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Reconsidering Historical Definitions of Overfishing and the Balance between Sustainable Use and Overexploitation

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Overexploitation and sustainability have been core concepts in the management of renewable resources since the 1600s. Traditionally, these terms were directly linked to one another, so that overexploitation was truly unsustainable. In fisheries management, the connection between them was severed when maximum sustainable yield became the guiding principal for many management bodies in the 1950s. The current tendency is to consider fishery management a failure if a stock is 'overfished'. However, the abuse of such terms has led to inappropriate negative perceptions of management systems and the fishing industry. By tracing the origins of the term 'overfishing' we demonstrate that modern management systems that link overfishing to an optimal fishing mortality reference point do not adhere to the traditional concept. We suggest a revival of historical definitions of overfishing, based on short-term time horizons. Such a reinterpretation would define sustainable use as harvesting up to the reproductive surplus of the resource, while overexploitation would be indicated by harvesting more than could be naturally replaced in a given year. By re-defining overfishing as unsustainable fishing mortality, the unwarranted negative perception of fisheries can be avoided and promote conservative fishing techniques.

Keywords: Sustainability, overfishing, fisheries management, ICES history

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1. Introduction

In the last three decades, ‘overfishing’ and ‘sustainability’ have become central topics for fisheries management around the world. However, these terms have come under attack for having ambiguous definitions depending on the management body or user-group (Kates et al., 2005; Hilborn and Stokes, 2010; Rothschild, 2011). The lack of an operational definition is often cited as a key limitation of the concept of sustainability from a scientific standpoint (Quinn and Collie, 2005). Without quantifiable measures it is impossible to identify whether an action is sustainable (Wefering et al., 2000). Concomitantly, the perceived ambiguousness of these definitions creates a lack of understanding about what needs to be accomplished and a call for more research instead of action (Ludwig et al., 1993). The circularity inherent in these terms has led to ignorance and unsustainable exploitation in some cases, but has also caused an overly-pessimistic outlook that is largely due to a mis-identification of sustainability or rebuilding targets (Hilborn, 2002; Hilborn and Stokes, 2010).

The lack of connectivity between the long-term principles that drive the concept of sustainability and short-term actions that can be implemented to achieve these goals further complicates successful management (Pauly et al., 2002; Kates et al., 2005). Many precautionary management approaches developed in recent decades have been successful in achieving sustainability, but successes have not been recognized because of inappropriate definitions and targets (Hilborn and Stokes, 2010). In the United States, the Magnuson-Stevens Fishery Conservation and Management Act mandates rebuilding plans that allow stocks to grow to the biomass that can produce maximum sustainable yield (MSY) in a pre-determined timeframe. The attempt to achieve sustainability by imposing theoretical, uncertain, and arbitrary requirements is counter-productive. Arbitrary rebuilding timelines often lead to overly stringent management actions that, in turn, undermine stakeholder acceptance and adoption of conservative fishing practices (Hilborn et al., 2002; Hilborn and Stokes, 2010).

Beverton (1998) stated that management has “been trying to be too clever” and too formulaic, especially when it comes to developing ‘sustainable’ fisheries to end ‘overfishing’. An historical review of the development of these two terms helps to understand how the terms developed, providing insight into their intertwined nature and how current fisheries policy incorrectly uses each. Incorrect implementation of overfishing and sustainable terminology has led to unnecessarily stringent management, overly pessimistic fisheries outlooks, and unwarranted hardship to fishing communities.

2. History of the Concept of Sustainability

The modern definition of sustainability is often cited from the 1987 United Nations ‘Brundtland’ Report (World Commission on Environmental Development) titled “Our Common Future”, although credit is owed to the 1972 Club of Rome Report “Limits to Growth” (Meadows et al., 1972) for reinvigorating the use of the term in the modern political age (Grober, 2007). The Brundtland Report defines sustainability as meeting “the needs of the present without compromising the ability of future generations to meet their own needs.” The focus of this definition is the realization that society must balance the needs of individuals with the limitations of the environment, while taking into account the present without sacrificing the future. In other words, when assessing the potential impacts of human growth and resource exploitation, an holistic approach must be taken that accounts for and balances economic, social, and environmental factors (Johnston et al., 2007).

Johnston et al. (2007) estimate that there are currently over 300 alternate definitions of sustainability within environmental management. This ambiguity is often the major criticism of sustainability because the concept provides no guidance on how to measure whether or not an action can be considered sustainable (Wefering et al., 2000; Johnston et al., 2007; Quinn and Collie, 2005). However, others cite ambiguity as one of the strong points of the definition, because it allows for adaptability to many situations, while providing guiding principles (Kates et al., 2005; Bosselmann, 2008). Investigations into the historical roots of the concept provide insight into what sustainability means and how it can be achieved.

2.1 Sustainability in Forestry

The fields of forestry science and fisheries science share many common traits branching from their both studying the utilization of renewable resources. However, two key differences exist that play a role in the development and eventual management of each. The first difference is that the effects of harvest can be directly observed on land, while these effects can only be inferred from samples of remote aquatic habitats. Secondly, forests generally regenerate more slowly than fish populations, causing surplus production to be lower. Accordingly, developed nations were quicker to realize the exhaustibility of timber products than fishery resources. Many of the debates that were to occur regarding the exhaustibility of sea fisheries in the late 1800s (e.g., the discussions that were to occur during the 1883 Inaugural Fisheries Congress) had actually taken place in forestry over two centuries earlier (Grober, 2007).

The realization that timber resources would soon become severely limited led initiatives across many of the European countries in the late 1600s to investigate ways to maintain timber supplies (Grober, 2007; Pisani, 2007) similar to how the modern energy crisis sparked the debate leading to the Brundtland Report's attempt to categorize sustainable development (World Commission on Environment and Development, 1987). Spurred by worries from the British Royal Navy that lack of old growth timber would threaten their military status (Grober, 2007), John Evelyn published *Sylva or a Discourse of Forest-Trees and the Propagation of Timber in His Majesties Dominions* in 1664. The main treatise was that the current generation must harvest the forests in such a way that "posterity might have trees fit for their service," which could only be accomplished by appropriate husbandry and the perpetual planting of new trees to replace those that were harvested (Grober, 2007; Bosselmann, 2008). This work supported the concept of maintaining the resource for future consumption, while providing a suggestion of how to attain this goal (i.e., planting a tree for every tree that is harvested). Thus, the basic tenets of harvesting a renewable resource were born: extract only as much as can be replaced in order to maintain the standing stock.

The term sustainability is often credited to Hanns Carl von Carlowitz in his 1713 book *Sylvicultura Oeconomica oder Naturmässige Anweisung zur Wilden Baum-Zucht* [*Forest Economy or Guide to Tree Cultivation Conforming with Nature*] in which the idea of continuous use that balances harvest and growth is developed (Grober, 2007; Pisani, 2007; Döbel, 2008). Carlowitz expounds the virtues of economical usage of forest resources in order to maintain them in perpetuity (Keiner, 2005). The German term 'Nachhaltigkeit' used by Carlowitz, which literally translated as lastingness or durability, is thus the basis for the English term 'sustainable'

(Pisani, 2007). The true underpinning of the concept involves responsible and conservative-minded harvesting in such a way as to maintain enough young trees to balance those that are removed. Thereby, a constant and healthy standing stock is provided for future generations (Bosselmann, 2008).

The concept of sustainable use has been around since the founding of society, but Carlowitz was able to name the general idea of taking only what is needed from nature, while maintaining resources at a level that can equally support future generations. The concept of 'sustained yield' continues to be the focal doctrine in all natural resource management. However, the precise meaning and operational definition of sustainable use remain elusive (Wiersum, 1995). Despite current definitions being muddled in questions of what is to be sustained, how it is to be measured, and how social and economic factors impact sustainability, the historical definition of sustainability provides clear guidance on the concept (Grober, 2007). Borrowing the 'sustained yield' idea from forestry, early theoretical fisheries science was almost entirely developed around the concept of sustainability. However, before sustainability could be realized, fisheries scientists first had to realize that fisheries resources could be exhausted similar to forests.

2.2 Recognizing and Defining 'Overexploitation'

In many ways, the concepts of 'sustainability' and 'overexploitation' (i.e., 'over-use', 'overharvest', or 'overfishing') are opposite sides of the same coin. The idea of sustainable use implies using a resource in such a way that its productivity is maintained in perpetuity. By contrast, unsustainable use implies that a resource is being extracted at such a rate that threatens future productivity. The basic problem becomes that the resource is being 'over-used' causing depletion in the standing stock. The conceptual view demonstrates that an unsustainable harvest must imply overexploitation, while the opposite is also true: sustainable use means over-use is not occurring. Thus, a resource that is harvested to such a degree as to decrease the standing stock and threaten its future productivity is being overexploited (Hunter, 2002).

As with the case of the term 'sustainability', definitions of 'overexploitation' have transformed over the years and taken on more holistic meanings (Smith, 1994). The result of which is a rather ambiguous term that is closely associated with sustainability, but not necessarily directly linked (Beverton and Holt, 1957). Heino and Enburg (2008) claim that the modern version of

> "Overexploitation refers to exploitation that is more intensive than some agreed limit. Again, it is not in the realm of science to define such limits, although scientists can advise on possible choices. Overexploitation can be defined as unsustainable, or vice versa, but often these terms are not tightly coupled."

Despite the ambiguity of modern terms, the historical concepts remain a key aspect of current definitions. Considering the history of over-use provides insight into what the concept entails. The understanding that resources could actually be over-used and eventually exhausted was a necessary impetus to pursue sustainable practices.

Returning to the field of forestry, the 'French Forest Ordinance of 1669' is one of the key documents pushing for 'bon usage' and 'reducing use according to capacity' (Grober, 2007; Bosselmann, 2008). Similarly, Carlowitz (1713) urged that 'timber must be used with care,' because there was a limit to exploitation of renewable resources, and continued over-use would ultimately lead to the destruction of the forests (Grober, 2007). Unsustainable use and overexploitation were clearly synonyms, which refer to harvest that decreases that standing stock by removing more than the reproductive surplus in each year.

At the turn of the 19th century, the implications of the strain of human existence on the limits of natural resources were beginning to become fully realized. Thomas Malthus's 1798 "*Essay on the Principle of Population*" argued that human "population must always be kept down to the level of the means of subsistence" (p. vii). Malthus's model does not represent reality, because the human population has been able to increase food production to accommodate population growth without stagnation (Baumol et al., 2007). However, Pauly (1994) contends that the idea applies for fisheries systems because long-term sustained yield must remain relatively constant and cannot continually increase to meet the demands of a growing population. The lasting impact of Malthus's essay was the idea that natural populations were limited by their environment. This idea was later encapsulated in the carrying capacity term, which represented the maximum number of individuals the environment could sustain, in Verhulst's (1838) logistic equation (Angelini and Moloney, 2007). As Angelini and Moloney (2007) point out the work of Malthus and Verhulst would later become the foundation of modern fishery science, and in many ways 'sustainability', because it was the basis of the surplus-production models developed in the 1940s and 1950s.

2.2.1 Origins of Overfishing

In ocean fisheries, the 'exhaustibility' of natural resources was debated, even though the limits to harvest of renewable resources such as forests, whale populations, and lake fisheries were clear. Cleghorn (1854) is widely attributed with first using the term 'overfishing,' but does not clearly define the definition of the word (Smith, 1994; Taylor, 1999). In his arguments, however, Cleghorn (1854) relates overfishing with unsustainable removals that decline populations to such an extent as to make them 'economically extinct,' and that such practice will inherently limit use by posterity (p. 241):

> "May we not have drawn over liberally on our shoals of herring? With such appliance may we not have overfished the sea? That a river or lake may be overfished, or that the whales between the tropics and at the poles may have their numbers so thinned that the fishing would cease to pay, will be readily conceded; but nobody here ever dreams of imputing the failures in the herring fishing to our having overdone it."

Although Cleghorn "suffered much local persecution for his views of the herring question" (Bertram, 1869; p. 232), his outlook was accepted by some contemporary scientists. Bertram (1869) discussed the overfishing problem quite extensively in his book "*The Harvest of the Sea*", and warned that (p. 287):

> "The combined ignorance of naturalists and fishermen has much to do with the scarcity of white fish…unless some plan be hit upon to prevent overfishing, we may some fine morning experience the same astonishment as a country gentleman's cook who had given directions…to supply the kitchen with a certain quantity of

> grouse…for a number of years she found no lack, but in the end the purveyor…told her she need look no more…for on that day the last grouse had been shot….the cook had unfortunately never considered the relation between guns and grouse."

The question of whether fishing could effectively alter natural fish populations became one of the key points of contention during the 1883 Fisheries Exhibition in London (Smith, 1994; Sims and Southward, 2006). Thomas Huxley (1883) opened the convention with his oft-cited speech proclaiming the sea fisheries 'inexhaustible' under 'current modes of fishing', but noted that certain sessile demersal species (e.g., oysters) and anadromous species (e.g., salmon) may be susceptible to 'exhaustion' by fishery practices (Rozwadowski, 2002). Ray Lankester (1883; p.11), on the other hand, argued that it would be an error to think that the number of fish in the ocean is great enough "in comparison with man's degradations as to make his operations in this respect insignificant."

By the turn of the century the 'overfishing problem' was widely accepted by many fisheries institutions refuting the claims of inexhaustibility of the seas. Attempts to solve this problem formed a key basis for the development of the International Council for the Exploration of the Sea (Rozwadowski, 2002; Jakobsson, 2003). The general idea of overfishing at this time was the "state in which the more you fish the less you catch" (Dymond, 1948; p. 64), but, after much debate, the committee on overfishing concluded that the definition was "too severe fishing, meaning that more fish or a better quality of fish were taken away than natural production could replace" (Rozwadowski, 2002; p. 51). Petersen (1894, 1903) highlighted the main effects of overfishing, which included a decline in catch rates, a decrease in mature fish, reduction in average size, and 'destruction of immature fish.' Kyle (1905) proposed that the rationale behind overfishing was an economic issue that may not have a tractable scientific solution (Smith, 1994; Angelini and Moloney, 2007).

The concept of overexploitation stems from the idea of unsustainable harvest of a resource, over-use implies taking more than is sustainable and removing more than the regenerative power of the standing stock. Consequently, continued overexploitation is expected to lead to local extirpation if economic pressure is high and habitat degradation continues (Reynolds and Peres, 2006). In fisheries the term 'overfishing' carries the same basic implications as highlighted by Peterson (1894; p. 60) who cites forestry as an analogy for fishing: "if care is not taken to replace the large trees with smaller ones, the forest cannot continue every year to give its maximum profit." Thus, overfishing in its basic form is taking more from the stock than it "could produce by new growth" (Peterson, 1894; p.58). Yet, ambiguity in the definition has caused problems in correctly identifying the exact causes of over-use in oceanic systems (Taylor, 1999). With the application of theoretical models for assessing resource yield, the definition of overexploitation has become further confused. 'Unsustainable' and 'overexploitation' were historically synonymous, but over-use began to be associated with any harvest greater than the maximum sustained yield (Schaefer, 1954b).

2.3 Model-based Definitions of Sustainability and Overfishing

The early conceptual definitions of sustainability and overfishing were largely empirical and focused on short-term dynamics and expectations. Sustained use involved taking less than the reproductive surplus. By contrast, any harvest that decreased the standing stock was generally assumed to be overexploiting the resource. Early fisheries models attempted to describe population dynamics with the main goal of identifying overfishing from a theoretical framework. Russell (1931) presented “in a simple way the essential conditions of the problem,” which were that biomass fluctuated due to the addition of new recruits, growth of individuals, and removal from the population caused by fishing and natural mortality. This formulation was similar to that presented by Baranov (1926) and reiterated the idea that sustained yield results from balancing regeneration with harvest, but must also account for natural declines (Angelini and Moloney, 2007; Rozwadowski, 2002). One of the main points was that “stabilization may take place at various levels, depending on the magnitude of catch...but the aim of rational exploitation is to get the maximum yield annually, compatible with maintaining stocks at a steady level” (Russell, 1931; p. 10). The point of maximum ‘sustainable’ yield was argued to occur at the point of maximum growth, but identifying the location was limited by the extent of fluctuations in natural populations.

Russell’s (1931) approach was not suitable for analytical use because each of the terms contributing to biomass were not independent, and there was no way to estimate parameters or determine sustainable levels (Beverton and Holt, 1957). However, his approach organized a way of thinking about fisheries and the ‘overfishing problem.’ The idea of a maximum or ‘rational’ level of yield would come to dominate fishery modeling and management for the next century. Despite arguing that a maximum yield must exist, Russell (1931; p.10) states that “the ideal of a stabilized fishery yielding a constant maximum value is impracticable” due to natural variations and oscillations of fish populations. The problem of natural fluctuations has been ignored in most theoretical approaches and is likely the main reason for the failure of equilibrium and stable-state models of fishery dynamics (e.g., maximum sustainable yield; Holt, 2006).

The implication of Russell’s (1931) basic theory is that overfishing occurs when catch leads to a “progressive diminution” in stock biomass. However, he also demonstrated the importance of the size distribution of the population and size of capture of individuals, because these factors are intertwined in determining sustainable fishing. Harvesting will decrease the size distribution of individuals in the population, but at intermediate levels this can increase the growth rate of the population by reducing competition on smaller individuals that have higher individual growth rates, yet lower competitive fitness compared to large, older fish. However, excessive harvesting will reduce adult biomass and subsequent recruitment (i.e., recruitment overfishing). Harvesting at too small a size would also lead to suboptimal production, because fish would be harvested before they could achieve their productive potential (i.e., growth overfishing). Thus, beyond conceptualizing sustainable fishing, Russell (1931) also warned of the implications of unsustainable fishing, which extended beyond a reduction in biomass.

A decade earlier, Pearl and Reed (1920) ‘reinvented’ the logistic function for population growth, unaware that it had been originally described by Verhulst 80 years earlier (Kingsland, 1982). The main theory underlying this approach was that the rate of population decreases is in a linear proportion to population size, which leads to a symmetric sigmoid growth curve and a parabolic curve of growth rate against population size (Kingsland, 1982; Holt, 2009). The main limitations of the model stem from its oversimplification (i.e., assumption of linear density-dependence of growth), lack of empirical fit to the symmetrical curve, infinite time frames needed to reach equilibrium (e.g., carrying capacity), and lack of depensation at low population sizes (Beverton and Holt, 1957; Kingsland, 1982; Holt, 2007a). However, the limitations of the logistic curve did not prevent it from being used to guide fisheries management through the latter part of the 20th century (Smith, 1994).

The logistic model was first developed for marine species by Hjort et al. (1933) in an attempt to study the dynamics of the blue whale fishery. These early fishery scientists were intrigued by the idea that the sigmoid growth curve implied an inflection point where maximum production occurred due to compensatory processes (Smith, 1994; Angelino and Moloney, 2007). They recognized that although any level of fishing would decrease the biomass from its maximum (i.e., the carrying capacity), levels of yield would initially increase before eventually declining (Smith, 2002).

As defined by logistic growth, the sustainable catch at each population size is equivalent to the slope of the curve of population size plotted against time (i.e., the rate of growth at that point; Beverton and Holt, 1957). The point of maximum regeneration, and hence optimum harvest, was analytically derived and demonstrated to occur at 50% of the carrying capacity (Saetersdal, 2008). However, the location of maximum growth differs depending on the form of the dependence of growth rate on population size (Holt, 2007b).

Michael Graham (1935, 1939, 1943) continued the work of Hjort et al. (1933) by further developing the sigmoid theory and applying it to marine fish species. He was less concerned with the mathematical theory than with the general concept that growth in natural populations appeared to demonstrate a generally s-shaped pattern with low density, high growth, and a composition of younger fish at low population sizes, while the opposite was true for large populations near the carrying capacity (Holt, 2009). Although recognizing that a pure mathematical treatment was able to provide the same result (e.g., either the logistic or integral of the Gaussian curve), Graham preferred an empirical approach by deriving sigmoid growth solely from fishery observations.

Despite recognizing the importance of the inflection point of the sigmoid curve, in terms of identifying the ‘optimal’ yield, Graham was much more interested in the more general concept that “limiting the effort will restore profit to a fishery” (Graham, 1943; p. 156). This was the basis for his “Great Law of Fishing,” which stated clearly: “Fisheries that are unlimited become unprofitable” (Graham, 1943; p. 155). The main resultant hypothesis of this theory was that regulations should be enacted that control effort in order to help fishermen improve profits, the latter being the motivation for effort reductions (Holt, 2004). However, Graham did not argue for maximum yield, but instead urged step-by-step effort reduction to improve both the health of the fish stocks and the profit of fishermen (Holt, 2008a, 2009).

Schaefer (1954b) provided the formal introduction of the term ‘maximum sustained yield’ when he fitted the logistic model of Hjort et al. (1933) to the biomass of California sardine. The goal was to provide “factual information to facilitate maintaining the populations of the tropical tunas and of the tuna-bait fishes at levels which will permit maximum sustained catches year after year” (Schaefer, 1954b; p. 27). By assuming logistic growth and that catch per unit of effort (CPUE) was proportional to stock size, it was demonstrated that equilibrium catch (equivalent to the rate of growth of the population) plotted against CPUE (proportional proxy for average population biomass) formed a parabola with a maximum at 50% of the CPUE associated with the carrying capacity. The maximum was initially termed ‘maximum equilibrium catch,’ and the curve was fitted to data of observed catch and CPUE leading to an estimate of MSY. This also led to a mathematical definition of overfishing as a level of effort that “drives the population down to levels where the natural rate of increase, and the corresponding equilibrium catch, is less than the maximum” (Schaefer, 1954a; p.54).

Even though the surplus-production approach of Schaefer (1954b) and the sigmoid theory of Graham (1943) are based on similar principles, tracing back to the idea of balancing production with harvest as laid out by Russell (1931), the two methods led to distinctly different management approaches (Holt, 1998). Holt (2009; p. 9) quotes Graham as questioning the completeness of MSY theory: "I do wonder whether we have hold of sufficient theory...I am still teaching this: 'Find which direction to go and take a small step that way.'" In another paper, Holt (2006; p. 49) summarizes the European approach as an attempt to develop regulations that "ensure continuity and stability" of the fishery, which differed greatly from the North American approach of "optimization of fishing" by seeking MSY. Mainly, Graham (1935) was more interested in "economy of effort" and improving the profitability of the fishery than moving to a single theoretical maximum point, since this ignored the impact on the economics of the fishing industry.

Surplus-production approaches at this time also ignored the relationship between biomass and size or age composition. Early logistic models (e.g., Hjort et al., 1933) modeled populations by numbers, while Schaefer's (1954b) approach dealt with biomass without formally addressing how this transition from numbers to weight might impact the results (Holt, 2006). Most importantly, though, it was ignorant of the composition and structure that might occur within a population (Holt, 2007b). Beverton and Holt (1957) addressed this concern with the development of yield-per-recruit (YPR) analysis that identified sustained levels of yield for an age-structured population. In YPR the fate of a given cohort is calculated over time based on the selectivity of the fishery (i.e., age of entry or recruitment), somatic growth, fishing mortality, and natural mortality.

Many approaches to overfishing assume that the population is in equilibrium with regard to age-structure, and that the catch in one year is made up of multiple cohorts with identical dynamics. Assuming equal selectivity every year an age-based fishing mortality can be applied, and steady state sustainable yield-per-recruit can be calculated as a function of fishing mortality or biomass. Constant recruitment is also commonly assumed (Holt, 2007b). As an extension to YPR Beverton and Holt (1957) developed the self-regenerating yield model, which accounted for density dependence by incorporating a stock-recruit curve into the calculations. A key feature of this approach was that depensation could occur at high fishing mortalities and low densities, which could lead to slower rebuilding and the possibility of extinction at finite levels of fishing mortality (Holt, 1998, 2006, 2007b, 2008b). By introducing maturity-at-age into the YPR model, spawning stock biomass-per-recruit (SSBR) can also be calculated, which, unlike the peaked or asymptotic curve given in YPR analysis, results in a continually declining curve as a function of fishing mortality.

In modern fishery science, overfishing is determined by the relation of fishing mortality to an 'optimal' or pre-determined rate that is believed to achieve management objectives. These 'targets' have been termed biological reference points and almost all stem from YPR, SSBR or biomass dynamics (e.g., logistic growth) analyses. The concept of associating overfishing with a pre-determined level of fishing mortality can be attributed to Schaefer (1954b) who assumed that any effort greater than that associated with attaining MSY was 'overfishing'. A similar relation occurs with YPR analysis where 'growth' overfishing occurs when effort is greater than that required to attain the maximum YPR. Although not as precisely defined, 'recruitment' overfishing is associated with fishing at a level that greatly reduces spawning potential and reproductive capacity as associated with a certain percent of the maximum (unfished) level of SSBR. Despite the importance of operational definitions of overfishing, Graham (1951) warned that "more restricted definitions might prevent something being done when it needs to be done; or might cause regulation when there is no need for it."

2.4 Evolution of Sustainability Concepts in Modern Fisheries Science

Quinn and Collie (2005) divided modern fisheries science into four main periods based on the predominant viewpoint and underlying basis for sustainability, which includes the classical, neoclassical, modern, and post-modern periods. A related historical categorization involves separation by how sustainability is derived, with three main classifications: model-based, management-based, and legislative-based (Table 1). As described by Quinn and Collie (2005), model-based approaches were popular until the 1990s and focused on maintaining fisheries. The 'modern' period was dominated by the precautionary approach, which shifted focus from fisheries to fish, and the goal became to maintain productive stocks to ensure against uncertainty and environmental fluctuations. This approach relied heavily on stringent management with less consideration for economic implications. Finally, the 'post-modern' era has developed in the last decade. It is governed by a holistic view of sustainability that incorporates biological, economic, societal, and ecosystem aspects. In reality, these recent "warm and fuzzy notions," as Quinn and Collie (2005) describe the current concept of sustainability can be viewed as legislative-based. They are negotiated agreements that attempt to be all-encompassing, but in the end have little meaning.

Since the ratification of the United Nations Convention on the Law of the Sea (UNCLOS; UN, 1995) and more recently the Sustainable Fisheries Act amendment to the Magnuson-Stevens Fishery Conservation and Management Act (MSA; DOC, 1996) in the United States, sustainable harvest has become directly linked with achieving MSY, and overfishing is defined as fishing mortality greater than that necessary to achieve MSY. In the MSA the goal of fisheries management is defined as 'optimal yield,' which is "prescribed on the basis of the MSY from the fishery, as reduced by any relevant economic, social, or ecological factor," and "overfishing occurs whenever a stock or stock complex is subjected to a level of fishing mortality or annual total catch that jeopardizes the capacity of a stock or stock complex to produce MSY on a continuing basis."

3. Redefining Overfishing

Sustainability has been contracted from its original basis as any harvest that does not decrease the standing stock to any fishing that jeopardizes attainment of MSY. Moreover, overfishing occurs whenever fishing mortality or effort is greater than that required to achieve MSY. However, these definitions ignore the historical context and original relationship between sustainability and overexploitation. The term overfishing, as it is currently used in fishery management, is arbitrarily defined. Claiming that any fishing effort greater than that which leads to attainment of MSY results in overfishing naively umbrellas both sustainable and unsustainable levels of harvest under a single slogan. Although fishing effort above that associated with MSY may not lead to optimal productivity, this does not imply that fishing at these levels is unsustainable or will cause detrimental impacts long-term productivity.

Historically, sustainability refers to maintenance of fisheries resources, while overfishing refers to declines. Although this line of reasoning may be oversimplified, it lies at the heart of successful management. If a fishery maintains a constant stock size or allows the stock to increase, it must be sustainable, and, therefore, is not overfishing. If this trend is maintained over time, long-term sustainability goals will eventually be reached, thereby linking short-term actions with long-term goals. Additionally, by re-defining ‘overfished’ and ‘overfishing’ status indicators based on historical definitions, incentives to adhere to conservative fishery techniques will be instilled in stakeholders. These incentives are achieved by educating the public so that false perceptions of a fishery caused by incorrectly using the term overfishing are eliminated, thereby improving the marketability of a given resource compared to those that are actually harvested unsustainably and overfished.

4. Discussion

Fisheries scientists are generally split over the concept of sustainability in fisheries. Those that support the ‘shifting baseline’ theory tend to believe that sustainable fisheries are possible, but only if large scale marine protected areas are developed and large portions of the world’s fishing fleets are decommissioned (Pauly et al., 2002). Pauly et al. (2002) conclude that “there is little point in sustaining stocks whose biomass is but a small fraction of its value at the onset of industrial-scale fishing,” but others admit that attempting to rebuild to past states may not be feasible due to alternate stable states and irreversibility of some processes (Pitcher, 2005). At the extreme end of this continuum are those that believe “sustainability is mythic” because all fisheries act to truncate age-structure, and thereby alter the genetic and evolutionary progress of marine species (Longhurst, 2006). However, many scientists view sustainability as an inherent property of natural resources that can be attained under correct management that instills conservative fishing techniques (Hilborn, 2005). Greater than optimal fishing effort has been a concern in fisheries for centuries but does not necessarily preclude sustainable use (Rosenberg et al., 1993; Hilborn, 2002).

We argue that the concept of sustainability is well-founded and is an inherent property of renewable resources. Although any amount of harvesting acts to truncate age-structure, reduce population size, and alter species composition, it may be sustainable. From the opposite viewpoint, that any fishery is inherently unsustainable, any use of the environment by humans would also be deemed unsustainable, especially any agricultural systems, which alter landscapes and release pollutants. Any use of a resource alters an ecosystem, but to be sustainable it must not result in net loss or irreversible changes in ecosystem functioning that may lead to destruction of components or the entire system (Fresco and Kroonenberg, 1992). Thus, contrary to what some scientists argue, the concept of sustainability is clear and achievable under sufficient management.

Despite low abundances of some species, the world’s marine fish species are not on the verge of collapse. However, management decisions must be made that are sustainable to both the fish and fishery. It is important that, as Hannesson (2004) claims, we make sure sustainability does not become “a convenient slogan for those who would preserve oceans as pristine wilderness and send the fishermen packing”. Sustainable development of the earth’s resources is a fine balance between human needs and the natural functioning of the ecosystem. It must be remembered, however, that the protein provided by harvest of the ocean’s populations are invaluable to society and necessary for the maintenance of human life. In no other environmental interaction are humans considered to be in balance with pristine environments. It is unrealistic to think that the oceans can be returned to pristine states of nature. Instead, sustainability is about striking a balance with nature and determining what can be removed without drastically altering the state of natural processes, while ensuring that future generations are able to obtain similar benefits from these resources.

When the term 'sustainability' was first developed by those studying forestry in the 1600s, it was understood that a balance between human growth and resource extraction must be made, and this would only be possible if removals were less than or equal to the natural productivity of the resource. After centuries of overexploitation it appears that for many fisheries, the tides have finally turned and that sustainability has been achieved. In the future, care must be taken to ensure that the focus on the sustainability of fish populations does not drown out the sustainability of fishing communities.

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7. Tables

Table 1. An historical categorization of the basis for modern views of sustainability in fisheries science.

Sustainability Categorization	**Basis**	**Focus of Protection**	**Quinn and Collie (2005) Categorization**
Model	Model Estimates of Equilibrium Harvest	Fishery	Classical and Neoclassical
Management	Precautionary Approach	Fish Stocks	Modern
Legislative	Holistic/Negotiated Outlook	Fish, Fishery, Society, Ecosystem	Post-modern