Multi-Indicator Adaptive Assessment & Management Framework
(As applied to queen conch)

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Multi-Indicator Adaptive Assessment & Management Framework (As applied to queen conch)

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SEDAR 103: US Caribbean Application of Alternate Assessment Methods

Summary

Multi-indicator adaptive assessment and management frameworks are a model-free approach to assessment and management that use empirical data to track the status of fishery populations that cannot be modelled based on MSY-derived reference points. Instead, harvest-based trigger points are developed for a suite of indicators, and management responses defined (i.e., harvest control rules) for when the trigger points are exceeded. Queen conch is one of the most valuable fisheries within the US Caribbean, yet no traditional assessment methodologies have been applied to the available data. This is largely due to unique characteristics of queen conch biology, including indeterminate growth, no direct metric of age, declining fecundity in older females, and a marked Allee effect as evidenced by a minimum adult density required for reproduction. While developing a multi-indicator adaptive assessment and management framework requires a multistep consultation process among management agencies, and example for the Puerto Rico queen conch fishery is presented here based on seven indicators and corresponding thresholds derived from the literature. Data come from existing in-situ benthic surveys and port sampling. In this example, the indicators proposed are as follows: (1) Density of exploitable stock, (2) Size composition, (3) Recruitment, (4) Frequency of reproduction, (5) Total number of trips, (6) Spatial distribution of fishing effort, (7) Trend in catch, and (8) Trend in price/lb (in constant dollars). Harvest control rules could take the form of mandated decreases or increases in allowable catch level (ACLs). An analysis of existing management measures relevant to the indicators may suggest alternative management approaches.

I. Introduction

The queen conch, *Aliger* (formerly *Lobatus* and *Strombus*) *gigas*, is a large gastropod that supports fisheries throughout the Caribbean. Intensive exploitation during the 20^{th} century has resulted in significant population declines, leading to its listing under Appendix II of the Convention on International Trade of Endangers Species of Flora and Fauna (CITES) in 1992- Continuing overexploitation across its range has led to a designation as as “Threatened” under the U.S. Endangered Species Act in 2024 (NOAA 2024), and as “Near Threatened” by the IUCN in 2025 (Tallowin 2025). Due to both its volume of landings and economic value, the queen conch fishery is one of the most important within the US Caribbean, particularly in Puerto Rico and St. Croix, USVI.

Despite its importance, few assessments of conch populations or fisheries have been conducted, and those that have can only offer limited advice. The reasons for this are mostly linked to the unique life history of queen conch, which render data collection difficult to interpret or invalidate some required assumptions for many commonly used population assessment and sustainable exploitation models. These unique biological features have been detailed in CITES Secretariat (2026) and are briefly reviewed here.

A. Unique Aspects of Conch Biology

Queen conch show determinate growth in shell length. At about the onset of maturation, conch cease growing in shell length and begin the formation their characteristic adult flared shell lip. Further shell growth occurs only as a thickening of the shell (Appeldoorn 1988a), which includes the interior spaces (Randall 1964). There are two important consequences of this. First, there is no single quantitative metric that can be used to assign age by size. Shell length could be used for estimating age in juveniles (but see below), while lip-thickness can be used for adult age, assuming the age at the onset of maturation is relatively constant. Second, the length of adults is fixed at this time, which means meat weight and fecundity also become fixed. However, this is further complicated by the fact that continued interior shell thickening reduces the volume inside the shell significantly with age (Randall 1964), which leads to reductions in both meat and gonad weight, and presumably fecundity (Stoner et al. 2012b). This questions how to conceptualize Froese’s (2004) third pilar of fisheries management: protect the megaspawners. The oldest conch may not be the most fecund but maybe the largest mature conch are, regardless of age.

Adult queen conch show high spatial variability in shell length, presumably due to strong habitat influence (Alcolado 1976, Appeldoorn 1994, Appeldoorn et al. 2018, Tewfik et al. 2019). This variability affects the ability to use shell length to estimate juvenile age. It also points to a high variability in expected meat yield and fecundity. For example, in the data from Appeldoorn et al. (2018), adult conch (lip-thickness>10 mm) ranged in shell length from 160 to 283 mm and cleaned meat weight from 52-416 g, the latter representing an 8-fold difference. By site averages (N=9), the weight ranged from 92-215 g, representing a 2.3-fold difference. Because size becomes fixed at about the time of maturation, these differences remain regardless of age, i.e., small adults cannot grow into large adults.

Conch reproduce through copulation (D'Asaro 1965, Appeldoorn 2020), and while adults can roam over substantial distances given time and continuous habitat (Appeldoorn 1987), their movements tend to be largely localized within broad aggregation sites (Glazer et al. 2003, Kough et al. 2006). This coupling of copulation with restricted movement suggests that the maintenance of adult spawning densities should be an important management goal, especially within the context of spatially variable exploited population densities. Fishing can drive local densities below the critical threshold for reproductive activity, triggering Allee effects that impair population recovery even when harvest pressure is relaxed (Appeldoorn 1988b, Stoner and Ray-Culp 2000, Stoner et al. 2012a; Farmer and Doerr 2022). An Allee effect significantly impacts assumptions regarding population growth functions used in statistical biomass assessment and catch forecasting models

B. Queen Conch Management

Currently in the US Caribbean, the queen conch fishery is managed jointly by the Caribbean Fishery Management Council (CFMC) and the local agencies for Puerto Rico and the US Virgin Islands. In Puerto Rico, most the appropriate habitat falls within the 9 nautical mile territorial limit. The CFMC determined queen conch to be overfished in 1989 (reaffirmed in 2005), and in 1997 all Federal waters around Puerto Rico and the US Virgin Islands (except St. Croix) were closed to conch fishing (Baker et al. 2016).

In Puerto Rico, queen conch has a closed season from August 1 to October 31, and a minimum size limit of 9 inches shell length OR 3/8 inches shell lip-thickness. In addition, there are daily quotas (number of conch), being the lesser of 150/person or 450/boat (commercial) and 3/person or 12/boat (recreational) (Delgado et al. 2020). Commercial quotas are typically filled. The minimum size limits in the territorial and Federal waters of the USVI are the same as for Puerto Rico, but the closed season runs from June 1 to October 31, and there are no daily quotas (VIDFW 2024). An annual catch limit (ACL) is set for St. Croix by the CFMC, but enforcement is limited to the Federal waters off Lang Bank.

In the US Caribbean, only one attempt at assessment has been conducted, that within SEDAR 14 in 2007. No assessment was possible at that time due to data limitations, notably the lack of variation in catch per unit effort (SEDAR 2007), though the report recommended an increase in effort towards fishery-independent benthic surveys, which at the time were conducted at 5-year intervals under the SEAMAP-Caribbean program. Baker et al. (2016) reviewed the data from all surveys on Puerto Rico's western platform (1987-2013) and noted improvements in overall density and size structure suggesting that the minimum size limits and closed EEZ were showing positive results, though density did not increase beyond 2006. This review of status over time represents the best assessment to date. While it could not estimate any reference points, it was able to show improvements in stock status. Baker et al. (2016) also recommended a number of methodological changes, particularly replacing long transects with circular plots that would increase sample size, estimate area surveyed more accurately, enhance catchability of small juveniles, and allow more targeted stratification by depth and habitat type. The SEMAP-C has adopted and tested these recommendations and is moving toward conducting surveys every two years.

In the absence of quantitative assessment methodologies providing reference points and stock status evaluations, several attempts have been made to use a multi-indicator approach coupled with harvest control rules (HCRs) for queen conch assessment. A multi-indicator management framework is a model free assessment procedure that uses biological & harvest-based indicators in conjunction with harvest control rules (HCRs) to provide guidance on future exploitation through relative adjustments to previous TACs and management measures.

The universally recognized best managed queen conch fishery is the Jamaican fishery on Pedro Bank. This fishery is largely for the export market, so its landings are carefully monitored under CITES permits. Benthic surveys by divers are routinely conducted to give estimates of density, exploitable stock, and “age” structure using a combination of shell length classes for juveniles and lip-thickness and degree of shell erosion for adults (Tewfik 1997). A HCR rule sets the annual quota to 8% of the exploitable stock (based on Medley 2008) with precautionary limits at both low and high stock sizes, as well as protected areas to act as additional buffers (Smikle 2010), but annual quotas can be reduced or even set to zero if there are sufficient signs of trouble, such as a lack of evidence of recent recruitment, or declines in catch per effort.

Another management plan based on multi-indicators and HCRs was developed for Belize (Harford et al. 2016). Here, trends in catch, CPUE, and pre-season estimates of mature conch density (from field surveys) were used as indicators, with thresholds developed against reference levels to indicate significant change that would trigger a management response (to either increase or decrease the annual quota). Although this assessment approach was fully developed, its implementation deviated from the stated plan and invalidated some of the indicators, so its application remains untested.

Under CITES Appendix II, queen conch exporting countries are required to certify that supporting harvests do not put the conch population or its role in the environment at risk. This certification is known as a Non-detriment Finding (NDF). However, lack of expertise, resources, or understanding with the process has led to variable, and in some cases questionable, approaches to preparing or producing NDFs. In response, CITES has developed draft guidelines for queen conch NDF development (CITES Secretariat 2026) that is currently in the process of being tested in selected jurisdictions. This process examines a series of potential indicators (depending on available data) for Conservation Concern, Biological Risks, Harvest Impacts, and Trade Impacts. The rationale for each indicator is given, and criteria are provided for estimating the associated risk as low, medium, or high. In addition, the process calls for an assessment of the rigor of existing management regulations and a gap analysis comparing these existing regulations to identified risks.

C. Project Objectives

Given the importance of the queen conch fishery to the US Caribbean and the current lack of an existing quantitative assessment methodology to produce MSY-based reference points and, thus, estimates of stock status, the objective here is to develop a multi-indicator adaptive assessment and management framework for queen conch. This approach is based on the indicators developed within the CITES Secretariat (2026) guidelines that would be applicable to the data sources available within the region. These would be coupled with suggested management actions (HCRs) when threshold levels of risk are exceeded. Focus will be given to the situation in Puerto Rico due to potential differences in available data between there and the US Virgin Islands.

II. Method Description

A. Data Inputs

The data inputs are listed in Table 1. The first source of data are fishery-independent benthic surveys of the conch population. Conducted under the SEAMAP-C program, these have historically been done via diver-based long visual transects using underwater scooters at 5-year intervals (Baker et al. 2016). Moving forward, using circular plots, these surveys will occur on a biennial basis. However, due to capacity limitations, surveys will not be conducted in St. Croix, where the USVI commercial fishery exists. In addition, the SEFSC intends to supplement this effort with additional stations, which will increase sample size and the precision of population estimates, with the potential of estimating actual population size. Yet the priority given to support sustained funding for this effort remains uncertain. For this reason, the focus here will be for the Puerto Rico fishery.

Data to be obtained from these surveys include density, size structure, and reproductive activity. Size structure is based on length classes for juveniles and lip-thickness classes for lipped individuals. This will allow density to be calculated by size class, which would feed into a number of potential indicators, such as adult density, or juvenile:adult ratio, in addition to a more generic average size. It will also allow tracking of potential recent recruitment. As surveys will be conducted during the closed season during the time of peak reproduction (Appeldoorn et al. 2011), divers will also record reproductive activity (i.e., spawning, copulation, pairing).

The other primary source of data is from monitoring of landings, which is done via commercial catch reports and landings inspections. Conch are typically landed without the shell, so landings are reported in weight. Via individual meat observations, landings inspections have the potential to also identify the proportion mature (using external reproductive features) and the level of processing (needed to convert weights to numbers), and construct weight-frequency distributions. While this would require additional training, it may also be feasible in the near future using AI-assisted photo-based data collection. At present, the available data useful for indicator development would be landings, number of trips, and location of fishing (the latter is reported relative to 2 x 2-nautical mile grid cells).

Lastly, the price per pound that conch sells for is obtained from surveys of fish houses and fishery co-ops. These data can be used to develop an indicator of changes in demand.

B. Analyses/Data Outputs

Table 2 gives examples of potential indicators as developed in CITES Secretariat (2026) that have potential application in Puerto Rico given the nature of the available data. The actual indicators to be developed and used requires consensus among stakeholders, particularly between the CFMC and the PR Dept. of Natural and Environmental Resources in order to have compatible regulations. Nevertheless, for the purpose of illustration, a set of potential indicators could be as follows: (1) Density of exploitable stock, (2) Size composition, (3) Recruitment, (4) Frequency of reproduction, (5) Total number of trips, (6) Distribution of fishing effort, (7) Trend in catch, and (8) Trend in price/lb (in constant dollars).

With indicators of risk being as shown in Table 2. However, for all parameters trends over time would also be an important consideration. Low risk would indicate a potential for harvest increase while high risk would indicate the need to reduce the catch.

Having a large number of indicators allows for a more nuanced assessment of the state of the resource, but runs the risk of having sets of indicators pointing toward different levels of stress, such that it may lead to confusion and prove difficult to obtain a consensus for change when one is truly warranted. One solution might be to partition the indictors into two groups. In this case, the first four, obtained from the benthic surveys, are indicative of the state of the population, and a composite score could be generated from these four. The latter four indicators are more indicative of the state of the fishery, and again a composite score could be developed. In both cases using the average of the four indicators would be the simplest, using a 2 for low stress, 1 for medium stress and 0 for high stress. An overall score would combine the two composites, though one could argue that the one describing the underlying population should be given more weight, especially since the variability of these estimates can be calculated. In the example in Figure 1, the indicators from the benthic survey are given a weight of 1.5.

C. Implications for Management

Once procedures are set up before hand, the final, the composite average score would provide a specific interpretation on the status of the stock in terms of risk being low medium or high (i.e., on a scale of 2 to 0). Established trigger values would then mandate specific management actions, i.e., HCRs. Figure 1 gives an example of HCRs using a conservative approach. The actual degree of conservation might correspond to the P* value, which is set by the CFMC. In this example, an overall score > 1.5 would indicate the stock is healthy and catch (or effort) levels could be increased by, say, 20%. In contrast, a score of < 1 would indicate a condition of high stress requiring a decrease in these levels by perhaps a similar amount.

Management effectiveness, especially with respect to those indicators achieving high-risk scores, should also be evaluated. For example, it may be more desirable to affect a reduction in risk by increasing size limits, extending the closed season, or enhancing enforcement than to specifically alter the annual catch limit.

D. Caveats

There are three main caveats to consider. First, this multi-indicator approach is largely untested, so establishing such a multi-indicator assessment approach will be new to all parties. Critically, consensus needs to be obtained for all steps of the process: (1) the indicators chosen, (2) their respective definitions of low, medium and high stress, (3) the weightings given to each indicator as they are combined into a composite score, (4) the trigger values requiring mandated management response, and (5) the magnitude of that response. This process will require substantial orientation, education and discussion. Fortunately, a substantial amount of work has been done int this direction with respect to identifying key potential indicators, their rationale, and their interpretation (CITES Secretariat 20206).

Second, none of the indicators mentioned directly assesses the relationship between the extent of reproductive activity and spawner density. The current SEAMAP-C conch sampling protocol calls for only one 10-m radius circular plot to be conducted at each site. That yields minimum spawning densities of 32 conch/ha for a lone spawning female, 64 conch/ha for a mating pair, and 95 conch/ha if there are three adults present. As such, there is minimum resolution at this low end to detect a density-based Allee effect threshold to reproduction (Stoner and Ray-Culp 2000, Stoner et al. 2012a, Delgado and Glazer 2020). Because the survey sites are selected in a stratified manner, it is likely that most of the sites sampled will not support spawning aggregations, unlike the surveys by Stoner and Ray-Culp (2000), Stoner et al. (2012a), and Delgado and Glazer (2020) (see Appeldoorn 2025). Thus, the sampling protocol is poorly positioned to address the question of a minimum threshold density for reproduction. Nevertheless, this might be demonstrated over multiple surveys. However, the real question is not whether, or where, a density-based Allee effect threshold exists, as much as whether there is documented reproduction going on, and the suggested indicator of frequency of observed reproductive activity seeks to provide a quantitative measure of this.

Third, because benthic surveys are schedule to be biennial, new assessments could only be made every other year. However, once the data are available, the assessment would almost be automatic.

III. Applications of the Method

Currently, this method not been applied and so remains untested. However, two examples exist to illustrate how such indicators can be developed and interpreted. One is the work of Harford et al. (2016), who developed multi-indicator assessment methods for both queen conch and spiny lobster in Belize. Unfortunately, the indicators devised were incorrectly implemented, so this case remains untested. The other is the CITES

NDF Guidelines for queen conch (CITES Secretariat 2026), which is currently in the process of being tested within selected queen conch exporting states in the region.

IV. Discussion

Under Section (h) of National Standard 1, for "stocks for which data are not available either to set reference points based on MSY or MSY proxies, or to manage reference points based on MSY or MSY proxies...councils may propose alternative approaches for satisfying requirements of the Magnuson-Stevens Act other than those set forth in these guidelines. Councils must document their rationale for any alternative approaches.." (50 CFR 600.310(h)(2). This language suggests that a multi-indicator assessment approach should be a viable option for queen conch, in that it establishes an assessment process that results in a quantitative score that can be compared to established reference points, Pre-determined management options are required when the reference levels are exceeded (for both good and bad). Furthermore, the introduction here provides a suitable rationale for the adoption of this approach.

In the absence of adopting this approach, the management of queen conch will most likely stay as is. Currently in the US Caribbean, queen conch is listed as a Tier 4 species, that is, its ACL is set by assuming some relationship between the catch level observed during a period of steady catch and MSY. There is no particular validity to this assumption, but it allows the approach to fall within the MSY-based National Standard 1. As such, using a period of steady catch as a baseline is just an approach where there is only one indicator (annual catch), and an "assessment" that is based on empirical observation. Furthermore, an assessment can only result in a lowering of catch if an ACL is exceeded. There is no formal mechanism within this assessment framework for increasing the catch if indeed the set level is below MSY.

An alternative approach would be to wait and see if the new benthic sampling program has sufficient statistical power to measure overall population size. If so, this would open up the possibility of using methods based on estimating overall removals from the population. However, one could argue: why wait? The multi-indicator approach is conceived as being adaptive, such that, as experience is gained, new or modified indicators could be introduced or substituted for existing ones. One example of this would be the potential for establishing an indicator based on spawning-density, currently thought to be a critical factor in affecting potential recruitment overfishing (Stoner and Ray-Culp 2000, Stoner et al. 2012a, Delgado and Glazer 2020, CITES Secretariat 2026). With the new survey protocol calling for the recording of reproductive activity, this potentially be related to density if there are sufficient number of reproductively active conch observed, but as mentioned above, there may not be sufficient stations within reproductive aggregations to develop a reliable indicator.

Management Strategy Evaluations (MSEs) have been used to assess the applicability of various data-poor approaches to managing fisheries stocks (e.g., Sagarese 2019). This approach generates a model for a theoretical population based on the known life-history of the target species. This provides a comparison of the modeled population with one characterized as data-poor, i.e., where uncertainty is introduced into key aspects of the life-history and the fishery. Despite the documented issues that the unique biology of the queen conch generates for the application of such models, there is a heuristic model developed by Harford (2021) that allows for merging of size-based metrics for juveniles and adults, with the input of the extent of local variations in size structures. This approach could be used to construct an MSE for any multi-indicator approach to assess its effectiveness in maintaining a health conch population without forgoing potential yield. Obviously, this would comprise a valuable learning tool for all parties during the process of deciding on potential indicators, their respective thresholds and resulting management actions, and would give management agencies a relative assessment on the degree of uncertainty inherent in the approach.

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VI. Tables and Figures

Table 1. Potential data for queen conch indicator development

Data for Indicator Development	Data Source
Density	Biennial benthic surveys: SEAMAP-C, SEFSC
“Size” Composition	Biennial benthic surveys: SEAMAP-C, SEFSC
Frequency of reproductive behavior	Biennial benthic surveys: SEAMAP-C, SEFSC
Landings	Catch reports, landings surveys
Number and location of trips	Catch reports
Price per pound	Surveys of Fish Houses & Fisher Co-ops

Table 2. Indicators and risk assessments potentially applicable to the Puerto Rico queen conch fishery. Extracted from Tables 6.2 & 8.1 in CITES Secretariat. 2026.

Indicator	**Impact Severity** (Risk)		
	Low (=2)	Medium (=1)	High (=0)
Density	Harvestable population density > 100 conch/ha	Harvestable population density < 100 conch/ha but >50 conch/ha	Harvestable population density < 50 conch/ha
Spawning density	Spawning density (i.e., mature adults) > 300 conch/ha	Spawning density < 300 conch/ha but > 185 conch/ha	Spawning density < 185 conch/ha
Average size of conch in the population	Average size well above minimum size. Average size increases over time	Average size significantly above minimum size. Average size is variable but no long-term trend	Average size approaches minimum size. Average size decreases over time
Size composition of population	Conch found in oldest size/age classes	Some old individuals occur	No individuals found in oldest size/age classes
Recruitment	Many conch observed in the field in the smallest size classes (age 1+)	Some conch observed in the field in the smallest size classes	Few or no conch observed in the field in the smallest size classes
Distribution of fishing effort	Spatial/depth distribution of effort is constant over time	Spatial/depth distribution of effort changes slightly over time	Spatial/depth distribution of effort changes over time to deeper depths or sites further away
Reproduction Frequent	Mating, copulation and spawning are frequently reported by fishers/surveyors	Mating, copulation and spawning are occasionally reported by fishers/surveyors	Mating, copulation and spawning are infrequently or not reported by fishers/surveyors
Trend in catch	Catch is decreasing over time	Catch is steady or slowly increases over time	Catch is increasing rapidly over time
Trend in price per weight	Price per weight is decreasing over time	Price per weight is steady or slowly increases over time	Price per weight is increasing rapidly over time

Figure 1. Example application of a multi-indicator approach for queen conch using indicators derived from fishery dependent and independent sources.

Step 1: Individual indicator scores **Step 2:** Population & fishery average scores

Indicator	Score	
Density	0	
Size composition	1	Average score = 1 (moderate stress)
Recruitment	2	
Freq. reproduction	1	
Catch trend	1	
Price/lb trend	1	Average score = 0.75 (moderate stress)
Number of trips	0	
Spatial Distribution	1	

Step 3: Weighted aggregate score

	Score		Weight		Weighted Score
Survey based indicator average =	1	x	1.5	=	1.5
Fishery based indicator average =	0.75	x	1	=	0.75

Weighted Average = 1.125

Harvest Control Rule (Range = 0 - 2)

Indicator Score	Status	HCR
>1.5	Low stress	Raise ACL by 20%
1 to 1.5	Moderate stress	Keep ACL unchanged
<1	High stress	Reduce ACL by 20%, and Review Mgt Measures

Final Determination: Keep ACL unchanged