Methods for Assessing the Vulnerability of African Fisheries Resources to Climate Change

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Methods for assessing the vulnerability of African fisheries resources to climate change

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ABSTRACT: Because of the dietary and financial importance of fisheries resources in many African countries, concerns have been expressed regarding the potential for adverse impacts to fisheries resources from climate change, and a need has been identified for assessment tools that can evaluate the potential for impacts in a timely and cost-effective manner. This paper presents a framework and set of methods for assessing the potential effects of climate change on fisheries resources in Africa. The framework identifies the need to first link predicted climate changes to changes in the aquatic environment, and only then can potential impacts to aquatic resources be evaluated. The approach developed for Africa was constrained by several factors, including availability of existing data and assessment technologies, and the need for a rapid evaluation of potential climate impacts. The assessment approach employs a variety of methods including empirical models which predict changes in mortality, maximum sustainable yield, and yearly catch, a bioenergetics model, and a habitat suitability model. Previously developed or newly derived site-specific empirical models can be used to compare mortality, yield, and annual catch estimates among historic, current, and predicted climate conditions. Similarly, bioenergetics modeling can be used to compare growth rates and biomass production among different climate conditions. Habitat suitability models can be developed for current climate conditions, and the effects of changes in climate-driven habitat variables such as water depth, temperature, and current velocity on habitat suitability can be evaluated for different climate conditions. Use of these approaches is recommended because they can utilize existing ecological data and do not require extensive new data collection activities, they are not technologically complex, and they can provide evaluations of potential climate change impacts in a timely and cost-effective manner.

KEY WORDS: Bioenergetics model · Climate change · Empirical models · Fish yield · Habitat suitability index Tropical freshwater fisheries

INTRODUCTION

A variety of changes in climatic conditions following atmospheric CO_2 enrichment have been predicted (Smith & Tirpak 1989, Mearns et al. 1990, Meisner & Shuter 1992). These predictions include increased air temperatures, regional shifts in precipitation, and seasonal changes in the timing and duration of precipitation events and sea level rise. These climatic changes can, in turn, affect water temperatures, alter the timing and duration of extreme temperature conditions, change the magnitude and pattern of annual stream flow, and alter surface water elevations and shorelines of lakes and reservoirs (Carpenter et al. 1992).

Climate change country studies provide technical support to help developing countries and countries with economies in transition prepare studies that address climate change (Dixon et al. 1996). The country studies include 3 principle elements: inventories of greenhouse gas emissions; assessments of vulnerability of selected resources to climate change and adaptive responses for limiting potential adverse impacts; and assessments of mitigation options to reduce greenhouse gas emissions or enhance carbon sinks (Ramos-

Mane & Benioff 1995). Natural resource sectors initially addressed by the U.S. Country Studies Program include energy, forestry, agriculture, and water. Several African countries identified the need for the development of vulnerability assessment guidance for fisheries resources in Africa, particularly when the fisheries represent a major food or economic resource. In addition, some countries are concerned with maintaining the diversity of their fish species.

In this paper we present an approach and identify a set of methodologies for evaluating the potential effects of climate change on fisheries resources in Africa. To identify assessment approaches suitable for Africa, we reviewed existing methods used in other parts of the world for evaluating climate change impacts to fisheries resources, identified the climate factors that may affect fisheries resources in Africa, and evaluated the applicability of those approaches to Africa.

CURRENT APPROACHES FOR ASSESSING THE EFFECTS OF CLIMATE CHANGE ON FISHES

The vulnerability of fishes to climate change is dependent on the nature of the predicted change as well as the nature of the fishery and its species and habitats (Regier & Meisner 1990). Although climatic changes will affect most species to some degree, some species may be particularly vulnerable. For example, the isolating factors which led to the evolution of the unique fish assemblages present in African rift valley lakes such as Lake Malawi also limit or prevent the migration of fishes to aquatic habitats in other drainage basins. In the event of climate related reductions in habitat quality or quantity, fishes in these habitats would be unable to migrate to potentially more suitable habitats in other drainage basins. In riverine systems, many species rely on inundated floodplains for reproduction, nursery habitats, and successful recruitment, and the life cycles of these species are strongly dependent on the temporal cycle of the rainy and dry seasons (Welcomme 1985, Lowe-McConnell 1987, Moyle & Cech 1988). The life histories of these species could be disrupted by changes in the timing, magnitude, and duration of the rainy or dry seasons. In coastal areas, sea level rise may alter the salinity of estuarine habitats, inundate wetlands, and reduce the abundance of or eliminate submerged vegetation, thereby adversely affecting those species which rely on these coastal habitats for reproduction and recruitment.

Three general approaches have been used to evaluate potential impacts to fisheries resources from climate change: (1) predicting changes in the availability of thermal habitat by evaluating changes in the thermal structure of lakes and streams (Christie & Regier 1988, Magnuson et al. 1990, Matthews & Zimmerman 1990); (2) predicting effects of temperature changes on physiological processes, particularly growth and feeding (Hill & Magnuson 1990, McCauley & Kilgour 1990, Regier et al. 1990); and (3) predicting impacts of changes in physical habitat features (i.e. water temperatures, flow rates, and water levels) to important life history stages such as migration periods and spawning times (Table 1). These general approaches have been identified by some researchers as the basic framework for evaluating climate change impacts to fisheries resources (Regier & Meisner 1990, Shuter & Meisner 1992). Studies that have evaluated potential impacts of

Table 1. Assessment methods for evaluating the effects of climate change on fish resources

Parameter	Method	Source
Thermal habitat availability	Predicted changes in the availability of suitable thermal habitat from modeled water temperature and thermal biology information	Christie & Regier (1988), Magnuson et al. (1990), Matthews & Zimmerman (1990), Coutant (1990), Meisner (1990)
Fish yields	Fish yield regression model	Schlesinger & Regier (1982, 1983)
Physiology, growth, bioenergetics	Arrhenius models of process-response relationships	Regier et al. (1990)
	Bioenergetics model	Kitchell et al. (1977)
	Estimate availability of optimal growth temperatures	Hill & Magnuson (1990)
	Estimate available thermal growth units	McCauley & Kilgour (1990)
Life history effects	Comparison of life history phenology with predicted environmental changes	Coutant (1990)

climate change on fisheries in temperate and northern latitudes have primarily followed the first 2 approaches, and have focused primarily on the thermal aspects of climate change. In addition, a number of studies have used empirically derived models to examine the relationships between fishery production (as yield or catch) and precipitation (Welcomme 1980, Garcia & Le Reste 1981, Tyus & Karp 1991) or temperature (Schlesinger & Regier 1982, 1983). Although many of these studies were not conducted specifically to evaluate potential climate change impacts, they represent a fourth approach for evaluating the effects of climate change on fish resources.

LINKING CLIMATE CHANGE PREDICTIONS TO ECOLOGICAL RESPONSES

Several general circulation models (GCMs) are available for predicting changes in climatic conditions for a 2 × CO_2 scenario (Houghton et al. 1992). The model results provide predicted values for approximately 70 climatic variables, including air temperature, mean monthly precipitation, sea level rise, and solar radiation. For Africa, predicted changes in climate conditions vary among regions (Unganai 1996, this issue). Mean annual air temperatures may increase 3 to 4°C, while precipitation may increase or decrease by as much as 20%, depending on location. Although GCM outputs include predictions of air temperatures and precipitation magnitude, duration, and distribution, they do not provide direct information on water quality or hydrological parameters that affect fisheries resources. Thus, a fisheries vulnerability assessment must translate the predicted atmospheric climate changes into changes in lake and sea levels, stream flow, dissolved oxygen levels, and water temperatures (Meisner et al. 1987, Thomann & Mueller 1987, Christie & Regier 1988, Kennedy 1990, Rogers & Fiering 1990, Schaake 1990). Only when these linkages are made can the ecological and biological responses (such as growth rates, reproductive success, mortality, and distribution) of fisheries resources to climate change be identified and evaluated (Fig. 1). Some approaches that have been used to link conditions in the aquatic environment to climatic conditions are identified in Table 2. These methods typically rely on large historic databases and use empirically derived models or complex computer models.

FISHERIES RESOURCES IN AFRICA

The major aquatic habitats present in Africa include, but are not limited to, (1) the Great Rift Lakes such as Lakes Malawi and Victoria, (2) man-made reservoirs such as Lake Kariba, (3) large river and floodplain systems such as the Nile and Zambezi Rivers, and (4) coastal habitats including estuaries, mangrove swamps, and deltas. This diversity of habitats supports an even greater variety of ecologically and/or economically important species.

Ten ichthyofaunal regions based largely on present-day drainage systems have been delineated for Africa (Lowe-McConnell 1987). These are dominated by the Niger, Nile, Zaire, and Zambezi River systems, and also include several inland drainage areas associated with lakes. Among the riverine systems, the Zaire River (including its major tributaries) contains the most

General Circulation Model predictions

Altered air temperature, precipitation, solar radiation, wind speed

↓

Link climate changes to marine and freshwater environmental conditions

- Predict surface water temperature from air temperature
- Develop thermal profiles
- Predict sea and lake levels and river hydrographs
- Quantify physical changes in habitats due to changes in sea and lake levels using topographic information
- Quantify areal extent of floodplain inundation

↓

Identify habitat parameters vulnerable to predicted changes in marine and freshwater conditions and collect appropriate biological and fisheries data

- Physiological parameters (thermal niche and tolerance)
- Habitat requirements (flow, substrate, depth) and other life history information
- Individual process rates (growth and mortality rates)
- Historic fish yield or catch estimates
- Develop temperature-process relationships

↓

Implement assessment approaches

- Develop empirical models to predict fish yields from historic data and GCM climate predictions
- Develop habitat suitability models and predict fisheries response to changes in habitat quality
- Evaluate changes in growth using bioenergetics model and temperature-process relationships
- Predict changes in habitat abundance and thermal suitability

Fig. 1. Conceptual framework for linking predicted climate changes to environmental conditions in aquatic habitats and predicting biological responses of target fish resources

Table 2. Methods for linking predicted changes in climate to the physical conditions of surface waters

Parameter	Method	Source
Water temperature and DO profiles: lakes	Hydrodynamic model	Blumberg & Di Toro (1990)
	One-dimensional water quality model	Stefan et al. (1993)
Water temperature and DO profiles: streams	Stream temperature model	Delay & Seaders (1966)
	Temperature model	Stefan & Preud'homme (1993)
Surface water temperature: lakes	Regression analysis — water temperature vs air temperature and other variables	Schlesinger & Regier (1983), Shuter et al. (1983), Hill & Magnuson (1990)
Lake levels	Stochastic water basin models	Rogers & Fiering (1990)
	One-dimensional water balance model	US Country Studies Program (1994)
Flows: rivers	Regression analysis using precipitation and stream flow data	Byron et al. (1989)
	Regression analysis to develop stage-discharge relationships	Gordon et al. (1992)
	Aerial photography to develop surface water area maps	Snider et al. (1994)
	Water balance models	Schaake (1990), US Country Studies Program (1994)

diverse fish fauna (Table 3), with about 690 species of which 80% are endemic (Lowe-McConnell 1987). The lacustrine systems in Africa (particularly the rift valley lakes) contain the most diverse and unique fish assemblages found anywhere in Africa, if not the world. For example, Lake Malawi has more than 240 fish species of which more than 90% are endemic, and another 500+ species are awaiting taxonomic identification (Lewis et al. 1986). In contrast, North America has 3 major ichthyofaunal regions with about 950 species, 740 species north of Mexico (Hocutt & Wiley 1986, Moyle & Cech 1988). The North American fish fauna is represented by 18 families, fewer than found in either the Niger or Zaire Rivers or in Lakes Chad or Tanganyika.

FACTORS CONSIDERED DURING SELECTION AND EVALUATION OF ASSESSMENT METHODS

In our selection and evaluation of methodologies that could be suitable for use in Africa, we focused on approaches that (1) are readily straightforward to implement, (2) do not require extensive computer equipment or specialized analytical instrumentation, (3) can be applied to a variety of species and habitats, and (4) can be completed in a timely manner (Sathaye & Meyers 1995). The evaluation of assessment methods for applicability to Africa considered a number of environmental, biological, and technical issues, as well as time, effort, and cost constraints. Only limited resources are available for climate change country study vulnerability assessments. Countries have to fulfil their obligations to meet the needs of the UN Framework Convention on Climate Change (UNFCCC), and the availability of in-country technical staff needed to perform the assessments is variable and often limited (Dixon et al. 1996). These limitations largely rule out implementation of laboratory and field studies to generate new data. Instead, the assessments must rely largely on existing available data (Ramos-Mane & Benioff 1995).

The African nations possess a variety of lacustrine, riverine, and marine habitats with over 800 species of

Table 3. Approximate numbers of fish families and species in the principle drainage basins of Africa (Lowe-McConnell 1987)

Drainage basin	No. of families	Total no. of species	No. of cichlid species
Niger River	26	134	10
Nile River	17	115	10
Zaire River	24	690	40
Zambezi River	18	110	20
Lake Chad	23	176	13
Lake Turkana	15	39	7
Lake Albert	15	46	9
Lake Edward/George	8	57	40
Lake Victoria	12	238+	200+
Lake Tanganyika	19	247	136
Lake Malawi	9	242+	200+

freshwater and marine species. Because of this great diversity in habitats and species, no single assessment approach is suitable for use by all countries or for all fisheries resources. A further complicating factor in selecting assessment methodologies for Africa is the limited availability of natural history, physiological ecology, limnology, hydrology, and fisheries yield data. Although technically complex methods using geographic information systems, remotely sensed data, and hydrodynamic models have been used in a number of climate change studies in other parts of the world (McCormick 1990, Minns & Moore 1992), the necessary computer hardware and software for these approaches is frequently limited or unavailable in African nations. Although we targeted both freshwater and marine resources, the latter focused primarily on nearshore penaeid shrimp fisheries. Penaeid shrimp represent a major economic and subsistence fishery resource for coastal countries. Because the effects of climate on marine fisheries is best understood for coastal areas and poorly understood for deep water open ocean areas (Kennedy 1990), the marine methods we evaluated were limited to those applicable for nearshore environments only.

APPROACH SUGGESTED FOR AFRICAN COUNTRIES

As a result of the diversity of fisheries resources and aquatic habitats present in Africa and the inability of any single method or approach to adequately evaluate potential impacts to all the species and habitats present in any one country, we suggest a weight-of-evidence approach (EPA 1992) for evaluating potential climate change impacts on fisheries resources. A weight-of-evidence approach uses multiple lines of evidence to identify the nature and evaluate the significance of potential impacts. The assessment methods also represent a suite of approaches that can be tailored for a particular country, habitat type, climate variable, and fishery resource.

The methods identified for use in Africa target different aspects of the fisheries resources (Sagua 1993). Some methods evaluate the effects of climate change on habitat availability and suitability, while others evaluate the effects on growth, feeding, mortality, and timing of life history parameters. Still other methods evaluate the effects of climatic conditions on annual catch or yield. Many of the suggested methods require linking GCM predictions of air temperature and precipitation to changes in water temperature, hydrology, and sea level, while other methods use the GCM predictions directly (Regier & Meisner 1990). The suggested methods do not address such ecologically important factors as nutrient cycling and primary productivity, eutrophication and other water quality issues, community structure and function, predator-prey interactions, or fishing methods, success, and pressure.

Three categories of predictive models are represented by the methods identified in Tables 4–6: bioenergetics models, habitat suitability models, and empirical models. Bioenergetics modeling is directly applicable to evaluating the potential effects of climate change on fisheries resources and permits predictions of fish growth and biomass under different temperature scenarios (Hill & Magnuson 1990). The use of habitat suitability models is identified for both freshwater and marine systems and permits evaluation of changes in the suitability of particular habitats relative to climate-driven changes in environmental conditions. Although there is some disagreement regarding the use of habitat suitability models, these models are used by the U.S. Fish and Wildlife Service and others to evaluate potential environmental impacts to fisheries resources (Armour & Taylor 1991) and have been evaluated in South Africa and found to be useful for identifying minimum instream flows for endemic fish fauna of the Olifants River (Gore et al. 1991).

A number of the methods employ empirical models to predict a particular response by the fishery to a change in a particular climate-related variable or set of variables. For example, Pauly (1980) developed empirical models for predicting changes in the natural mortality in a fish stock as a result of changes in the average annual surface water temperature, while Sagua (1993) developed an empirical model to predict mean total catch from mean river discharge. Both mean annual surface water temperature and mean annual river discharge are direct functions of air temperature and precipitation, respectively. The use of site- and resource-specific empirical models, or models previously developed using African data, is strongly recommended because such models allow for a rapid evaluation of a fisheries response (such as mortality or yield) to a change in a climate-dependent environmental variable such as water temperature or stream flow.

Specific methods to address freshwater fisheries resources are summarized in Table 4, while methods for evaluating coastal marine penaeid shrimp resources are summarized in Table 5. Each of these methods evaluates the potential effects of a single climate-affected variable, namely water temperature, stream flow, and lake or sea level, and may or may not be species-specific. Three other methods, summarized in Table 6, employ species-specific bioenergetics, habitat suitability, and natural mortality approaches, can be used in either freshwater or

Table 4. Suggested methods for evaluating the effects of climate change on freshwater fisheries resources

Climate variable	Assessment method	Habitat applicability	Output and assessment of vulnerability	Data needs	Source
Temperature	Develop empirical models to predict maximum sustainable yield (MSY) from air temperature and the morphoedaphic index. If site-specific data unavailable, use previously developed empirical models	Lacustrine	Maximum sustainable yield estimated for target lakes under different mean annual air temperature scenarios. Assess vulnerability by comparing MSY among the temperature regimes	Historic and predicted mean annual air temperatures; limnological data to calculate the morphoedaphic index	Schlesinger & Regier (1982, 1983)
Temperature	Identify habitats where water temperature exceeds species tolerance. Approach must convert GCM predictions of air temperature to water temperature	Lacustrine, riverine	Identification of habitats where species-specific temperature tolerance is exceeded. Assess vulnerability by comparing extent and distribution of unsuitable habitat among the temperature regimes	Historic and predicted air and water temperatures; species-specific temperature tolerances	Jobling (1981), Magnuson et al. (1990), Matthews & Zimmerman (1990), Meisner (1990)
Precipitation	Develop empirical models to predict annual fish yield from surface water area and precipitation. If no lake-specific data, use previously developed empirical models	Lacustrine	Estimated annual yield under historic and predicted precipitation regimes. Assess vulnerability by comparing fish yield among the precipitation regimes	Historic and predicted precipitation and surface water area; annual fish yield	Rogers & Fiering (1990), Crul (1992), US CSMT (1994)
Precipitation	Assume habitat abundance is directly proportional to surface water area. Use water balance models and map analysis to predict surface water area	Lacustrine	Assess vulnerability by comparing habitat abundance for historic and predicted precipitation regimes. Identification of known habitats that may become drained or inundated under different lake levels	Historic precipitation regimes and lake levels; predicted precipitation regimes; locations of important habitats such as spawning and nursery grounds	Rogers & Fiering (1990), Snider et al. (1994), US Country Studies Program (1994)
Precipitation	Use water balance models to develop hydrographs for predicted precipitation regimes and evaluate changes in relation to timing of known important life history events	Riverine	Assess vulnerability by comparing hydrographs under historic and predicted precipitation regimes and identifying which hydrograph-related life history activities would most likely be affected	Historic and predicted precipitation; phenology of species-specific life history activities	Schaake (1990), Byron et al. (1989), Tyus & Karp (1989, 1991), Welcomme (1985)
Precipitation	Develop regression models, or use previously developed models to predict annual catch from maximum floodplain area or mean river discharge	Riverine	Predict annual catch and assess vulnerability by comparing estimated annual catch among historic and predicted flood conditions or mean river discharge	Historic precipitation, stream flow and floodplain inundation; historic annual catch	Welcomme (1976, 1980), Welcomme & Hagborg (1977), Sagua (1993)

marine habitats, and can simultaneously evaluate multiple climate-affected variables. The choice of methods for use in any particular country will be dependent on the habitats and fisheries present in that country, the availability of environmental and ecological data, and the nature of the predicted change in climate.

CONCLUSIONS

Selection of methods

The methods identified in Tables 4–6 represent 'suggested' assessment methods. Because it may be difficult to validate any particular method, it is recom-

Table 5. Suggested methods for evaluating the effects of climate change to coastal marine penaeid shrimp fisheries

Climate variable	Assessment method	Output and assessment of vulnerability	Data needs	Source
Precipitation	Estimate total annual shrimp catch using empirically developed models that predict catch to previous years' total annual rainfall	Models provide estimate of annual shrimp catch. Vulnerability assessed by comparing shrimp catch under historic and predicted precipitation regimes	Historic and predicted total annual rainfall; historic annual shrimp catch for each shrimp fishery area of concern	Garcia & Le Reste (1981)
Temperature	Estimate shrimp yield from mean annual air temperature using exponential relationships of the Arrhenius form developed with site-specific data. If site-specific data are unavailable use previously developed models	Models predict annual shrimp yield. Assess vulnerability by comparing annual yield under historic and predicted air temperatures	Historic and predicted mean annual air temperatures and commercial shrimp yield for the shrimp fishery area of concern	Regier et al. (1990)
Sea level	Developed empirical models to predict annual shrimp yield from areal size of known shrimp habitats. Use map analysis to estimate changes in habitat size due to sea level rise	Model is used to estimate annual shrimp yield for different habitat sizes. Changes in shrimp habitat due to sea level rise are then used to predict shrimp yield. Vulnerability is assessed by comparing. In the absence of historic yield data, annual yield may be inferred from differences in habitat availability	Areal abundance of aquatic vegetation and historic annual shrimp yield for the shrimp fishery area of concern	Turner (1977, 1992), Turner & Boesch (1988)

Table 6. Suggested methods for evaluating the effects of climate change on fisheries resources in freshwater and marine habitats

Climate variable	Assessment method	Habitat applicability	Output and assessment of vulnerability	Data needs	Source
Temperature	Estimate species-specific growth and feeding rates under different temperature regimes using Fish Bioenergetics Model 2	Lacustrine, riverine, and coastal marine	Assess vulnerability by comparing growth and feeding rates among historic and predicted temperature scenarios	Species-specific bioenergetics data (i.e. respiration and ingestion rates; historic and predicted temperature regimes)	Kitchell et al. (1977), Hill & Magnuson (1990), Hewett & Johnson (1992)
Temperature	Use empirical model to estimate species-specific natural mortality rates	Lacustrine, riverine, and coastal marine	Estimate natural mortality rates and assess vulnerability by comparing rates among historic and predicted air temperatures	Historic and predicted air temperatures; species-specific asymptotic length or weight	Pauly (1980, 1983)
Precipitation and temperature	Develop species-specific habitat suitability index (HSI) models that incorporate water temperature and hydrology as habitat variables	Lacustrine, riverine, and coastal marine	Estimate habitat suitability for specific habitats using HSI models and assess vulnerability by comparing values under historic and predicted climate scenarios	Historic and predicted hydrological conditions and water temperatures; species-specific habitat	Turner & Brody (1983), Hays (1987), Crance (1987)

mended that as many of the suggested methods as possible be implemented to adequately evaluate impacts to fisheries (Sagua 1993). However, final selection of methods will be largely dependent on the nature of the fisheries resource of concern and on the availability of appropriate data. Short of extensive, long-term, experimental field and laboratory investigations, the methods identified provide the best predictions possible, within their limitations (Sathaye & Meyers 1995).

The final choice of methods is at the discretion of the fisheries staff that will be performing the actual assessment. For each fishery type (lacustrine, riverine, and coastal marine), the in-country staff may select 1 or more of each of the suggested approaches, or may opt to use other methods not identified in this report.

Integration of results and determinations of vulnerability

The approaches identified for use in evaluating potential climate change impacts to freshwater lacustrine and riverine and coastal marine fisheries resources in Africa represent a dichotomy of methods. Methods such as the bioenergetics and habitat suitability models will permit the evaluation of potential climate change impacts to individual species. In contrast, other methods evaluate potential impacts to overall yield or catch. These latter methods cannot be used to identify potential effects of climate change on individual species of concern.

The species-specific approaches will be the most problematic to employ, largely due to the relative absence of species data on life history and physiology. In the absence of species-specific data, professional judgement may be used to estimate life history and bioenergetics variables. Difficulties associated with developing empirical models for predicting catch from environmental conditions will be largely associated with the absence of hydrological and environmental data.

As previously discussed, the overall approach for identifying potential impacts from climate change to fisheries resources follows a 'weight-of-evidence' approach. This approach relies on multiple lines of evidence to evaluate the potential for adverse or beneficial impacts to fisheries from climate change. However, the methods identified in this report are not fully integrated and could give conflicting results or, more likely, results in the same direction but of differing magnitudes. For example, estimates of mortality using the relationships developed by Pauly (1980) may indicate adverse impacts under a particular climate-temperature scenario, while estimates of maximum sustainable yield using the relationships of Schlesinger & Regier (1982) may indicate a positive impact under the same temperature scenario. The evaluation of multiple results may rely heavily on the professional judgement of the fishery biologists performing the vulnerability assessment. It should be remembered that the results of the fisheries vulnerability assessment are not intended to provide a quantitative, definitive identification of the nature and magnitude of impacts to fisheries resources that would occur for a particular change in climate. Rather, the assessment is meant to provide an indication of the potential of adverse impacts to fisheries resources, and provide a preliminary indication if, or which, fisheries resources may be at risk.

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