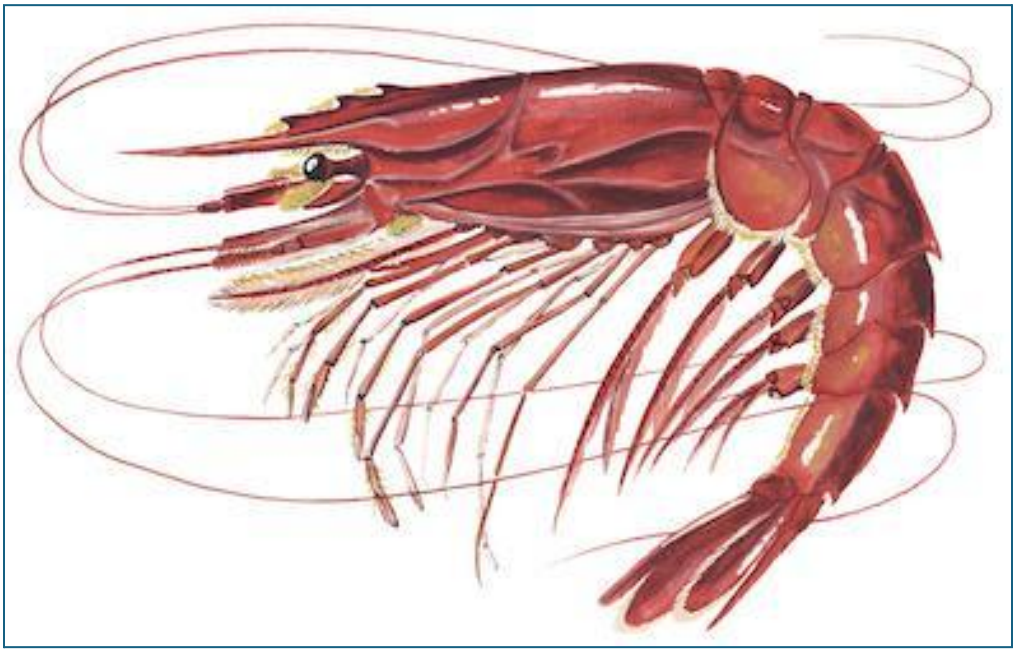
Fisheries Management Plan (FMP)
for the
Liberian Multi-species Deepwater Shrimp Fishery



National Fisheries and Aquaculture Authority (NaFAA)

June 2024

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List Of Acronyms

BRD – Bycatch Reduction Device

CMA – Co-Management Association

CPUE – Catch Per Unit Effort

EEZ – Exclusive Economic Zone

FAO – Food and Agricultural Organization (of the United Nations)

FCC – Fishing Concession Contract

FCWC – Fisheries Committee of the West Central Gulf of Guinea

fMEY – Effort (in fishing days) at MEY

FMP – Fisheries Management plan

fMSY – Effort (in fishing days) at MSY

GDP – Gross Domestic Product

GEBCO – General Bathymetric Chart of the Oceans

GFW – Global Fishing Watch

GOM – Gulf of Mexico

IUU – Illegal, Unreported, and Unregulated fishing

LSMFP – Liberia Sustainable Management of Fisheries Project

MEY – Maximum Economic Yield

MPA – Marine protected area

MSY – Maximum Sustainable Yield

MT – Metric Tons

NaFAA – National Fisheries and Aquaculture Authority

NM – Nautical Miles

OCC – Opportunity Cost of Capital

SAM – Swept Area Method

SSF – Small-scale fisheries

TED – Turtle excluder Device

VMS – Vessel Monitoring System

WTO – World Trade Organization

Executive Summary

This Fisheries Management Plan (FMP) is for deep-water industrial shrimp and the species assemblage caught with it. It is based upon an analysis from two years of experimental fishing data under an agreement between the Government of Liberia and SOPERKA, a partner with Grupo Pereira, a Spanish company. These data and the results of these analyses, as well as other data from Global Fishing Watch (GFW), were used to develop an analytical framework that underpins the FMP's proposed actions. The methodology is based on the surplus production model used in fisheries economics. This FMP can be used by NaFAA to organize the management of their deep-water shrimp fishery. The Gulf of Mexico Shrimp FMP from the United States was also consulted.

The FMP fulfils the Amended Fisheries Law of Liberia by assuring that the deepwater shrimp fishery will be managed to control long-term overfishing and excess capacity. It provides for the regular collection and analysis of reliable catch and effort data, as well as scientific data on directed fisheries and subsequent bycatch, some of which is commercially important, and all of which is important to public managers as this fishery develops. The data collected should meet the Law's criteria of "best available scientific information," which makes explicit comparisons to other countries' FMPs. Further, Liberian fisheries law requires that these fisheries provide social and economic benefits to the Liberian people. Many of these objectives strongly resemble the language of the Sustainable Fisheries Act of the United States, which argues that amendments to any FMP must be demonstrated to "maximize the net benefits to the nation."

Liberia faces economic headwinds. Although real GDP has been rising since 2003, annual growth in GDP (in 2022) is at 2.6%. Inflation was projected to increase to 8.2% due to election-related speculation in 2023, easing to 6.5% in 2024. Fiscal deficits are expected to stabilize at 4.0% in 2024. However, fiscal deficits have been worsening for the country, making it even more important to increase receipts to pay for public projects. The current account deficit (related to foreign trade balances, foreign currency deposits, and remittances) is projected to decline to 16.2% in 2024 due to improved exports. Public debt is projected to rise to 56.9% in 2024. The risk-adjusted opportunity cost of capital, as reflected by Liberia's debt market, is elevated. The annualized yield of 3–6-month T-bills in Liberia is over 16%, as compared to about 5.4% for U.S. T-bills. This suggests very high capital costs, which reflects the fact that future benefit streams from natural resources, such as fisheries, will have a lower value in Liberia than in other countries. For fisheries management, high capital costs, expressed in bond yields and interest rates, means that tendencies towards overexploitation and depletion or extinction of certain vulnerable stocks such as scarlet shrimp are likely. This is exacerbated by high prices as well. In Liberia, despite the Law, behavior aimed at realizing benefits today will compete with the urge to manage sustainably long term.

Coupled with these concerns, four governance indicators collected from the World Bank paint a difficult picture for fisheries management: Control of Corruption stands at -0.9 (on a scale of -2.5 to +2.5), Government Effectiveness -1.4, Regulatory quality -1.0, and Rule of law -0.9. The Ease of Doing Business Index, published by the World Bank in 2019, ranked Liberia 175 out of 190

countries. If correctly implemented, the measures in this FMP should contribute to improvements in governance scores, and with the right partners, it would increase the contribution of the fishery to the Liberian economy.

The economic environment for public management of fisheries is also different and, in some ways, more complex in Liberia than in countries like the U.S. Overfishing in the U.S. has been mainly due to competition among numerous firms, driving the fishery to the open access or "free-for-all" position in the absence of good collective management. Public managers can help slow this competitive drive by advocating policies aimed at controlling effort and capital accumulation.

Liberia has been dealing with one company and three of its vessels. This company is a subsidiary of a multinational corporation based in Spain. In the U.S. case, the resource rents from the shrimp fishery are dissipated into the local economy; that creates some employment and overcapitalization. However, in the Liberian case, there is a license fees of 10% calculated on the ex-vessel value of the catch and an export fee that is 10% based on the market value of the landed catch . Under-reporting catch, always an issue in public management, may still be important for the Liberian case. The Liberian shrimp FMP must therefore contend with vertically integrated multinational firms that exert an important amount of market power on the buyer's side for fishing access.

To counter this, the FMP presents an approach that helps Liberia to sustainably manage the fishery over time by being much stricter about what concession holders should do to stay in good standing. It depends crucially on concession holders providing accurate logbook data on both Catch (kilograms of both target species and all commercially valuable bycatch) and Effort, in 24-hour fishing days. These data are then collated by NaFAA, analyzed, and reported to the concession holders at the beginning of each season. They are then used to determine the aggregate effort for the fishery for the following season. The FMP requires active participation of vessel owners in the scientific assessment of stock using the Swept Area Method (SAM) every year. These are used to produce year-on-year analyses of standing stock. The methodology for using this approach is described in the FMP and in a companion Excel file. The values of standing stock of scarlet shrimp in 2021-2022 may not be reliable because the data collected were not randomized. However, between 2021 and 2022, the ***relative stock*** of scarlet shrimp declined by 57%. This is backed up by data from GFW, which recorded intense fishing during these years in Liberia's EEZ, but because of the agreement, it was completely legal.

NaFAA asked for a catch and effort analysis, necessary for managing the fishery going forward. This was done, although the data are poor and not enough to statistically estimate a yield-effort function. It was derived using mathematical methods and should be validated on a year-by-year basis, where each year provides an additional data point. The estimated model says that the scarlet shrimp fishery is ***already over-exploited***. Using the logic of these fisheries models, the effort in the Liberian EEZ should be reduced to 72-74 days. Both scientific data and Catch-Effort data should be collected from that operating year, and another surplus production model should be re-estimated after 2021-22 data are further validated. The amount of effort in days as defined by this FMP should be collected every year for review and decision on the effort

to apply the following year, and so on for every year after. This process of data collection, analysis, consultation, and decision of the effort to apply in the coming year is discussed in the FMP. The management method is based upon the "traffic light" approach, which is tied to three important indicators from the surplus production model estimates: the percentage change in yield of scarlet shrimp and the species assemblage in two adjacent years, the percentage change in effort over two adjacent years, and the ***elasticity of yield with respect to effort*** over adjacent years. These indicators are explained in the FMP.

The success of this FMP depends on how well public managers in Liberia can manage their relationship with concession holders. If concession holders are uncooperative, and their behavior cannot be stopped, no more benefits to Liberia will be forthcoming, and the target species of deep-water shrimp will be economically extinguished in short order. With noncooperative partners, it may be better for Liberia to have no agreement than to have a bad faith agreement with legalized access. However, if a cooperative partnership were possible, the two-year model suggests that exploitation of the resource at 72 days (MEY) or 74 days (MSY) of effort would yield a revenue (and catch) which is higher than in open access, with rents (conservatively) from collective management of between 14.765 million Euro (at MEY) and 14.752 million Euro ***a year***. A 50/50 split of the resource rent at MEY (7.383 million Euro), yields a capitalized value for Liberia of 53.523 million Euro at 16%, the approximate annualized yield on public debt in Liberia. However, this calculation assumes that the concession holders become reliable partners.

For these reasons, the FMP aims for tighter control of both the catch and effort statistics. A closed season during the spawning season of scarlet shrimp has been proposed. The FMP proposes a more intensive and open use of the NaFAA website for management purposes. The Liberian fisheries law, the (approved) FMP, and all amendments thereto should be published on the NaFAA website. Concession holders to this fishery and their parent companies should be part of the public record and posted on the NaFAA website. NaFAA should hire not only biostatistical expertise, but economic expertise for this FMP and others that will be developed. This expertise should be immediately used by NaFAA to develop new fee schedules. This new expertise should also be charged with independently evaluating fees and royalties for fisheries resource use, and charging fair values for the resources used, rather than relying on values proposed by concession holders. This will need to be done to defray the increased costs of public management. The FMP proposes more rigorous vetting of partners based upon their performance and cooperation, and expulsion for non-cooperation. This may include granting access to the Liberian multi-species shrimp fishery only with a signed Fisheries Concession Contract, which should be much more detailed than the experimental fisheries agreement. Constructing such a contract will need further research by the new economic staff hired by NaFAA. Concession holders must agree to a check-in inspection of their hold prior to fishing in the Liberian Zone, and a check-out inspection prior to leaving Liberian waters. They also must participate actively in the collection of accurate scientific and management data necessary for the management of the fishery they use.

1.0 Basic management principles from the Fisheries Amended Law of 2019

The objective of the Fisheries Amended Law of 2019 is to ensure the long-term management, conservation, development, and sustainable use of the fisheries, aquaculture resources, *and* related ecosystems for the benefit of the people of the Republic of Liberia.

To make this objective operational, this FMP makes reference to on-going investment in information acquisition in support of both management of the stocks and management of the ecosystem, through regular scientific and economic monitoring. It also must address the question of determining benefits from the fishery, and the distribution of these benefits.

In Section 2.2., Fisheries, and by extension the multi-species shrimp fishery, is defined as a natural asset and heritage of all of its people. The Government, with NaFAA as its principal agency for fisheries and aquaculture, plays a central role in managing this natural asset and heritage. This section also contemplates a management for the benefit of present and future generations of Liberians. The management and economic implications of these broad principles are that the investments in scientific information must be of high quality, regularly collected, and in perpetuity. The management plan therefore must be substantially able to provide its own means of financing regular data acquisition of sufficient quality to effectively satisfy the broad objectives of the law.

Part b of Section 2.2 enjoins NaFAA to manage these fisheries sustainably to achieve socio-economic benefits. The indicators used to validate the existence of these benefits includes economic growth, human resources development, employment, and sound ecological balance. This FMP will suggest various economic and ecosystem indicators that are in line with these precepts, but which are measurable or more directly managed.

Part c of Section 2.2 states that management measures will be based upon the best available scientific information. This information, as stated in the above mentioned law, will be used to "maintain or restore stocks at levels of producing sustainable yield, qualified by environmental and economic factors, including fishing patterns, the interdependence of stocks, and relevant international standards." This statement contemplates a management system based upon a clear understanding of modern notions of sustainability. It also contemplates taking into account changing international standards. There are some countries that use trawl techniques in the shrimp fisheries, both legally and illegally, to remove the maximum amount of biomass of all species, including shrimp, in the shortest possible amount of time and in the most cost efficient manner. However, fishing in this way is not sustainable. Liberia, by its fisheries law, aligns itself with other countries that are attempting to eliminate these wasteful practices. This FMP will introduce management practices aimed at reinforcing that alignment with the objectives outlined in Part c.

Part d of Section 2.2. calls for the application of precautionary and ecosystem approaches to management and development meaures at a standard that is "equal or superior to agreed international standards", and that take into account the need to conserve habitats and biodiversity. It is difficult to propose a simple management plan that respects these criteria for a multi-species fishery. This is because trawling technology can be very non-selective, and the

biological nature of predator and prey relationships between shrimp and other species that prey upon them make it such that catching non-target species is difficult to avoid. Yet these technologies continue to be used in areas of the world where there is less surveillance and active management. This FMP will use precautionary approaches that meet international standards, drawing on the shrimp fisheries management experience of other countries such as the United States and Australia. It is also anticipated that the evolution of this plan over time will inevitably need to address bycatch reduction and habitat destruction, just as we see in other shrimp fisheries in other countries.

Part f of Section 2 states that resources shall be allocated consistently with international standards and, among other things, to promote employment and develop the fisheries and aquaculture sectors of Liberia. For purposes of this FMP, one interpretation of this clause is that resources such as the shrimp, all the bycatch, and the ecosystems shall be used primarily to provide maximum sustainable net benefits to the Liberian people. Most other countries include language saying that fisheries management measures must demonstrate that they will maximize net benefits to its citizens, and not just to the fisheries sector. Although it is rare that this can be demonstrated quantitatively, there are measurable indices (like local employment, creation of new businesses, rising incomes of Liberians, more capital improvements in fishing infrastructure on Liberian soil, lower levels of extreme poverty and hunger, more access in Liberia to fish and shellfish at reasonable prices, etc.), that can and should be used to demonstrate that plan measures maximize net benefits to Liberian citizens.

Part i of Section 2.2 of the law provides key guidance on the sort of issues that policies should manage. Overfishing is the first issue, and excess capacity is the second. However, to make this clause operable, this FMP provides a framework for making reliable assessments of real effort and catch of any fleet that uses their resources, as well as assessing standing stock. From these notions managers gain an understanding of the more complex issue of industrial capacity in the fishery. However, information must be carefully and continuously collected on a regular basis. These data, collected over time, allows managers to decide whether a fishery is being fished sustainably. This requires a substantial knowledge among the managers of both fishery science and economics.

Parts j, k, and l of Section 2.2 assure that customary fishing rights will be recognized and access to customary fishing ensured[1]. It also asserts that the interests of artisanal and subsistence fishers will be considered, and their participation in the management of their respective fisheries is expected. Presently, no artisanal or subsistence fishers participate in deepwater shrimp fisheries. However, this FMP and others should anticipate the possibility that small-scale fishers involved in coastal fisheries could be affected by a deep-water fleet (and vice versa), by having conflict resolution mechanisms built into the plans, where potential conflicts are discussed and resolved

[1] The customary fishing rights referred to in Section 2.2j of the 2019 Law is mainly intended for Liberians in the small-scale fishery sector. Presently there is no customary fishing at the small-scale for deepwater shrimp. However, there is an important discussion to be had about whether this fishery should be developed exclusively as an industrial trawl fishery for foreign resource users or should smaller scale vessels that are Liberian-owned be eventually included?

between different parts of the industry, which are then incorporated into the respective FMPs. In general, this FMP assumes that the main beneficiaries of this management are the Liberian people, who are therefore potentially all stakeholders. In that regard this FMP promotes the idea that representatives of different fisher groups may at any time raise issues and demand participation in the management of any fisheries resource, including deepwater shrimp.

Clause m of Section 2.2 recognizes that conservation and management measures, notably those that arise from this FMP, may require coordination between Liberian government officials and regional fisheries management organizations to which they belong.

Clauses n and o of Section 2.2 promise implementation of the FAO Code of Conduct for Responsible Fisheries and other internationally agreed plans of action and guidelines. In the context of this FMP, it is assumed that the legal framework of the Fisheries Law of 2019 assures that the measures adopted will be consistent with all international agreements where appropriate.

In Chapter 3 of the Revised Law of 2019, provisions are made for the creation of co-management fisheries associations based upon area and users. Fisheries Management Plans are also mentioned. Co-management associations (CMAs) have been established in five of the nine coastal counties of Liberia. Their main function is to help jointly manage the fisheries with NaFAA.

Chapter 4 section 4.2 of the Law of 2019 states that the Director General has the responsibility for FMPs for any fishery or area in the Fisheries Waters and shall ensure consultations with relevant stakeholders including the Fisheries Advisory Council in the development of each plan. This FMP, which is the first ever, will draw on FMP experience from other nations having a multi-species trawl fishery for shrimp and with laws that are like Liberia's.

2.0. Management Objectives and Strategy: Overview of public fisheries management

2.1. Monospecific Management

The bioeconomic management objective and strategy is best understood by first looking at one species. Scarlet shrimp is the example, because it is the deepwater species that is the most sought after, and commands relatively higher prices per kilogram, especially in Spain. It is also the species which appears to be the longest lived, is slower growing, and is therefore the most susceptible to biological and economic overexploitation. In searching for and targeting this species, other species, both of commercial and non-commercial value, are captured as well. This complication is discussed in section 2.2 below.

Most animal populations grow in a way that makes it possible to map the biomass of the stock to the change in the biomass over time, say, in a year. As a species fills its habitat, the rate of biomass growth of the population increases, reaches a maximum, and subsequently declines, as the total biomass of the population gets larger.

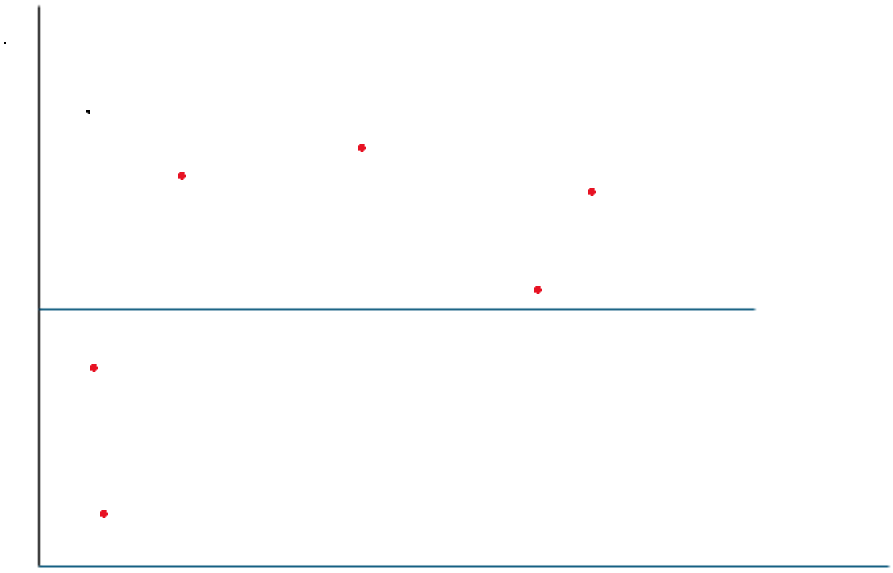
A small group of vessel owners (say three) fishing on a virgin stock could, if they collaborated with one another, collectively take just enough catch to keep everyone in business on a perpetual basis. If they can do that over several years, they would be "sustainably harvesting" from that stock. The vessel owners would soon find that they would be better able to manage the fishery if they shared three pieces of information. They would need to have a common measure of ***effort***. If the vessels were roughly the same size and used the same trawl gear, they could measure the ***number of dragging hours*** (from the time the net hit the bottom to the time it is pulled up) in the season. These hours, divided by 24 hours would give ***fishing days***. As they got more sophisticated, they might decide to take the geographical position, the time, and the date of each haul. This is because scarlet shrimp patches may not be stationary over the year; they may move around. Vessel owners would need to pool that data ***by year***. They would also need to carefully weigh the ***catch*** of each haul in kilograms, and pool that for the year. Finally, they would need to eventually put in place a ***sampling program***, so that they could randomly measure ***size distributions*** of the captured scarlet shrimp, as well as other commercially valuable species. This is important to provide information on the health of the scarlet shrimp stocks, but also to measure the relative sizes, because buyers may pay higher prices for more uniformly larger shrimp. There are numerous examples in the fisheries management literature of fisheries associations in charge of an area voluntarily waiting for the optimum time to harvest a target species to maximize size, and therefore revenue.

If the group of three vessels vary their collective effort over the years through trial and error, it will begin to see a parabolic relationship between their total catch of scarlet shrimp and their total days of effort. This is called the yield-effort curve (Figure 1). A mathematical derivation of the yield effort curve is in **Annex 1**.

As described in the example, this relationship is built as a collaborative project over several years. It requires assiduous investment by either private enterprise or public management (or more likely both) to collect and analyze the data. The example described here is the optimistic case of a small group of fishing firms led by some forward-thinking managers who have decided to maximize sustainable profits over time, by varying their collective effort together. In this example, they collected 6 years of good quality catch and effort statistics (the red dots in Figure 1). This type of "private management" has happened in fisheries before. As the number of years and the sample size gets larger, subsequent statistical estimations of the yield effort curve become more refined. The blue lined parabola is an example of such a statistical estimation, based on the 6 data points.

Every point on this estimated yield-effort relationship in Figure 1 (the blue parabola) is "sustainable"[2]. The fishers found out from this that a massive amount of effort (near point B) yielded the same sustainable yield as a more moderate amount of effort (at point A).

[2] Since we are assuming that these fishers are highly skilled at managing their collective effort and are motivated not to cheat on their partners.



Collective effort (F) in number of 24- hour fishing days per year

Yield (Y),
in kilos of scarlet
shrimp/year
A

B

Note: Each point on the curve is in long-run equilibrium
with the growth dynamics of the population.

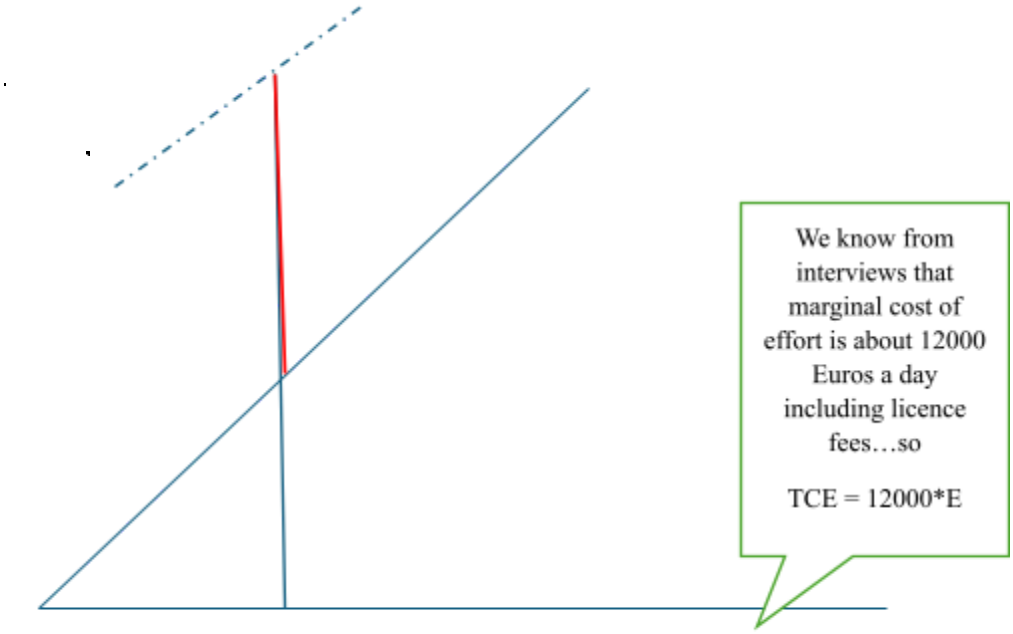
Figure 1. An estimated yield effort relationship for the scarlet shrimp fishery after six years of data collection.

If the three vessels collaborate for six years, they may be able to statistically estimate the yield effort relationship with more accuracy. The more data points (years), the clearer and more accurate the relationship becomes.

If these vessel owners coordinate among themselves, and more importantly, if they could exclude others from using the resource[3], they might try to vary their collective effort so that they are using that effort efficiently. One way of doing that is for them to apply an amount of total effort, such that the ***long-term marginal costs of effort*** equal ***the long-term marginal revenues***. To be able to manage in that way, the Association will need to collect additional information. They would need to collect the landed prices of scarlet shrimp ***by size***, so that they could form a ***weighted landed price per kilogram,*** according to the size distribution data they collected earlier.

[3] It could be argued that SOKOTA was doing exactly that during 2021-22.

They would multiply this price index to the total catch statistics, transforming the relationship into a ***revenue-effort relationship*** (Figure 2).



Total Effort measured as 24-hour fishing days per year

Total revenue
(kilos per year) X
(weighted average
price per kilo)
in Euros.

dollars).
A: OCC = 0

B: OCC = ∞

TCE

C

F*

Figure 2. Open access versus profit maximizing application of effort.

An association of fishing firms with good long-term managers would choose to produce at point A, where yearly profits and resource rents together are maximized (the red bar AC). In the "free for all" position (point B), all firms go their own way and fish competitively. Stocks usually

become depleted or extinct, resource rents are dissipated, and each firm only makes a profit from their own labour and other inputs.

To reach point A, the Association would try to understand their costs of fishing by looking at the ***marginal cost per day of fishing, averaged between running days and fishing days***. We have obtained uncorroborated evidence that for the experimental fisheries, the ***marginal cost*** of running an industrial deepwater trawler targeting shrimp is about 12000 Euros (including licence fees). It follows that the ***total cost in Euros*** is 12000*Days. This information is found on **Figure 2**.

The points on the "Revenue-effort curve" are also "sustainable". They map directly to the yield-effort relationship. From the standpoint of retaining resource rents, or profits from holding natural assets, it is better to exploit the stock at point A than at point B. Since there is a cost to using days of effort and since the application of excessive effort also increases habitat loss and bycatch loss[4], the association would want to use as few days as possible, to maximize their profits by ***collecting the resource rent as well as their normal profits (the vertical red bar, AC)***. At this level of effort, total profits are maximized for the association. Also, in an environmentally uncertain world, it is better to be at point A, because it provides the most protection against environmental events which could extinguish the stock. Because trawling can be environmentally costly in terms of bycatch and habitat loss, it makes sense to minimize damage to habitat and other species by minimizing the excessive use of effort. For these and other reasons, a well managed fishing association would try to manage their effort nearer to point A and avoid point B. This leads us to ask why we often find fisheries being exploited at the "free for all" open access point B, if A is such a good choice.

In effect, point A is where most rational firms and public managers would like to be. However, whether it is a private group, or public management, or something in between, such as a co-management agreement, they all confront ***organizational costs***, the most important being ***data collection and management costs, including analytical costs***. Firms as well as public managers must have clear objectives, must meet regularly, and must have data collection programs as well as analytical capacity in natural science and in economics. They must also be led by rules that can be effectively enforced through investments in surveillance. This means having a functioning coast guard or activists who raise the costs of illegal activity by exposing it to public scrutiny.

Sustainable fishing over time and yields on forms of capital - The management strategy above becomes more complex when we consider the fishery as part of the broader economy. It becomes more complex in two important ways. First, the monetary policies of a country as well as the operation of capital markets in the country will have an impact on how ***Natural Capital***[5] like fish stocks, are exploited. It has long been known (Hotelling,1931) that there is a link

[4] Which for now may be difficult to measure in Euro terms, but which are nonetheless real costs to the economy of Liberia.

[5] The formal definition of Capital is a physical means of production that provides a stream of services over time. Capital can be produced, for example cars and houses, or it can be naturally occurring, like a stock of fish.

between rates of extraction of natural resources and the "interest rate", or more precisely, the ***opportunity cost of capital (OCC)***[6]**.**

A well-run resource monopoly, which often makes trade-offs between investments over time and thereby will have a positive OCC, will try to use effort that will keep them very near point A but slightly to the right of it, for as long as possible. This is because with a positive OCC, members of the economy will prefer to manage their assets such that the yield in percentage points of that asset equals their OCC; the returns they would receive in alternative investments. So, for example, in an economy of high inflation rates, the degree of impatience for yield today will incite people to fish harder, converting their landings to other investments and consumption goods that they value more in the present.

Finally, OCC is also affected by the overall economic condition of a country. If capital markets are difficult to use, interest rates on loans high, and if there is a lot of hunger and poverty with reduced life expectancy, this results in a sort of "short-termism" behavior that makes everyone in the economy want all things now rather than later. ***This is even more true for users of resources who are not invested in the country at all, but simply come to fish and then land the catch elsewhere***. For these foreign fishers, sustainability of Liberian fish stocks may not be an important consideration for them. Once the stocks and the habitat are damaged, they simply move on down the coast. Even for domestic fishers living in Liberia, economic conditions may be so difficult that it incites people to "fish like there is no tomorrow," with no motivation to conserve natural stocks. A fishery composed of those who have a very high personal OCC, with no public control, will end up at point B, where all resource rents are dissipated and profits for each fisher are low. In the case where OCC is very large, extinctions of slower growing animals and plants result. Because of the realities related to capital markets and interest rate, most private and public management falls somewhere between A and B. In fisheries, movement towards B uses more effort (and if the fisher is Liberian, this means more employment for Liberians), more environmental costs, and possible biological over-exploitation. At point A, managers have maximized profits including resource rents, reduced effort, and therefore have ***reduced employment*** for Liberians. They have a very long-term view on sustainability, which means their OCC (the desire for benefits today) is closer to zero. In fact, most publicly managed investments like roads, bridges, and even sustainable fisheries management, imply that citizens and investors are willing to take the long view and accept lower yields in exchange for greater net benefits over more years.

For the reasons cited above, opening a shrimp fishery in Liberia without at the same time considering how it would be managed will result in a fishery at point B. Worse still, if the fishery is essentially a foreign operation that is not motivated to conserve resources, with only 10% charged as export fees and some employment going to the Liberian economy, most of the

[6] The "opportunity cost of capital" is the yield (usually as an annualized percentage rate) that a resource owner can obtain in an alternative investment by selling (disinvesting in) the naturel asset. As this value gets larger the tendency to overexploit a resource becomes greater, pushing the long-term application of effort away from point A (OCC=0) and towards Point B (OCC approaches infinity).

resource rents described in **Figure 2** will be banked in another country, ***and*** the resource in Liberia will be exhausted.

In these situations, governments and their fisheries ministry must step in and do the organizational work of the domestic fisher organizations, who may not be equipped by themselves to do the sorts of analyses suggested in this FMP. In this case, NaFAA must make long-term investments in the infrastructure of public management, which involves working with fishers, data collection and analysis, as well as management and enforcement of fisheries law. This is done to push the fishery towards point A. With sound management by both public and private instances, this will generate resource rents that can be used to finance management initiatives, which will in turn result in a sustainable fishery that generates wealth for the country. At least that is the hope.

2.2. Multi-species fishery management with Bycatch

It has long been known that the monospecific case, although easy to understand, needs to be adjusted to the realities of the actual fishery.

Wilson (1982) argues that for trawlers, public managers need to fashion policy that will give fishers more agency in their decision-making on the ocean. This is because of the ocean environment can change seasonally or over longer periods, the mobility and patchiness of the target species may change over the year, and there is uncertainty associated with prospection. Fishers therefore tend to communicate with each other about the position of stocks, and the presence of bycatch species, to gain more useful information. They do this because bottom trawling technology is, without this additional information, very non-selective. In the hunt for scarlet shrimp, draggers will bring up other shrimp species that are valuable to them, as well as many species that prey on the shrimp, and other species which are completely accidental and either commercially valuable or not valuable at all. This all must be sorted on deck. On the other hand, public managers want fishers to respect time and area openings and closures, avoid bycatch, especially species which are harvested by other fishers, and to not obstruct data collection efforts from observers. Early management models for shrimp fisheries in the Gulf of Mexico focused upon the population dynamics of the prominent species of shrimp, and ignored the other species or merged the catches of species having similar lifecycles. In the absence of cost and price data, some public managers have attempted to manage effort and investments in the fishery through limited licencing, and in so doing making sure that sustainable yields in the fishery were reasonable enough to avoid over-exploitation.

So, multi-species management, which is the most realistic case, needs to deal with these realities. One way of dealing with this is first to recognize that although most fishers of deepwater shrimp would prefer to target scarlet shrimp all the time, they will catch other species of shrimp and other bycatch species. That much is evident in the raw data from the experimental fishery. Targeting scarlet shrimp brings up other species including other shrimps, prawns, lobsters, cephalopods, and finfish. Some of these have commercial value while others are discarded because they have no commercial value. Some examples of commercially valuable bycatch used

for examples in this FMP can also be found in **Annex 2**. These are the allied species that are part of the ecosystem to which scarlet shrimp belong. This will be called the ***species assemblage associated with targeting scarlet shrimp.***

The second important management idea is that scarlet shrimp, because of their relatively high prices per kilogram, their slower growth and lower fecundity, and their relatively longer life expectancy, are more vulnerable to economic and biological over-exploitation. So, if they are managed sustainably, then there is a higher likelihood that other species in the assemblage will be managed sustainably as well. In this sense, managing scarlet shrimp sustainably will act to shelter other species. This is why in this FMP scarlet shrimp might be viewed as an ***umbrella species***. However, there may be other species in the assemblage that may have characteristics that make them even more vulnerable than scarlet shrimp. This could include longer lived and slower growing species. These other stocks may not be protected by the umbrella offered by sustainable scarlet shrimp management. These issues may need to be eventually considered in future management plans.

However, this approach is far better than no approach at all and allows us to discuss management options within a well-known framework of sustainable management. To use these management approaches requires that we calculate the ***weighted average price*** of both the entire species assemblage caught, compared to the weighted average price of scarlet shrimp[7]. We have assumed that the prices offered on the "bill of sale" are the best information for now. An example of this calculation is explained in **Annex 2** and the companion Excel file. From this, we can calculate the total revenue from scarlet shrimp captures, as well as the additional revenue streams from other incidental catches while scarlet shrimp was being targeted.

There are draw-backs to this approach as applied to Liberia. For example, in the cases of the Gulf of Mexico shrimp fisheries, researchers know that the landed prices come from well established markets, where small scale fishers meet processors and prices are established. Some of these markets are public, while others are negotiated with onshore processors. Liberia does not have the same clarity in their data. To our knowledge, the vessels who took part in the experimental fishing never docked in Liberia (according to GFW) even for inspection. They landed the catch in Dakar or in Abidjan. It is therefore less clear how, exactly, the catch was inventoried by NaFAA inspectors[8]. The price quoted was the sale price obtained from the vessel owner[9]. Given that SOPERKA is a subsidiary of a Spanish company, it seems reasonable that

[7] The prices on the fishing manifests, that Liberia relies on for the calculation of total revenues from which they obtain export fees, are the landed prices in Dakar or Abidjan reported by SOKOTA. See Annex 4 for a discussion of why these prices should be independently verified by NaFAA.

[8] The catch is landed in the presence of Liberian fisheries inspector. Every time a vessel landed in Dakar or Abidjan, Liberian inspectors are present. Their costs of travel, including daily subsistence allowances, are borne by the vessel owner. The quantity per species landed in kilograms are recorded by the inspectors. However, because these vessels did not always make dedicated trips to Liberia, and fished in other zones according to GFW, it remains unclear how the catches were differentiated at the quay. This system may lead to under-reporting catch.

[9] It is still unclear whether these are landed market prices at Dakar, or internal prices established between two subsidiaries of the same firm. See **Annex 4** for a discussion of this.

most of this product is shipped directly to the EU, and that the vertical integration of the supply chain would make it difficult to determine "landed price." These uncertainties should be resolved, so that the data are as accurate and fair as possible.

2.3 Calculation of standing stock using the swept area method

One of the problems with parametric estimations based upon a year-by-year approach is that the yield-effort relationship is based implicitly on carrying capacity and the intrinsic rate of growth of the species. Refer to **Annex 1** for a discussion of this. Both are difficult parameters to measure from fisheries production data because they are implicit and must be recovered using data from scientific surveys. Further, it is known that these parameters can be affected by changes in habitat quality (which can be natural or caused by humans), ocean temperature, and other environmental factors, which will affect the yield-effort relationship through time.

It would be therefore worthwhile to have a way of measuring the total biomass associated with carrying capacity for each species of shrimp. One method of deriving sustainability indices would be to calculate the standing stock, S, of the target species and for each period (minimum two periods). This can be done by using the "**swept area**" method, or SAM. This approach requires us to have exact measures of the trawl opening while the net is being towed, and to have accurate catch measurements for both the target species and the rest of the species assemblage[10]. Under special circumstances and using careful thinking about co-mortalities for a species assemblage, this method may also be useful in monitoring many non-target species as well.

Then, by knowing the towing speed and the elapsed towing time (the difference between beginning and ending times) or by calculating the square kilometers of swept area using geometry and trigonometry functions (see **Annex 3**), one can calculate the "swept area" in square kilometers of each haul. These sweeps can be summed to provide a total area sampled, and the average yield of each target species in kilograms per square kilometer, can be calculated.

Using modern mapping methods such as Google Earth[11] and software such as Arc-GIS[12], along with visual tracking data from Global Fishing Watch[13], the habitat for each targeted species can be defined bathymetrically, using freely available data from the General Bathymetric Chart of the Oceans (GEBCO) website[14]. These data can then be projected onto coordinates on a map of the Liberian EEZ. From there, the habitat area in square kilometers can be calculated for each target species. This is particularly useful because it assumes (correctly) that each species is distributed in well-defined and often in overlapping "***patches***", and that these patches ***do not*** cover the entire Liberian EEZ. The Liberian EEZ covers a lot of ocean area (249,734 Km^2), much of it beyond

[10] This requires the length of the headrope, excluding the width occupied by the doors, and adjusted by the degree of curvature of the net, which is itself related to the speed of the trawl and the depth. See **Annex 3** for a more detailed discussion.
[11] https://earth.google.com/web/@0,-4.84619995,0a,22251752.77375655d,35y,0h,0t,0r
[12] https://www.arcgis.com/index.html
[13] https://globalfishingwatch.org/
[14] https://www.gebco.net/data_and_products/gridded_bathymetry_data/

the natural habitat of many of the species in this plan, and possibly beyond the technological capabilities of an industrial class bottom trawler. With this knowledge in hand, the catches of the sweeps per square kilometer in kilograms can be projected to these habitat areas, to give a value of S for each target species caught for the year. Once that St_{-1} and S_t (say, for 2021 and 2022) are calculated in this way, it is a relatively easy to derive a relative abundance measure of standing stock. It is also quite easy to use standing stock estimates to help managers and fishers understand the impacts of their fishing, and to adjust their application of effort to better avoid biological over-exploitation. The approach is straight-forward but requires that managers take an incremental approach to management. We use the framework from **Annex 3** to develop a calculation for standing stock of scarlet shrimp for 2021 and 2022. This information in the Excel file entitled "***Wilson's shrimp fishery analysis V1 02-20-24***" was used to calculate an estimate of standing stock for 2021 (1,446,757 kilograms) and 2022 (613,919 kilograms). We found that there was a 58% ***decline*** in relative abundance of the stock, according to the "samples" we took[15]. We verified this result by an ANOVA analysis (also in the same Excel file), to see if this result might be statistically significant. An index of kilograms of scarlet shrimp per kilometer of each haul was formed for 2021 and 2022. The sample size was 453 observations for the two years. We then asked whether the year of the activity might have had an impact on yields per kilometer. The simple regression explains about 15.7% of the total variation in the sample. However, the variable DUM22 has a parameter of -3.597 kilos/kilometer from 2021 to 2022. This says that on average kilos per kilometer of scarlet shrimp ***declined*** by 3.597 kilos during 2021-22. The significance of this variable is well beyond a 99% confidence interval ($P= 9.73 \times 10^{-19}$); near certainty.

There are, however, a few drawbacks to the method and to our calculations, that will require further refinement by NaFAA scientists and managers. The most important drawback is that most surveys in a scientific analysis are aimed at getting a random sample of catch over the entire habitat for each species. However, the experimental fishing activity of 2021-22 seems aimed at maximizing the probability of capturing scarlet shrimp over a relatively narrow band of its habitat. This involved a lot of fishing in the same places, and so it cannot be considered a random sample of the entire habitat of 14000 square Kilometers as estimated in **Annex 3** using GFW map tools and using GEBCO bathymetric data. In looking at the behavior of the three vessels contracted by Liberia in 2021-22 using Global Fishing Watch (GFW), these vessels tend to fish intensively and repeatedly over a relatively small band of habitat along the coast; a form of "over-sampling." There is no time in this consultancy to see what happens over the fishing year, but we can guess that as the fishing area gets disturbed and "swept" multiple times, that fishing on subsequent days experience declining production per day. There may be in-migration of shrimp from outside the swept zone, but this is conjecture.

[15] This amounted to choosing the most consistent vessel in terms of effort for the two years (the el Amine), filtering the data for depth, eliminating observations that had obvious data errors and calculating the distances trawled (see Annex 3). It also involved estimating the habitat area of scarlet shrimp using GFW and GEBCO bathymetric data.

The method is also sensitive to the opening of the net. That determines the swept area of the net in square kilometers[16]. Doing calculations of standing stock assuming one trawl configuration with a smaller opening while the true configuration has a larger one will bias the stock abundance estimations upwards. Trawling for extended periods biases the stock estimation upwards because catchability increases as the net fills. This method is also sensitive to the targeting strategies of fishers and is most applicable in a case where fishing is more random and un-targeted. A fuller discussion of the SAM is found in **Annex 3** and the companion Excel file cited above.

3.0. Description of the Fishery in Liberia

When the fisheries expanded in the early 1980s and before the civil war started in 1989, the Liberian government had limited administrative capacity and lacked trained personnel and managerial competence. Corruption was also widespread. During the periods of prolonged civil war, which lasted until 2003, fisheries monitoring, and research was suspended, resulting in a situation where little was known about the fisheries, the status of stocks, or the marine ecosystem in general (World Bank 2007; Ministry of Agriculture 2014; Belhabib et al. 2016). Data from this time are unreliable (Jueseah 2021).

Based on FAO data, the total catch landed in Liberia ranged from 6,463 to 18,731 tons/year from 1980 to 2019. Total catch increased in the 1980s reaching a peak in 1987 of about 18,700 tons. Landings then decreased sharply. During and immediately after the civil war, Liberia's capacity to monitor its fisheries was almost non-existent (MRAG 2005; Ministry of Agriculture 2014; Belhabib et al. 2016). Catch data reported by FAO for Liberia, during these periods, are "educated guesses" (Belhabib et al 2016).

Most of this historical overview and references was abstracted and edited from Jueseah (2021). The industrial fleet consists of coastal trawl and offshore large pelagic (tuna) vessels (MRAG 2013; Ministry of Agriculture 2014). Since 2008, however, there has been a decrease in the number of coastal trawlers. Since 2013 there have been on average five coastal industrial vessels which are owned mostly by foreigners, i.e., Spain, Greece, Russia, and China, who operate through joint ventures with locally registered fishing firms (MRAG 2013). During the civil war, governance in the fisheries sector was nonexistent and fishing was generally unregulated resulting in illegal, unreported, and unregulated (IUU) fishing (Braimah 2012). Since 2004, successive governments have concentrated on governance of the fisheries sector resulting in exits from the coastal industrial fishery (Chu et al, 2017; Jueseah et al, 2020). In 2010, Liberia reserved a 6-mile zone for the small-scale fisheries (SSF). Trawlers no longer had access to most of their main target species such as shallow water demersal species and coastal shrimp (Chu et al, 2017; Jueseah et al, 2020). Coastal trawlers increasingly targeted pelagic species resulting in a large increase in catch by trawlers. This subsequently provoked a policy change in 2017 to a 4 NM exclusion zone. Coastal trawlers supply most of their catch to the local market as frozen

[16] A NaFAA official made follow-up calls to vessel owners as well as the captains of the vessels in the experimental fishery to be sure that two nets were not used during the experimental fishery. The vessels in the experimental fishery were all stern trawlers and only one net was used per haul. The vessels had observers on board as well. Pair trawling using two vessels is not allowed in Liberian fisheries, although it is unclear from the Fisheries Law whether using two nets with booms from a single vessel is also illegal.

whole fish, but some is also exported (MRAG 2013; Ministry of Agriculture 2014). Presently (as of March 2024), there appear to be 32 vessels operating in Liberia, according to GFW. Of these, there are 11 trawl vessels (6 Chinese, 4 Spanish, and 1 Norwegian), and two Chinese vessels of unspecified type ("fishing").

Crustacean species in the Liberian coastal waters includes shrimp, crabs, and lobsters. In the 1970s, there was an industrial shrimp fishery (Shotton 1983). At the time, Shotton estimated an MEY (Maximum Economic Yield) for the coastal shrimp resources at 800 tons for 14 vessels, valued at US$ 5.7 million. Between 2013 and 2020, the total shrimp catch of the few trawlers operating in Liberia averaged around 30 tons/year (Jueseah et al, 2020).

3.1. Oceanography and habitat

Most of this discussion has been abstracted and edited from Ssentongo (1987). Liberian waters lie between two major upwelling areas of West Africa. One area is associated with the Canary Current to the northwest and the other is associated with the Benguela Current to the east. The width of the continental shelf is generally limited by the 100 m isobath. The shelf is generally wider off Central Liberia and narrower at Cape Palmas and off Robertsport. In the northwest, the slope starts at 300 m, whereas it starts at 100–120 m in the southeast. Beyond this depth, the sea floor has canyons and rocky outbreaks which limit trawling. The coastal sector between Timbo and Blo, where the shelf has a gentle slope to a depth of about 800 m, is ideal for trawling.

The continental shelf area up to 200 m is about 18400 km2 whereas the length of the coastline is about 590 km. The continental shelf is narrower in the coastal sector between Monrovia and Robertsport/Cape Mount. The continental shelf is wider in the southern sector between Monrovia and the border with Côte d'Ivoire. The coastline of Liberia exhibits depositional and erosional features (sandy beaches, lagoons, estuaries, mangrove swamps, rocky bottoms, etc.). Liberia has many coastal rivers which influence the depositional and erosional features. The areas surrounding the river estuaries are good spawning and fishing grounds.

The hydrographic regime of Liberian waters is affected by a relatively stable, shallow thermocline lying at mid-shelf and affecting the distribution of fish. The average depth of the thermocline is between 20 and 35 m in most areas of West Africa. In Liberia, the thermocline can be as shallow as 12 to 14 m. Consequently, there is lack of renewal of water, low productivity, and dominance of river influence as opposed to upwelling.

High temperatures, high humidity, and heavy rainfall in the coastal sector of Guinea, Sierra Leone, and Liberia affect the various fisheries. Liberian surface waters (part of the Guinea surface water) are uniformly warm (26–28°C) and of low salinity, mostly less than 32% S. The relatively low salinity is due to heavy rainfall and high river discharge. In Liberia, the highest river discharge occurs during the period June-November, which is the rainy season. It has been reported that there are important demersal finfish and shrimp fisheries around the estuaries of these rivers.

3.2. Target species in this FMP

The principal target species for this FMP are found in Table 1. For purposes of this plan, the deepwater shrimp fishery, according to recent fisheries law placing the outer limit out to 4 NM instead of the older limit of 6 NM, places 4 of the 6 species listed in this table in more direct competition with SSF operations that exist or may exist in the future. These are the Southern pink shrimp, Guinea shrimp, Caramote prawn, and possibly deepwater rose shrimp. In fact, the bathymetric range of exploitation by the experimental fishery was for 2021 and 2022 (raw data) was from 19 m (with 12 hauls shallower than 50 m) to 2623 m (with only two hauls below 1000m, out of 1572 hauls).

This casts doubt on the idea that there is no possible competition between the SSF and the deepwater shrimp fishery. The movement of the SSF boundary to 4 NM places the two in potential conflict. This possibility must be anticipated by NaFAA. Also, the language of the Liberian fishing law managing fisheries in the interests of all Liberians, does not match with much of the management conversation which seems aimed at "reserving" the deepwater shrimp fishery for foreign nations. It may be more clearly in the interests of the nation to encourage domestication of the fishery as much as possible to support other sectors of the Liberian economy. There are different ways of doing this, by studying nationalization strategies of Iceland, Canada, and the U.S., to name a few examples.

Table 1. Six species of shrimp caught in the Liberian EEZ and some life history statistics.

ENGLISH NAME	SCIENTIFIC NAME	Depth range (M)	Usual Depth (M)	Life (Yrs)	Overfishing risk
Southern Pink shrimp	*Penaeus (Farfantepenaeus) notialis*	3-720	3-100	1-2	Low
Caramote prawn	*Penaeus kerathurus*	0-93	5-40, rare to 75	2-3	Low
Guinea shrimp	*Parapenaeopsis atlantica* Holthuispenaeopsis atlantica (Balss, 1914)	1-60	10-40	1-2	Low
Deep-water rose shrimp	*Parapenaeus longirostris*	*20-828*	150-400	2-3	Low
Striped red shrimp	*Aristeus varidens*	300-1134	400-600	About 2	?
Scarlet shrimp	*Aristaeopsis edwardsiana (Johnson, 1867) Plesiopenaeus edwardsianus*	274-1850	400-900	*3-4*	High

Source: Sealifebase.ca; https://brill.com/downloadpdf/journals/cr/93/9-10/article-p1047_5.xml ; Holthius 1980.

3.3. Bycatch species

The part of this species assemblage that is caught along with the target species is poorly known, in part because the data from 2021 and 2022 were not collected systematically during the experimental fishery. We do know from a manifest obtained from the vessel Sokone and the Excel file furnished by SOPERKA that some of the kept species included African Angler fish (Rapé), Octopus (probably vulgaris), cuddlefish (Pota), "other cephalopods", "blue" fishes (pescado azul; probably "oily" fishes), langostino blanco (probably Farfantepenaeus notialis), "camaron langostino" (possibly caramote prawn), crab (no other indicator) and hake (probably Merluccius senegalensis (Senegalese hake)). Other terms found on the manifest were "Bocas" (possibly Lutjanidae). There were no names for rejected species recorded. It is not clear whether spiny lobster, were part of any of this group, although they should have been represented in the data.

There is only one other record we found at depths related to the species assemblage associated with deep sea shrimp. There was one 30-minute trawl at a station from the FAO/NORAD demersal trawl survey that revealed additional information (Table 2).

Table 2. List of species catalogued by R/V Dr. Fridtjof Nansen survey 2019409 Station 9 (Liberia) 28/08/19 using a Bottom trawl for fish, Lat N 4°28.64; Lon W 9°6.51

SPECIES	CATCH/HOUR		% OF TOT.	CSAMP
	Weight (kilos)	numbers		
Ijimaia loppei (tadpole fish)	1108.85	129	71.15	
Nematocarcinus africanus (spider shrimp)	160.70	29401	10.31	
Malacocephalus laevis (softhead grenadier)	93.70	9593	6.01	0
Nematocarcinus africanus (spider shrimp)	31.39	24	2.01	0
Gadella imberbis (beardless codling)	18.86	635	1.21	
Glyphus marsupialis (kangarou shrimp)	17.39	6434	1.12	
Aristeus varidens	16.83	812	1.08	
Lamprogrammus exutus (legless cusk eel)	16.71	121	1.07	
Neoharriotta pinnata (sicklefin chimera)	14.88	8	0.95	0
Lophius budegassa (blackbellied angler)	10.70	12	0.69	
Sargassum spp	10.19	0	0.65	
Raja clavata (Thornback ray)	7.60	8	0.49	
Yarella blackfordi (lightfish/dragonfish)	7.52	213	0.48	

Coelorinchus caelorhincus	7.24	46	0.46	
Myxine sp. (hagfish)	5.81	86	0.37	
Lamprogrammus exutus (legless cuskeel)	5.29	74	0.34	0
Malacocephalus laevis	4.36	28	0.28	
Merluccius senegalensis (Senegalese hake)	4.10	10	0.26	
Neoharriotta pinnata	3.82	6	0.25	
Octopus vulgaris	3.30	4	0.21	
Etmopterus pusillus (smooth Lanternshark)	1.59	28	0.10	
Ebinania costaecanarie	1.23	2	0.08	
Zenion hololepis (dory family)	1.19	275	0.08	
Benthodesmus simonyi	0.92	30	0.06	
Bembrops greyi	0.92	127	0.06	
Selachophidium guentheri	0.44	5	0.03	
Raja miraletus	0.44	2	0.03	
Chaceon maritae	0.44	24	0.03	
Nemichthys scolopaceus	0.36	22	0.02	
Illex coindetii (broadtail shortfin squid)	0.32	2	0.02	
Talismania longifilis	0.32	4	0.02	
Bathyuroconger vicinus	0.32	10	0.02	
Conger conger	0.16	18	0.01	
Ariomma melanum	0.12	4	0.01	
Stomias boa boa	0.12	4	0.01	
Diretmus argenteus	0.09	6	0.01	
Polymetme corythaeola	0.07	2	0.00	
Argyropelecus gigas	0.06	14	0.00	
Ephyrina ombango	0.05	0	0.00	
Coloconger cadenati	0.04	2	0.00	
Heterocarpus ensifer	0.03	38	0.00	
Parapenaeopsis atlantic	0.02	2	0.00	
Chaunax pictus	0.01	2	0.00	
Chascanopsetta lugubris	0.00	18	0.00	
Total	**1558.48**		**100.00**	
Duration was for 30.2 minutes; start depth- 488m; end depth- 478m; wire out 1080m; speed 3.3kn.				

Although this was a demersal fish trawl, at a little over 400 meters, they did bring up scarlet striped shrimp, as one would expect, but also many other species, many not commercially valuable. The consultant keyed out part of the list using Google. It is not necessary for a working vessel to have the same sampling protocol as a research vessel. However, it is reasonable to expect that the kept species should be reported in a way that allows NaFAA employees to readily identify the species.

3.4. Regional and international considerations related to the deepwater shrimp FMP

Liberia is party to the Fisheries Committee of the West Central Gulf of Guinea (FCWC). The FCWC has six‑member countries (Benin, Côte d'Ivoire, Ghana, Liberia, Nigeria, and Togo). Approval was given to establish the FCWC) in 2006.

The principal interest for this FMP is that since many resources are shared among the resource users of the FCWC member countries, it may be that decisions made for the management of the deepwater shrimp fishery may eventually need to be harmonized with this organization. One important area of harmonization may be in data collection. The capture fisheries of resources in West Africa, especially those members of FCWC, continue to be under pressure. Policies to address this have been often ineffective, leading to difficulties in management, in part because of distrust of the available data. This may also hamper sustainable exploitation and management of the fisheries. The consequence is declining fisheries resources, degradation of livelihoods, increasing poverty, and decline in the contribution of the sector to the country's economic growth. The lack of reliable data is also an obstacle to effective decision making on marketing, investment. This affects the quality of fisheries data that is generated for planning and management purposes (FAO, 2020).

The TCP project RAF/TCP/3512 of the FCWC is an example of how this organization is attempting to harmonize data collection systems by improving or introducing an updated fisheries data collection system, the **Open Artfish** software. To allow the FCWC to provide advice on fisheries management for the region, the Member Countries were asked to submit the list of minimum core fisheries indicators that are included in the "Pan‑African Strategy on the Improvement of Fisheries and Aquaculture Data Collection, Analysis and Dissemination". The first goal of this Programme is to help FCWC members manage collecting, compiling, and disseminating the list of core fisheries indicators.

This FMP can contribute to discussions on why certain indicators are collected, and exactly how they might be collected to help manage fisheries. Most data programs driven by international organizations start big – imagining a large, centralized system aimed at coordinating a common protocol for data collection. However, the costs of such organization can be considerable, and may result in a "one size fits all" approach to data collection which may not fully respond to the needs of public management for a country like Liberia. One important issue is how to prevent unnecessary "rent leakage," or how to retain benefits for the country which can in turn help it grow sustainably. Good public management can fill these data gaps in an economical way, by focusing on what data are necessary to fulfil specific management goals. We have discussed that managers of this FMP will need certain types of data for the plan to function well. Data collection efforts are focused on one fishery, based on a well-known methodology of sustainable fisheries management, aimed at helping both the resource user and the public managers to make clear decisions that are based on reliable data. Done well, it will generate high quality data that are used directly to manage fishing effort, which will result in improved contributions of this fishery to the Liberian economy. This is the advantage of a focused management plan approach.

Liberia is also a party to the World Trade Organization (WTO) since 2016. The WTO has been, for many years, an important focal point for trade issues related to fisheries. This is because fisheries have been and will continue to be one of the most contentious areas of international trade. The sector world-wide has been plagued with excess capacity brought on by excessive subsidies, that have in turn resulted in spectacular stock crashes, even in supposedly well-managed fisheries like those of Canada, for example. While it is incontestable that liberalized trade of goods and services that are traded on open markets under free competition

raises the welfare of both exporting and importing countries, this claim is more ambiguous for goods that use factors of production that are collective in nature. It is also contentious because, since the enclosure of the world's oceans in the late 1970's, it has become increasingly clear to some economists that trade in fisheries products can negatively affect sustainability goals of a nation, especially if this trade has been incited by the recognition by some that they can take advantage of a lack of "hard frontiers" and "loose" contracts. Having frontiers that are easy to cross makes it very costly to control activities in an EEZ, even if the territory is legally recognized. This has led in the past to explosions of IUU fishing, which has in turn incited the emergence of organized efforts to help nations like Liberia better control activities in the EEZ. One important innovation since 2012 has been the Global Fishing Watch platform; an outgrowth of a collaboration between the NGO Skywatch and Google.

Liberia clearly views this fishery as export oriented, and in the short to medium term, that might be necessary until sufficient infrastructure is built in Liberia. The exchange can be viewed as Liberia exporting access to seafood, and receiving a combination of fishing and processing services, payments, and taxes in return. But what if the "buyer" of access to fish offers ***too much*** of their service, in order to remove as much product as possible? The argument here is that international trade issues become complicated when the goods are not traded on a free and competitive market. This is especially true for public goods such as deepwater shrimp. Liberia, as a member of WTO, may want to use its membership to exert more control over the way in which "exports" are removed from their EEZ through the complaints process set up by WTO.

3.5. Current Exploitation

Because the deep-water shrimp fishery has had a long pause until 2021, most of what is known recently about the fishery is due to the experimental fishery in 2021 and 2022, contracted by the Government of Liberia and the Spanish-Senegalese company Grupo Periera/SOPERKA. These activities have been extensively covered in the FMP and supporting documents, especially the companion Excel file.

3.6. Status of the fishery in terms of Effort, catch statistics, and standing stock

3.6.1. Analytical overview of status: using the "Traffic Light" approach

This FMP has a framework and a data collection methodology aimed at estimating a catch-effort relationship, indexes of total revenue and effort, and ***standing stock*** using the Swept Area Method (SAM). See **Annex 3** for a technical discussion of SAM. These three basic pieces of information can be used, on a year-by year basis to determine:

a. The standing stock of scarlet shrimp and its change over time,
b. Effort and its change over time,
c. Catch of scarlet shrimp and allied species, and their changes over time.

However, now we want to use the collected data to demonstrate how decisions could be made in the fishery over time. In other words, how does NaFAA, and more importantly an interested fishing partner, make their decisions about what to do in an upcoming season? We will use the language of "traffic lights." In most parts of the world, people who drive automobiles are familiar with traffic lights. Traffic lights are clear indicators both to the driver and the regulator when there may be dangers of road accidents. The driver knows that if he "burns" (drives through) a red light, he may be stopped by the police and given a fine. But more importantly, if he burns a red light, he could have an accident and could even be killed or injured. Worse, he may kill or injure someone else. Further, even if he survives the accident, his insurance may not indemnify him for his own injuries because he is at fault. He may even face criminal charges. Fisheries managers in Canada and elsewhere have tried to adopt this approach to better control effort in the fishery because effort levels in the fishery must be controlled, and often by similar methods.

This management approach views scarlet shrimp as the principal target species. Since this species also appears to have a life history which would make it more vulnerable to exploitation[17], it is also considered an "umbrella" species[18]. This is in line with Liberian fisheries law, which advocates precautionary approaches to fisheries management. Targeting scarlet shrimp will catch other species as well. Some of these bycatch species are commercially valuable while others are not. Some of these species may be even more vulnerable than scarlet shrimp, and they risk being extinguished under the plan, without further protection. These issues should be addressed in subsequent plan reviews. Managers should anticipate that those who are affected by the shrimp fishery may well be other fishing groups, or even the public at large, which is why the annual reports, as well as the meetings, should be published on the NaFAA website.

In this analysis, we view 2021-22 as the reference years for measuring and reporting changes to the fishery. It is recommended that for all subsequent years we gather the same information, but using better techniques, and that changes between the most recent year and the year immediately preceding be done ***on a regular basis*** between the fishing seasons. At the beginning of the fishing season (year t), the plan management team would hold meetings with the concession holders and other affected stakeholders to provide information on the changes in the indicators over the last year (t-1 or 2022) and the year previous (t-2 or 2021). In our case, we are looking at the activities of 2021-22. This could take the form of a written annual report on the fishery, which should be made public on the NaFAA website. The three key biological indicators are:

a. (S(22) - S(21)) / S(21) = %dS(t); Percentage change in standing stock of scarlet shrimp;
b. (Y(22) - Y(21))/(F(22) - F(21). Change in yield (Y) of scarlet shrimp for a change in effort, 2021 to 2022. This value was negative when we controlled for the missing data from Sokone in 2022.

[17] From the data we have today, these are longer lived, slower growing and with a lower intrinsic rate of population growth. These data may change with more scientific information.
[18] An umbrella species is the species that is selected for sustainable management, because conserving that species will imply the conservation of other allied species.

c. ((F22 + F21)/2)/((Y22+Y21)/2). Average Effort (F) divided by Average Yield from 2021 to 2022. These are positive values.

These indicators measure the direction and magnitude of change. Normally, a fishery beginning exploitation on a virgin stock would experience a fall in standing stock (St) over time (a negative value). So, in early days of a fishery a value over two periods of, say -0.02 may not be surprising or alarming, and so managers might take that as a "green" light. A value of zero or a positive value may also indicate a "green" light, because for a value of zero the industry might be in equilibrium with the stock, whereas in the (rarer) case of a positive value, catching capacity may be temporarily smaller than the standing stock. This might occur because of favourable environmental conditions for the stock. But if this value is -0.58, as we found in our SAM estimations for 2021-22, this suggests that the standing stock has diminished in relative terms by 58% over the last two periods. This should be taken as a "RED" light, meaning that managers at NaFAA should recommend ***reducing*** collective effort in the coming year. If the standing stock falls again dramatically, this will issue another "red light"; a halt in the fishery to allow for stock rebuilding. The halt may be verified by a resource survey to measure standing stock for that year. This FMP anticipates that the fishery will employ the "swept area method" (SAM) for calculating standing stock of scarlet shrimp and relative abundance of allied species. However, the experimental fishing protocol with Grupo Periera/SOPERKA and the way the data were collected for 2021-22 does not permit estimations of standing stock for either year that are reliable. A detailed discussion of why is found in **Annex 3**. This annex also provides a habitat map and estimation in km^2 for scarlet shrimp using GFW and bathymetric data from General Bathymetric Chart of the Oceans (GEBCO). Calculations of standing stock for 2021-22 are given as computational examples, until more precise data are collected using the more careful scientific survey presented in **Annex 3**.

Multiplying b and c above gives the ***arc elasticity of yield (Y) with respect to effort (F)***.

$$\varepsilon Y = (Yt-1 - Yt-2) / (Ft-1 - Ft-2)* ((Ft-2 + Ft-1)/2) / (Yt-2 + Yt-1)/2)) = -9.82.$$

Evaluation of the arc elasticity piecewise over adjacent years may need to be interpreted more carefully, especially if there is missing data, as there was in 2022. Another approach is to re-estimate the yield curve every year with new data and revised older data and generate ***point estimates*** of yield elasticities. For our model based on two observations in the companion Excel file, we calculated ***point estimates*** of the Yield elasticities for every level of effort. The values are found by taking the first derivative of the yield function and multiplying it by effort at each level.

Point estimates range from +1 to about -195 ***for this model only***. The point estimate for 2021-22 is -5.12; a Red Light. It is a Red Light because the elasticity value is negative and large[19]. These values can be divided into pre-MSY values, which are positive but decreasing in effort, and post-MSY values, which are negative with increasing absolute values with more effort. If the fishery is found in the negative zone, a reduction in effort towards the MEY/MSY target for the following year is advised.

[19] A 1% increase in the effort produces a ***more than 1% decline in the yield***.

Other important measures are the various measures of effort and yield, ***taking account of the revenues generated and their costs of production.***[20] This usually includes three important elements that are discussed in texts looking at the ***economics of the fishery***: The average cost of effort in days, the total revenue of the fishery over a period, and the resource rent generated by fishing[21]. These measures are complicated by the fact that there are different grades and sizes of the different species, and these have different prices according to these grades. Therefore, a weighted average price needs to be calculated for scarlet shrimp as well as the entire species assemblage. A discussion and an example of weighted price indexes is found in **Annex 2** of this document.

Assuming we can calculate a reliable weighted price index for scarlet shrimp as well as for the whole species assemblage, and assuming that we are confident that the marginal cost of a fishing day is indeed 12000 Euros, we can present an analysis like one we saw in Figure 2, but with more realistic figures attached. However, with the additional information on price and cost, we have an even more accurate portrait of the fishery from a sustainability point of view. Consult **Figure 3**.

This analysis summarizes much of the information about the fishery and presents it as a "map." The vertical axis is the total revenue (the red curve) and total cost of effort (F) (the green line) measured in fishing days (the horizontal axis). This is a portrait of how the fishery was managed by NaFAA and SOPERKA after two years and compares that management to other possible management positions or solutions. The ***control variable*** is F. In other words, we want to manage the fishery to avoid over-exploitation and economic waste, and the most direct way to avoid over-exploitation and waste is to control effort, directly or indirectly. The estimated values are the result of using mathematical programming techniques to the data of 2021-22. There are some added bonuses to this type of analysis. One is that it allows us to determine the level of effort and ***the rents that were retained by the fleet*** (assuming there were no other fees or side-payments and that their reporting was accurate), as well as the effort and rents that could be received with better management, or improvements in the quality of the data.

Scarlet shrimp in this FMP is considered an "umbrella species." By that, we assume that fishers generally prefer catching scarlet shrimp because the value per kilogram is the highest. However, they also catch other valuable species. The revenues from other shrimp species as well as other commercially valuable bycatch appears to be about 27%, according to data provided by the vessel Sokone. This additional revenue stream has been factored into this analysis by scaling up the revenue function for scarlet shrimp by 1.2745.

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[20] Most ministries now also have economists who understand natural resources, especially fisheries. NaFAA should invest in candidates coming from reputable economics departments.

[21] Natural capital, including fish stocks, can be managed sustainably to generate a stream of resource rents, which some economists (Henry George) have called “gifts of nature.” This is different from profit. Profit is what a producer gets over and above his costs and can be thought of as a reward for his organizational skills. Resource rents are a windfall that has little to do with the producer except that he or she was in the right place at the right time. This is why most governments feel justified in charging royalties and fees for natural resource use.

How well have Grupo Periera/SOPERKA and NaFAA managed the experimental fishery compared to the different management objectives that they might follow? With the data we have now (which could change with further investments in data and analysis, and better or more well-defined concession contracts), the "free for all" or "open access" effort level is F=144 days. The data that was given to the consultant suggests that in 2022 the SOPERKA vessels delivered F=127 days. However, while doing this analysis, it was discovered that the vessel Sokone had not reported 2022 data. After several requests from the Consultant through NaFAA, the company sent an incomplete data set which the consultant did not use, because it contained barely half of the days that they fished (about 85 days), using estimates by Global Fishing Watch (GFW).

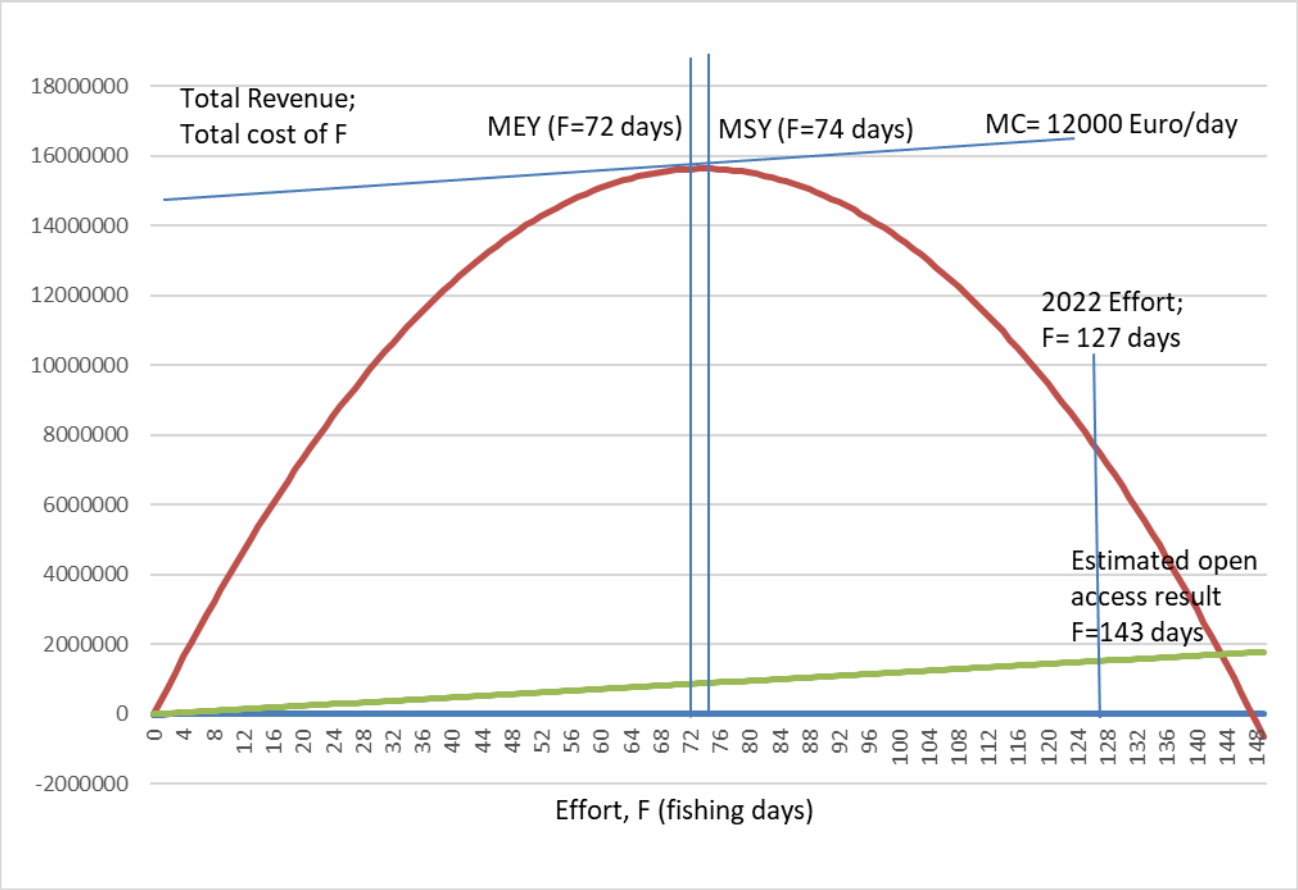


Figure 3. Economic analysis of the deep-water shrimp fishery with different management solutions.

The inclusion of these missing data will affect the form of the yield-effort relationship as well as the revenue-effort relationship. In fact, its inclusion (if we had it) would further suppress the yield-effort relationship. Adding an accurately reported data set from Sokone would result in an even further decline in the sustainable yield of scarlet shrimp, putting it even closer to the "open access" position. For example, if we add 85 more days (the GFW estimation of fishing in the Liberian zone) to 127 days, this brings us to F=212 days. This is well past the point of economic exhaustion of the resource according to this model.

Compare this result to the effort at MSY (74 days) or the effort at MEY (Maximum Economic yield, 72 days). ***These management solutions would be consistent with one vessel fishing deep-water shrimp full-time in the Liberian EEZ.*** Even more important than the promise of reduced habitat destruction and reduced over-exploitation of the resource is that more moderate applications of effort to this fishery would boost receipts for Liberia, especially under a new fiscal policy. A summary of this analysis is found in **Table 3** below. More modest levels of effort, according to these data, would yield a return that is much higher than the costs of the effort expended. It would also reduce the incidental catch and reduce the destruction of habitat.

Table 3. A comparison of management outcomes in terms of Effort (in days), Total Revenues, Total Costs of effort, and resource rent (in Euros).

	Open Access	Actual data	MSY	MEY
Effort (Days)	143	127	74	72
Total Revenue (Euros)	1719885	7484079	15637124	15624603
Total cost (Euros)	1719873	1524000	884979	859936
Resource rent (Euros)	11	5960079	14752145	14764666

These results were found using non-linear mathematical programming (using non-linear optimization tools found in Solver, a module that comes with most versions of Excel).

Using the actual GFW values of 127days + 85 days, the three vessels, if they had been competing among themselves under normal situations, they would not be taking home 5.96 million Euros in total resource rents, but closer to ***zero resource rents***. They would made their normal profits (which are unknown to us since we have little detailed information on their costs of production; NaFAA needs trained economists for that). However, as point out in **Annex 4**, these vessels were not operating competitively. They are part of one company, SOPERKA, in partnership with a Spanish company. So, it is more likely that the objective was to extract the maximum catch possible for the two years. Then, when the product was extracted and landed outside of Liberia, it would be done at a price that would maximize profits between the two branches of the firm (Grupo Periera and SOPERKA). The product (along with the resource rent) would enter the value chain destined for Spain, and the resource rent would be patriated outside of Liberia. In both cases (competitive and strategic) there was too much effort in the fishery for these two years from Liberia's point of view. A discussion of over-exploitation and industrial organization under ***imperfect competition*** is found in **Annex 4**.

The actual situation therefore resembles the "free-for-all" situation under competition in terms of the effort applied, but with the strategic aim of ***extracting as much resource rent as possible once legal access was obtained with the agreement***. The actual catch made in Liberia in 2021-22 may not be known with precision; at least ***we*** do not know with precision. And the prices obtained by the sale of the catch in the Dakar or Abidjan may not reflect the actual market but rather an internal transfer price, as discussed in **Annex 4**. Three industrial trawlers in Liberia's relatively small coast of about 341 miles (590 Km), trawling at optimum depth for

deepwater shrimp, and specifically for scarlet shrimp, and "experimentally fishing" throughout the season is likely the reason for the relative stock decline in 2021-22. The two-year sustainable catch of scarlet shrimp at open access suggested by the model is 189 MT. Our estimated two-year catch of scarlet shrimp based upon declared values is about 138 MT, when we take the average catch per day in 2022 (214.56 Kg.) and multiply this by the 85 missing days for Sokone. If there was systematic under-reporting, our analyses would show the catches smaller and the stock estimates to be relatively weak in the second year. If prices were not true market prices but some internal price (as discussed in **Annex 4**) then the total revenue would be further biased downwards. The data we have so far could be explained by a "hit and run" non-cooperative strategy. Legal access was gained on favorable terms. Then "no holds barred" fishing occurred specifically to remove resource rents from Liberia at least cost and patriate them elsewhere. ***This interpretation, if verified, should lead managers at NaFAA to be very cautious. Correcting the problems with contracting, data collection, and validation of previously collected data, before opening the fishery again should be top priority[22].***

Another important comparison is between the present state of the fishery and the Maximum sustainable yield (revenue) position. Notice that the number of fishing days necessary to achieve MSY is only about 74 days; roughly the seasonal activity of one vessel. If NaFAA could hold effort at this level until the stocks regained equilibrium in a few years, ***the public-private enterprise under the assumptions of this model would be earning a resource rent of 14.752 million Euro a year***. However, their partner may be making at least that already using the strategy described above. If so, a public-private partnership with this group may not be easy to negotiate.

However, if public management of this resource had the objective of maximizing the amount of resource rent retained, NaFAA would want to manage the effort of SOPERKA in such a way as to maximize economic yield, or MEY. The number of fishing days would fall to about 72 days. ***The total resource rents are slightly higher than at MSY at 14.765 million Euro***. NaFAA would be in a better position to insist on a change in their taxation policy to capture some of this rent for Liberia. Are Liberia and Liberians getting their fair share of the wealth from this fishery? By all appearances they do not, because the main beneficiaries are foreign nationals who probably bank most of the proceeds in their own countries. The rest of this wealth is dissipated through fishing activities, but these activities also favour other economies as well, leaving Liberia with little resource rent, exhausted resources, ***and*** more habitat destruction than is necessary.

The data collection effort should be improved, certainly, and this should involve a much clearer contractual relationship between Liberia and future partners. It also seems clear that there was too much effort applied to this fishery, mainly for strategic reasons. The estimates of the yield-effort relationship should be improved by collecting data from a fishery having an effort level of between 72 and 74 days, by improving the data collection terms of concession contracts

[22] As IUU fishing gets placed under greater scrutiny by initiatives like Sea Shepherd, GFW, and the development of low earth orbit satellite companies, this will push fishing companies to try and strike access deals that are more formalized. However, this will require that the seller does his/her due diligence, and contract negotiations for this access carefully done.

that benefits Liberia more, and by forcing Grupo Pereira/SOPERKA to provide a full accounting of activities at sea for 2022. The consultant discovered other serious problems in data collection and reporting by the partners. The collected data however suggests that the experimental fishery ***has already biologically and economically over-exploited the scarlet shrimp resource over the last two years***, and that effort levels in that fishery should be scaled back to between 72 and 74 days. A more careful validation of the landings data by changing how data are reported might yield some improvements in the analysis, but this can only happen if data collection protocols change, so that management decisions indeed use the best information available. Experimental fishing could continue but only under a more carefully written Fishing Concession Contract (FCC) aimed at improving data collection, collaboration in scientific surveys, and accurate catch and effort reporting backed up by independent verification by NaFAA through Global Fishing Watch. ***It is recommended not to invite vessels back into Liberian waters if they cannot or will not seriously record and report catch and effort data.*** This, as well as respecting the fisheries law and the FMP rules, should be the basic criteria for access to the Liberian EEZ. A resolution of these issues will require continued investment by Liberia, which is why it is important that the Liberian public finances benefit from the resource rents by better fisheries management and by a more transparent fiscal policy.

The framework provided in this FMP can be used on later data sets. Even the data for 2021-22 are valuable and should be improved by forensic analysis[23]. They should be added to by collecting more data on subsequent fishing campaigns in future. The surest way to sustainably manage the resource is to continue collecting and analyzing data, and to share the results of these analyses with stakeholders and the public, and by upgrading the web presence of NaFAA.

The evidence from the economic model gives us, therefore, a "**Red light.**" ***Scarlet shrimp are already over-exploited***, and although other species in the assemblage may be safe, prudence dictates scaling back the effort in future to between 72 and 74 days, and to verify the response of the target stock by our indicators. Any concession holder should know that it is now very easy for NaFAA managers to verify the actual presence and activity of a vessel using GFW. Even their illegal activities outside of the Liberian EEZ are recorded and are made public to anyone.[24] ***Reducing the number of licences or concessions to one vessel is likely the best course of action for Liberia now, because the activities of one vessel are more easily monitored independently.***

3.7. Life histories of the main species group

Since the FMP focuses on the deepwater shrimp fishery, which is composed principally of 6 species that occur in the areas that industrial trawlers are likely to fish, we focus our attention on these species. In addition, since the principal target species is scarlet shrimp, we spend relatively more time describing its life history. Deepsea shrimps in general have biological traits such as

[23] This should include recovering the full activities in 2022 of Sokone from SOKOTA and validating it using GFW data.

[24] According to GFW vessel reports, which we forwarded to NaFAA, all these vessels fished in marine protected areas (MPAs) during 2021-22. Information from reliable sources assure us that industrial trawl fishing in the marine protected areas we cited (Gorée and Sangomar) is illegal.

slow growth, late maturity, and low fecundity, making them especially vulnerable to over-exploitation as compared to coastal shrimp species (Nandakumar et al. 2001). For this reason, detailed studies on the biology of the species are necessary before its exploitation by commercial vessels are allowed (Ganga et al. 2012). Of the deepwater species, scarlet shrimp seems the most vulnerable to over-exploitation because of its biology, ***and*** the fact that they are so valuable on the market. This is why scarlet shrimp are considered in this FMP as an "umbrella" species.

However, this fishery is multi-species, like many other shrimp fisheries, and so management interest in other species that are part of this assemblage must be considered as well. We continue to be interested in all the allied species as well as shrimp represented, because they make up the food web of the ecosystem that almost certainly overlaps the habitat of scarlet shrimp. Some of these species will be effectively protected by the sustainable management of scarlet shrimp. Others such as spiny lobster (Langoustine) may not be which may require attention from NaFAA staff in the future. In addition to the life history descriptions below, consult Table 1.

Scarlet shrimp (Plesiopenaeus edwarsianus) – This benthic species is found throughout the tropical/temperate world at a depth range of 274-1850 m, (Whertman et al. 2012). This is the reference depth we used in our example of calculating standing stock using the swept area method. Its complete life cycle occurs in the deep sea, as opposed to many Penaeids, which have a part of their life cycle in shallow water. Holthius (1980) gives a usual depth of 400-900m. They are found on muddy bottom. The species feeds on crustaceans, sediment, fishes, cephalopods, anthozoans, polychaetes and echinoderms. Ganga et al. (2012) reports a sex ratio that is significantly weighted to females. Little was found about when spawning occurs for this species. However, background research for Amendment 8 to the Gulf of Mexico multi-species shrimp fishery FMP (1995)[25] has this to say about a closely related species, the Royal red shrimp in relation to the scarlet shrimp:

> "*Royal red shrimp, along with scarlet shrimp (Plesiopenaeus edwardsianus), are among the largest of the deep-water shrimp species. The largest specimens of royal red shrimp examined by Perez Farfante (1977) were 219 mm total length (tl) (female) and 173 mm tl (male). Klima (1969) recorded a female within the 225-229 mm tl length class and a male within the 180-184 mm tl length class. The sizes at which maturation occurs were determined by Anderson and Lindner (1971) to be about 155 mm tl for females and 125 mm tl for males.*
>
> *Anderson and Lindner (1971) reported that on the St. Augustine (Florida) Grounds, royal red shrimp spawn throughout the year,* ***with a peak between January and May****.*
> *Recruitment begins when the shrimp are approaching one year of age and are less than 100 mm tl. Maturity is reached in about three years. Most shrimp on the grounds are mature, and the life span appears to be* ***no less than five years (bold added)****.*
>
> *Anderson and Lindner (1971) present evidence from length samples for three distinct, younger, age groups of royal red shrimp on the St. Augustine Grounds. If the peak of*

[25] https://gulfcouncil.org/wp-content/uploads/Shrimp-Amendment-8.pdf

spawning is in March, both sexes would be about 100 mm tl at 1 year of age. The older age groups which were present in the samples probably represent two or more additional years, giving a minimum lifespan of five years. Recruitment to the fishery is believed to start at about one year of age, but the shrimp are not fully recruited until about two years of age and recruitment may not be complete until the shrimp are mature – about three years old.

Small royal red shrimp were scarce or absent from the collections made on the St. Augustine Grounds. In the combined length distributions, 55 percent of the females were longer than 160 mm tl and 61 percent of the males were longer than 125 mm tl (the lengths at which each sex is fully mature). Only 4 percent of the females and 6 percent of the males were less than 100 mm long. The smallest shrimp sampled were in the 56–60 mm length class. The authors concluded that gear selectivity did not cause the scarcity of shrimp under 100 mm long and the absence of them under 56 mm long. Apparently royal red shrimp do not appear on the St. Augustine Grounds at sizes smaller than about 55 mm. The habitat of these smaller sizes of shrimp is unknown."

The authors of Amendment 8 point out that, especially for deepwater species, scientific information such as length at age and length at maturity is rare for species like scarlet shrimp, in part because these larger species of deepwater shrimp become quickly overfished, thereby limiting opportunities for sustainable management. This places managers in the position of having to piece together life history data after the fact, by looking at scientific data collected on related species. This conclusion is reinforced by looking at websites like Sealifebase (https://www.sealifebase.ca/summary/Aristaeopsis-edwardsiana.html)

Striped red shrimp (*Aristeus varidens*) -Holthius (1980) gives the distribution of this species on the continental shelf of West Africa, from Morocco to Namibia. The habitat depth is from 300 to 1,134 m, most commonly between 400 and 600 m. They live on a mud bottom and are exclusively marine. The maximum total length (female) is 190 mm. There is no information on length at maturity. The maximum length from other sources is 12.0 cm tl male/unsexed, and 20 cm tl (female).

Deepwater rose shrimp (*Parapenaeus longirostiris*)- Distribution in the East Atlantic: from Portugal to Angola, also in the entire Mediterranean. Distribution in the West Atlantic: from Massachusetts, U.S.A. to French Guiana. Depth from 20 to 700 m, but usually between 150 and 400 m. Bottom type is generally mud or muddy sand. The species is exclusively marine. Maximum total lengths are 160 mm for males, 186 mm for females. However, they are usually shorter at 140 mm (male), 160 mm (female). Holthius (1980) claims that this is the most important commercial species of the Mediterranean coasts of Spain, France, and Italy. Also, it occurs in Algeria, Tunisia, Greece, and Turkey and is of commercial value. Outside the Mediterranean the species is fished by trawlers in the area between S. Portugal and Rio de Oro and off Senegal; however, it is not of great importance there. In the southern part of the Gulf of Guinea the fishery for the species at depths between 200 and 325 m is very productive.

Guinea shrimp (*Parapenaeopsis atlantica*)- Distribution: Eastern Atlantic along the West African coast from Senegal to Angola. Depths from 1 to 60 m (most abundant between 10 and 40 m). Bottom type is mud or sandy mud. This is a marine and estuarine species. Maximum total length 173 mm (usually less: 60 to 90 mm (males), and 90 to 140 mm (females). The species is fished practically throughout its range but is not so abundant that it is a main target for a fishery. In the Ivory Coast, Cameroon, and Congo (Brazzaville) it is fished by trawlers (Crosnier & Bondy, 1957:5,6). There was historically some fishing in Nigeria using trawls (Thomas, 1969:415). Since the species occurs in shallow waters, it is a part of native inshore fisheries. (Summary by Holthius (1980)).

Caramote Prawn (*Penaeus kerathurus*)- Distribution: Eastern Atlantic: from the south coast of England to Angola, and the entire Mediterranean. It inhabits a depth 5 to 40 m, seldom to 75 m. Bottom type is muddy sand. The species has a Marine and estuarine life cycle. Size: Maximum total length up to 180 mm (male), 225 mm (female); the average length is 110 to140 mm (males) and 130 to 170 mm (females). This species is fished all along the Mediterranean coasts and is an important product of the inshore fishery, because of its large size and excellent taste. Along the West African coast, the species is of minor importance. (Holthius, 1980).

Southern Pink shrimp (*Penaeus (Farfantepenaeus) notialis*). Distribution in the Eastern Atlantic is the West African coast from Mauritania to Angola. In the Western Atlantic it is in the Greater Antilles from Cuba to the Virgin Islands; Atlantic coast of Middle and South America from S. Mexico (Quintana Roo) to Brazil (S. to Rio de Janeiro). Depth is from 3 to 100 m, rarely as deep as 700 m, usually between 3 and 50 m. They are found mainly on mud or sandy mud, and sandy patches among rocks. It is a marine species, but juveniles pass a part of their lives in estuarine environments which overlaps the SSF zone. Maximum total length is 175 mm (male), and 192 mm (female); maximum carapace length is 41 mm (male) and 48 mm (female). This is one of the most important commercial shrimp species of the Greater Antilles and the Atlantic coast of South and central America and the Antilles, both on a local and commercial scale. It is also an important target species for fisheries in West Africa, both locally and by foreign trawlers (Holthius 1980).

4.0. Collecting and analyzing data

4.1. Collecting data

Since a considerable amount of time has elapsed since the last active fisheries for shrimp in Liberia, the experimental fishery is taken as the first step in the establishment of this fishery, and the agreement as well as the products of the experimental fishery provide an important first step.

The consultant received the raw data on June 22, 2023. Several discussions with NaFAA staff identified different ways to treat the data for certain analytical methods, such as the swept area method (SAM), to estimate stock abundance. On 31 July the agreement between SOPERKA and the government of Liberia was received.

A positive aspect of the experimental fishing agreement between SOPERKA and the Government of Liberia was that it operationalized a working arrangement between a firm and

Liberia, and established some structure for that arrangement which included the generation of data destined for stock assessments. The ground rules of the experimental fishery that would generate these data were simple: 1) SOPERKA vessels would only conduct experimental fishing beyond 4 nautical miles[26]; 2) Vessels would engage in random sampling of the area; and 3) they would keep at least 6 nautical Miles apart with no parallel tows. In retrospect, this agreement was too vague for the needs of NaFAA or this FMP. This FMP tries to make any future agreement or concession clearer and more equitable.

On the other hand, it is likely that SOPERKA, which is part of a larger multinational and vertically integrated company (Groupo Periera from Vigo Spain[27]), benefits from economies of scale and scope[28]. These benefits allow them to extract resources from regions where they can exert their market power.[29] A more ample discussion of the implications of their industrial structure is found in **Annex 4**.

In any case, as described in detail here and elsewhere in the FMP, there are many improvements that should be made to this or any working arrangement, especially concerning data collection and analysis.

The agreement between NaFAA and SOPERKA SA led to a data collection effort that was flawed, which in turn limited the subsequent analyses that could be done. For example, the sampling was to be random and aimed at shrimp and cephalopods. However, in looking at GFW vessel activity for the three vessels in 2021 and 2022, there was no attempt to randomly sample the habitat area of scarlet shrimp. A "scientifically derived" habitat area for this species was probably not likely to have been explicitly known to the vessel operators. But when we look at the actual fishing activity using GFW, those operating these vessels knew what they were doing. They could have planned a fishing campaign that would have generated some data that was more useful to NaFAA. Also, no mention of cephalopods was made, unless one of the categories in the data set was incorrectly named. The lack of rigor in the data collection is a serious issue which impeded this analysis.

There are other important gaps in the data. Overall, once received for analysis, the raw data had many typographical errors that needed interpretation or correction. Some vessels reported depth as fathoms (brasse) while others recorded meters. Recording the time of day was confusing for one vessel, which meant many observations had to be excluded. Most hauls were from 3-6 hours, but because of different time formats from different vessels, this complicated the calculation of elapsed time, which is necessary to calculate effort accurately.

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[26] Up to four NM is reserved for the Small-Scale Fisheries (SSF).

[27] https://www.pereira.group/. This group seems to be an example of the vertically integrated firm. The same group is involved in fishing, processing, sale, storage, distribution, and canning.

[28] ***Economies of scale*** refer to the idea that as a firm gets bigger, their long run average costs (LRAC) decline, making it easier to clear a profit. ***Economies of scope*** refers to the idea that as a firm expands the number of related products/services their costs can decline as well, making it easier to realize a profit. This can only happen if the organizational costs of the firm are lower than those of the surrounding market offering the same products/services.

[29] Firms can act as ***monopolists***, the most common form of ***imperfect competition***, where there are many buyers and one seller. A monopolist will sell products at prices where the marginal costs of production equal the marginal revenue derived from consumer demand. Firms may also act as ***monopsonists***, where many sellers (imagine many coastal countries of Africa…) face one buyer of access (SOPERKA). Consult also **Annex 4**.

The raw data also suffers from imprecise or incomplete naming of species, especially ones that are off target. Managers at NaFAA should curate this information to understand what was caught more precisely and to make it available on their web page in a photo gallery with scientific names as well as English, French and Spanish common names.

There was also no explicit convention in the agreement on how to calculate "effort," and the effort measures offered by the different vessels were unusable because there seemed to be no common methodology used. This is a serious issue, because this variable is the cornerstone of all fisheries science, economics, and management. For this reason, we recommend using methods which will yield more consistent effort measures across vessels. These methods are outlined in the U.S. Gulf of Mexico Shrimp fisheries management plans, which have been operational since the early 1980s. See **Annex 1** of this FMP and the companion Excel file. We recommend that each vessel licenced in Liberian waters give detailed technical information about the vessel, including (among other things) length, horsepower, gross tonnage, age of vessel, head-rope opening and dimensions of the trawl, and an estimate of the variable costs to run the vessel per 24-hour day. These variables are important to calibrate the yield-effort relationship over time.

We recommend that NaFAA conceive and produce ***their own version of a standardized Excel reporting sheets for this fishery*** (in English, French, or Spanish) that is more simplified, tied to a photo gallery, and freely available to all fishers, attached to their permit, and published on the NaFAA website. More generally the key elements (in addition to a detailed instruction sheet on the Excel page telling vessel staff ***exactly*** how to fill out the log) that should be retained for an Excel file are the following:

First three columns:

(**Column 1**) Year of record (2021 for example) Vessel name, Flag, Home port, Call sign, Length, Type of trawl (stern, boom, or side), Head rope length, Horsepower, Max depth of hauls, age of vessel, etc.

(**Column 2**) The values for each of these headings

(**Column 3**) Notes explaining movements. For example, if the vessel checks out of the Liberian EEZ and lands at Dakar during the season, this should be noted on the Excel log. Only ONE official Excel log per year per vessel.

(Column) Date – day-month

(Column) Haul – H1, H2, H3, etc.

(Column) Starting Time – 24-Hour time, 0h00 -24h. This can be converted more easily to decimal time which can be more easily used to calculate elapsed time of the haul.

(Column) Starting Latitude- Preferably by ***decimal degrees, which are easier to use in calculations.*** Remember the negative signs on the South and West coordinate. Alternatively, use degree/minute/second (with N+ S- E+ W-). Example: 05º05'30 N. Absolutely NO French commas for decimals. Absolutely NO hybrid representations, (05º05.008 N). The idea is to

make it easy for NaFAA staff to use **Annex 3** and the Excel file to be able to calculate distances and corroborate fishing logs with movements provided by GFW.

(Column) Starting Longitude- Same comments as above. The west coordinate is negative.

(Column) Starting Depth- In meters only.

(Column) Ending Time - Same as above.

(Column) Ending Latitude -Same as above.

(Column) Ending Longitude- Same as above.

(Column) Ending Depth-Same as above.

(Column) Scarlet Shrimp (Kilos) Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Striped red shrimp Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Southern pink shrimp. Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Crab. Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Rapé- (anglerfish?) Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Caramote Prawn- Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) Deepwater rose shrimp- Specify genus and species, common English name of the species, and if possible French and Spanish names. Add to NaFAA photo gallery.

(Column) CMATL- After several attempts, starting in June of 2023, to get an explanation of what this was, and after repeated internet searches, this remains unexplained. If this is a standard category of catch, then it needs to be explained.

(Column) Tailed striped red shrimp- NaFAA should supply a conversion factor to round weight, or ask the vessel to provide a conversion. Better yet, it should be agreed between NaFAA and concession holders what this conversion factor is, and it should be applied to get round weights. For this analysis, SOKOTA managers supplied the factor of 1.40 to get round figures this species.

(Column) Cabeza (Heads)- A better description is necessary in English. If these are the result of tailing, then this should be explained in the Excel sheet instructions to the fisher. NaFAA staff should add a first sheet with detailed instructions as to how to fill out the log.

(Column) Hake- Specify genus and species, common English name of the species, and if possible French and Spanish names. If there are different species taken, supply separate columns. Add to NaFAA photo gallery.

(Column) Tailed scarlet shrimp- see comments above.

(Column) Divers (Other kept species) – Render the heading into English. This column should be broken out into however many columns needed to count the commercially valuable species, which probably includes things like langoustine (spiny lobster which are nowhere present in the Excel file we received). Specify genus and species, common English name of the species, and if possible French and Spanish names. Take a photo record and publish to photo gallery as needed. If they are important enough to be kept for sale, NaFAA needs to know what they are, exactly, for their own accounting.

(Column) Total – In kilos; see comments above. NaFAA needs to make sure that the totals for each vessel match these Excel log sheets.

(Column) Discards- Observers (we assume that two observers are always present because Liberian law requires it) should break this column out and ***at least*** take photo records of the things thrown overboard and pass the species list to the crew for inclusion in the log sheet. Fishers may not care about these things, but they may become important for other scientific or management purposes.

Generally, we are arguing for much more precision in the data collection activities of all vessels using Liberian resources. SOKOTA probably shared their Excel files with NaFAA. However, those files reflect their own interests, and not those of an organization charged with the public and sustainable management of their fisheries. But NaFAA can take this idea, which is a good one, and produce an Excel log sheet which is easier to use for both the vessel owners and NaFAA. This, along with more careful species identification and a photo gallery, would be a very useful tool for everyone, and would encourage people to visit the NaFAA website.

4.2 Analyzing the data

Most estimations of yield and effort assume a time series of data, taken from fisheries dependent data coupled with fisheries "semi-independent" surveys. These data need to be collected every year. As the fishery has just started, NaFAA has only collected two years of data, which is not enough to ***statistically*** establish a yield-effort relationship, which is necessary to establish MSY and fMSY as well as MEY and fMEY. We used algebraic approaches to obtain a Ricker function for scarlet shrimp with only two observations. There was not enough resolution in the data to obtain similar measures for the other species. The methodological issues and their resolution are discussed elsewhere in this FMP, in **Annex 1**, and in the companion Excel file. More reliable data capable of identifying sustainable exploitation will have to be added over time through sustained investments in data gathering. That project lies outside the scope of this assignment.

But in order analyze the position of the fishery after 2022, we also needed to obtain information on the average running costs per day in Euros, and a weighted average price of the actual species

assemblage that was kept because of targeting scarlet shrimp. Late in 2023, NaFAA staff sent us a manifest of "Landed prices" and kilograms of different species and market grades of the species assemblage caught from. We used this to impute a weighted average price for the species assemblage, which was then used to create a total revenue curve for the fishery. These analyses are found in **Annex 2** and in the body of the FMP, as well as in the companion Excel file.

In December 2023 we independently discovered (using the GFW platform) that one vessel (Sokone) had fished the Liberian EEZ in 2022, but never reported their catch and effort to NaFAA for that year, or at least it was never entered on the Excel file sent to us in June of 2023. While unfortunate, there are two important lessons to take from this: 1) NaFAA staff should independently verify ***themselves*** what resource users are sending them, and force their compliance to the terms of the contract. Otherwise, they should cancel the contract with vessel owners that do not comply: 2) The importance of third-party research tools like GFW, Google Earth, and NGO websites cannot be minimized. Since Liberia does not yet have a deep-water Coast Guard vessel, learning to use every tool available (and especially GFW) to carefully monitor those who are fishing Liberian waters should be a top priority.

This consulting contract analyzed the experimental fishing data for the purposes of doing stock analyses necessary for more efficient public management, as well as providing a draft FMP with specific actions for making this fishery more sustainable and beneficial to the Liberian economy. This is in line with recommendations made in a white paper by Jueseah (2021). However, the outputs of this activity should be viewed as only the first step of a more long-term investment by NaFAA in the acquisition of scientific information used to assure that the fisheries are indeed sustainable over the long term. Working with users of a public resource requires that public managers communicate clearly what they intend to do, and what they expect from guest fishers. But it also requires them to continue to gather information, not only on the state of the stock, but also the effort in the fishery. This requires close cooperation with the resource users themselves. Building that cooperation is job 1 of the plan and cannot be handed off to anyone else.

5.0. Management measures applied to the multispecies deep-water shrimp fishery

Many of the propositions below are aimed at dealing with issues that normally arise in the public management of fisheries. The main issues are 1) efficient data collection at the points of capture and at the points of sale, and the validation of these data by ***independent verification***, especially catch (incidental, discards, and target species) and effort; 2) including elements of a licence or concession that would result in improved data collection, analysis and reporting of results; and 3) developing management frameworks and protocols aimed at communicating effectively with resource users and the public. Many of these issues have also been raised in the Inception Report and in discussions with NaFAA managers[30].

Some of the issues that have arisen since the inception report reinforce the need for NaFAA to have an FMP in place ***before*** proceeding with opening the fishery. It is also important to realize

[30] See James R. Wilson, 2023, Inception Report, V2: Development of a Shrimp Fishery Management Plan for Liberia, August 16, 2023, National Fisheries and Aquaculture Authority, Liberia Sustainable Management of Fisheries Project (LSMFP; P-172012)), Loan No: IDA-V3100, 23p.

that allowing foreign nationals to use domestic resources poses an important problem from the standpoint of managing firm behavior through contracts. How do public managers in Liberia develop contractual relationships with these users that encourages rational investment in the Liberian economy, and a desire on the part of foreign investors to treat their access to Liberian resources like the valuable assets that they are? A partial answer may involve using resources that are now (for the most part) freely available, to change the working dynamic between NaFAA and their concession holders.

For this reason, GFW has been referred to often in the FMP as a tool for independently verifying activities in the Liberian EEZ. Another issue is that the experimental fishing vessels were obviously not motivated to provide data accurately or in a timely manner. This is a big problem for NaFAA, because the management methods which this FMP proposes, including the "Swept Area Method" (or SAM) for measuring standing stock of targeted shrimp, ***requires*** that the public manager have a more transparent and collaborative working relationship with guest fishers. ***Barring that collaboration, Liberia would be economically better off closing foreign access to this fishery and trying to develop it more locally.*** This is because if there is widespread fraud and corruption on the high seas (double-bagging, under-reporting or mis-reporting catch, and transfer pricing or other types of value chain fraud that we have discussed in **Annex 4)**, then management indicators will become biased, which will lead to recommendations that are not in the interests of the Liberian people, and are therefore contrary to Liberian fisheries law.

Another issue which touches on management is how NaFAA could improve the use of their website in the context of this FMP but all other FMPs to follow. Modern fisheries management relies on communicating with and educating the public through their webpages; it is not used just for getting licences, paying fees and fines, and learning about the hierarchy of the Authority. It can be used to communicate the things that the Authority does, why they do it, and how fishers can help make a fishery more sustainable by conservation practices, reporting resource piracy, reporting accidents at sea, finding out about upcoming management meetings, and so on. The webpage is a powerful tool for distributing information to the public and to the resource users. A review of the NaFAA website reveals that it is now largely aimed at foreign "investors" and catering to licence applications. This may not be the image that will attract the kinds of partners who are the most useful to Liberia. Changes should be made so that the web page is more useful to all clients including Liberians, and not just to foreign business. This may even require that the pages be rendered in the principal languages of Liberia in addition to English. This FMP will propose changes to the way different readers interact with the NaFAA website, to encourage more transparency in public management.

This FMP lays out the reasoning behind the plan, which in turn will suggest exactly what sorts of data to collect and how it will be used to manage the fishery. The management measures below describe the management environment that NaFAA managers should be aiming for.

1. ***Liberian industrial fisheries for shrimp to be closed until this FMP is formally approved by the Director General (DG) and the Advisory Committee to NaFAA -*** No access shall be granted for this fishery until the completed FMP is approved by the DG

and the Advisory committee, ***and published on the NaFAA website under the rubric "Deepwater multi-species shrimp Fisheries Management Plan (FMP)***.

2. ***The management Plan will include a closed season during the spawning season of the principal target species of shrimp or for reasons of seasonal effort management -*** Most fisheries have closed seasons during the spawning season, and this is also the case for shrimp, since spawning activities are usually associated with high degrees of aggregation of the species. The section on life history provides context for further regulatory changes to this FMP under the heading of "closed seasons". In addition, NaFAA reserves the right to consider a closed season as one management option among others like effort controls, if the scarlet shrimp resource is "red-lighted" by any of the indicators in this plan. Our present knowledge suggests that a closed season for scarlet shrimp should be early in each year, since peak spawning may occur in March, trailing off into late spring.

3. ***As part of the elaboration of fishing concession contracts, NaFAA will develop new fee schedules aimed at independently evaluating and charging fair resource rental fees or royalties to defray the costs of public management and for the benefit the Liberian people*** As discussed earlier, in the section on the state of the resources, it was seen that a reduction in access/effort will likely result in the concession holder gaining a "windfall profit" in the form of increased resource rents. However, public managers need to recover the costs of the management that makes these rents possible. Research will need to be done on this with fees adjusted to take regional context into account. However, and in reference to Iceland, a fishing nation,[31] Icelandic fishers in that country pay a resource rental fee of between 26-29% of the estimated total fisheries rent under optimal (MEY) management. Using a value of 29% and considering that the fishery would generate a rent under MEY management at 14.764 million Euros, that would amount to ***4.28 million Euros per year*** to the Liberian government, a part of which must be used for funding public management activities. This is a low reference figure, considering that concession holders in Liberia would be foreign nationals who may not be paying any other taxes, whereas Icelanders are more fully integrated into their economy. These amounts are reasonable considering the costs of data collection and analysis that will be required for NaFAA ***every year*** to help manage the resource at a reduced effort level.

2. ***Liberian fisheries law and all amendments thereto to be published on the NaFAA website -*** The document entitled, "An Act to Amend the National Fisheries and Aquaculture Authority by Adding Thereto the Fisheries and Aquaculture Management and Development (115p + annexes), shall be published on the NaFAA website.

3. ***Limitation of Industrial access to one (1) industrial vessel for the first five years following the approval of this FMP -*** The experimental fisheries conducted under contract with Grupo Pereira/SOPERKA, while potentially interesting, has revealed that

[31] Gunlaugsson, S.B. 2019. "The development of resource rent in Icelandic fisheries", *Fisheries Research*, 126-135.

the resource has been over-exploited. The data upon which to make more expansive decisions are very limited and have many errors and omissions that make it difficult to interpret. NaFAA may consider finding other partners who are more reliable at keeping records and sharing information. In addition, the management mechanisms to control effort are not at this time developed and fully operational in Liberia. Liberia possesses little coast guard infrastructure at present and must rely on third party help and GFW to do surveillance. The analyses above suggests that the scarlet shrimp is already biologically and economically over-exploited. The data collection so far shows important gaps in the management efforts by NaFAA scientists and the contracting party SOPERKA. As discussed elsewhere, a time series of only two years, used to estimate yield and effort relationships is extremely short. The number of yearly observations needs to be augmented, so that estimating the yield-effort relationship is statistically relevant.

4. ***Concession holders to this fishery and their parent companies shall be part of the public record -*** Under this management plan, NaFAA shall keep and publish a list of foreign resource users as well as copies of their concession contracts. This will also be published information on the NaFAA website under the rubric of the Shrimp FMP. This information should include the names and call numbers of vessels authorized to fish in the Liberian EEZ for deep-water shrimp. NaFAA personnel involved in fisheries statistics should become account holders with Global Fishing Watch (GFW), and this and other web tools should be used intensively to monitor foreign fishing activity in the Liberian EEZ, to validate claims made by concession holders.

5. ***As part of this FMP as well as others to come, NaFAA shall do its due diligence as public managers by acquiring and maintaining not only resident biostatistical expertise, but economic expertise as well -*** The public management of fisheries in many nations is not the exclusive province of the fisheries scientists anymore. Many ministries also employ economists, often those with experience not only in fisheries biology but also in natural resources and environmental economics. This expertise is used to provide guidance on marketing, market chain analysis, international trade, macroeconomics, sustainability questions, the estimation of economic benefits and costs of regulatory decisions, and more. One important area, as seen in the analysis above, is to provide independent information and validation on two important issues: the landed value of the commercially traded species that are extracted from the Liberian EEZ, and the appropriate royalties, or Liberia's share of the resource rents, that arise from intelligent public management.

6. ***Access to the Liberian multi-species shrimp fishery shall be granted only with a signed Fisheries Concession Contract -*** A concession contract can be thought of as different from a licence or permit to fish. Usually, a licence assumes that the licensee has learned the rules of that economy sufficiently to merit a licence for a certain activity. A concession contract on the other hand spells out these rules, refers to them, and makes

sure that both parties, the government of Liberia and the concession holder, understand what is expected of each other. It is also a guarantee to the concession holder that he has access to the EEZ for a set period (say, 5 years) which can be extended, if the concession holder has not violated any regulations. In the case of this FMP, the primary expectation is that Effort and Catch and all other data related to vessel operation listed on the electronic Excel logbook ***must be accurately recorded for each haul***. For purposes of the FMP "Catch" means the target species of shrimp, other shrimps and crustaceans of commercial value, commercially valuable finfish, commercially valuable cephalopods, as well as incidental catch to be returned to the sea. The inventory of commercially valuable species is the responsibility of the crew of the vessel, subject to oversight or verification by NaFAA. Scientific measurements and a summary of the rejected catch is the responsibility of the observers. The contract should also include a protocol that deals with the key ***"economic" parameters*** associated with the activity. These are: 1) the negotiation of an appropriate royalty per kilogram that the concession holder will pay for each species over the contract period; 2) a ***discovery of and negotiation over*** the landed prices in the coming season, that are consistent with the actual market chain of the product; 3) The reporting and validation of the average daily operating costs of each vessel ***excluding the royalty paid***, for each operating season. This last parameter is crucial in establishing royalties and the optimum level of effort. NaFAA managers should verify all these data by direct contact with the vessel owners, by independent research, and by their own inspections. These will include publicly available statistics such as found on the World Trade Organization's website, academic resources, trade journals, and other third parties, like GFW, other NGOs, and watch groups.

7. ***Concession holders must agree to a check-in inspection of the hold prior to fishing in the Liberian Zone, and a check-out inspection prior to leaving Liberian waters -*** To encourage accurate data gathering from guest fishers, fishing vessels must report to Monrovia for a "check-in inspection" by NaFAA inspectors ***prior to fishing. A similar inspection will take place after the fishing campaign is completed and before the vessel leaves Liberian waters***. NaFAA inspectors will inventory the catch (if any) that has already been taken from other zones and perform all other inspections to assure that Liberian catch will not be under-reported. During the fishing trip, each vessel will be monitored using GFW for trans-shipments at sea and exits from the Liberian EEZ. At the end of the fishing trip, the vessel will report back to Monrovia for an exit inspection of the inventory and verification of the stowed gear. The species and their quantities will be recorded and agreed upon by the NaFAA authorities at Monrovia. This inventory is the one which will establish the royalties and other fees guest fishers pay, under the agreed range of landed prices under the contract. Disputes over what was caught in the Liberia EEZ will be resolved ***before the vessel leaves***. After Check-out the vessel will leave the Liberian EEZ by the most direct route with the gear stowed and will be monitored using GFW. Vessel owners will be charged by the person-day for inventory services in Monrovia for both check-in and check-out. It is therefore recommended that guest

fishers check in with an empty hold, if possible, to minimize costs due to delays related to the check-in inspection.

8. ***Concession holders will participate actively in the collection of accurate scientific and management data necessary for the management of the fishery under the Fisheries Law and this FMP -*** There are four areas of participation in data collection which will be expected from each licenced vessel throughout each fishing year:
    - ***a.*** Each vessel will provide accurate effort data, making it possible for NaFAA managers to calculate the number of hours of trawling by each vessel, for the entire time in the Liberian EEZ. These data will be entered onto Excel files which can be downloaded from the NaFAA website, and which will be also sent as attachments to the contract. Effort measurements will be independently verified by GFW for each vessel. Vessel Monitoring transponders must be always turned on by concession holders while engaged in fishing operations.
    - ***b.*** Each vessel will provide accurate catch data of the target and commercially valuable bycatch species retained on board. On the Excel logbook made available by NaFAA, each vessel must list the commercial catch in kilograms, by species, and by haul. The species list on the Excel logbook supplied by NaFAA will include the scientific names of the species, plus the name in French, Spanish, and English, of the principal target species and commercially valuable bycatch species, in kilograms. To help with identification, NaFAA will publish photographs of principal commercial species for this fishery, with their names, on their website for easy reference.
    - ***c.*** As part of the on-going survey effort by NaFAA that follows cycles of maturation of the shrimp species, observers will sample the catch of all shrimp for scientific purposes. A protocol for a scientific survey is found in ***Annex 3.***
    - ***d.*** Observers, with the assistance of vessel managers, will be allowed to identify, measure, sex, size, and photograph any species retained for commercial purposes, as needed. These photographs along with their local names, their generic and specific names, as well as the English/French/Spanish names will be published in the photo gallery of the Shrimp Management part of the NaFAA website.
    - ***e.*** Observers will be permitted to photograph and take measurements on any rejected species for scientific purposes, especially commonly encountered species, before discarding them. These will also be photographed and published on the NaFAA website with their scientific names.
    - ***f.*** NaFAA managers will collect complementary data from third-party sources, including photographs from citizens and other fishers, and data from GFW.

9. ***Concession holders are required on entry into the Liberian EEZ to indicate the type of rig used, whether it be a single trawl or a boomed double trawl and the head-rope length of the trawl -*** Reporting on logbooks will be verified by observers and inspectors, as well as with third party data sources, such as GFW. The Excel Logbook will allow

recording of the type of rig by each haul. Pair trawling with two vessels is prohibited and subject to banning the offenders from the Liberian EEZ.

10. ***Just before the opening of each fishing season, one vessel will be contracted by NaFAA to "sweep" the habitat area for scarlet shrimp to assist NaFAA in establishing a measure of standing stock of scarlet shrimp and closely allied species using the "swept area" method -*** This is conducted as a ***scientific survey*** with specialists in fisheries biology aboard. There may also be an ***economist or marine surveyor*** aboard to gather information on the daily average running costs of the vessel, as data for calculations of resource rent. These data are public and will be used in NaFAA annual reports. The scientific protocol is to conduct normal fishing operations, but with ***one net*** of regulation size with ***known head-rope length, normal towing speed for a single net, and tows of no more than an hour in a randomized fashion***. Otherwise, all aspects of the hauls will be under normal operating conditions. Each haul and its bycatch, regardless of whether the bycatch is normally kept or discarded, will be weighed by species. A standard measure of shrimp will also be sorted by species, sexed, and sized in a way that conforms to market standards and scientific standards for population dynamics analyses. Commercially valuable bycatch will be identified, weighed, sexed, and sized. This information will be used to calculate standing stock of scarlet shrimp, as well as the relative abundance of allied species. The assisting vessel will be allowed to keep this catch to defray costs but will pay the resource rental fee per kilogram. A detailed discussion of this is found in **Annex 3**.

11. ***Managers will adopt a "Traffic Light" approach in planning the concession holder's application of effort in a future open season -*** This FMP started with a conceptual management model of the shrimp fishery, which was then operationalized with the data from the experimental fishery. These analyses produced several interesting results. However, one surprising result was that with the level of effort applied to this fishery, there was little difference between management with three vessels and management in open access, where resource rents are effectively dissipated. Hence, NaFAA managers should write a concession contract for only one vessel of the same general size and capability of the three that fished in the zones in 2021 and 2022. The objective would be to try to obtain effort levels nearer MSY or MEY, to see if catches and revenues improve, and to see if an improvement in data quality would make a difference. The three indicators are 1) the percentage change in standing stock; 2) the elasticity of output (described above); and the actual effort in the fishery compared to the effort at MSY, the effort at MEY and the effort in open access. the position of any of these could suggest status quo activity or expansion (green), caution (yellow) or a course reversal (red).

6.0. Monitoring and review of the FMP over time

It is recommended that the FMP be reviewed every 5 years or as needed, whichever is sooner. If the fisheries advisory committee, with public consultation, deems that any part of the FMP

should be amended, then a panel of scientists and economists will be called to investigate alternative amendments to the FMP to address the problems raised. The main two criteria for choosing an amendment to the FMP is ***whether the Liberian people would experience a net gain in their own well-being with the amendment over the status quo, while at the same time guaranteeing sustainability of the underlying stock***. This type of reasoning avoids changes to the FMP that are harmful to the Liberian economy. It also prevents the fishery from being exploited unsustainably. To preserve transparency in the fisheries sector, a sector which is known to be susceptible to resource piracy and corruption, meetings to review FMPs should be open to the public at large. Further, documents and deliberations produced during FMP reviews are public information and will be published in a timely manner on the NaFAA website under a tab reserved for the multispecies deepwater shrimp fishery.

7.0. Development of the fishery

The contents of this FMP outline a plan for making decisions about how much effort to allow into this fishery and the conditions under which such changes can take place. The approach is consistent with how other countries manage shrimp resources as well as other fisheries resources, and it directly addresses the desires of the Liberian government to use the precautionary principle and to foster sustainability and ecosystem integrity as outlined in their own fisheries law.

The FMP uses terms and examples which have emphasized the importance of collaboration and joint management of this complex public good. We talk about "forward thinking managers", versus the "free-for-all" behavior that occurs when sustainable management fails. The implication is that these managers (the concession holders, the Authority, and the public) must have frank discussions regularly about their fishery based upon reliable data, and how activities on the ocean as well as activities in government affect the welfare of Liberians and the sustainability of the underlying stocks. The FMP also insists on timely, transparent, and verifiable collection of data, which is essential for good management. There can be no intelligent decisions made on the sustainable management of these resources without the data collection efforts mentioned in the plan, which also must be done ***on a yearly basis***. Failing that, this fishery cannot develop in the way the Law demands. Investing in sustainable fisheries management by the government of Liberia and the concession holders will be costly and time consuming. It will require active cooperation with NaFAA by those who hold concession contracts; something that seems lacking now. It will require that the NaFAA exert its own due diligence as well, by making transparent and independent assessments of exactly how catches are verified once taken, how the landing prices are arrived at, and exactly what is being caught. These things are far from clear now, since the experimental fishery delivered its inventory to foreign ports, forcing NaFAA managers to do their due diligence at a disadvantage, and with an increased probability of tampered data.

The data collection efforts of NaFAA and SOKOTA during 2021-22, while a step in the right direction, should be greatly improved. As the FMP points out, these activities will need to be on-going. Only further data collection and analysis will reveal if NaFAA will be able to increase

effort in this fishery above one vessel. But what is known now, based upon two years of data collection under the present conditions, is that the "umbrella" species (scarlet shrimp) is already over-exploited. It will take at least 5 more years of stock assessment, and accurate catch-effort statistics, as well as yearly meetings with licensees and concession holders with annual reports by NaFAA using the simple traffic light approach suggested here, to understand more fully the sustainable levels of effort for this fishery.

If, after this period of time, NaFAA and the concession-holders demonstrate that they are capable of working together and acting as the "forward thinking managers" outlined in this plan, and if they demonstrate that the management of this fishery is in the best interests of Liberian citizens, they should be able to generate over these five years "green lights"; they will have achieved at least a form of verifiable sustainability. However, failing to collect the necessary data upon which to evaluate all other activities must be considered de facto a "red light." This is because abandoning systematic data collection is the first sign of "free-for-all" behaviour, which must be avoided. Managing these fisheries will require a serious long-term investment in data collection, analysis, and the exercise of due diligence on the part of NaFAA.

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9.0 Annexes

Annex 1

Notes on the bioeconomics of fisheries, the U.S. Gulf of Mexico Shrimp FMP, and the Liberian fisheries

All fisheries must deal with the issue of gear selectivity, targeting species, and bycatch. However, this is particularly the case for trawling. For this reason, fisheries managers should consider most demersal trawl fisheries as a multi-species. However, doing so means that many may be affected by decisions that are made in the shrimp FMPs, and therefore could be considered "stakeholders".

Garcia (1988) points out that measuring abundance (which we call S) of tropical shrimp species can be complex, in part because the stock is affected by environmental factors, can be seasonal, and can have life histories that involve a lot of moving around, usually from shallower areas to deeper areas as they mature. We will discuss here how to put a research protocol in place to address the problem of measuring stock health, using different sampling methods. Any management plan that is based (as they must be) upon biological and economic considerations will need to measure the effect of abundance or stock on the productivity of vessels. There are relatively fewer shrimp species that spend all their time in the deep ocean, and because of slow growth and lower fecundity, these species can be expected to be rapidly depleted in an unregulated fishery. And since shrimp fishing is essentially a multi-species fishery, we must consider the management case where a fisher may need access for species which he/she hopes to target in a season, including bycatch allowances for unwanted species. In general, the trawl fishery in more evolved management systems is complex and must accommodate not only the fisher's need to change targets as needed, but the manager's need to monitor the impact of those changes on other fishing groups and the public. A concession system in Liberia will likely need to consider fishing operations that have scarlet shrimp as their main target, but with the understanding that other species will also be caught either as directed catch or as bycatch.

The shrimp management plan for the Gulf of Mexico (GOM) (see Nance et al, 2008), which has been in existence since 1981 and is a multispecies fishery also, outlines a few practical measurement issues that may also be important to Liberian fisheries managers. One important thing to do is to define the basic unit of measure for effort. It seems reasonable in more modern times in West Africa to retain the "haul" as a meaningful basic unit. Vessels fishing off Liberia do "hauls" of durations composed of hours and minutes of dragging. When the holds are full, they report to the authorities, pay the use fees, and off-load their catch or "check-out" and return to homeport to off-load their catch. Older more established systems in the U.S. had elaborate systems of verifying the landings at every port, usually through a "fish ticket" system, in part

because catch and effort reporting had to be geared to the small operator who, in the U.S. case, is exclusively American[32].

The product chain in Liberia is more integrated because many of the vessels do primary processing of the catch on-board, rather than delivering to an onshore processor in Liberia. While simpler, the Liberian economy may lose much of the benefit arising from the fishery. In the United States of the 1980's, the processing plant was likely a firm wholly owned by Americans, and played an active part in stock assessment and fisheries management by collecting information on the weight of "head-on" and "head-off"(tailed) shrimp and other species that they bought, as well as the name of the vessel and other information that would attach the vessel to the landing. In the past, before electronic logbooks, there was a separate sampling regime to collect even more detailed information on the position and depth of fishing, certain technical aspects of the vessel (Length, GRT, horsepower, size of trawl, number of rigged trawls, whether the vessel used a Bycatch reduction device (BRD) or Turtle Excluder device (TED), hours of towing, time of day, season, etc. See Nance et al, (2008). In the U.S. case all these data were used to develop a sampled profile of the type of effort used. These other technical aspects of effort become very important as data are collected over time.

In the case of Liberia in the 21st century, managers at NaFAA may need to take on more of these measurement responsibilities, especially as the fishery becomes more nationalized. A new Liberian fish ticket system may need to allow for a "check-in/check-out" system for foreign fishers, where vessels must tie up in Monrovia to be inspected and "checked in" to Liberian EEZ on arrival and inspected and "checked out" of the EEZ on departure. There will need to be discussions on whether Liberia should require a "hold empty" rule at check-in. In other words, to make assessment of catch easier for NaFAA officials, there may need to be rules in place which do not permit entry into Liberian EEZ with fish captured from other countries on board. There may need to be additional rules outlining that Liberia expects no fishing in its EEZ before checking in or after checking out, and instructions on how gear should be stowed at check-in and check-out. This is to avoid biased estimations of stock, effort and catch. For local fishers with smaller vessels and for all fishers who sell in local markets, NaFAA may need to develop their own "fish ticket" system of collecting data as well, which will eventually allow NaFAA to follow the fishing effort in these fisheries where observers and VMS tracking is not practicable. In effect, the biggest challenge will be to eventually develop a system of vessel registration for local vessels, and a sampling program for small boats, which will allow for a statistically relevant estimation of that effort, as well as the catch landed. This is because although the management bias is to talk to foreign fishing firms because they are large, seemingly wealthy, and are often easier to talk to, the real motors of grass roots economic growth, in Liberia as in the U.S., are the small-scale producers who live and work in the country. This is important to have a complete picture of the entire fishery that catches shrimp.

Defining Nominal Effort- Once the trip details of the protocol are understood, it is important to include a protocol for obtaining standardized measurements of nominal effort. For example, we

[32] And therefore, the economic benefit of this activity was still fully felt in the American economy (though with the inefficiencies of overuse of labor and capital…).

can define nominal fishing effort as the total time that the vessel is dragging the net in a trip (from the time the net hits bottom to the time it begins to be drawn up, for example). The GOM protocol fixes the unit as a fishing day, which is the number of 24-hour periods of ***actual trawling*** by a vessel in a trip. Since it appears that most work in West Africa uses days as well, we suggest that the GOM norm be adopted to provide clarity to the data and reporting. In other words, if a trip contained 10 tows (2.5hours, 3hours, 3hours, 2hours, 3.5 hours, 1.5 hours, 3hours, 2.5 hours, 3.5hours and 3.5hours), the sum of these tows is 28 hours or 1 and 4/24 days. It is then straightforward to calculate vessel nominal effort per trip, per year, over the fleet per year (the sum of all vessel's days), and, if the effort is linked to position and depth, a spatial distribution of effort. This latter consideration is particularly important because multi-species fisheries will target certain species by depth and geographic position. This targeting often is related to the life histories of different target species and non-target species. There is an added benefit of having a clear measure of nominal effort. If managers can also obtain information on the total costs of running a vessel in a 24-hour period, then they have one important piece of information needed to calculate the total costs per fishing day. This is important in calculating resource rents, which is useful in setting licence fees for different target species, or establishing the number of days of effort which will maximize rent potentially flowing into the economy, whether it is charged as a licence fee or not.

Nominal Effort and Real Effort- In a year and over a given fleet that is homogeneous (imagine a fleet of identical vessels), effort can be considered as nominal. However, in an actual fishery, differences in catching power between vessels, and the changes in the catching power over time will eventually have to be considered. This is one of many important issues explored by those who are interested in bioeconomics (for an overview, see Anderson (1977), Clark (1973, 1990), Cunningham et al (1985) Hartwick and Olewiler (1998) Wilen (1976) Bjorndal (1987), Bjorndal and Conrad (1987), Hannesson et al (2010), Squires (1992) , and Squires and Vestergard 2013)).

This literature can be used to build an approach that could be useful in describing real effort and its effects on the yield-effort relationship. This is important for describing the resource over time. The development below explains why this is important.

To economists, the relation between inputs and outputs for a firm or a group of firms is a Production Function. There are two main ways to describe production. One is to look at all firms (or vessels) in, say a fishery, and relate physical output per year to factors that contribute to the long-term productivity of the vessel. Such an estimation, proposed originally by Cobb and Douglas (Douglas, 1976), is a representation of the typical firm from the sector in the long term[33]:

$$Y = AC^aL^bS^c \qquad (1)$$

Economists believe that a firm's productivity depends upon Capital use (C), Labor use (L), and land, or natural resource use (S). The symbol A is an estimated parameter, and the estimated exponents are called ***production elasticities***. This formula can be adapted to the fishery by adding proxies for capital and labor. One proxy in the fishery proposed is effort. Effort in most

[33] This approach originally assumed that we have a sector composed of different sizes of firms.

bioeconomic analyses is produced from capital and labor and technological advances to produce catch. This is important to note because later, when we look at the yield-effort relationship over time, the parameters A,a,b,c may change over time, and changes in their values will make nominal effort more or less productive. The more productive nominal effort becomes, the less it takes to catch the same weight of fish. While that is good for the firm, this may be challenging to the public manager because without measuring these changes, CPUE measures may become difficult to interpret over time. The same can be said of stock conditions (S). As stocks become healthier, yields increase, causing CPUE to rise, and vice versa for stock declines. But if there is no protocol in place to measure S, changes in CPUE may incorrectly be attributed to changes in abundance, when in fact it is attributable to another productive factor, like real effort.

We can change the basic model to reflect the fishing problem:

$Y = qf^aS^b$ (2)

In this relationship, Y is catch per trip. In the shrimp fishery, this is usually related to how the product is delivered and sold. If the product is usually sold whole (head on) the weights are head-on. If they are delivered head off, then a conversion factor is applied to get whole or round weight.

The parameter q is the "catchability coefficient". This is essentially no different from the parameter A, except that economists are saying that over time, ***technological change as well as other factors positively influence catch***. The productive factor nominal effort, f, because of the way we defined it above, will usually not explain Y fully.[34]

Another important departure from more traditional fisheries science is how economists handle the stock biomass S (for applications with real data on stocks of fish, see Bjorndal (1987), Bjorndal and Conrad 1987), and Criddle, 2008). This is viewed as an important factor of production; so important that it deserves its own variable in the production function. The stock is considered therefore to be another form of capital, natural capital. Its inclusion in empirical management will require a data gathering program aimed at establishing abundance measures of the different species of shrimp.

The two other parameters are elasticities of production for f (a) and S(b). These measure the relative contribution of the variables in the production function, for a 1% change in the target variable. Usually, the parameter b is thought to be 1[35], unless the behavior of the stock makes the elasticity show up as greater or less than 1.

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[34] This is because f is simply time towing a net. It does not consider the size of the net, the horsepower of the vessel, the navigation aids on board, the length or other physical characteristics of the vessel, the date of vessel construction, and the experience of the skipper and crew. These facts need to be recorded as well. In other words, most models of fisheries management from a purely biological perspective do not consider capital accumulation and technical change; or these important factors are expressed in the parameter q. These are very important elements of real effort and catch, which must be considered especially in heterogeneous fleets and over time, because these variables affect the form of the yield-effort relationship. They in turn affect MSY nominal effort by making it more productive, placing pressure on stocks.

[35] A 1% change in the stock yields a 1% change in catch.

Economists and fisheries scientists attempt to define these parameters by building statistical or mathematical models of production. Analysts have tried to use different characteristics of the fishing vessel that are related to the capital value of the vessel. Some of the data that are collected in other shrimp fisheries is the 1) horizontal net opening; 2) net type; 3) vessel characteristics such as horsepower, capital value, age of the vessel, length, gross tonnage; 4) presence or absence of navigational devices or sonar; 5) the use of bycatch reduction devices (BRDs) and Turtle Excluder Devices (TEDs); and 5) human capital measures, including years of experience of the skipper and crew.

As a simple example, equation 2 above might be expanded by adding other variables like vessel length (L), horsepower (HP), and the age of the vessel (Age), in addition to nominal effort:

$Y = Af^aS^bL^cHP^dAge^e$ (3)

This can be estimated by taking the trans-log and using regression methods or other mathematical programming:

$Ln(Y) = ln(A) + a*ln(f) + b*ln(S) + c*ln(L) + d*ln(HP) + e*ln(Age) + \varepsilon$ (4)

If we have the technical features of the three vessels that did the test fishing and if we have confidence in the nominal effort that was reported, we could estimate the productivity per year of the three vessels. Statistically speaking, such an estimation would provide a "long run snapshot" of the fleet, especially if the vessels are heterogeneous in size and fishing power (which usually they are). These estimations, if correctly done, would capture real effort and its impact on the catch of each vessel. This can be used over time to impute the MSY and fMSY. The same can be said for S. Having stock or abundance measures allows managers to separate out the effects of catchability from the stock effects. Without them, it is difficult to interpret CPUE.

Deriving a Yield-effort Relationship by aggregate means- The second way to look at production is by aggregate means (see for example Cunningham (1985) or Hartwick and Olewiler (1998)). This means that the variables f and S are for the whole fishery, usually by year. This method is easy if the vessels are homogeneous enough to treat the entire vessel as a unit of nominal effort (see, for example, the authors cited above or any good book in resource economics with a chapter on fisheries). The important empirical point is that this is an aggregated estimation by ***year***. This means that most of these analyses are based on many years of data. Liberia has only two years of data, which may not be sufficient, if the aim is to use statistical methods.

The general form of the aggregate production function in the long term is:

$Y = qf^aS^b$ (5)

Next, we need a population growth curve. One is the logistic growth function.

$dS/dt = rS(1-S/K)$ (6)

If we know the intrinsic rate of growth, r, and the carrying capacity, K, in weight, this can be operationalized if we have a sample of the years of observations, or if we know the two

parameters of this equation for a given species. This states that the growth of a population starts at 0, and as the population increases, that growth reaches a maximum (at k/2) and declines to zero when the population reaches carrying capacity, K, in kilograms or metric tonnes. If fishing only removes growth (one definition of sustainability), then the yield-effort curve constrained by the growth function becomes:

$Y = qf^a(K(1-q/af^a))$ (7)

Note however that the relation will be affected by q (catchability), and a, the production elasticity of effort. An increase in the parameter "a" compresses the yield curve, moving the fMSY to the left. If f is not adjusted for this, then the stock can become biologically over-exploited much more rapidly.

A second way to calculate a yield effort relationship is to assume that the yield function is quadratic. Using Riker's (1953) method, calculate aggregate Catch per Unit Effort (CPUE) by year. Then, run a regression or use mathematical programming to estimate:

$CPUE = Y/f = \alpha + \beta*f + \varepsilon$ (8)

Multiplying both sides by f gives:

$Y = \alpha f + \beta*f^2$ (9)

But Y was previously defined as $Y = qf^aS^b$, which means that catchability, and the production elasticities of effort and stock, as well as the stock, will all affect the position of the yield curve over time. If there is no program to evaluate stock, and no attention to collecting data on q and a, (like vessel characteristics) then CPUE and fMSY become difficult to interpret over time.

Calculating standing stock S, using the swept area method, and deriving sustainability indices- Another method of deriving sustainability indices would be to calculate the standing stock, S, for each period (minimum two periods). This can be done by using the "swept area" approach, or SAM. This approach requires the surveyors to have exact measures of the trawl opening while the net is being towed[36]. Then, by knowing the towing speed and the elapsed towing time (the difference between beginning and ending times), one can calculate the "swept area" in square kilometers of each haul. These sweeps can be summed to provide a total area sampled, and the average yield of each species in kilograms or tonnes per square kilometer, can be calculated. If the habitat for each targeted species can be defined, then the catches of the sweeps per square kilometer can be projected to these total areas, to give a value of S for each species caught for the year. This method is sensitive to the targeting strategies of fishers and is most applicable in a case where fishing is more random and un-targeted, which may not be our case. However, once that St_{-1} and S_t (say, for 2021 and 2022) are calculated in this way, it is a relatively easy to derive sustainability indices.

Start with a logistic growth specification:

[36] This requires the length of the headrope, excluding the width occupied by the doors, and adjusted by the degree of curvature of the net, which is itself related to the speed of the trawl and the depth. See Annex 3 for a detailed description of the method.

$dS/dt = rS(1-S/k)$. (10)

Remembering that at the sustainable equilibrium, $dS/dt = Y$, the yearly catch.

$Y = rS(1-S/k) = rS - (r/K)S^2$. (11)

Since we have observed values of Y and S, these values can be estimated by using mathematical programming tools like Excel Solver (with two observations) or statistically, using regression tools, also found in Excel. The parameter estimates are values of r and r/K. for given values of Y and S for each year, the parameter K can then be derived:

$K = S(1/(1-(Y/rS))$. (12)

The parameter K can be re-introduced into the yield-effort relationship in equation 7, and an estimate of q and a can be made using mathematical programming or statistics.

These specifications assume **yearly** catch and effort data collected by an ongoing program. Assuming that the nominal effort is well-defined, the estimation of the parameters α and β for two years of data could be derived using simple algebra, if the CPUE in the second year is smaller (and f is larger). This would yield the negative parameter values consistent with theoretical expectations. However, these "boot-strap" mathematical estimations can yield no further information statistically, because with only two observations, there are no degrees of freedom in the estimations. Variance of the estimate is therefore non-existent in this case.

Annex 2

A weighted price index for the species assemblage resulting from targeting scarlet shrimp

Most trawl fisheries that target a species like scarlet shrimp, and which do not try to avoid bycatch will bring up other species that are commercially valuable. Some of these may be other shrimp species that share the habitat. Other species may also share the habitat because of their relation to the target species, like a predator for instance. We want to have an idea about the actual revenue streams that arise from targeted fishing of scarlet shrimp. While these revenues come predominantly from scarlet shrimp, it is seldom the sole source of revenue.

Fisheries managers at NaFAA should take inventories of a hold before a vessel leaves the fishing zone, using their own corroborating information on landed and retail prices of the species caught in Liberia destined for export, to be sure that these values are accurate. In looking at the bill of landings, it is unclear if NaFAA managers can corroborate these data by their own agents, for reasons we outline in **Annex 3**. If the bills of landings are uncorroborated with respect to the quantities caught and the prices by species and market form, we would expect attempts at under-reporting for both price and quantity caught, because it is reasonable for fishers to want to avoid the export tax. However, that behavior will lead to a stock analyses and estimates that are biased downwards, a lower Effort-Total revenue curve, or both. This is why NaFAA managers still need to verify for themselves the total catch in kilograms of both shrimp species and bycatch retained for commercial purposes, graded by size and product condition for each species. For this example, we will assume that the landed prices and catches are accurate. The grading for scientific purposes should also be calibrated to make it easy to construct the commercial grades as well. Call this Wt or total catch. The inventory should also divide the total catch into Ws (catch in kilograms of all shrimp species) and Wb (catch in kilograms of bycatch, by species). Each of these categories should then be graded by species and market characteristics. For an example of such a break-down, refer to **Table 2-1**, which was based upon a bill of landing of one of the experimental fishing vessels. Usually, size and condition of the product (tailed or not, for example) are important ways to distinguish the catch that are related to market prices per kilogram.

NaFAA should require that concession holders keep accurate and independently verifiable records of inventory, to properly account for the 10% export fee charged. NaFAA should also have employees who have training in economics independently collect market data at retail and at wholesale levels for each of the species, as well as their market characteristics. Their objective would be to obtain or estimate reasonable landed prices for every species retained, as well as the market characteristics of these products. These prices are important because it allows for the calculation of weighted average price indexes of the entire species assemblage each year, or other indexes of different sub-components of the species assemblage.

As an example, one of the fishing vessels that took part in the experimental fishery, the Sokone, provided a “bill of landing” that specifies catch by species and grade as well as landed prices. In

this example, the most important elements of that list were included, but not all since we are interested in discussing the methodology of calculations while providing a realistic example. A more thorough validation of prices and catch from all three vessels should be conducted if not already done.

To calculate weighted average prices accurately, the catch must be by species and market grade, and the "landed price" for that grade per kilogram must be reported. A "weight" can be calculated by dividing the weight per species and grade by the total weight of the catch. These weights are then multiplied by the prices by market form and then summed.

A spreadsheet analysis on Excel[37] reveals that the weighted average price across all market forms for Scarlet shrimp, taking account of the weight of the species assemblage, is 15.34 Euro per kilogram. For the species assemblage ***including scarlet shrimp*** the weighted average price in this realistic example is 19.24 Euro. From the spreadsheet and the Table below, we can calculate the Total Revenue from scarlet shrimp (74242 Euro) and the total revenue from the entire species assemblage including scarlet shrimp (168885 Euro). The factor by which the total revenue of scarlet shrimp should be augmented to account for the entire species assemblage is (168885-74242)/74242 = 1.275. This reporting should be extended to all the vessels and standardized for purposes of taxation and for fisheries management.

An accurate estimate of the augmentation in revenue due to the species assemblage resulting from making scarlet shrimp a target is important because it enables us to see clearly where the fishery is on the revenue- effort relationship regarding points A and B mentioned in the methodology of the plan. If effort is nearer to the point of intersection of total cost and total revenues of the species assemblage, the fishery may be in dynamic equilibrium, but it is not operating efficiently from an economic point of view and may be over-exploiting the stock of scarlet shrimp. If the effort level is closer to point A, the fishery is being managed more efficiently both from an environmental standpoint and an economic standpoint (depending on interest rates).

[37] Wilson's shrimp fishery analysis V1 02-20-24.

Table 2-1. Sokone's raw catch and landing price data for a total catch in kilograms of the species assemblage, used for the calculation of the weighted average prices of the species assemblage and scarlet shrimp.

Market Category per kilogram	Weight Kilograms (Wt)	Prices (Euro/kilo)
Blue& Red shrimp LT 30	505	25
Blue& Red shrimp 30/40	443	22
Blue& Red shrimp 40/50	447	17
Blue& Red shrimp 50/70	576	12
Blue& Red shrimp +70	942	8
Blue& Red shrimp Tails 1	55	12
Blue& Red shrimp Tails 2	196	5
Blue& Red shrimp heads	28	5
Bocas 1	62	25
Bocas 2	54	17
Bocas 3	50	10
Bocas CH	64	8
Bocas Azul	0	8
Pechos 1	180	8
Pechos 2	134	6
Pechos 3	94	6
Pechos Ch	108	6
Pechos azul	0	6
Scarlet Shrimp		
6/8	267	70
9/12	435	68
13/20	758	55
21/28	755	45
29/34	697	40
35/40	1235	35
Tailed 1	280	25
Tailed 2	126	20
Heads	288	15
Weighted average price per Kilogram of Scarlet shrimp; Sum $((w_{ss,m})/Wt)*P_{ss,m})$		15.34
Weighted average price per Kilogram of the whole species assemblage; Sum $((w_{k,m})/Wt)*P_{sbkm})$		19.24

Annex 3

A Swept Area Method (SAM) to survey the biomass of target species and allied species of the catch assemblage using commercial demersal trawlers

There is nothing in the experimental fishing contract with SOKOTA or in the actual behavior of the fishing vessels in 2021-22 (that we gathered using GFW) to suggest any type of scientific curiosity aimed at establishing stock or abundance measures, much less the application of SAM. Preoccupations with the state of the stock on the part of SOKOTA appear to have been secondary.

However, there is no lack of excellent literature on how to do scientific stock and abundance analyses of demersal trawling (Sparr and Venema 1998; Pauly (1980) are but examples. Most of these studies and guides do not provide much discussion about the costs of collecting the information to do a stock analysis. Most of the earlier work was produced in regions of the world where funding for data acquisition in fisheries, while not abundant, was substantial enough to produce methodologies capable of collecting good scientific information. Because of the time and money costs of doing rigorous surveys, most of its practice has mainly remained in the hands of fisheries scientists from nations having well-developed public management of fisheries.

However, with the development of satellite and mapping technology, as well as the development of a number of management tools such as Global Fishing Watch (GFW), and the inclusion of community monitoring and citizen science into the management of natural resources, it is now possible for countries who have limited funding to do government-led surveys to obtain estimates of important management data using these different methods of fisheries management that were produced decades ago. Some examples can be found in more recent papers on the swept area method (see the reference section in this annex). This annex provides a modern "how to" guide for a comanaged stock survey, between holders of fishing concession contracts and public fisheries mangers, using on the one hand a commercial vessel, and on the other, a team of managers and scientists from a fisheries ministry.

It is important to have at least one reliable fishing vessel to help conduct the survey. We think that it is important that the vessel-owner sign a Fishing Concession Contract. We think that a 5-year contract would be sufficient to encourage compliance and some reasonable expectations from the vessel owner. That contract allows the company and a vessel to fish in the EEZ of Liberia. The terms of this contract, among other things, requires the vessel's active participation in a "scientific survey." This would mean that for a few days at the beginning of the fishing season, the vessel would be called upon to help with surveys that are organized and managed by the management arm of NaFAA. However, unlike earlier manuals that suggest special equipment for the survey, we propose that the gear used be the same gear used in actual fishing, and that the catch on the vessel (except for scientific sampling for onshore laboratories) remain with the vessel, as partial compensation for their participation. Public managers may also need to additionally compensate the vessel for its time. However, such compensation within the framework of a concession may be to the benefit of the agency as well as the contracting vessel,

because the data collected can be used to better target levels of sustainable effort which have lower total costs of extraction, thereby raising profits as well as royalties. Gathering scientific data on stocks and using these data to make joint management decisions has been demonstrated elsewhere in this plan to be worth the effort.

The survey protocol

Sparr and Venema (1998) provide a detailed game plan for doing scientific surveys, from the sampling strategy to the determination of catch weight of all the surveyed species. The only thing that is different in this plan is that, at least to start, the rig of the gear and the fishing behavior remain the same; Scarlet shrimp is still the main target species, ***and therefore the species assemblage caught will likely reflect that fishing behavior***. A focused fishery is considered by scientists that specialize in SAM to be a source of bias, although targeting species that are the most valuable is a common practice among fishers. However, collecting data using a clear methodology, even with gear and fishing behaviors that are "biased," may be preferable to no data at all, or data that are generated without inputs from public managers. Sampling should nevertheless be done in a way that is more random (no multiple drags over the same area), and the sampling strategy should be simplified by taking random samples of one-hour tows in areas where the vessel managers suspect that scarlet shrimp are most likely to be present. This would then be a form of stratified random sampling, in the sense that sampling is based upon the general knowledge of the crew about the habits of species but would control for variations in density by being more randomized within the likely habitat. Towing would need to be at a consistent velocity as much as possible because variable velocities will affect the swept area, as described below.

The objectives of the scientific surveys would be to collect reliable data on the biomass of scarlet shrimp, which is a key species for the fishery, although not the only one. It is also important for scientists and managers to collect information on other valuable commercial species that are caught along with scarlet shrimp, as well as non-commercial species.

Using Pauly (1980), who himself cited others, the sampling strategy for the scientific survey, apart from the few simple sampling strategies we propose above (randomly sampling areas which the fishing crew consider to be the most likely to yield scarlet shrimp), the steps are the following for each haul of one hour.

First, crew-members, scientists, and observers should work together on the survey, because the data produced will guide decision making on the recommended levels of effort for the fishery, ***and therefore the possible profits and royalties to share***. However, scientific sampling using an operating fishing vessel does not mean business as usual for the vessel. For the scientific survey, it is the scientists and their helpers who must oversee the cataloguing of catch. Standard fishing practices once the catch is on board should be suspended until the catch has been processed, catalogued, and recorded. We have adapted a checklist for the survey from previous authors, especially Sparr and Venema (1998):

1. Remove any venomous creatures or live large animals (like turtles) from the catch and throw overboard noting their presence in the scientific data.
2. Remove debris, corals, and plants, making a written and photographic record of the type of material.
3. Remove larger fish and place in a box. At this point, no differentiation is made between commercially valuable species and rejects.
4. Wash and mix the remainder of the catch, to assure random distribution of the smaller catch in the samples.
5. Place catches into boxes, and fill to roughly equal weights; however, take the net weight of each box exactly.
6. Count the number of boxes of smaller fish and crustaceans and record the number of boxes.
7. Randomly choose ***1 box in 5*** for sub-sampling on a sorting table.
8. Record the net weight of the box, and then, for commercially valuable species (especially shrimp), key out the catch to genus and species, and place in separate piles. For non-commercial species, make taxonomic groupings according to family and genus. For the shrimp species, grade them according to market norms for the EU. Weigh each sub-sample and count each subsample. Then for each sub-sample, collect length frequency data using size in millimeters and sex the shrimp caught. Repeat this process for all the chosen boxes of the haul.
9. Sum the subsamples across the sampled boxes to get weights by species and market grade.
10. Multiply these weights by the ratio of unsorted (U) to sorted boxes (S) (U/S) to get an estimated total weight of the haul by species and market grade.
11. Weigh and count larger fish by genus and species taking selected photo records for the NaFAA webpage.
12. If the same species occur as “large” and “small” in boxes, combine the weights by species for a total species weight and a total species count.
13. Perform other measurements as time permits, and as needed. For example, since demersal fisheries for shrimp can have important amounts of commercially important fish and other species that prey on shrimp, these species might be checked for size at age, weight, and maturity. This might involve taking otolith or scale samples for ageing. Surveyors should be equipped with cameras to take digital photos, which can be published to NAFAAs website under a tab entitled “shrimp fishery management plan; photo gallery”. If NAFAA has a laboratory, surveyors may want to take samples or whole specimens of key species to preserve for future study on shore. Investments in laboratory capacity for storing biological information is important for higher level

scientific work. This work can benefit the economy directly through, for example, education[38]. Finally, surveyors should note and comment on oceanographic conditions, weather, or operational activities that might make the haul in question unique. Informed notetaking is important.

This gives a general guide to the actual survey procedure. Given the coastline of Liberia, we estimate that a good survey could last from 5 to 10 days. While a concession-holder might complain that this is an important draw on his time, the survey provides additional information to the vessel-owner and to Liberia about fishing strategies that are likely to be more productive. And while the survey data would be public, those who would benefit from the information will be limited, because Liberia's coast can now be easily monitored using Global Fishing Watch (GFW), and concession contracts would be limited, to preserve the resource rents and reduce management costs. This protocol differs from a full-on scientific survey procedure of the last century in that we assume that there will be biases in the data because we are using working vessels. However, it is felt that a careful survey with biases clearly explained is better than a survey that will never take place, or worse, a survey where the biases are not understood.

Developing habitat maps using different approaches in the 21st century

To do the swept area method, one must have an idea of the habitat area at least for the principal target species, because this will be used as a reference area that will be used for calculating standing stock of the target species.

A simple way of arriving at this habitat area is by using Global Fishing Watch (GFW) and noting the behavior of the fishing firms themselves. Experienced fishers have a wealth of information about living stocks which normally they do not want to share, especially with public managers. However, attitudes about co-management are changing, and with GFW, this information is now available for free; for the fishers themselves and for public managers at NaFAA. Getting a rapid measure of habitat area can be done by creating a free account with GFW and then reading about the features in the platform. Then, opening the map, find where Liberia is, and then, focus on the Liberian EEZ[39]. Then, switching on the "EEZ" option, one can see the Liberian EEZ clearly. Then, clicking onto that space will open a dialog box for "analysis". Choose an analysis of fishing activity with the effort toggles switched on. When we did this for specific periods of time (2021-22) we are able to see all of the vessels who used the Liberian EEZ, including the experimental fishing vessels (Kanbal III, Amine aka Sokone, and Sokone aka Amine).

The analyst can then "pin" a vessel and see their entire activity in the EEZ, as well as outside of it, for the period in question. As an example, we have shared the GFW vessel profiles and itineraries of all three vessels for 2021-22 with NaFAA. In the same GFW application the

[38] This is because higher education adds to "knowledge capital," which is thought to be an important driver of endogenous economic growth. See the works of Paul Romer.

[39] It is also very interesting to look at the activities of fishers using the Liberian zone and how they behave in other EEZs along the coast.

analyst can also overlay a bathymetry map from GEBCO[40], which allows one to see where the vessel fished, and at what depth they fished, in meters.

We first used a simple approach of estimating linear paths for different groups of points on the map, and then measuring a width that would cover all the deviations from the linear path. We used the "ruler" tool in GFW that allows one to calculate distance in kilometers. From that, we are able to trace a band of likely fishing area along the "most likely" path. This we calculated as an area in square kilometers, for each of the three vessels. Technically, these vessels should be fishing deepwater shrimp, but a small sample size of hauls were as shallow as 50 meters. For the time being, we have kept the entire GFW dataset for the three vessels. The results of a simple calculation of habitat in square kilometers is shown in Table A3-1.

Table A3-1. Estimation of the most desirable habitat in square kilometers of scarlet shrimp, based upon fishing behavior of the three vessels in the study, using Global Fishing Watch (GFW) data.

Vessel	Kilometers sq. 2021	Kilometers sq. 2022
Kanbal III	9335	3380
Sokone aka. Amine	7735	7347
Amine aka Sokone	7895	6937
Source: GFW		

There are several things to note from this table. First GFW records Sokone and Amine as aliases for each other, which may mean that they are one and the same vessel, or that they work closely together. One of the ways vessels work closely together is to pair-trawl. Also, one may act as a tender to underreport catch. Either way, NaFAA and its coast guard should investigate, because the one activity is illegal and the other would bias stock estimates. However, the effects of targeting seem apparent, because the number of square kilometers covered in 2021 seems larger than in 2022. There were only 220 fishing events for Kanbal III in the Liberian EEZ, as opposed to over 1000 for Amine/Sokone, suggesting that that vessel covered less area in the second year. Excluding Kanbal III activity in 2022, the table suggests that the deepwater shrimp habitat preferred by fishers covers about 7000 to 9000 km^2 of the Liberian EEZ of 249,734 Km2, or about 2.8% to 3.6% of the Liberian EEZ. This may be an under-estimation of the size of the habitat since this method relies on the fishing technology currently in use and cost minimization behavior on the part of the fishers, rather than the known habitat parameters, usually depth in meters. On the other hand, however, these limits to accessibility may be overstated because according to scientific surveys the natural distribution of scarlet shrimp is from 274 meters to 1850 meters; and the experimental fisheries occasionally fished at deeper than that lower depth.

[40] https://www.gebco.net/data_and_products/gridded_bathymetry_data/

This suggests a second approach, which is to use GFW with a GEBCO bathymetry overlay. This is easily done by toggling on the bathymetry overlay and turning off the other toggles. Then, a filter in the bathymetry toggle can be applied to only show depths between 274 meters and 1850 meters, within Liberia. Using the ruler option, it is tedious but simple to calculate the area by breaking it down into smaller polygons and adding up the areas. So, applying bathymetry to the map has developed a screenshot where the light grey area encircled by the green line is the habitat for scarlet shrimp.



Figure 3-1. Screen-shot of the habitat area for Scarlet shrimp in the Liberian EEZ (source: GFW). An estimation of the area using simple measuring tools is about 14000 sq Km, or about 5.6% of the Liberian EEZ.

Having a habitat area for scarlet shrimp off Liberia's coast based upon scientific data on bathymetry would have been possible but extremely expensive to accomplish in the 1990s. Now, any nation can have these tools at their disposal for free[41].

Calculating the swept area for the scarlet shrimp surveys

One objective in using the SAM is to control the variables that might bias the catch (and therefore the estimate of the stock). An important variable is towing speed and the tension on the lines and doors to be able to have an area swept by the trawl that is as uniform as possible.

[41] A specialist in GIS has suggested an even more accurate measurement. Filter the GEBCO data in the Liberian EEZ for the desired depths and calculate the area using the pixels which have a standardized area. The number of pixels at desired depth multiplied by the pixel area gives habitat areas in square kilometers.

Calculating the swept area is a matter of determining the area the trawl sweep during tows, which can be found by the using the following formula from Sparr and Venema (1998):

A= D*HR*X, Where;

D= distance in kilometers. This can be found by multiplying the towing speed by the elapsed time of the haul. These measurements, as well as latitude and longitude at the start and the finish of each haul, should be routinely recorded for each haul for all fishers in the Liberian EEZ, and submitted along with all other requested data by NaFAA as part of the concession-holder's obligations under the concession agreement. Compliance with scientific surveys and logbook data is one determinant for the continuation of the contract.

HR= Head-rope length, which in the experimental fishing case the managers at SOKOTA said[42] was uniformly 85 meters.

X= Fraction of the head-rope length due to the speed of the tow and the drag of the net. The scientific literature suggests a value of between 0.4 and 0.66. Pauly (1980) has recommended a value of 0.5. Further research on this is necessary, but beyond the scope of this contract.

So, for example, a vessel towing a single net with an opening of 85 meters (0.085 Km) at 2.8 knots for 1 hour would, after conversion to kilometers (2.8 knots = 1.852*2.8 = 5.19 km/hr), would yield:

$A= 5.19*0.085*0.5 = 0.22km^2$

the distance can alternatively be calculated with the help of trigonometric functions. One suggested by Sparr and Venema (1998) is (in Excel format):

$D= 6*((lat1-lat2)^2 + (lon1-lon2)^2 + Cos^2*(0.5*(lat1 + lat2)))^{\wedge 1/2}$;

Where lat is latitude, lon is longitude, and Cos is Cosine. Another formulation we used in the Excel file provides a clearer picture of how to use latitude and longitude, after converting the coordinates into decimal format and further converting it into radians. Readers are encouraged to carefully study the companion Excel file, and consult the myriad of You Tube tutorials on the subject. Knowing that the radius of the earth is 6378.1 km at the equator, this function can be used:

D= acos(sin(lat1)*sin(lat2)*cos(lat1)*cos(lat2)*cos(lon2-lon1))*6321.

Where acos if the arc-cosine trig function, and cos is the co-sine function.

[42] This was in an e-mail response to NAFAA which was then transferred to us from Sidy Kandji on 23-09-23. This claim should be empirically verified by observers on the ground prior to any survey, since we think this claim of uniform headrope length for all vessels may not be accurate.

It is a simple (though tedious, if the data are not uniform) matter in EXCEL to calculate distances by using these functions, inserting the radian values for latitude and longitude at the beginning and the end of the haul. Excel treats trigonometric functions as math commands, making the calculations relatively easy.

It is imperative for the vessel master to record the latitude and longitude coordinates at the beginning and the end of the haul in an accepted format. Decimal degrees are preferable for management, although the usual latitude and longitude figures (with the direction North(+) South(-) East (+) and West (-)) at least in degrees and minutes, can be used after conversion in Excel. It is also important for the master to record the ***elapsed time*** of the tow as a check. Next, to avoid confusion and to make it easier to code the time data, the beginning and ending times should be "military time", or a 24-hour clock (1h for 1AM 12h for noon, 13h for 1PM, and so forth to 24h…midnight). This will make it easier to calculate ***elapsed time in decimal values*** (or the time at the beginning and the end of the tow), starting from the time the net hits bottom and is being pulled to the time it begins to be pulled up.

Adding up the various catches of target and allied species then allows managers to know the catch per square kilometer (Y/Km^2). This can then be used to get an estimation of biomass or standing stock, by multiplying this value by the habitat area of the target species, in this case scarlet shrimp. For example, if we obtained an estimate of 1000 kg per km^2, and using the habitat area of 14000 km^2, that would suggest a standing stock of scarlet shrimp of 14 metric tons.

While the method is straight-forward, the interpretation of the results is less so. This method assumes that the bridles on the trawl exhibit no "herding behavior"; which it does in most cases. The spread of the net also varies by haul speed, weather, current velocity, and warp length. Many species occur in "patches" in the habitat area; they are not uniformly distributed at all times of the year. If this patchiness is pronounced in the species and no attempt is made to randomize hauls, then biomass estimates will be overestimated, as will be the case with the data for the experimental fisheries of 2021 and 2021. Catchability[43] depends upon the duration of the haul, as well as other characteristics of the net, and in fact the entire vessel and crew plays a role as well. The accuracy of the stock estimation for the target species depends upon the behavior of the vessel master and crew. An experienced vessel master who is actively searching for scarlet shrimp may, with a more randomized approach, provide better estimates of standing stock of scarlet shrimp than a fisher that is inexperienced and unfocused. However, biomass estimates for all species will then be a function of the targeting behavior on scarlet shrimp. Changing targets to other species, which can often occur, makes stock assessments of scarlet shrimp less reliable. This is possibly why we were able to find a yield effort relationship for scarlet shrimp but not for the other shrimp species using the experimental fishing data. However, because the targeting behavior appears to have been very focused when looking at GFW data on the three vessels, the stock estimates from that fishery would likely over-estimate standing stock. On the other hand,

[43] A notion from fisheries biology which economists recognize as a parameter affecting aggregate production, and is therefore a technological parameter.

the more the trawl gear is used non-selectively, the more reliable the estimates of multi-species abundance and biomass will be.

An example

Although no one who has read the literature on SAM will conclude that the experimental fisheries of 2021-22 was an attempt at a scientific stock assessment, we can use our technical knowledge and common sense to get some biased estimates of stock abundance, while trying at the same time to minimize the worst of these biases. Start with the vessel. We excluded Kanal III data because it appeared to have inconsistent days of effort between 2021 and 2022. We are excluding Sokone data, because this vessel had the most errors in data recording and the most confusion in data recording. Also, Sokone failed to even turn in their data for 2022; or at least it did not appear on the Excel file we received. This leaves the el Amine. Next, we filtered the data to include only hauls deeper than 232 meters and shallower than 1850 meters; the approximate range we found consulting the scientific literature on the life histories of the species. We point out that most hauls were shallower than 500 meters. Next, we focused on all the hauls, even though the normal haul of between 3-4 hours will over-estimate the stock. We did however clean the data to make sure that there were no false signals. We also used GFW fishing activity reports for the three vessels, although the reporting of latitude and longitudes in the data provided by SOKOTA made it difficult to corroborate the reports. Samples also had to have an intelligible latitude and longitude for the beginning and the end of the haul; those that did not meet that bar were removed from the sample. Then we calculated the distance of the haul using trigonometric functions (found in the companion Excel file). This gave the distance of each haul in kilometers. This information was used to calculate an estimate of standing stock for 2021 (1446757 kilograms) and 2022 (613919 kilograms), for a percentage ***decline*** in relative abundance of the stock of about 58%. We verified this result by performing a regression like an ANOVA analysis, to see if this result might be statistically significant. An index of kilograms of scarlet shrimp per kilometer of each haul was formed for 2021 and 2022. The sample size was 453 observations. We then asked whether the year of the activity might have had an impact on this variable. The regression itself only explains about 15.7% of the total variation in the sample. However, the variable DUM22 has a parameter of -3.597 kilos/kilometer from 2021 to 2022. And the significance of this variable is well beyond a 99% confidence interval ($P= 9.73 \times 10^{-19}$).

There are, of course, all sorts of reasons why we obtained such a negative result. It is possible that the master of the el Amine modified his fishing behavior between 2021 and 2022, targeting more on other shrimp species. It is possible that the catch in 2022 was somehow under-reported compared to 2021. But it is also possible that the vessel simply tried the same behavior of 2021 and discovered less abundance. In looking at the GFW data on the el Amine in 2021-22, the last explanation seems as likely as any.

So, in a management context, most reasonable people would give this result at least a “yellow light.” They would also try to collect more information on the state of the fishery with much more precision than we see in these data.

Concluding remarks

This annex provides information on how to calculate standing stock using the swept area method, using more accepted scientific approaches in a commercial setting. Some of the features of commercial fishing can be useful for a scientist, if it is known what is being sacrificed for access to vessel time. However, at least for a few days at the beginning of the season, vessel-owners need to be good sports about a more scientific approach to stock estimates and management. After all, the objective of sustainable management is to use ***the least amount of effort to make the most amount of money***[44]. It is also true that fishing all-out on narrow geographic targets may not yield the best estimates of standing stock. And it may not be a very intelligent fishing strategy for a company that has exclusive access to a stock. Surveys based upon such behavior are more likely to simply overestimate stock due to migration from other non-sampled areas between seasons; patches of the resource may move over time, hence the need for a careful approach to stock assessment.

This raises issues that have also been discussed by other specialists in the swept area method for calculating standing stock. Targeting behavior of fishers will restrict the "sampling" area of the habitat and is therefore not random. There may be technical limitations of the gear or cost concerns of the vessel owners that make them want to fish some areas more intensively (like depth, rocks, topography, wrecks, or other obstructions). Second, the experimental fishery is at best a partial view of what went on outside of a few species, with very little scientific data collected on the target species or the incidental species. Changes in the velocity of towing would also affect the area of the sweep, as well as the length of time of the haul. There is also likely an "oversampling phenomenon" whereby catches over time fall as the same ground is scraped repeatedly over the season.

Nevertheless, our example shows indirectly that if we use one vessel with an experienced master who does not change his targeting behaviour from one year to the next, then we may be able to live with other biases, because managers are mainly interested in incremental change. For example, the percentage change in an estimate over time is used to generate a decision for the following season. That season in turn produces information for another subsequent decision in the future, and so on. If the sampling behavior does not change without managers knowing it, decisions can still be made with imperfect indexes compared over shorter periods.

The quality of the data does not permit other analyses of the stock assemblage except for possibly some species of commercial value, because the cataloging of incidental catch in the experimental data was so poorly done that it casts doubt on much else these vessels reported. Vetted concession holders who have a stake in the success of a managed fishery and who will assist in an actual stock assessment survey with NaFAA will need to be found to obtain more useful estimates.

[44] Although, see our comments on the effects of market power and imperfect competition on the part of the partner demanding access summarized in Annex 4.

Annex 4

Market Structure, Firm Behavior, and Governance: Economic Explanations of "free-for-all" fishing

FMPs start with the assumption that the primary reason for public management is to ***avoid overexploitation of fisheries resources*** by ***better controlling the effort of fishing firms***. Firms exert Effort…days of fishing…in ways that is often called a "race for the fish." This race eventually leads to overcapitalization of the fleet, causing dissipation of resource rents and resulting in a "free-for all" situation. In the long term, only normal profit, and very little of that, is made by each firm. This FMP aims to rectify overexploitation of the resource in general by ***controlling effort*** in the fishery by various means.

The standard narrative in economics is based upon a "***perfectly competitive***" market structure. This market structure is associated with ***market economies; economies where all goods have well-functioning markets***. The narrative assumes that we have many buyers and sellers, easy entry and exit by both buyers and sellers, perfect (symmetric) information, and clear property rights to the goods being exchanged. In this context, buyers and sellers will ***maximize their own well-being and the well-being of the entire economy*** through voluntary exchange.

But fisheries and other ***collective goods*** people use do not always have well-defined markets. The surplus production model (the model of resource growth) is an environmental constraint.[45] Fishing firms conform to the standard competitive model in many ways. However, one big difference between standard or "perfect competition," based on markets, and the fishing sector is that marine fish resources are collective goods that are often (but not always) managed by collectives of users, and in many cases, this includes public agencies. Sometimes, the public managers themselves do not do a very good job of managing the resource in the interests of the public, so they are forced to work closely with other groups to "co-manage" the resource. Unless special provisions and rules are made to jointly exploit the resource, the competition in the fisheries sector can be fierce, leading to the same results as the standard competitive model. However, the underlying fish stocks are often damaged or destroyed because of the competition.

Once the vessels deliver their catch to processors, who then pay them by weight and grade, the catch enters the market economy. Often the prices are negotiated before the season and are public information. The price data generated from these markets and market chains is usually public information, and therefore can be collected by public management agencies like NaFAA.

In the fisheries management cases of the U.S. and elsewhere, the FMPs seldom consider governance issues beyond the ones having to do with the actual fishing activity, i.e., overfishing, underreporting, high grading, illegally targeting protected species, etc. Also, although there may be irregularities in public management, in many cases it is not a common occurrence.

[45] The interested reader can consult any good intermediate text in microeconomics, as well as a text in natural resource economics, such as Hartwick and Olewiler (1998).

Dealing with fraud in business and corruption of public officials is seldom raised as part of an FMP; these are matters taken up by the courts.

However, in the case of fisheries management in Liberia, these key assumptions of public management of fisheries may not always hold. The experimental fishery was the result of an agreement between a government and one firm. That firm is part of a multi-national corporation with several offices worldwide. The three vessels that fished as part of the agreement also fished during 2021-22 in Senegal, The Gambia, Ivory Coast, and in two Marine Protected Areas (Sangomar and Gorée), according to Global Fishing Watch (GFW). The experimental fishing in Liberia appeared to be intense[46], and focused on catching scarlet shrimp and getting it out of the Liberian EEZ. Our estimates of the Export taxes collected (based upon the revenues estimated at open access at the landings prices provided by only one manifest provided by NaFAA) was around 1.7 million Euros a year. The firm paid no licence fees under the agreement.

Given what transpired in 2021-22 and the results of these analyses, it is fair to ask what ***other economic conditions*** might have resulted in an apparent over-exploitation of the resource after only two years of fishing if it was not the standard "competitive" fisheries situation. We will explain these other conditions below.

Market structure, firm behavior, and this FMP- The FMP appealed to the idea that under certain circumstances, competitors can cooperate to maximize their own collective well-being. We presented the idea of a "public-private" management relationship where partners recognize that the sustainability of a resource can be jeopardized by applying too much effort, and that there may need to be a reduction of effort ***to achieve sustainability and to make more money***. Under cooperative management, benefits could be shared with gains going to each partner.

The problem with that reasoning is that getting cooperation from foreign firms may be difficult. Liberia's situation is an example. One commenter at the workshop of 15 April 2024 suggested that calculating resource rents for the purpose of distribution between partners was a "difficult thing to do," implying that the task should be abandoned, as it has been in other parts of West Africa. Of course, with no economics expertise at NaFAA and uncooperative partners, it is indeed difficult to do. But this can be rectified by hiring managers who understand economics, finance, and agricultural marketing, and who can suggest resource use fees that, with intelligent effort management, data gathering, and analysis, can generate a stream of receipts for Liberia into the future. This is done in many other countries with their fisheries. Liberia can do it too.

Students in economics also spend a lot of time learning about market structures other than the competitive free market model, usually starting with the ***case of collective goods*** discussed above. We ask more detailed questions about why firms exist in the first place, and why some are large and efficient while others are less so. Answering the question of firm size and function has to do with understanding the ***organizational costs of the firm***; especially how much it costs for a firm to make a component of a good or service within the firm, versus how much it costs to buy the component on a market to use in the construction of a good or service. If the internal

[46] An estimate of reported catch, assuming the inclusion of the 85 missing fishing days of Sokone in 2022, is about 138 MT of scarlet shrimp captured by the three vessels over two years.

organizational costs for "making" is less than the costs of "buying," the firm expands, or ***integrates different functions that were part of the market***. This process of integration can be accelerated in conditions where markets are expensive to operate, or where they do not function well, or do not exist. In these cases, integrated companies can become strong. And then, firms can begin behaving like ***imperfect competitors, exerting what economists call "market power."***

An important example of "imperfect competition" is monopoly behavior. Monopolies are common in modern economies. A large and well-managed firm facing many buyers for a unique product might decide to maximize both profits and ***scarcity rents*** by producing only enough so that the ***marginal costs of production equal the marginal revenues to be had from the consumers of the product***. Prices of the product rise, production falls, and consumers lose a part of their benefits to the firm. There is also a net economic loss to the economy because of monopoly behavior. In the case of fisheries, a "state monopoly" has often been suggested to control overexploitation. For example, the FMP discusses the case of a public-private enterprise, whose members reduce effort to maximize resource rents. By doing so, they may ***reduce their production*** and may also ***raise prices***. However, the sustainability of certain resources in the species assemblage ***will be better assured because of this***. Monopolies that maximize resource rents can be sustainable and more environmentally friendly, although the rest of the economy may pay for that result. ***This is especially true if the resource rents are taken out of the home country by the firm***.

A large and integrated firm may not be a monopolist on the selling side. It may compete with other companies of similar size in places like Spain. ***But a firm might be monopolist on the buyer's side in West Africa;*** economists call this ***monopsony behavior.*** Pereira/SOKOTA needs to maintain legal access to fishing grounds, especially in this time of heightened surveillance of IUU fishing worldwide. Liberia's managers, seeking access to the European market, want a partnership. But since investors in Liberian deep-water shrimp fishing were scarce[47], Liberia accepted to work with this group under an official agreement. ***This granted the vessels legal access to the Liberian EEZ***, at terms that we believe were very beneficial to the firm, because this was legal access with few strings attached. However, it appears that the objective of the fleet was to have "free-for-all" fishing in 2021-22 anyway, much like in a competitive open access situation, specifically to ***maximize the transfer of resource rents from Liberia to elsewhere***. Economists call strategic behavior like this, between two or more uncooperative partners, a ***non-cooperative game[48].***

In addition to being able to negotiate favourable terms of legal access, the three vessels in question were allowed to leave the Liberian EEZ and to land their catch in Abidjan or Dakar with Liberian inspectors present on arrival of the vessel. However, it is still not clear to us why this guarantees an accurate recording of catch made in Liberia, unless the inspectors are physically present with the vessel when it leaves Liberia. The terms of how the catch is

[47] We do not know if there are any Liberian nationals who expressed interest or how well the call for investors was distributed. Wehye, in personal communications suggested that scarlet shrimp was reserved for companies having industrial sized vessels and therefore was considered a foreign fishery.
[48] In honor of John Nash, a mathematician, who wrote on the same subject.

accounted for needs to be more carefully written in concession agreements to avoid under-reporting of catch.

Finally, the firm may have had advantages due to the way prices per kilogram were established. In discussions with NaFAA staff about the prices per kilogram of catch landed in Dakar (or Abidjan), we were not sure how these prices per species were established. They do not seem to be the result of a negotiation with NaFAA. Companies that have subsidiaries, such as Grupo Periera/SOKOTA, may engage in ***transfer pricing***,[49] to gain tax advantages.

Transfer pricing is an accounting and taxation practice that allows for pricing transactions internally within a business, between subsidiaries that operate under common control or ownership. Transfer pricing is especially used in ***cross-border transactions*** to take advantage of differences in tax jurisdictions. For example, a company knows that they must pay 10% export taxes on the total value of a catch. They may therefore try to reduce the reported catch and the price per kilogram of catch to minimize the tax incidence of the export.

A transfer price can also be used to determine the cost to charge another division, subsidiary, or holding company for services rendered. Transfer prices should reflect the going market price for that good or service, but often they do not.

Multinational corporations are legally allowed to use transfer pricing methods to allocate earnings among their subsidiary and affiliate companies that are part of the parent organization. However, companies sometimes misuse the practice to reduce their taxable income, thus reducing their overall taxes. The transfer pricing mechanism is also a way that companies can shift tax liabilities to low-cost tax jurisdictions.

To understand how transfer pricing impacts a company's taxes, consider a manufacturer of seafood products that has two divisions: Division A, which catches scarlet shrimp, and Division B, which gets scarlet shrimp to the Spanish market. Division A may sell the shrimp to other buyers as well. Division B pays Division A for the shrimp, possibly at the prevailing market price that Division A charges other buyers. These prices would then be close to a market price.

But suppose that Division A charges a ***lower*** price to Division B instead of using the market price. As a result, Division A's sales or revenues are lower because of the lower pricing. The export tax is then lower for the parent company. On the other hand, Division B's Costs of Goods Sold are lower, increasing B's profits. Division A's revenues are lower by the same amount as Division B's cost savings. In this case there is no financial impact on the overall corporation, unless the two divisions reside in different tax jurisdictions.

Suppose that Division B is in a higher tax country than Division A. The overall company can save on taxes by making Division B look less profitable. There have been cases in many industries where products destined to high tax zones like the EU have been mislabelled as product of a lower grade and value to reduce tax incidence of the partner in a high tax area.

[49] https://www.investopedia.com/terms/t/transfer-pricing.asp

By charging above or below the market price at each step in a market chain, companies can use transfer pricing to shift profits and costs to other divisions internally, to reduce their taxes. But this means that the pricing transactions that occur internally within businesses and between subsidiaries may not necessarily be market prices. They may well be lower.

For example, we calculated a weighted average price for scarlet shrimp based upon the "landed" prices in Dakar. We estimated 15.34 Euros per kilogram for a delivery made by the vessel Sokone to Dakar. The project Globefish, an initiative of FAO to follow the international trade of seafood products[50], reports three grades of wholesale scarlet shrimp in Spain of 90, 65, and 25 Euros/Kilogram. The companion Excel file has a simple analysis where we calculated the average weighted price at wholesale in Spain of the landings in Dakar by Sokone. The estimated weighted average price of the six grades (broken into three grades) ***gives a weighted average price of 50.72 Euros per kilogram*** for the weights of the grades made in Dakar. This gives a percentage change between the landed value and the wholesale value of about ***2.31 times the landed value on the one manifest we saw***. However, in looking at other markets for wild-caught large white shrimp on the Gulf coast of the U.S., the average price margins from 2012 to 2022 is 26% to 40%[51]. So, if we reduce the weighted wholesale price in Spain for scarlet shrimp by 26% to 40% to reflect what a competitive market might value this catch as in Dakar, ***we obtain a price of 40.25 to 36.23 Euros per kilo landed at Dakar***. Both values are quite a difference from 15.34 Euros/Kilo. So, where did the difference (14.49 to 24.91 Euros/kilogram) go? Probably not to Liberia.

These are only rough estimates, based upon a quick Internet search and with very limited data offered by NaFAA employees very late in this contract, and what we know about marketing margins for large shrimp elsewhere. However, this result supports the idea that this partnership may not be a good deal for the Liberian people. This also explains why SOKOTA was keen to get as much as they could out of Liberia's EEZ, thus simulating an "open access" result.

NaFAA can get a better idea about appropriate fees to charge when each manifest and every species from 2021-22 is reviewed and compared to what is known about marketing margins for shrimp in West Africa and the wholesale markets in Spain (we suggest as a first source Globefish). A review of the academic literature in agricultural economics on market chains for seafood would be also important to build local expertise as well. We would advise against making any agreement, until better fee information is collected and negotiated as part of any future concession agreement. This is because the wholesale market value of scarlet shrimp is so high in Spain, and the opportunity costs for capital in Liberia is so elevated, that overexploitation of this resource is practically guaranteed without stricter management measures.

[50] https://www.fao.org/in-action/globefish/prices/en/

[51] https://msmarketmaker.wordpress.com/2021/02/22/shrimp-price-margins-from-dockside-wholesale-retail-markets/ ; https://hortmarine.wordpress.com/2019/04/24/wholesale-margins-over-dockside-prices-of-gulf-shrimp-rising/.

Governance **–** Issues of governance and ease of doing business are certainly on the minds of the new leaders of the Liberian government because they have chosen to concentrate on Agriculture, Roads, Rule of law, Education, Sanitation, and Tourism (or ARREST). For this reason, we have added this section on how economic realities in Liberia affect management using this FMP.

The economics summary that we have added to the FMP includes some recent Governance indicators for Liberia. These indicators fall on the positive or negative side of zero, between +2.5 and -2.5. The score is a ranking of Liberia compared to all other countries. A strongly negative score means a lower rank, and it may indicate a problem. Some people do not think that these indicators have anything to do with economics or economic performance of a country. However, investors from outside Liberia who might be tempted to bring their funds and expertise may be put off by difficulties they encounter in Liberia. The last "Ease of Doing Business" index published by the World Bank in 2019 places Liberia at 175th out of 190 countries. In the workshop one commenter pointed out that, even though NaFAA actively searched for partners, only one company agreed to the terms of the experimental fishery, which were in fact quite liberal. Is it possible that NaFAA could make improvements in how they market themselves to the world? This FMP proposed different ways of presenting NaFAA on their website. Such changes may produce dividends by generating more interest in Liberian fisheries by a broader public. The idea is to make it easy for visitors to the web to get to know the laws, to find FMPs, to be apprized of meetings, or to contact an officer by e-mail if they would like to discuss fisheries issues in Liberia, and to provide scientific information and a photo gallery that will help visitors understand and identify the species being fished.

Here is an example of the evolution of fisheries management because of the interaction between management and the public. One of the things that was discovered by public managers at the Gulf Council in the U.S. during the 1990s was that, while bureaucrats were busy managing the commercial fishery for different species, they became aware that ***tourism…and especially sport fishing tourism… was rapidly becoming an important source of economic growth in many coastal states of the U.S.*** In terms of contribution to economic growth, sport fishing groups began to rival traditional commercial fishing operations, changing the market structure of private enterprise, and thus requiring modifications to several FMPs, and provoking more moves by everyone (including tourists) towards more selective and sustainable fishing. Many fisheries in the Gulf of Mexico, are followed by commercial fishermen, tourists, and environmental activists. This is now reflected on the websites of the Gulf Council in the U.S. and in the FMPs. Tourism in the Gulf of Mexico now includes many activities that are ***non-consumptive,*** like wildlife observation. These activities also contribute to the economic growth in important ways.

Enacting and publicizing clear policies that forbid corrupt practices by government agents may incite certain investors to look at Liberia favorably. Some countries and institutions (like the World Bank) have also included a "corruption hotline." Many fisheries and wildlife management agencies offer an "illegal fishing/hunting hotline" where ordinary citizens can make anonymous

calls to make complaints or comments. A more general opening of the NaFAA through changes to their website could change the structure and nature of public management of fisheries.