergistic effects of these environmental conditions may exacerbate marine diseases (Groner et al. 2015), including those of abalone, and may increase disease risk in both the short and long terms.

In 2003, the first report of abalone herpesvirus (AbHV) was documented in Taiwan. The virus (AbHV) is transmitted horizontally, and infection causes abalone viral ganglioneuritis (AVG), which results in inflammation and decay of nervous tissues, with a 60%–95% mortality rate within 14 days (Corbeil et al. 2012) (Dang et al. 2011) (Hooper et al. 2007) (Lafferty and Ben-Horin 2013) (Lafferty et al. 2014) (Corbeil 2020). It is speculated that AbHV outbreaks also occurred in Dongshan County of Fujian Province, China from the late 1990s to early 2000s, which led to "significant economic damage to *H. diversicolor supertexta"* (Corbeil 2020).

After initial reports in Taiwan in 2003, an outbreak of AVG was found on several aquaculture farms in Victoria, Australia in December 2005. A few months later in May 2006, AVG had been spread to wild abalone stocks (e.g., *Haliotis rubra and Haliotis laevigata*) that were located next to abalone farms. Both wild and farmed abalone (e.g., *H. rubra*, *H. laevigata*, and their hybrids) of all age classes were affected, with mortalities up to 90% (Corbeil 2020). But the origins of AVG—whether it originates from the wild and is amplified on farms—remain unclear (pers comm., Nick Savva 2022).

The initial source of the outbreak in Australia appears to be linked to wild broodstock collection and exchange between a few farms (Hooper et al. 2007). Outbreaks on farms led to high mortality events in surrounding wild populations when the virus was introduced to seawater through the placement of infected abalone in sea cages and discharge of water from land-based operations (Corbeil et al. 2012) (Hooper et al. 2007) (Lafferty and Ben-Horin 2013). Following the outbreaks in 2006, wild populations and fisheries have recovered. Because current monitoring of wild abalone fisheries and populations has managers concerned that a potential AVG outbreak may be imminent, the closure of waters offshore of SW Victoria and a Biosecurity Control Order are in effect as of June 2021 (ABC 2021).

So far, AVG has only been observed in southern Australia, Taiwan, and China, but the disease's high virulence makes it a growing concern for the industry (Corbeil et al. 2012) (Hooper et al. 2007) (Jones and Fletcher 2012).

Criterion 7—Disease Conclusion

Overall, evidence of disease risk and/or occurrence remains moderate. However, the recent outbreak of AVG in wild populations is concerning. The current cause, transmission, and or amplification of AVG from farms to wild populations in Australia is not documented but should be evaluated as events unfold. As a result, the current disease risk is moderate and is consistent with the 2017 assessment.

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