

Title: A STRATEGIC ASSESSMENT OF THE POTENTIAL FOR FRESHWATER FISH FARMING IN LATIN AMERICA

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Application Tool: GIS.

Main Issues Addressed: Strategic planning for the development of freshwater fish farming in Latin America.

The general problem, or aim of the study, and the contribution of GIS, remote sensing and/or mapping to the solving the problem: The objective of this study was to estimate the potential for warm-water and temperate-water fish farming in the inland waters of Latin America in order to stimulate improved planning for aquaculture development at national levels, and at the same time to provide a tool to plan comprehensively for technical assistance activities by FAO and other national and international organizations.

Quite simply, this study could not have been carried out without the use of GIS. GIS played an essential role for the execution of the study in three ways: (1) spatial analyses were carried out to create commercial and small-scale fish farming models that integrated the five key factors that are important for determining the suitability for fish freshwater farming in levee ponds, (2) the GIS provided the spatial framework in which the yield potential of four species was estimated for all of Latin America, and (3) the GIS was the indispensable platform on which the small-scale and commercial fish farming models and the estimates of fish yield were brought together in order to map freshwater fish farming potential in a variety of ways for a number of fish species.

Main Environments: Inland.

Culture Systems: Ponds.

Organism Divisions: Freshwater fishes.

Genera and Species: Nile tilapia (*Oreochromis niloticus*), tambaqui (*Colossoma macropomum*), pacu (*Piaractus mesopotamicus*), common carp (*Cyprinus carpio*).

Target Country: All of the countries of Latin America excluding the Caribbean.

Target Audience: FAO and other national and international organizations that provide both technical and financial assistance for aquaculture development.

Duration of the Study and Year Begun: The duration, including the time from first discussions to the stage of a second and final round of outputs that are reported herein, was about one year.

There was one meeting between the authors to organize the work, and a full time three-week working session to put the analyses on a firm footing. For the remainder, communication was almost daily, by e-mail, of which there were nearly 300 messages logged.

Personnel Involved:

Fishery scientist who conceived, planned, and coordinated the study, and who was the principal author of report; part time for the full duration.

Bioresource engineer (modeler) who devised and tested the bio-energetics growth and production models and who worked mainly part time for growth and production estimates with one three-week full time stint.

Soils scientist, who prepared the pond soil and terrain suitability table and provided part time advice.

Hydrologist, who prepared the pond evaporation and seepage studies, and provided part time advice.

Agrometeorologist, who prepared the air temperature grids; part time.

Aquaculturists (5), who made up the expert group that weighted factors in commercial and small scale aquaculture models and who contributed only on a one-time basis.

Field verification personnel (8), full time for short duration.

GIS analyst, who devised and carried out the spatial analyses, wrote the description of the analyses and worked part time for the full duration.

Advisers at large (4), who provided data and advice from time to time.

A STRATEGIC ASSESSMENT OF THE POTENTIAL FOR FRESHWATER FISH FARMING IN LATIN AMERICA

Introduction

An important impediment to increasing the fish supply from aquaculture is a lack of good planning at national level. One reason for this impediment is that estimates of aquaculture potential are scarce that are both comprehensive and comparable over large geographic areas. Accordingly, the objective of this study was to estimate the potential for warm-water and temperate-water fish farming in the fresh waters of Latin America in order to stimulate improved planning for aquaculture development at national levels, and at the same time to provide a tool to plan comprehensively for technical assistance activities by FAO and other national and international organizations.

Materials and Methods

This investigation is similar in many ways to a traditional site selection study for inland fish farming. That is, the study examines how well sites satisfy the physical and economic requirements of the culture system and how well four candidate species will perform at the sites under small-scale farming inputs and two levels of commercial farming inputs. It differs only in two basic ways: (1) a GIS (ARC, Version 7.0.3, ESRI, Redlands, CA USA) was used to quantify the potential, and (2) the study is synoptic for all of continental Latin America. Each "site" that is being evaluated is grid cell of approximately 9 km × 9 km (at the equator), of which there are nearly one-quarter million in Latin America.

The study was carried out in five steps:

1. Each grid cell was analysed as to its suitability for the culture system – farming fish in levee ponds – based on a combination of five physical and economic factors: (a) urban market size and proximity, (b) potential for farm gate sales, (c) soil and terrain suitability for freshwater levee ponds, (d) water loss from ponds, and (e) availability of agricultural by-products as feed and fertilizer inputs.
2. The importance of each factor was established relative to all of the others in order to devise commercial and small-scale fish farming models by using multiple-criteria single objective decision making.
3. Each grid cell was analysed as to its fish production potential for four culture species at two levels of commercial farming and for small-scale farming using a yield model based mainly on water temperature, feeding levels and weights at harvest.
4. The commercial and small-scale site suitability models were used together with the species yield model to reach a combined evaluation of the suitability and yield of each grid for two levels of commercial fish farming and for small-scale fish farming.
5. The results were verified in the field.

A bio-energetics model was incorporated into the GIS to predict fish yields over large geographic areas. A gridded water temperature data set was used as input to the bioenergetics model to predict numbers of crops per year for four species: Nile tilapia (*Oreochromis niloticus*), tambaqui (*Colossoma macropomum*), pacu (*Piaractus mesopotamicus*) and carp (*Cyprinus carpio*). By varying input levels (feeding to 50% and 75% of satiation for commercial farming, and critical fish biomass for small-scale farming) and sizes at harvest, opportunities for two levels of commercial fish farming and for small-scale fish farming were identified.

In addition to the suitability of each 9 × 9 km grid cell for the production of the above-mentioned species, each grid cell was evaluated for a number of other factors important for fish-farm development and operation. These included urban market potential based on travel time proximity and population size of urban centres, potential for farm-gate sales based on population density, engineering and terrain suitability for pond construction using a variety of soil attributes,

water loss from ponds due to evaporation and seepage, and availability of agricultural by-products as feed inputs based on crop potential. Commercial and small-scale aquaculture models were developed by using a multiple criteria evaluation procedure. Weights on production and economic factors were assigned by a group of experts. Areas unavailable for inland fish farming development were identified by incorporating protected areas and large inland water bodies as constraints.

Finally, the yield potential of each grid cell for each of the four species was analysed using the growth model together with the other factors in the commercial and small-scale models to show the coincidence of each class of suitability with each range of yield potential.

Results

The results were quite positive for the development of inland fish farming in Latin America. They show that both commercial and small-scale fish farming is possible over vast areas without serious constraints, either from the lack of suitability of basic factors that are important for development and operation of fish farms, or from constraints of temperature on fish growth (Figures 1 and 2, respectively).

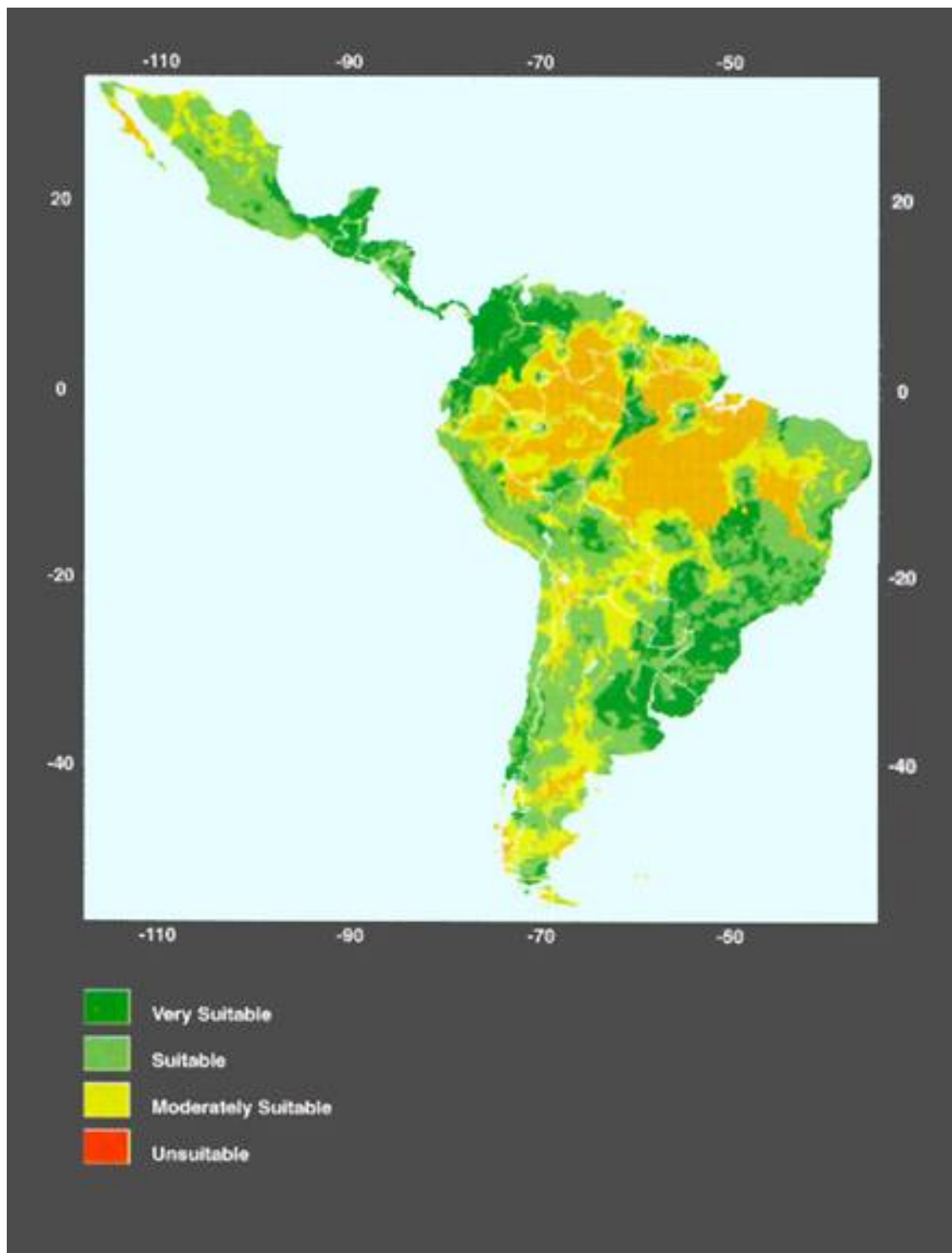


Figure 1 Suitability for commercial fish farming.

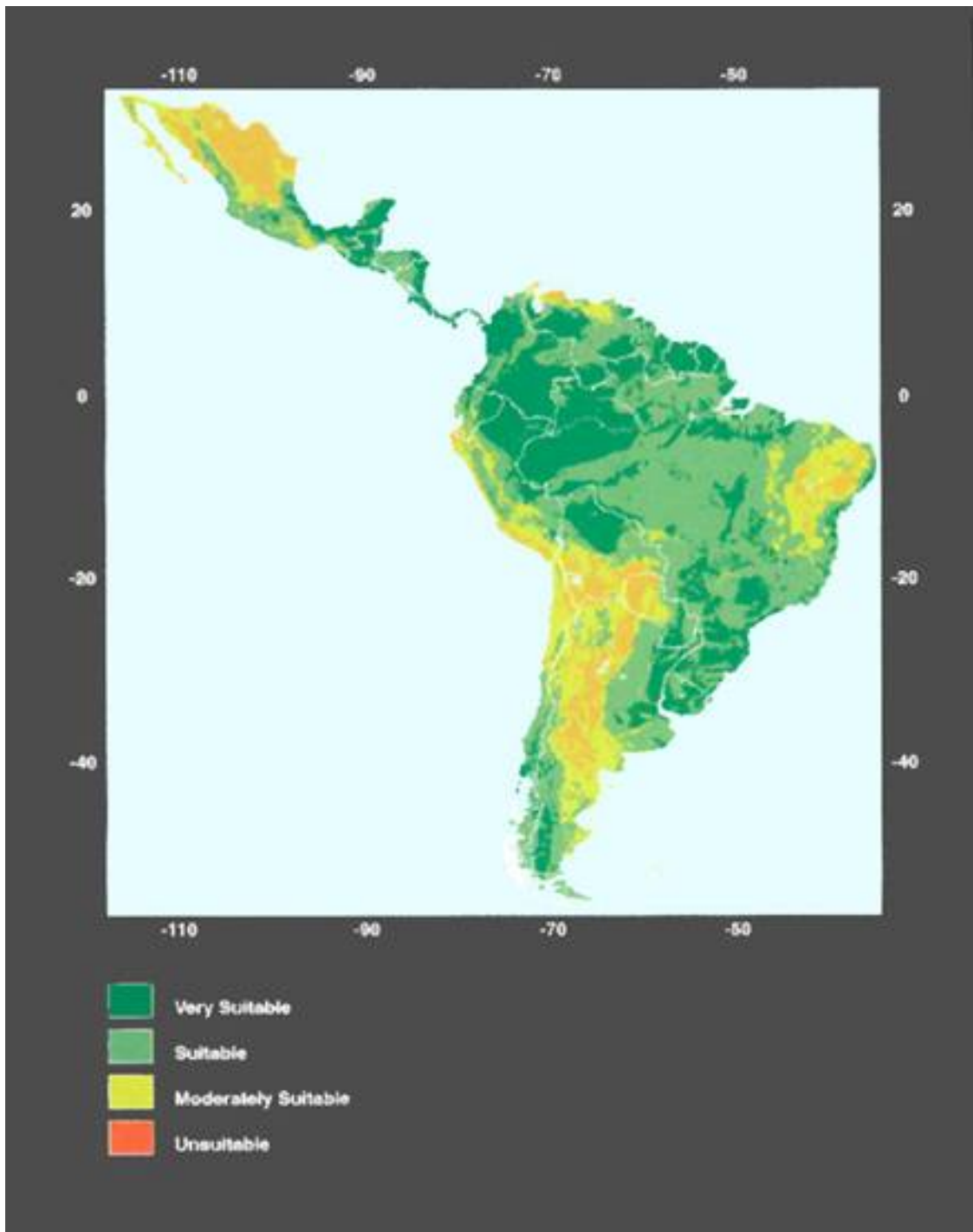


Figure 2 Suitability for small scale fish farming.

One of the most significant findings of this study is that, from a commercial fish farming viewpoint, combinations of relatively high population urban centres and nearby road infrastructure place large areas that are suitable for fish farming within easy reach of urban markets (Figure 3).

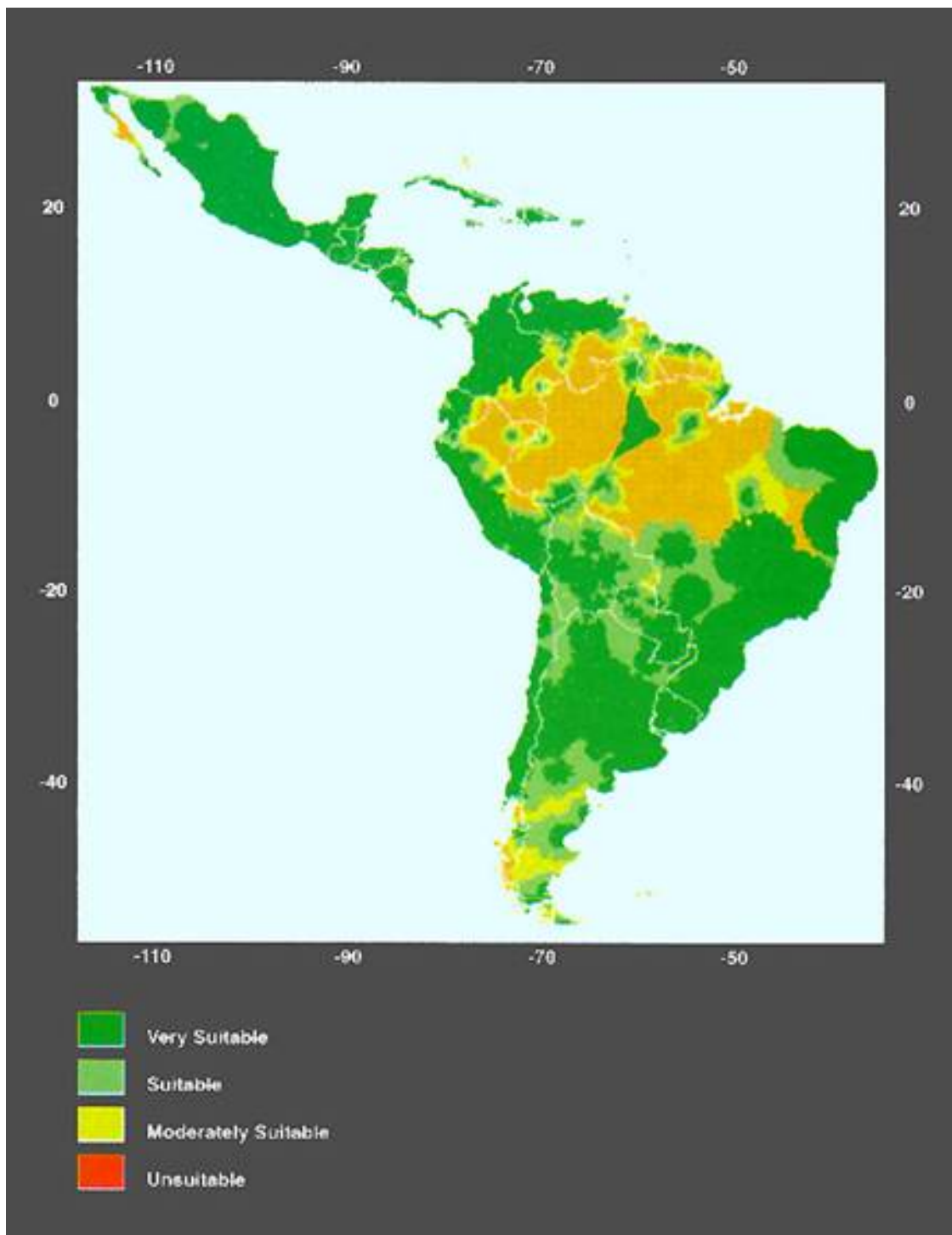


Figure 3 Potential market demand: commercial fish farming.

Another significant finding is that large areas of Latin America are suitable for the farming of a variety of species. The numbers of crops per year can be maximized by a combination of relatively high feeding rates and harvesting at moderate weights (e.g. Figure 4).

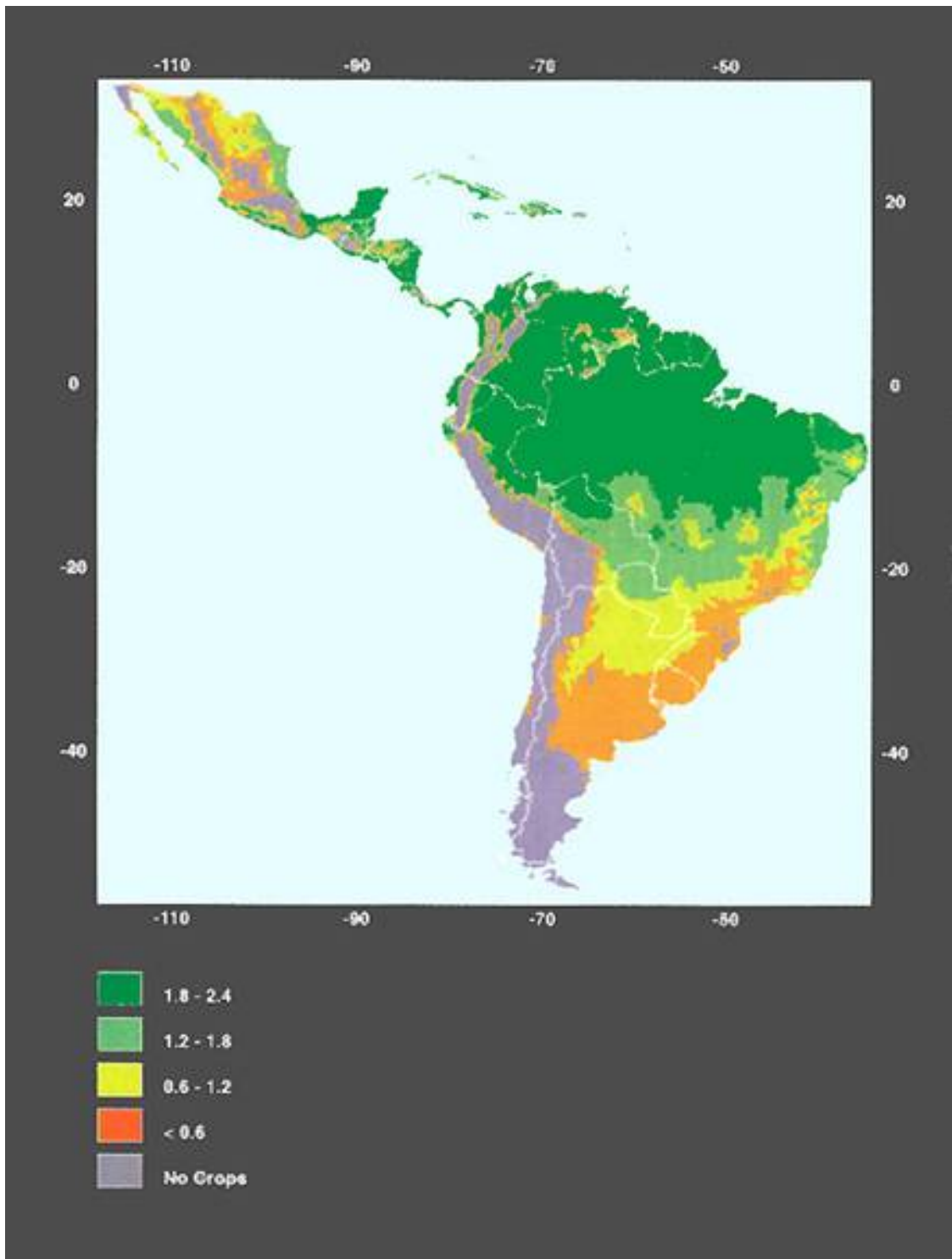


Figure 4 Potential yield (crops/y) of Nile tilapia fed at 75% satiation and harvested at 300 g.

From a country-by-country viewpoint, the results are also generally positive. For small-scale farming of Nile tilapia, 19 of the 210 continental countries have 6 to 100% of their national areas that rate at least suitable and from which at least 0.9 crops/year can be obtained (Figures 5 and 6).

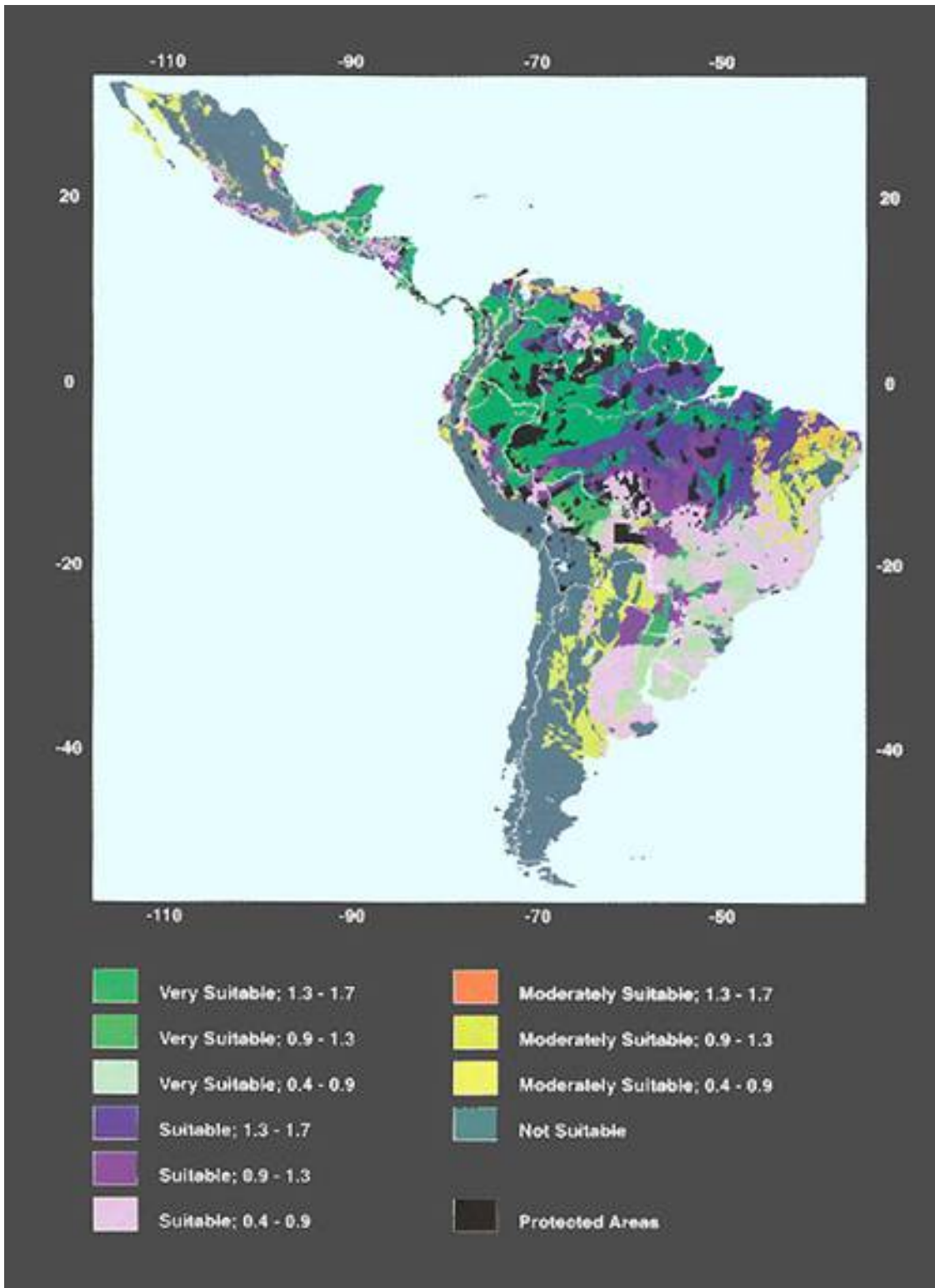


Figure 5 Suitability for small scale farming and potential yield (crops/y) of Nile tilapia with a CFB of 0.075 Kg/m³ and harvested at 150 g.

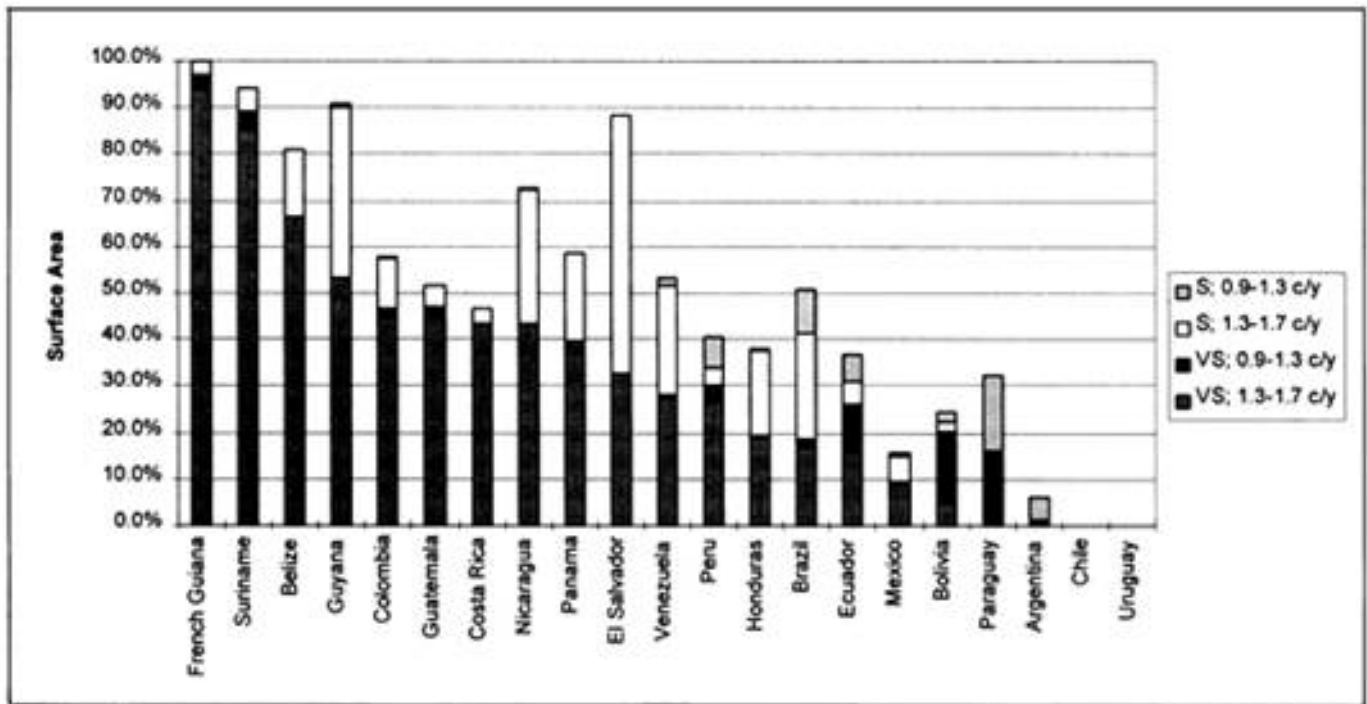


Figure 6 Relative Surface Area with Suitability for Commercial Farming and Yield Range Combined for Nile tilapia with a CFB of 0.075 Kg/m³ and harvested at 150 g.

The corresponding results for small-scale farming of carp are that all 20 of 21 countries have some areas that are at least suitable and these range from 24 to 100 99% of national surface areas (Figures 7 and 8). From these areas, at least 0.9 crops/y are possible.

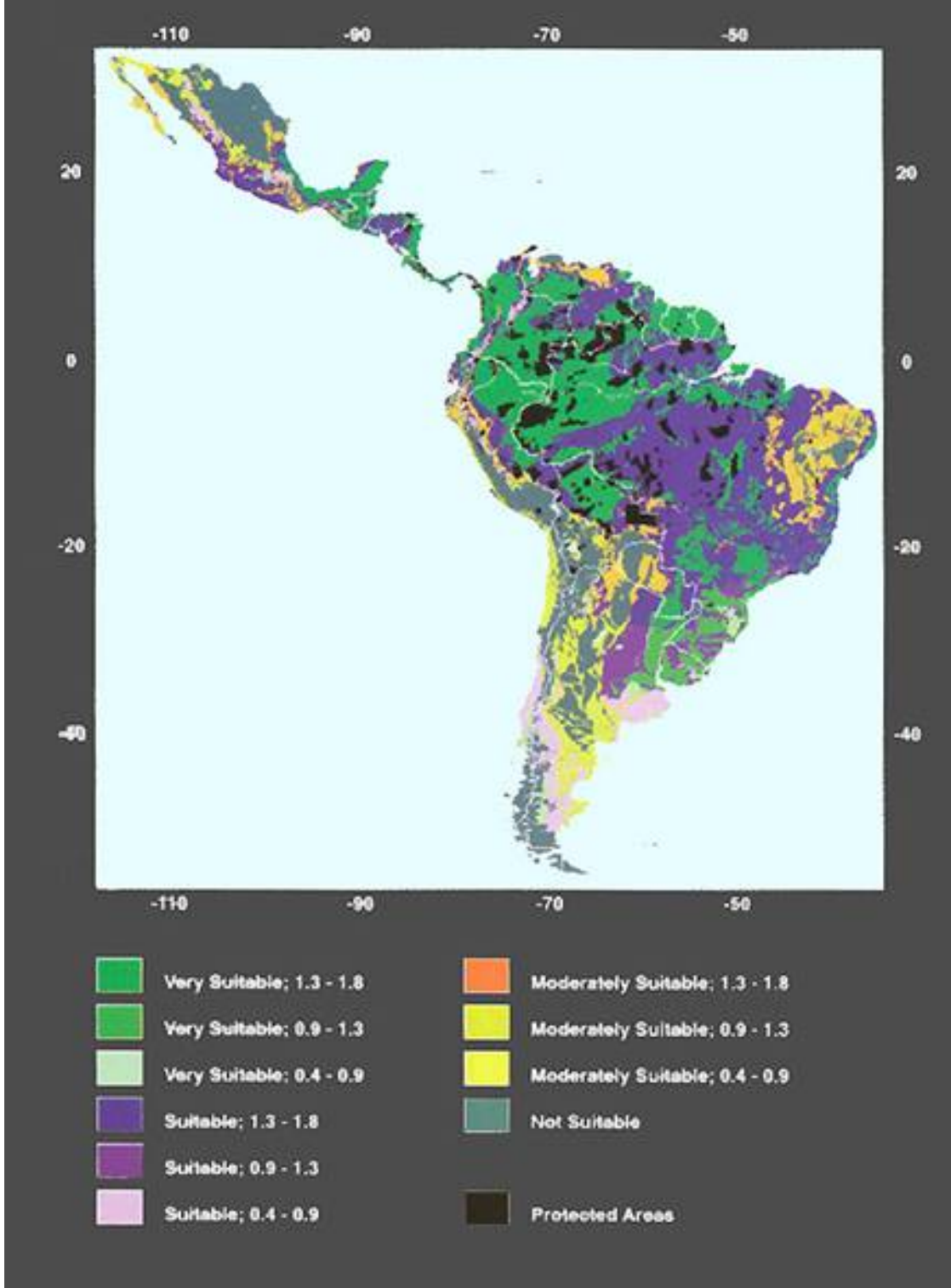


Figure 7 Suitability for small scale farming and potential yield (crops/y) of carp with a CFB of 0.075 Kg/m^3 and harvested at 350 g.

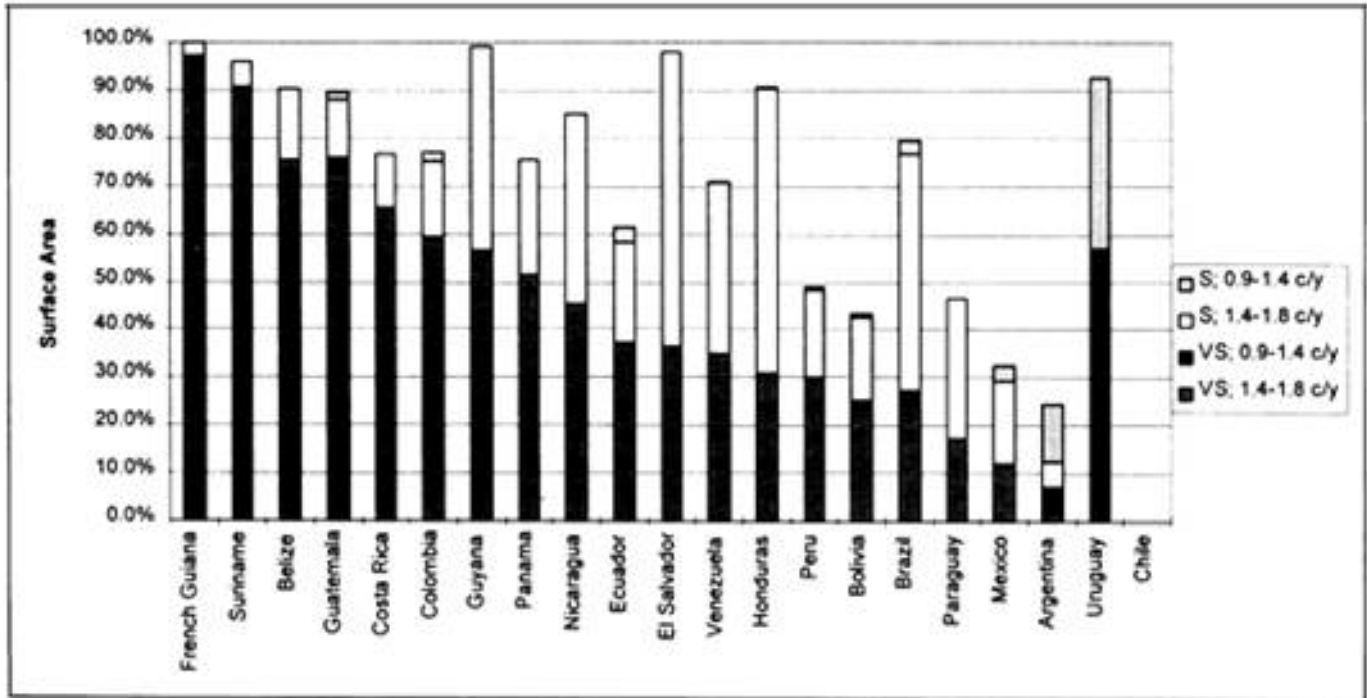


Figure 8 Relative Surface Area with Suitability for Commercial Farming and Yield Range Combined for Carp with a CFB of 0.075 Kg/m³ and harvested at 350 g.

Commercial fish farming of the Nile tilapia with the 75% feeding rate × low harvest weight combination is possible in 18 of the 21, the lowest number of countries (Figures 9 and 10) (17 of 20) is for the Nile tilapia.

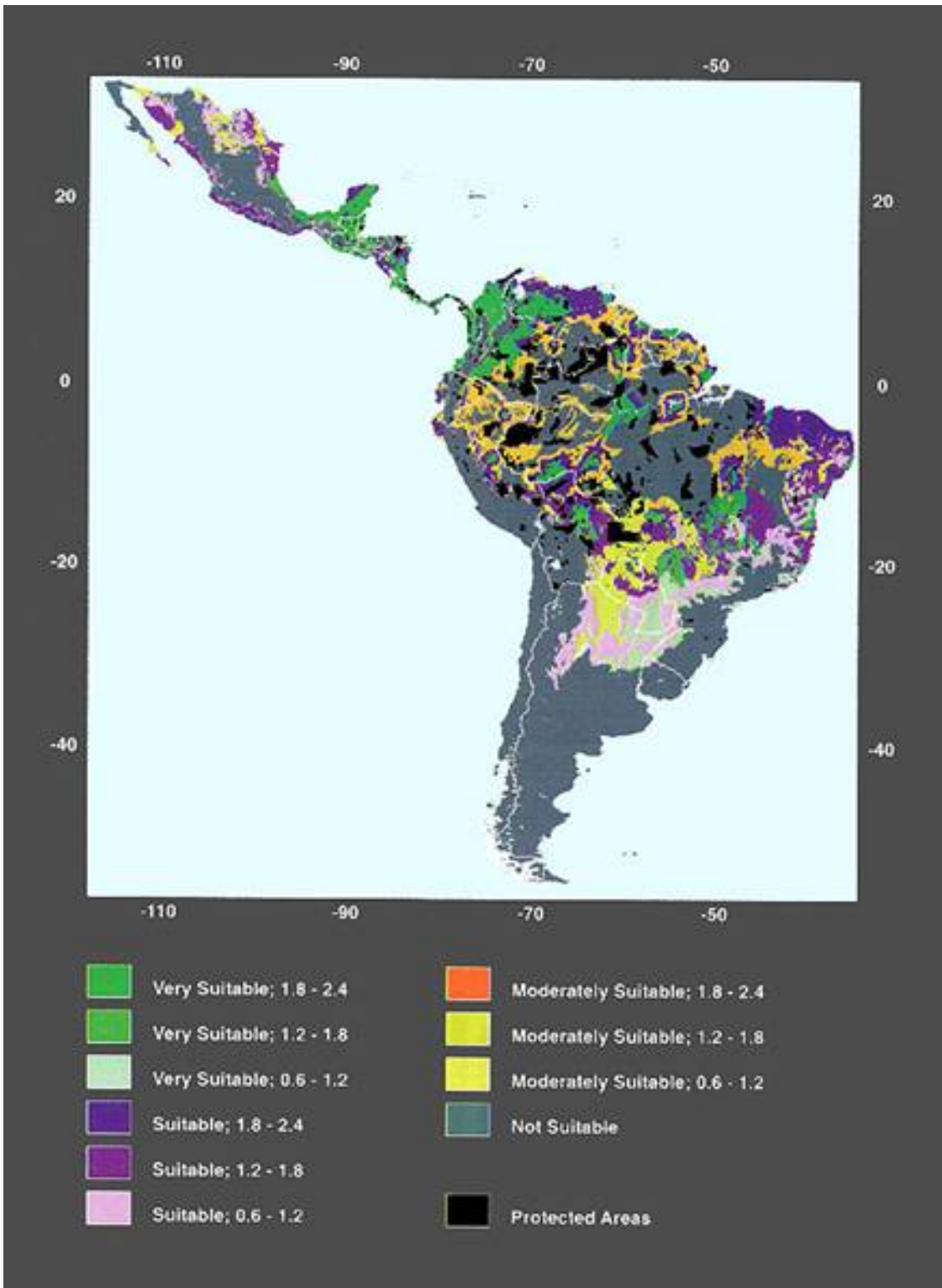


Figure 9 Suitability for commercial farming and potential yield (crops/y) of Nile tilapia fed at 75% satiation and harvested at 300 g.

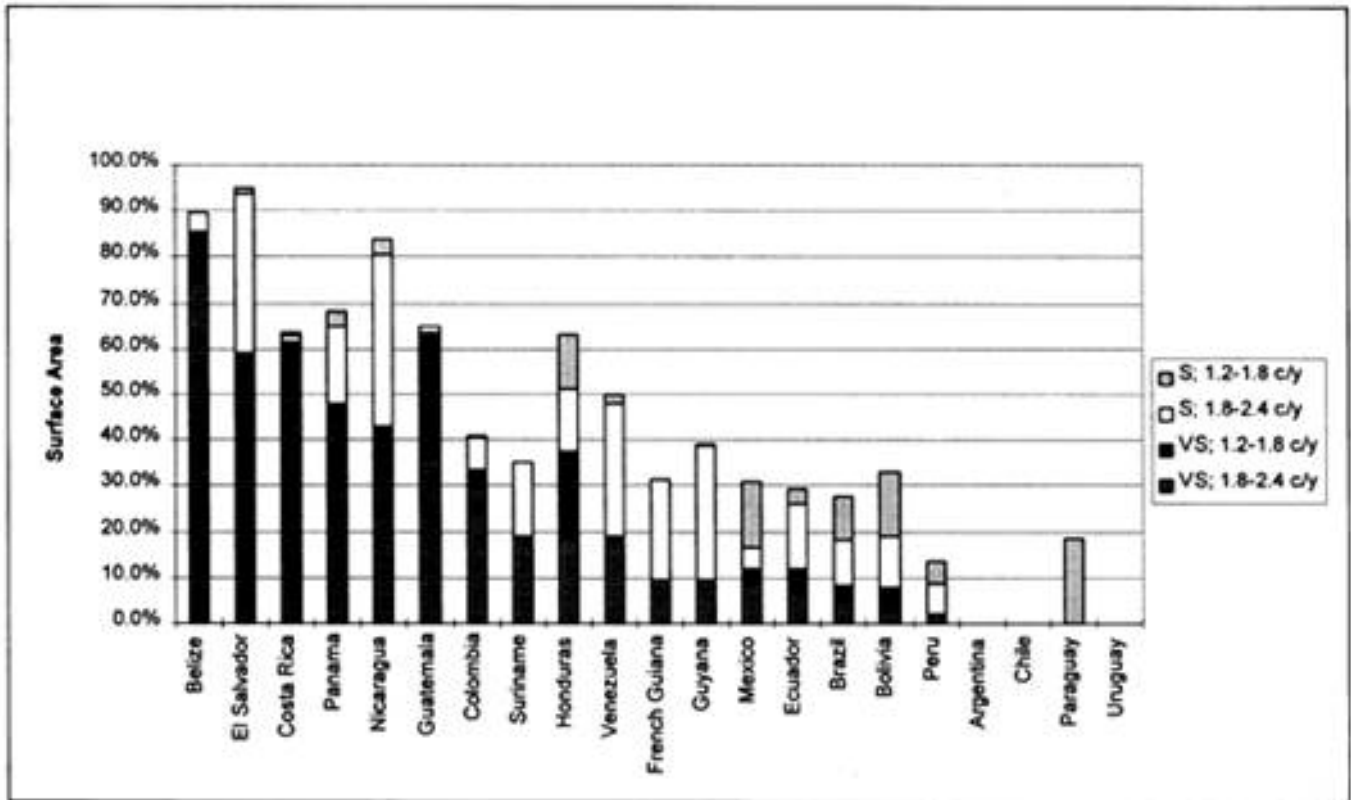


Figure 10 Relative Surface Area with Suitability for Commercial Farming and Yield Range Combined for Nile tilapia fed at 75% of satiation and harvested at 600 g.

The surface area of these countries that rates at least suitable ranges from 14 to 95% and at least 1.2 crops/y can be obtained. The corresponding results for carp are indicate that fish farming is possible in all 210 countries, with 4–99% of their national surface areas rated at least as suitable (Figures 11 and 12).

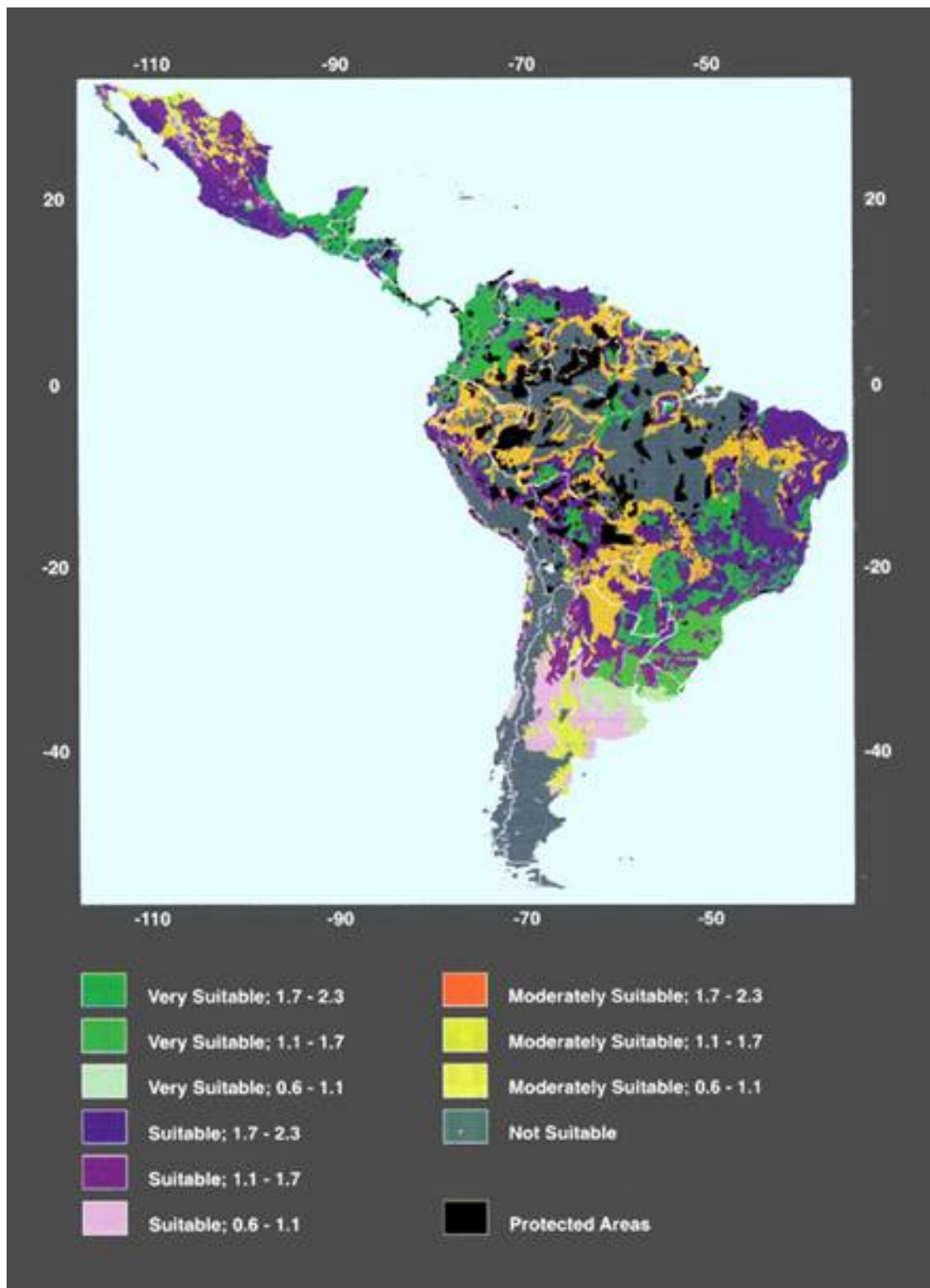


Figure 11 Suitability for commercial farming and potential yield (crops/y) of carp fed at 75% satiation and harvested at 600 g.

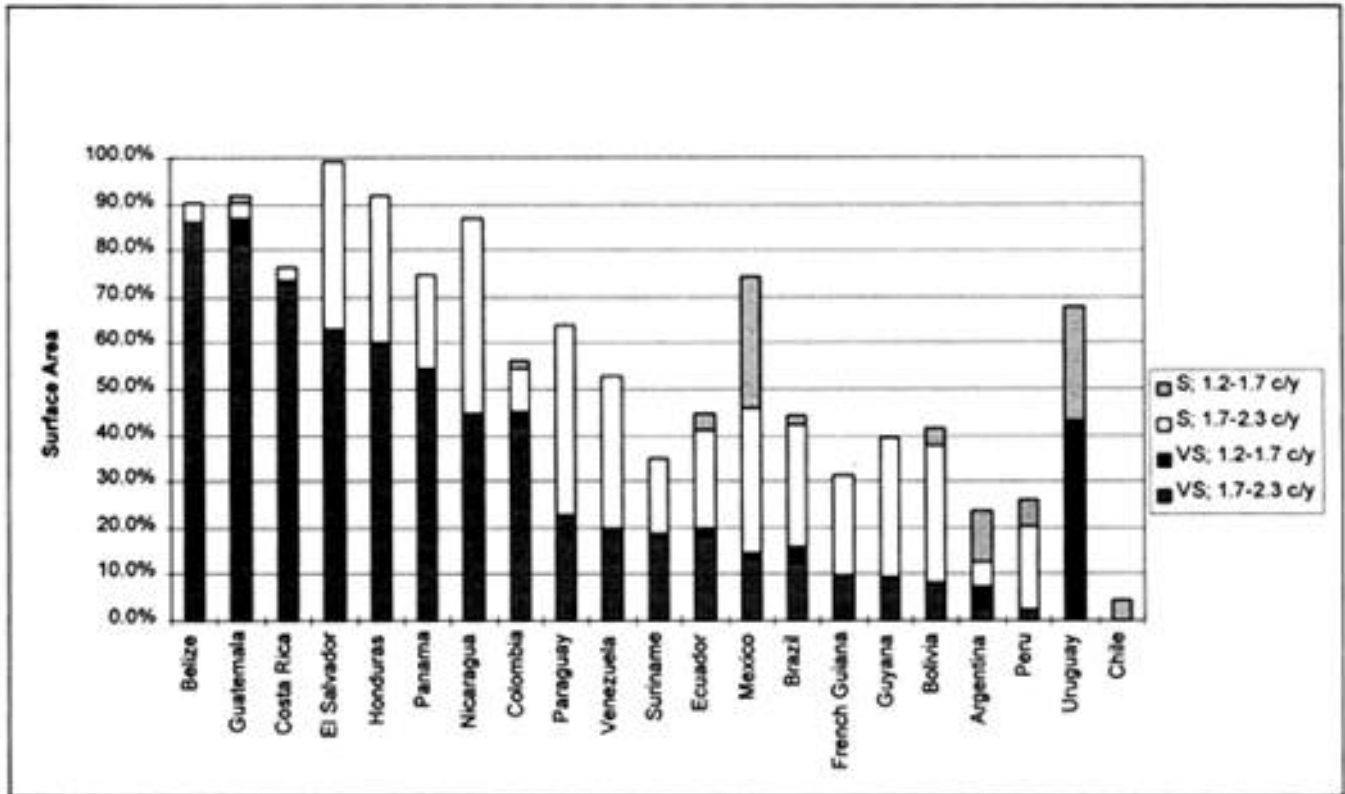


Figure 12 Relative Surface Area with Suitability for Commercial Farming and Yield Range Combined for Carp Fed at 75% of Satiation and Harvested at 600 g.

Further, at least 1.2 crops/y can be raised. Of the 210 countries, 198 and 187 can support tambaqui and pacu culture respectively, with the corresponding surface areas ranging from 8 to 99% and 18 to 98%. At least 0.7 and 1 crops/y are possible for tambaqui (Figure 13) and pacu (Figure 14), respectively.

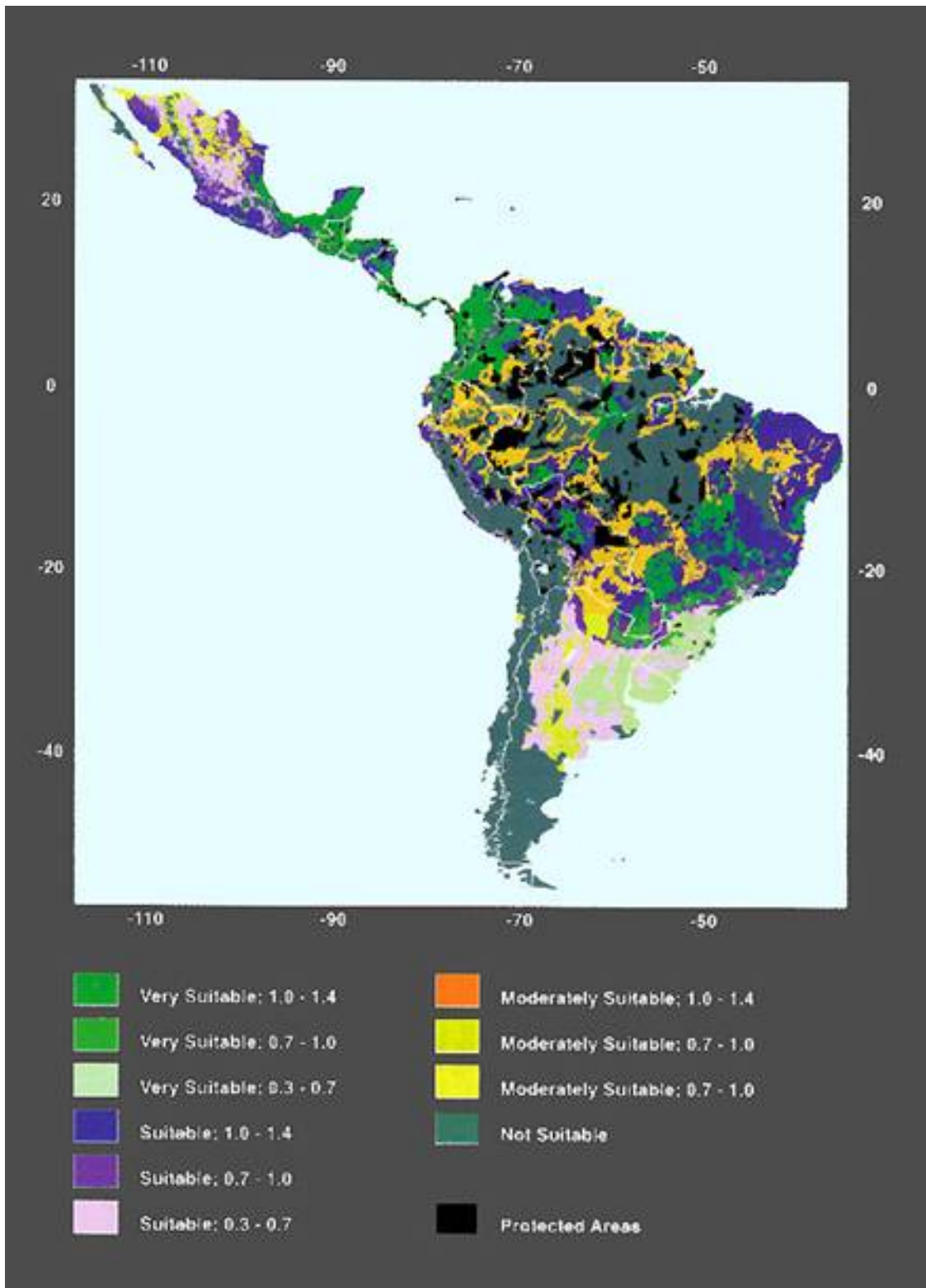


Figure 13 Suitability for commercial farming and potential yield (crops/y) of tambaqui fed at 75% satiation and harvested at 600 g.

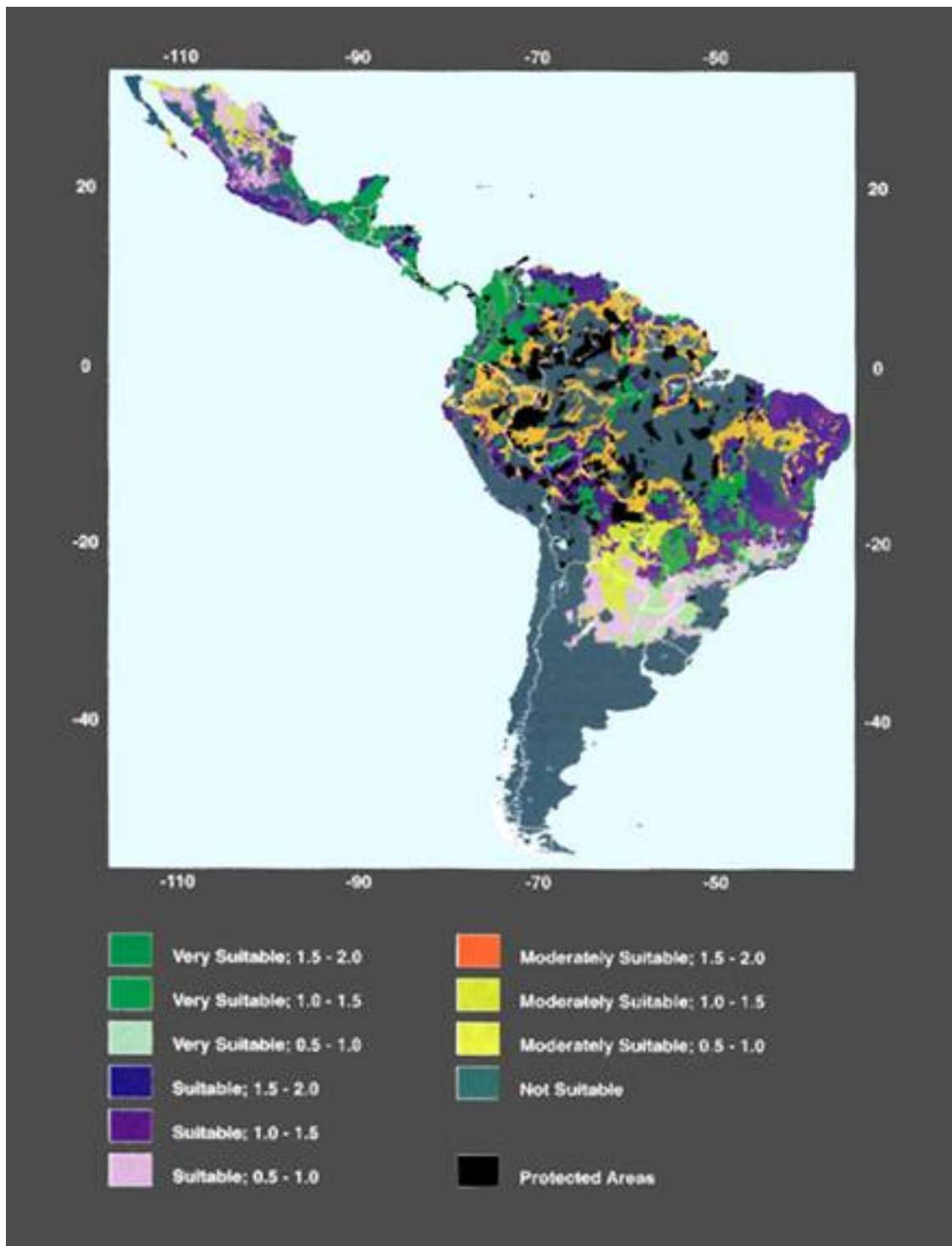


Figure 14 Suitability for commercial farming and potential yield (crops/y) of pacu fed at 75% satiation and harvested at 600 g.

Discussion

Unique Aspects of the Study

For the first time, bio-energetics models for four species were incorporated into the GIS in order to predict fish yields over a continental area.

Lessons Learned

Constraints

Two important constraints were placed on this study in order to save on time and costs: only already digitized (i.e. computer-ready) maps were employed for the analyses, and field verification studies were limited to one country. An underlying objective was that the results had to be comparable for every area and every country of the continent. This imposed an additional constraint on the data: they had to be comprehensive for all of the continental countries.

Problems encountered

Surrogate factors had to be used where data on actual factors were not available. For example, in order to estimate the availability of agricultural by-products as feed and fertilizer inputs for fish farming, it was necessary to use estimates of land suitability for agriculture because there were no comprehensive maps that show the actual spatial distribution of agriculture at a resolution that would have been useful in this study. Other examples are the use of population density as a surrogate for potential for farm-gate-sales and population size for market demand at urban centres.

Field verification

Although the verification exercise was carried out only in one country and involved information on farms culturing predominately tilapia, useful insight was gained into the utility of the commercial model and yield model to predict fish farming potential. The results suggest that the commercial model gives quite reasonable predictions for the weighted combination of the five factors that it incorporates. The yield model to a large extent is dependent on good predictions of water temperature. The lack of a complete gridded data set for weather variables may have been a primary reason for predicted temperatures being lower than values reported for actual farm locations. Lower predictions for yield potential may also be due to different strains of tilapia (e.g. with differing degrees of cold tolerance) being cultured. This problem can potentially be circumvented by re-parameterization of the growth model for cold-tolerant varieties of species such as Nile tilapia.

Future directions

Monthly temperatures averaged over many years were used as inputs for the bio-energetics models to estimate growth and production. An improvement would be to use stochastic weather data. Such data could be used to look at best and worst cases for the operation of ponds and for the production of fish. These analyses could include inter-annual temperature variations as they affect fish growth and production, and precipitation and evaporation as they affect water availability and pond operation costs. Another improvement would be the overlay of the results for commercial farming in order to establish where the best yields for all four species coincide.

Other improvements would require new data or new approaches. Among the most important are:

1. Land cover at 1 km resolution:
 - to enable better estimates of land actually available for aquaculture; and
 - to discern the actual kind and distribution of crop types that, in turn, would allow a better inference of availability of agricultural by-products as inputs.
2. A complete set of polygon data for protected areas, to include all of the countries of Latin America.
3. A set of 5-arc-minute precipitation data covering the Caribbean to allow inclusion of the Caribbean island states in the analyses of fish farming potential.
4. Extending the study to:
 - include more warm- and temperate-water species. However, in practice, even for those species that are most widely cultured and for which the data are most complete, there are still great gaps in data from operational fish farms. Such data should be included in the growth model. A further extension of this idea would be to improve the growth model to investigate polyculture opportunities;
 - include more intensive fish culture systems, such as flowing water and re-circulating systems; and
 - include cold-water species.

However, at a point not too far beyond that to which this study has gone, the utility of a continental-level GIS is lost, and it is much better to proceed to a national-level GIS in order to bring more factors into the analysis, and to take advantage of data at resolutions higher than are appropriate at a continental scale.