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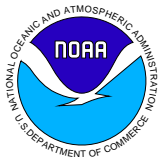
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**GRP MAP MAKER: A USER'S GUIDE TO SPATIAL MODELS OF FISH HABITAT  
COMBINING ACOUSTIC DATA AND BIOENERGETICS MODELS**

*(GRP Map Maker v. 2.8)*

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## PREFACE

GRP Map Maker is a set of programs written in IDL (Interactive Data Language) that produce descriptions of the spatial distribution of fish growth rate potential (GRP), Potential Consumption, and maximum growth potential using data on prey distributions and environmental characteristics (water temperature and light intensity). The core models are the so-called “Wisconsin” bioenergetic models and standard foraging models developed in the late 1970s. The program is a user-friendly, menu-driven code for use by researchers and students who want to use spatial models of fish bioenergetics without having to dig into the details of coding.

Users of GRP Map Maker should have familiarity with the assumptions of bioenergetics and fish foraging models. This users guide provides only a cursory overview of modeling assumptions, and use of the program can easily lead users to produce results that may have interpretation problems. It is up the user’s responsibility to be aware of model assumptions and the problems with violating those assumptions. Only the assumptions regarding the foraging model are dealt with in this document. To learn more about assumptions of bioenergetic models, I refer readers to the numerous works on bioenergetics models, specifically Kitchell et al. (1977), Hewett and Johnson (1992), and Hanson et al. (1997).

GRP Map Maker is a program originally developed for my own purposes. I have found that others can make good use of the program, thus I have upgraded the code to version 2.8. The menus are still primitive and are not designed as pull-downs like windows-type programs. In all likelihood, GRP Map Maker will never have such windows-type menus. However, it will be upgraded in the future, and as the developer, I am interested in receiving constructive comments regarding changes or additions to the program that users would find valuable. Please send comments to me at the address below.

Use of GRP Map Maker is open to anyone who may find it valuable. Researchers who use GRP Map Maker to analyze data and use the analysis in a publication should acknowledge the use of the software by citing this report. This report and the GRP Map Maker software may be accessed through the NOAA Great Lakes Environmental Research Laboratory ftp site:

[ftp://ftp.glerl.noaa.gov/publications/tech\\_reports/glerl-110](ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-110)

**Disclaimer:** By publishing this document, the GRP Map Maker is in the public domain. I will receive no monetary compensation for the downloading and use of this computer code or users guide. As a result, I will be unable to offer any technical support, except when used by direct collaborators. Individuals may use the software as they see fit, and do so at their own risk. Use of this software does not make myself, NOAA, or the University of Michigan responsible or liable for consequences resulting from its use.

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## **1.0 A SHORT INTRODUCTION TO SPATIAL MODELING WITH GRP MAP MAKER**

GRP Map Maker allows users to convert data on fish distribution and on simple environmental measures (water temperature, light attenuation, and surface light intensity) into measures of fish growth rate potential (GRP), fish maximum Potential Consumption, and maximum fish growth ( $G_{\max}$ ). These measures can be used as an index of environmental quality for fish (Brandt et al. 1992; Goyke and Brandt 1993; Horne et al. 1996) or as an index of potential consumption of prey by fish (Luo and Brandt 1993; Hondorp 1998; Walline et al. 1998). The studies cited above show that fish of different species and size classes can differ in physiology and foraging ability. Thus, the same environment may have quite a different value to fish of different species or size classes. The environmental measures computed by GRP Map Maker are not themselves unique, but the ability to view them in a spatial context is a recent development. The strength of GRP Map Maker lies in its ability to allow researchers to easily use fish foraging and bioenergetic models in a spatial context.

Spatial models like those produced by GRP Map Maker allow researchers to explore the role of spatial heterogeneity in determining environmental quality and predatory demand for food. This type of analysis assumes that local variation in the environment may play an important role in larger scale measures and thus must be accounted for. Lasker (1975) provides an example of the importance of spatial heterogeneity of fish populations in the environment. He showed that growth and survivorship of larval anchovies depends on the existence of ephemeral food patches, and that average values of prey density lead to starvation of the anchovy.

Advances in sampling technology have made spatial measurement of the environment far more feasible in recent years. Underwater acoustic technology has made measuring spatial distributions and abundances of fish populations quite feasible. When combined with spatial measures of the abiotic environment such as water temperature and light intensity, the key variable for modeling fish growth can be collected. Thus, describing environmental quality in terms of fish growth and describing potential consumption by fish in a heterogeneous environment can be a tractable and valuable tool allowing new insights into pelagic environments.

### **1.1. Defining Growth Rate Potential**

Growth Rate Potential (GRP) is the amount of growth predicted for fish with known prey availability and environmental conditions (Brandt et al. 1992). Fish distribution data are assumed to represent the distribution of prey available to the predator. GRP is a measure of the growth that an individual will receive in a specific location, and is calculated as consumption minus the bioenergetic costs related to metabolism (Appendices I and II). Spatial models of GRP make use of the spatial heterogeneity in the environment and clearly demonstrate how spatial variability can affect our view of habitat quality

(Brandt and Kirsch 1993; Goyke and Brandt 1993; Mason et al. 1995). Clearly, spatial averaging of food density and environmental variables can affect our understanding and appreciation of fish habitat quality (Mason and Brandt 1996).

Previous use of bioenergetic models generally incorporated averaged values of food availability, water temperature, and fish growth (Kitchell et al. 1977; Thornten and Lessem 1978). Sometimes applications using measurements averaged over wide areas produced unrealistic conclusions with potentially important problems for managers (Rand et al. 1994; Hondorp 1998). By including spatial heterogeneity in models of fish GRP, at least some of these drawbacks can be mitigated.

When computing GRP with GRP Map Maker, the forager species specified by the user is assumed to be a piscivore that feeds on the prey targets seen in the fish distribution data. The bioenergetics calculations performed are correct for the forager species and produce a description of environmental quality in terms of forager potential growth. The fish distribution data represent the prey for the predator only.

## 1.2 Defining Potential Consumption

Potential Consumption by fish is a measure of the maximum amount of food a known fish population could consume. It is a simple summation of the maximum consumption ( $C_{\max}$ ) of each individual fish across the entire sampled population.  $C_{\max}$  is a species-, weight-, and temperature-specific function of individual consumption that reflects the ability of an individual to intake and digest food. As such, when used to measure the potential consumption of food by a fish population, it can provide a useful measure of the strength of predation on a prey population that is important for studying ecosystems (Luo and Brandt 1993; Hondorp 1998; Walline et al. 1998).

The use of fish distribution data differs greatly when computing the Potential Consumption and GRP. When computing Potential Consumption, fish distribution data are assumed to represent predators that consume a prey population that is not depicted. Acoustic data are best at sampling the distribution and abundance of commonly found targets (MacLennan and Simmonds 1992). In many pelagic ecosystems the most commonly found fish are planktivores such as bay anchovy in Chesapeake Bay (Brandt et al. 1992), and rainbow smelt and alewife in the Great Lakes (Brandt et al. 1991; Goyke and Brandt 1993). Potential Consumption analysis treats these targets from the acoustic data collection as the important foragers and computes the potential consumption of food (commonly zooplankton) by these planktivores.

## 1.3 Defining Maximum Growth

The maximum growth of fish ( $G_{\max}$ ) as computed in GRP Map Maker is a measure of the suitability of temperature in the environment for a given fish species. As with GRP,  $G_{\max}$  is a measure based on the possible success of an individual fish and is calculated as consumption minus energetic costs. However, when calculating  $G_{\max}$ , an individual is assumed to achieve its maximum consumption ( $C_{\max}$ ) rather than a measure based on foraging success. As such,  $G_{\max}$  is a measure of the suitability of the temperature environment for a fish species and does not make use of data on fish distributions.

## 1.4 Uses of GRP Map Maker

The GRP Map Maker software package is designed to make producing maps of fish growth rate potential a task that requires less familiarity with the technical details of modeling than previous software

packages required. GRP Map Maker incorporates commonly used fish bioenergetic models (Hewett and Johnson 1992; Hanson et al. 1997) and commonly used fish foraging models (Gerritsen and Strickler 1977) to produce spatial descriptions of fish habitat as measured by growth rate potential. The program is operated through a simple set of input files and menu options. A program description and operating instructions may be found in the **Overview of GRP Map Maker**.

To make effective use of GRP Map Maker, a basic understanding of bioenergetics modeling is valuable. Hewett and Johnson (1992) and Hanson et al. (1997) provide good overviews of bioenergetic models for fishes. Because GRP Map Maker makes extensive use of the equations presented in those publications, I recommend these to readers who are unfamiliar with bioenergetics models.

GRP Map Maker is written in Interactive Data Language (IDL) and requires an IDL license to run. The output is saved in an IDL data format. Users who do not have IDL are welcome to rewrite the source code into a language of their choice, however, IDL's tools for visualization of large data arrays and its ability to easily manage large data sets makes it a particularly valuable program for this application.

## 2.0 MODELS USED IN GRP MAP MAKER

GRP Map Maker is composed of two major sets of models: bioenergetics models and foraging models. Each set is derived from well accepted previously published models. Here they are used for creating spatial descriptions of the environment. The part of GRP Map Maker that consists of new models is only that which relates fish foraging to light intensity. The effect of light intensity on fish foraging is based on data from laboratory experiments done by others, but have only been used in computations of fish foraging by J.A. Tyler and collaborators.

Here, readers will find a verbal description of the models used in GRP Map Maker. Mathematical details may be found in Appendices I and II.

### 2.1 Bioenergetics models

Bioenergetics models describe the limits of fish growth based on a simple mass-balance approach. Energy that enters via consumption ( $C$ ) must be accounted for in growth ( $G$ ), energy losses from respiration ( $R$ ), specific dynamic action ( $S$ ), egestion ( $F$ ), and excretion ( $U$ ):

$$C = G - (R + S + F + U) \quad (1)$$

Consumption is limited by the total stomach capacity and digestion rate which define  $C_{max}$ , the maximum daily consumption of fish. All of the parameters that affect fish consumption and growth in these models are functions of both fish weight and water temperature. Figure 1 provides an example of changes in  $C_{max}$ , respiration, and growth of a 50 g striped bass as water temperature changes. The equations used to describe  $C_{max}$ ,  $R$ ,  $S$ ,  $F$ , and  $U$  are specific to both fish species and size class. Considerable data have been collected on fish bioenergetics and at present, model parameters have been developed for no less than 27 fish species (Hanson et al. 1997) and at least one zooplankton species (*Mysis*, Rudstam 1989).

GRP Map Maker uses bioenergetics somewhat differently than most applications. The primary application of bioenergetics models is to calculate the amount of prey consumption by a fish or a fish popula-



tion. Data on fish size and growth can be reliably collected from the field. Laboratory studies provide reliable data on energetic costs of metabolism, excretion and egestion. Typically, the most unreliable measure in bioenergetics is consumption (Bartell et al. 1986) which is why the bioenergetics models generally are used to solve for fish consumption.

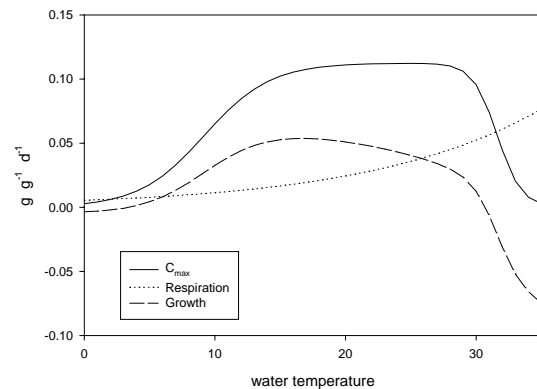
GRP Map Maker uses bioenergetics to determine growth rather than consumption. Consumption is found with the foraging model and is used as an input to the mass-balance equation to get predicted growth. In doing this, we rely on the foraging model to reasonably calculate consumption and must accept the assumptions of the foraging model to obtain growth calculations that we define as Growth Rate Potential.

## 2.2 Foraging model

GRP Map Maker uses the basic foraging model of Gerritsen and Strickler (1977). This model and an elaboration of it (Bailey and Batty 1983) are used to calculate encounter rates of fish and their prey. Fundamentally, the Gerritsen and Strickler model simply calculates the encounter rate of a randomly moving mobile predator with an immobile prey item. Bailey and Batty (1983) address the issue of encounter rates between randomly moving predators and prey. This model has been used to calculate prey encounter rates for predator fishes in spatial models of growth rate potential (Brandt et al. 1992; Brandt and Kirsch 1993; Goyke and Brandt 1993; Mason et al. 1995), in models of planktivore foraging (Aksness and Giske 1993; Giske et al. 1994), and in individual-based fish population models that use foraging to calculate fish consumption and growth (DeAngelis et al. 1991; Rose and Cowan 1993; Rose et al. 1996; Tyler and Rose 1997).

The foraging model computes fish encounter rates with prey by assuming that the fish searches a volume of water and encounters all prey items in that volume. The volume searched ( $VS$ ) is calculated as the cylinder with the radius equal to the reactive distance of the fish ( $RD$ ) and the length equal to the distance swum ( $DS$ ) in the foraging period (Figure 2). The reactive distance of the fish is a function of both the fish length and the size of the prey. Distance swum ( $DS$ ) depends on the fish's swimming speed and the time of the foraging period. Encounter rate with prey is found by multiplying volume searched by prey density.

Not all prey encountered are captured and consumed. GRP Map Maker includes a capture efficiency that accounts for encountered prey that are not captured. Capture Efficiency ( $C_{eff}$ ) is a simple factor (0-1) that describes the fraction of encounters resulting in captured prey. Capture efficiency can strongly affect predicted fish growth (Mason and Brandt 1996) and generally takes a calibrated value. The typical calibration is a simple adjustment of  $C_{eff}$  (or similar variable) until growth rates of model fishes fall within a range defined by growth data (Jager et al. 1993; Rose et al. 1996; Tyler and Rose 1997).



**Figure 1.** Temperature effects on bioenergetics of a 50 g striped bass. Pictured are changes in maximum consumption ( $C_{max}$ ), respiration, and predicted maximum growth as water temperature changes.



**Figure 2.** Volume searched by a foraging fish is that of a cylinder with radius equal to the fish reactive distance ( $RD$ ) and length equal to the distance swum ( $DS$ ).

*Light effects on foraging:* The effect of light intensity on fish foraging is a unique feature to version 2.8 of GRP Map Maker and has not been available in earlier versions of spatial models of fish GRP. The approach taken to model light effects on foraging is to add a multiplier with range 0-1 ( $LI_{fac}$ ) to the calculation of reactive distance ( $RD$ ). Thus,  $RD = RD \cdot LI_{fac} \cdot LI_{fac}$  itself is a function of light intensity. The functions controlling  $LI_{fac}$  are derived from laboratory experiments (see Appendix III). Light intensity decreases as water depth and water clarity increase. Because  $RD$  controls the diameter of the cylinder defining  $VS$ , then changes in  $RD$  can have a noticeable effect on  $VS$  and estimates of fish consumption.

The Gerritsen and Strickler model was developed for foraging planktivores, but GRP Map Maker uses it for all foraging fish. Obviously, this foraging model assumes a cruising predator that encounters and consumes prey indiscriminately. There is no prey selection, prey handling time is not strictly accounted for, and prey are assumed to be immobile. These assumptions are reasonable for a planktivore such as smelt or alewife, but may have problems when applied to piscivorous fish. However, judicious choice of model parameters may make these assumptions more or less acceptable. Very low swimming speeds may be chosen for fish that employ a ‘sit-and-wait’ type of foraging technique. Also, reducing capture efficiency may lead to prey capture rates that are appropriate for the prey being modeled. GRP Map Maker leaves responsibility for choices of parameter values for the foraging model up to the user, but the options available should provide sufficient flexibility to model the fish effectively.

### 3.0 AN OVERVIEW OF GRP MAP MAKER

GRP Map Maker includes a set of IDL programs and procedures that are designed to work together. GRP Map Maker version 2.8 is designed to work on UNIX workstations and on personal computers (Windows 95 or Macintosh) running IDL. Version 2.8 runs from within IDL and, as such, is not a stand alone program. Alter the code at your own risk. In general, changes will result in code that cannot be run.

GRP Map Maker requires a specific set of input files and produces three types of output files with results. The input files include data inputs, model parameter inputs, and menu option inputs. The output files include a summary of results in a simple ASCII file, the actual arrays of computed results in binary format specific to IDL, and graphics files (.GIF) of user-created maps. The outputs in the results file are

simple summary statistics. For more sophisticated analysis, users will have to write their own code, but can easily perform a RESTORE from within IDL to work on the saved data arrays.

GRP Map Maker is designed to construct spatial descriptions of fish bioenergetics (growth, consumption, metabolism) with data on fish size, abundance and distributions, and data on water temperatures. The data on fish populations has typically been collected with underwater acoustics. Thus, throughout this guide I will refer to fish population data as the *ACOUSTIC DATA* or the *ACOUSTIC FILE(S)*.

### 3.1 Program Files

GRP Map Maker v 2.8 consists of a set of 10 required files. The program will not run if any of these files are missing. Also, check your IDL paths to see that they include the directory(s) with these programs prior to running GRP Map Maker. The suggested way of using GRP Map Maker is to put all of the program files into a directory of its own and keep data files in separate directories. The files required by GRP Map Maker v 2.8 are listed in Text Box 1.

Programs:	GRPPARAM.PRO	GRPMAP28.PRO	
Procedures:			
Bioenergetics:	GRPCMAX1.PRO	GRPEGEX1.PRO	GRPESP1.PRO
Computations:	AREALCOMP.PRO	MAPGUTS28.PRO	
Foraging:	GRPCONS1.PRO		
General text:	GRPINTRO28.PRO		
Graphics:	GRPLOT.PRO	TELEV.PRO <sup>1</sup>	
Input/Output:	GRPACSTX.PRO	GRPMENU.PRO	

**Text Box 1.** Program files and procedures required by GRP Map Maker v. 2.8.

The program files are stand-alone IDL programs and can be run directly from IDL by entering *.run filename* at the IDL> prompt. The procedures are called by GRPMAP28.PRO and cannot be run directly from IDL. For GRP Map Maker to run, all of the supporting procedures listed above must be in the same directory as the main program or in a directory that is on the proper path. GRPPARAM.PRO does not call any procedures.

### 3.2 Top Menu

When the user first runs GRP Map Maker, s/he will be presented with the *Top Menu* from which s/he will select the data to be analyzed, the type of analysis to be conducted (GRP, Potential Consumption,  $G_{max}$ ), output file names, and the data to be saved.

Text Box 2 shows the options available in the Top Menu and the current values for a few select options, those for which a single answer of a current value has meaning are listed. As the user selects new values, the “current value” will change to reflect the most recent selections.

```

GRP Map Maker 2.8
  TOP Menu

1 : enter .GRPLIST file          current value
2 : operations and foraging parameters menu  NONE
3 : select Map Computation      GRP
4 : Plots menu

10 : Summary Results file       gpresults.txt
11 : Save .IDLGRP file         none saved
12 : Save .GIF file           none saved
Last saved .GIF file          none saved

88 : About GRP Map Maker
99 : Exit GRP Map Maker

enter selection :

```

**Text Box 2.** Top Menu of GRP Map Maker v. 2.8.

### 3.2.1 Computing options

*Enter .GRPLIST file (option 1):* Enter the .GRPLIST file needed for the requested analysis here. If a .GRPLIST is not entered, many of the options in the Top Menu will request that the .GRPLIST file be specified. The .GRPLIST file is critical because it specifies the directories containing the input data, directories to which output data will be written, bioenergetics parameter files, GRP Map maker operations and foraging menu options file, and fish distributions (usually from acoustic sampling) and water temperature data files. The details of the .GRPLIST file may be found in [The .GRPLIST file](#) below.

After entering a valid .GRPLIST file, GRP Map Maker will automatically move to the Operations and Foraging parameters menu. Upon exiting the Operations and Foraging parameters menu, GRP Map Maker will then compute and display a spatial map of fish GRP, Potential Consumption, or  $G_{max}$ , depending on the map computation selected (see option 3).

*Set operations and foraging parameters (option 2):* The operations and foraging parameters control the analysis display, the parameters used in the foraging model, and the computational mode. Details on the various options found in the operations and foraging parameters menu may be found under **Operations menu** and **Foraging parameters menu** below. Upon leaving the operations and foraging parameters menu, GRP Map Maker automatically computes and displays the analysis.

*Select map computation (option 3):* Select the computation analysis to be done by GRP Map Maker, GRP, Potential Consumption, or  $G_{max}$ . If a .GRPLIST file has been selected, GRP Map Maker automatically performs the computational analysis.

*Plots menu (option 4):* A variety of traditional plots may be made to explore the data input for analysis. Lots include basic bioenergetics computations, length-weight relationships, and distributions of fish with depth and temperature. More detail is provided in **the Plots menu** below.

### 3.2.2 Output file options

The options available at the Top Menu are briefly described below. For a full description of file outputs, refer to the section on **Output Windows and Files**.

*Summary results file (option 10):* Simple summary statistics are saved to a file with the default name of GRPRESULTS.TXT. The user may change the name of the file with this option subject to the constraint that it will have a .TXT extension. If users want to change the name of the Summary Results file after one has been opened, the current file will be closed and a second file opened. If the new name is the same as the old name, the first file may be overwritten.

*Save .IDLGRP file (option 11):* Data from the analysis performed with GRP Map Maker may be saved to a binary file with the extension .IDLGRP. The file is in IDL format and includes all data needed to use the results from GRP Map Maker for further analysis or to create graphs.

*Save .GIF file (option 12):* The graphic display may be saved in a .GIF file for later use. The display is saved exactly as viewed and then can be imported to various graphic packages for editing. Under the “current value” column users will find both the file currently saved and the file previously saved. When saving more than one graphics file, users may find the information on the previous file to be useful.

### **3.3 Processing Mode**

GRP Map Maker can be run in two different Processing Modes: *Single Map* and *Batch*. The user can control all of the outputs described in the Top Menu under Single Map mode, but is limited to performing one analysis on one data set at a time. Processing more than one data set under Single Map processing mode requires entering a new .GRPLIST file. Select the Processing Mode for an analysis in the Operations and Foraging Parameters menu, option 0. Failure to select the processing mode will not cause GRP Map Maker to crash as long as the .GRPLIST contains all of the proper information.

Batch processing mode allows the user to process multiple sets of data (pairs of acoustic and temperature files), all with the same bioenergetic and foraging model parameters. Batch mode is most useful for analyzing multiple sets of data collected under similar environmental conditions and seasons that require identical analysis. One example is the analysis of Potential Consumption of zooplankton by lavnun in Lake Kinneret, Israel (Walline et al. 1998).

Users are not allowed the same level of control over outputs under Batch processing mode as they are under Single Map processing mode. When running GRP Map Maker under Batch processing, the locations of the output windows are controlled by the program and all data are saved automatically in .IDLGRP files. The names of the .IDLGRP files are the same as the acoustic data files. Users are given an opportunity to alter the name of the .IDLGRP files that are saved during Batch mode processing by adding a string of characters at the end of the root file name used to identify the acoustic data file. That is, for an acoustic file name 09132020\_98.IDLDAT users should add a string such as “t1” to the .IDLGRP file name to produce the file 09132020\_98T1.IDLGRP. This feature is useful to distinguish between .IDLGRP files created from the same acoustic data but with different foraging parameter values.

### 3.4 Input Files

GRP Map Maker requires five different input files to run. They include the .GRPLIST file, a data file of fish abundance, size, and distribution (acoustics file), a data file of water temperatures, a file of bioenergetics parameters, and a file of operations and foraging parameter values.

#### 3.4.1 The .GRPLIST file

The .GRPLIST file is the critical file that defines the directories for data input and output, bioenergetics parameters, and operations and foraging parameters. This file is an ASCII file that must be written outside of GRP Map Maker and saved in standard ASCII format. Any file extension may be used, but a .GRPLIST extension is suggested.

The .GRPLIST file must include the following information in order:

- directory with data files (“*input directory*”)
- directory for output of saved data (“*output directory*”)
- file with bioenergetic parameters (path required)
- file with GRP Map Maker foraging and operations menu parameters (no path)
- file with acoustic data (no path)
- file with water temperature data (no path)
- done

*Batch Mode* processes a set of data files that use the same directories and parameters for bioenergetics, operations, and foraging (for more detail on Batch Mode processing see **Processing Mode** above). The .GRPLIST file for doing Batch Mode processing is identical to the above description except that more than one pair of acoustic data and temperature data files is specified. For example:

- ⋮
- file with acoustic data #1
- file with water temperature data #1
- file with acoustic data #2
- file with water temperature data #2
- file with acoustic data #3
- file with water temperature data #3
- done

**NOTE:** Acoustics and temperature files must be specified in pairs even if the same acoustics or temperature file is used repeatedly.

The .GRPLIST file must end with the string “done” and users should treat “done” as a “keyword” in that it can be used only as an identifier of the end of the .GRPLIST file. When this string is found in the .GRPLIST file by GRP Map Maker, the program stops reading the .GRPLIST file and will not process any data sets that follow.

#### *File locations and paths*

The .GRPLIST file is set up so that all input and output data are sent to specific directories. The input files, foraging and operations menu parameters, acoustic data, and water temperature data must all reside in

the *input directory*. Do not put a path name on those files. GRP Map Maker attaches the *input directory* to the names of these files. If the path for those files is a part of the name, then GRP Map Maker will abort when trying to READ and RESTORE the files. Files written by GRP Map Maker will be written to the *output directory*. The INPUT and OUTPUT directories may be the same or may be different depending on the way the user wishes to organize their data.

The file with bioenergetics parameters [3] must have a path attached to it. If not, GRP Map Maker will look for the file in the current directory. The bioenergetics parameters may be frequently used for many applications. Thus, it may be useful to have a single directory for all of the bioenergetics parameter files that a user may want/need that is separate from input data.

#### 3.4.2 Fish distribution (acoustics) data file

Data on fish abundance, size, and distribution input to GRP Map Maker is most commonly derived from underwater acoustic surveys, hereafter referred to as “acoustics” data. However, data with the same format have been created for strictly theoretical exercises (Brandt and Tyler 1998). Therefore, any data will work in GRP Map Maker as long as they have the same format as that typically input from acoustics surveys.

GRP Map Maker is designed to work with output from the Digital Echo Visualization and Information System (DEVIS) software (Jech and Luo 1998) and with the BSN\_FISH.WDG program (Jech, unpublished software). The procedure GRPACSTX.PRO reads data from the acoustics data file and transfers the variable (Table 1) to the main program for analysis. For users who wish to create their own fish distribution data for use with GRP Map Maker without using DEVIS or BSN\_FISH.WDG, the data file must include the DEVIS variables listed in Table 1. Note that multiple DEVIS variables are associated with some of the GRP Map Maker variables because different versions of DEVIS saved data under different variable names. The fish distribution file created must use one of these DEVIS variable names, but any of the variable names specified in Table 1 is acceptable.

#### 3.4.3 Temperature data file

GRP Map Maker requires temperature values for all of the cells defined in an acoustic data transect. The data must be in an array of the same size as the acoustic data and must be saved in the name: MEANTEMP. The raw data used to create MEANTEMP is commonly collected from vertical profiles or tow-yos with a temperature-depth probe. The data must be interpolated to create an array appropriate for GRP Map Maker. The program TEMP\_FILL.PRO may be used for this interpolation (Appendix IV)

#### 3.4.4 Light data

Light data may be used to explore the effect of light intensity changes on fish consumption and growth, but light data are not required by GRP Map Maker. A light data file is not input to GRP Map Maker nor included in the .GRPLIST file. Light data are entered in the Foraging Parameters Menu.

GRP Map Maker assumes that light intensity is uniform across the length of the transect, and that light intensity changes only as a function of depth and water clarity. If no light data are available, then setting the surface light intensity to a value of 0 (see **Foraging parameters menu**) will create a light intensity array with 0 values, in which case GRP Map Maker sets the reactive distance of the foraging fish to the

**Table 1.** Variables used by GRP Map Maker and the associated variable name(s) from DEVIS where they differ.

GRP Map Maker variable	Content	DEVIS variable
blank_dist	Blanking distance; distance below acoustic transducer in which data are not collected.	
nrpt	Report or horizontal bin number in the data array.	
nstr	Strata or vertical bin number in the data array.	
sizevec	Vector containing size class definitions.	
tgtden	Array of average absolute density of all targets in a cell. Dimensions: nrpt, nstr.	absdens, absdensfl
tgtdenz	Array of absolute density of targets in a cell separated by size classes. Dimensions: nrpt, nstr, size class number.	absdenssz, absdensszfl, absdensszp
tgrlen	Array of average length of all targets in a cell. Dimensions: nrpt, nstr.	avlenmm, avlenmmfl
tgrlenz	Array of absolute length of targets in a cell separated by size classes. Dimensions: nrpt, nstr, size class number.	avlenmmsz, avlenmmszfl, avlenmmszp
vbin_size	Vertical bin size. The depth of each strata or vertical bin.	
wc	List of array cells that are in the water column.	
xdcer_depth	Depth of acoustic transducer when collecting data.	

length of the forager (Appendix III, eqn 23). This, of course, will affect the calculation of fish foraging as described in the foraging model above.

To include light data, the user must supply two inputs: surface light intensity and the light extinction coefficient ( $E_{par}$ ). These may come from field data or estimated by the user to examine a set of “what if” scenarios. The surface light intensity ( $LI_0$ ) simply defines the light intensity at the water’s surface. Light intensity at depth is computed with the standard exponential equation:

$$LI_D = LI_0 e^{-E_{par} D} \quad (2)$$

Where  $LI_D$  = light intensity (lux) at depth  $D$ ,  $E_{par}$  = light extinction coefficient.

The light intensity for the most shallow points in LIGHTARR will not equal  $LI_D$ . This occurs because the



top vector of LIGHTARR is typically not actually at the surface. The dimensions of LIGHTARR are defined by the acoustic data, and the most shallow point of the acoustic data is not at the surface, but at a depth defined by the sum of XDCER\_DEPTH + BLANK\_DIST. Light intensity at the most shallow points of LIGHTARR accounts for the light lost in that depth.

### 3.4.5 Bioenergetics parameter file

GRP Map Maker uses the “Wisconsin” bioenergetics models, and the bioenergetics parameter file required by GRP Map Maker is nearly identical to that used by the “Wisconsin” models (Hewett and Johnson 1992; Hansen et al. 1997). The list of variables can be found in Appendix II.

#### *Creating a Bioenergetics Parameter File*

To create a bioenergetics parameter file for GRP Map Maker, run the GRPPARAM.PRO program from the IDL> prompt. GRPPARAM.PRO can either begin with an ASCII file or it can begin with an .IDL DAT file. The default is an .IDL DAT file. The program will first ask for the name of the parameter file. Entering ‘ASCII’ will allow the user to enter the name of an ASCII file. Otherwise the program assumes that the file is an .IDL DAT file and will perform a RESTORE on the file. The file is assumed to have the extension .IDL DAT. If it is not an .IDL DAT file, the RESTORE will fail and cause GRPPARAM.PRO to abort.

Changing parameter values is done simply by entering the assigned number of the parameter you wish to change and entering a new value. When starting from scratch or making many changes to the parameter file, it may be advantageous to start with an ASCII file. When creating the ASCII file, make a list of the values that the parameters should have (see Appendix II). GRPPARAM.PRO will read the list and allow you to make any necessary changes.

GRPPARAM.PRO includes options to plot the change in fish bioenergetics ( $C_{max}$ , respiration, egestion, excretion, sda) in relation to temperature for checking the parameters entered. Users will be asked to specify a fish weight and a temperature range for plots. This option is useful for detecting errors in bioenergetic parameters used by GRP Map Maker.

### 3.4.6 Operations and foraging parameter file

GRP Map Maker saves and restores parameter values for the Operations and Foraging menu in an ASCII file with 40 values. Users should begin with a copy of the file used for the demonstration (DEMOMENU.TXT) or from a previous user. GRP Map maker will look for the file in the *input directory* specified in the .GRPLIST file. Specifics of the various values in the operations and foraging parameter file are found under the **Operations menu** and **Foraging parameters menu** below.

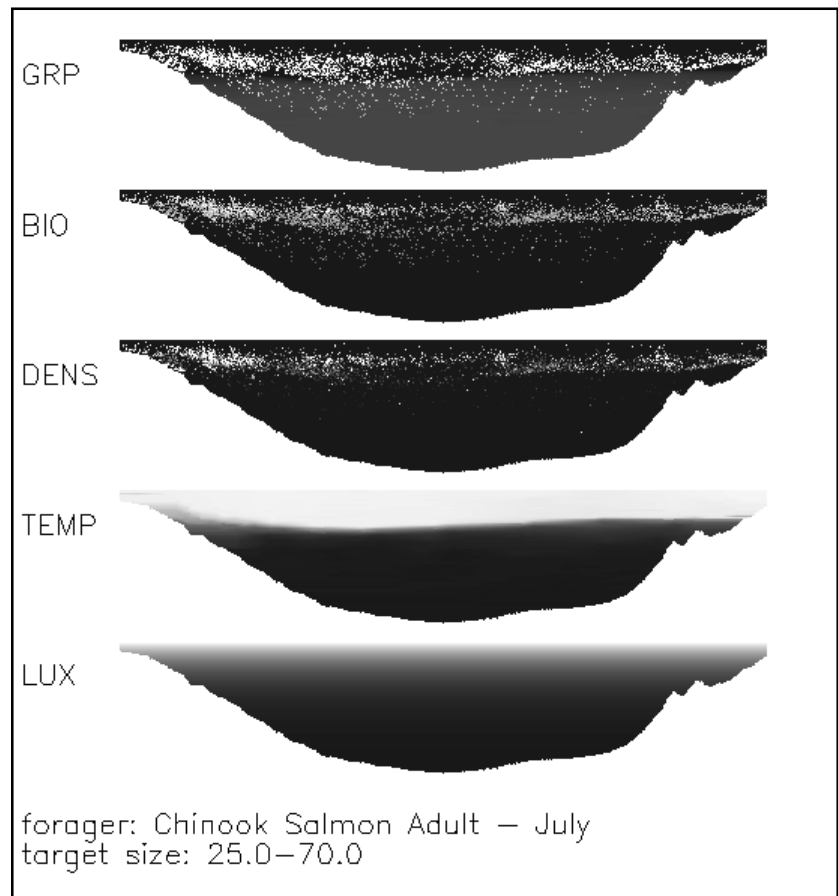
## **3.5 Output Windows and Files**

Results are produced in a series of graphic, text, and binary outputs for users to view as they analyze data, to save for later analysis, and to save for making figures. Output includes a graphics window, text written to the window from which GRP Map Maker is run, the .IDLGRP binary file to save data, and graphics (.GIF) files saved by the user.

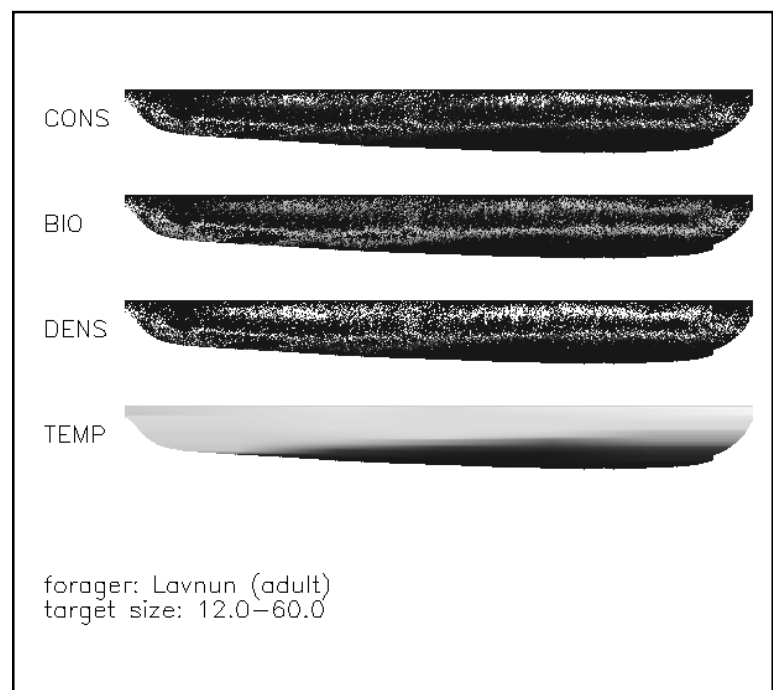
### 3.5.1 Graphics display window

The most noticeable output is the display window showing the GRP map generated from the data. This window opens automatically soon after the user leaves the Operations and Foraging Parameters menu. The title at the top of the output window identifies the acoustics data file used in the analysis (titles not shown on Figures 3, 4, and 5, but are visible when program is run). The display shows various outputs, from top to bottom: 1) GRP, Potential Consumption, or  $G_{max}$ , 2) Fish biomass density, 3) Fish numeric density, 4) Water temperature, and 5) Light intensity (lux). Fish biomass and numeric density are displayed on a log scale, all others are displayed with a linear scale (Figure 3). Text identifying each display appears on the right. The forager species and the size range of the fish displayed in the transect and used in the specific analysis (target size) are displayed at the bottom. The actual size of fish in the display and analysis will vary with the user's selection of the fish size class (**Foraging parameters menu**).

Only the displays relevant to the specified analysis are shown in the graphics display window. For example, if light data are unavailable and the user sets the surface light value in the Foraging Parameters Menu to 0.0, then light intensity will not be displayed in the graphics window. Light is not used for the analysis of Potential Consumption and is not shown when that analysis is selected (Figure 4). Similarly, neither light nor fish data are used in the  $G_{max}$  analysis and are not shown when  $G_{max}$  analysis is selected (Figure 5). The range of values displayed in the graphics display window, as well as window size,



**Figure 3.** Graphic display window of GRP analysis. Data collected on Lake Ontario (D.W. Hondorp).



**Figure 4.** Graphic display window of Potential Consumption. Data from lake Kinneret, Israel (P.D. Walline).

color table, and size of the displayed transects are all controlled in the **Operations menu**.

### 3.5.2 Output text displayed

GRP Map Maker computes a series of statistics that are displayed in the text window and are identical to those written to the summary results file. The summary statistics computed are the mean, variance, minimum, and maximum data values and results from the analysis (see Text Box 3). Some of the outputs change depending on the analysis selected.

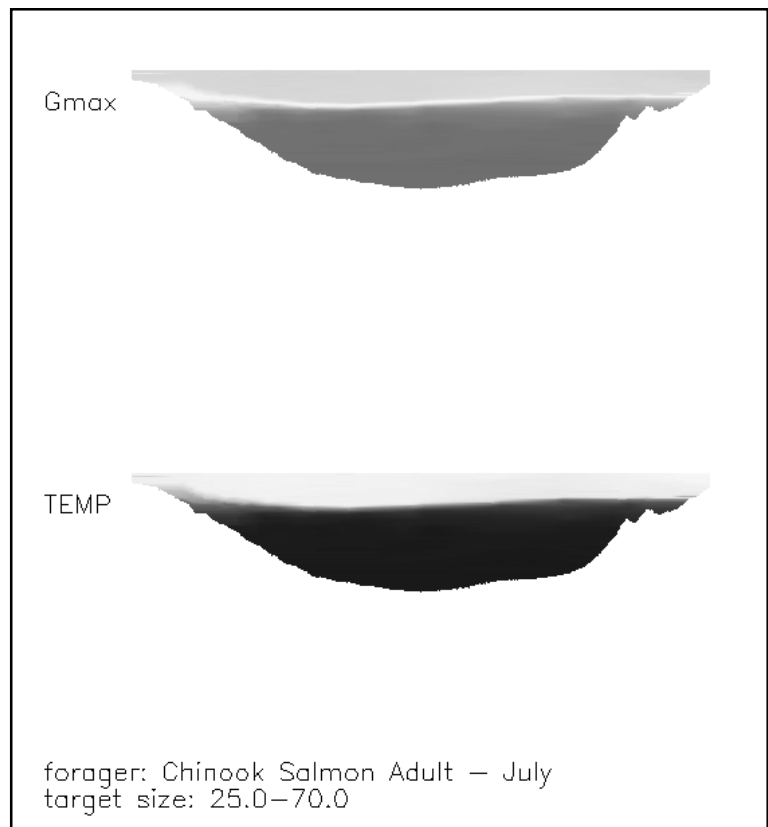
### 3.5.3 Summary results file

GRP Map Maker automatically writes an ASCII file of simple summary parameters used in the analysis and statistics from the analysis. The default file name is GRPRESULTS.TXT, but the name can be changed prior to running an analysis (Top Menu option 4). A summary results file created by running a set of demo data is found in Text Box 3. GRP Map Maker will write this set of information, both parameter and results summary, for each set of computations. If users only adjust the Graphics Display Window when in the Operations and Foraging Parameters menu, a new set of results is not written to the summary results file. GRP Map Maker does not check to see if a summary results file with the same name specified by the user exists prior to writing a new file. Overwriting existing summary results files may easily result.

The first table of summary results written below the parameters summary is based on the analysis shown in the Graphics Display Window. The summary results written include mean, variance, and minimum and maximum values of various measures. For a few measures, values are computed for the fraction of the cells in the transect with value greater than 0 (frac>0). Frequently, the most important measure of a transect is not the mean or variance of a measure, but the amount of the transect with positive values. For example, the mean GRP of a transect may have little importance for fish, but the fraction of the transect with positive GRP may be of critical importance.

The analysis shown in Text Box 3 is for GRP. The top line is a summary of GRP for the demonstration data, the second line shows the summary for those cells with GRP > 0. It also shows the fraction of the cells in which the forager's consumption reached the maximum. In the jargon of the Wisconsin bioenergetics model, these are the cells in the transect in which "P=1."

The first two lines of results written in the summary results file change with the analysis performed. In Text Box 3, the first two lines are for a GRP analysis. For a Potential Consumption analysis, the same



**Figure 5.** Graphic display window of  $G_{max}$  analysis from data collected on Lake Ontario (D.W. Hondorp).

```

acoustics file: /d1/mapmaker/demo/demoacoustx.idldat
GRP list file: demo.grplist
Reports:          115 Strata:          69 cells in WC:          2608

forager species: walleye
bioenergetics parameters: /d1/mapmaker/walleyepar.idldat
predator length:  450.000      weight:          985.000
swim speed:       1.00000      forage efficiency: 0.0500000
fraction of day:  0.500000     hours:          -12.0000
Cmax available:   0.500000     target size class: 0.00000
len-wt pars: A:  1.30000e-07   B:              3.82000
Prey Energy Den:  1800.00
surface light     1000.00      extinction coef: 0.250000
RD vs Lux eqn:   1.00000

          mean          var          min          max          frac>0
          GRP: -0.00342    0.00001    -0.00480    0.01245    0.0989
          Positive GRP: 0.00636    2.1091e-05 fraction P=1 : 0.0000
          BIOMASS den: 0.00264    0.00004    0.00000    0.08730    0.2504
          fish DENSITY: 0.02569    0.00444    0.00000    1.01337
          fish LENGTH: 34.59690  10.91944   21.10395   38.99228
          fish WEIGHT: 0.10293    0.00102    0.01489    0.15541
          WATER TEMP: 14.93694   0.23833    11.80470   5.14885

Bioenergetics Arrays:
  Consumption: 0.00770    7.0844e-05  6.5010e-09  0.02552
  Respiration: 0.00473    2.6154e-08  0.0036948  0.00480
  Egestion:    0.00122    1.7686e-06  1.0272e-09  0.00403
  Excretion:   0.00016    3.2149e-08  1.3849e-10  0.00054
  SDA:         0.00112    0.00000    0.00000    0.00370

areal integrations:
  GRP : -8.92738
  biomass: 1.72567
  fishden: 16.7728

```

Text Box 3. Contents of the Summary Results file (GRPRESULTS.TXT).

outputs will be computed for Potential Consumption. For a  $G_{max}$  analysis, only the first line of results is written.

The second table of results contains summaries of components of the bioenergetics models. Spatial descriptions of these results are not displayed in the Graphics Display Window. These results are included because they are often useful for understanding unusual GRP findings. The arrays of the bioenergetics are saved in the .IDLGRP file.

Fisheries data are often reported in units of area (e.g. fish biomass in  $g/m^2$ ). GRP Map Maker reports the areal integrated value of GRP, Potential Consumption,  $G_{max}$ , fish biomass, and fish numerical density at the bottom of the summary results file. These results are simply 2-D summations of the 3-D data used to compute the transect of GRP.

### 3.5.4. The .IDLGRP file

The results from GRP Map Maker may be saved in an .IDLGRP file for later use. The .IDLGRP file is a binary file that may be read by IDL with the RESTORE command. The file created will contain all data needed to produce figures, complete further analysis not included in GRP Map Maker, and to recreate the analysis performed by GRP Map Maker to produce the results found in the file.

A total of 24 variables are saved in the .IDLGRP file. These are listed in Table 2. The explanation in the table is sufficient for most variables, but a few warrant additional description:

AREALARR: This array variable (6 x nrpt) contains the areal summations of six variables, each stored in one vector of the array. The variables and vectors in which they are stored are: GRP (0), Potential Consumption (1),  $G_{max}$  (2), fish biomass (3), fish numeric density (4), and water temperature (5). Fish biomass, numeric density, and water temperature are computed for each analysis. The value of the vectors for GRP, Potential Consumption, and  $G_{max}$  are initialized to -9999 for each set of foraging parameter values. The vector for each map computation is

**Table 2.** Variables saved in the .IDLGRP file. Units provided for appropriate variable.

Variable	Content	Units
AREALARR	Array of areal integrated values in 5 vectors.	mixed
BIODENS <sup>1</sup>	Biomass density of fish targets in transect.	$g \cdot m^{-3}$
CONSARRSP <sup>1</sup>	Consumption calculated from the foraging model.	g
DEPTHARR <sup>1</sup>	Depth from surface.	m
DEPTHVEC	Vector of depth from surface.	m
EPAR	Light extinction coefficient.	
FISHCLASS	Fish size class used in analysis.	
GMAX <sup>1</sup>	Maximum growth for forager in each cell.	$g \cdot g^{-1} \cdot d^{-1}$
GRP <sup>1</sup>	Growth Rate Potential for forager in each cell.	$g \cdot g^{-1} \cdot d^{-1}$
LIGHTARR <sup>1</sup>	Light intensity in each cell.	lux
MEANTEMP <sup>1</sup>	Water temperature in each cell.	EC
MENUPARM	Vector of operations and foraging menu parameters.	
NRPT	Number of reports, or horizontal bins in arrays.	
NSTR	Number of strata, or vertical bin in arrays.	
PAR0	Surface light irradiance.	lux
PARM	Vector of bioenergetics parameters.	
PTCONS <sup>1</sup>	Potential Consumption by all fish targets in each cell.	$g \cdot d^{-1}$
SIZEVEC	Vector of size separators to define sizes of fish classes.	mm
SPNAME	Name of forager species used in analysis.	characters
TGTDEN <sup>1</sup>	See Table 1.	$number \cdot m^{-3}$
TGTDENZ <sup>2</sup>	See Table 1.	$number \cdot m^{-3}$
TGTLEN <sup>1</sup>	See Table 1.	mm
TGTLENZ <sup>2</sup>	See Table 1.	mm
WC	See Table 1.	

<sup>1</sup> Array variable with dimensions nrpt x nstr.  
<sup>2</sup> Array variable with dimensions nrpt x nstr x number of fish size classes.

filled when the appropriate analysis is conducted, e.g. when GRP is computed for a data set, vector 0 is filled, and vectors 1 and 2 remain unchanged. To fill all vectors in AREALARR the user will need to perform the analysis for each of the three map computations without changing the value of any of the foraging parameters.

**BIODENS:** This array contains the biomass density of fish targets in the fish distribution (acoustic) data used for the analysis. This array will change as the size class of fish used for the analysis (FISHCLASS) changes. If multiple fish size classes are used, BIODENS reflects the weighted mean of the biomass density of fish in each cell. The mean is weighted by the number of fish targets in the various size classes.

**SIZEVEC:** This vector contains the size separators that define the different size classes of fish in the acoustics data. The dimensions of the vector are number of size classes in the acoustic data +1. The most recent version of DEVIS saves this vector. Earlier versions of DEVIS and BSN\_FISH.WDG do not save this vector and for these data sets, GRP Map Maker computes SIZEVEC in the GRPACSTX.PRO procedure. The values in SIZEVEC are used to display the size range of the fish targets in the Graphics Display Window.

### 3.5.5 Graphics file (.GIF) output

The output from the Graphics Display Window can be saved in a .GIF format and imported into other programs. The graphics display windows shown in Figures 3, 4, and 5 were created by outputting .GIF files from GRP Map Maker. The .GIF files created for figures in this document are black-and-white, however by selecting a color table other than 0 (see **Operations menu**), users may control the colors used in both the Graphics Display Window and in the .GIF file outputs.

Although GRP Map Maker allows users to save graphics output to a .GIF graphics file, this is likely not the best way to create graphics output for most presentations. The .GIF output option available with GRP Map Maker is intended to quickly save files that may be useful in discussing results with collaborators or for similar uses. GRP Map Maker constrains the user's ability to control the graphics outputs. IDL has many powerful tools for creating high quality graphics for presentations and should be used to create graphics for slides or similar uses.

## **4.0 GRP MAP MAKER SUB-MENUS**

The menus that drive the computations and displays of GRP Map Maker are below the Top Menu level. The Operations and Foraging parameters are controlled from the same menu, but are presented separately below. Operations parameters allow the user to control the Processing Mode and the Graphics Window display. Foraging parameters allow the user to control the parameters used to compute the consumption of the foraging fish used in the computation of GRP. The Plots menu allows the user to display graphs of the computed data that may be useful in exploring the results of the analysis.

### **4.1 Operations menu**

Enter the Operations and Foraging parameters menu either from the Top Menu (option 2) or after entering a valid .GRPLIST file. The Processing Mode and the Graphics Display Window are controlled from the Operations Menu (Text Box 4). To change a menu option, enter the ID number at the prompt.

*Processing Mode (option 0):* To set for Single map (0) or batch processing (1) mode. The .GRPLIST file will differ for the two types of processing in that multiple data sets need to be specified for Batch processing. Batch mode is valuable for users to create many GRP maps where the light environment and foraging parameters will be the same for all transects.

*Window X dimension (option 2):* This option allows the user to change the horizontal size of the Graphics Display Window.

*Window Y dimension (option 3):* This option allows the user to change the vertical size of the Graphics Display Window.

*Graph X zoom (option 4):* The size of the transects shown in the Graphics Display Window can be adjusted with this option. This option controls the horizontal dimension of the maps in the display window. An integer value must be assigned. Assigning a non-integer value will cause the program to abort.

*Graph Y zoom (option 5):* This option controls the vertical dimension of the maps in the Graphics Display Window. An integer value must be assigned. Assigning a non-integer value will cause the program to abort.

*Graph Y spacing (option 6):* This option controls the amount of space between the maps in the Graphics Display Window. Note: it is possible to set this option to values that can cause maps to be overwritten onto each other or to be displayed outside the bounds of the window.

*Graph color table (option 7):* IDL allows users to select from 40 different color tables to display maps. This option allows the user to select the preferred color table. Commonly used color tables are 25 and 13. GRP Map Maker is written such that the background will be black for all color tables except for color table 0 (black-and-white); changing the background is not a user controlled option.

*Graph window number (option 8):* Many windows may be opened simultaneously in IDL. This option allows the user to change the window in which results are displayed. This option is included so that multiple displays can be viewed simultaneously. IDL automatically places the windows in the four corners of the monitor. Window numbers 0, 4, 8... will be placed in the upper right, numbers 1, 5, 9... in the lower right, numbers 2, 6, 10... in the upper left, and numbers 3, 7, 11... in the lower left. Window position may differ between UNIX and PC versions of IDL. Please refer to your IDL manual for specifics.

operations		
0	processing mode	0.000
		1.000
2	window X dim	350.0
3	window Y dim	350.0
4	graph X zoom	2.000
5	graph Y zoom	1.000
6	graph Y spacing	60.00
7	graph color table	25.00
8	graph window #	0.000
9	display GRP max	0.01000
10	display biomass max	0.5000
11	display fish density	0.1000
12	display lux max	50.00
13	character font	2.000
enter id of parameter to change or		
97: reprint menu option values		
98: finish, save new defaults		

**Text Box 4.** Operations menu parameters with values set from the demo data.

*Display GRP maximum (option 9):* The upper limit of the range for displaying GRP is controlled with this option. The lower limit is set to -0.005.

*Display biomass maximum (option 10):* The upper limit of the range for displaying biomass is controlled with this option. The lower limit is set to 0.001, and the display is set to a log scale.

*Display fish density (option 11):* The upper limit of the range for displaying numerical density of fish in the transect. The lower limit is set to 0.001; the display is on a log scale.

*Display light intensity maximum (option 12):* The upper limit of the range for displaying light intensity is controlled with this option. The lower limit is set to the minimum of the light array.

*Character font (option 13):* Font size of the text written to the Graphics Display Window is controlled here; commonly used size is 2.0.

## 4.2 Foraging parameters menu

The Operations and Foraging parameters menu is entered either from the Top Menu or after entering a valid .GRPLIST file (Top Menu option 2, see Text Box 2). The foraging parameters menu controls the parameters used to calculate consumption for GRP analysis (Text Box 5). Many of the parameters are not used for Potential Consumption or  $G_{\max}$  analysis. Which analyses require each parameter is noted in the descriptions below. To change a menu option, enter the ID number at the prompt.

The foraging parameters allow the user to manipulate key variables that affect the predator's encounter rate and consumption of prey. Although it is ultimately up to the user to select reasonable parameter values, some guidelines are provided below with the description of the menu options.

*Predator length (option 20):* Predator length is required for computing reactive distance (Appendix III, eqns. 20, 21) and for computing predator swimming speed. If no light data are available, and the light array is set to 0, then GRP Map Maker assumes that the forager's reactive distance is equal to its length to compute encounter rates with prey. Swimming speed is measured in body lengths/s, thus a predator length is required for this calculation. Used for GRP and  $G_{\max}$  analysis.

*Predator weight (option 21):* Bioenergetics equations are all species and size specific. To use the bioenergetics models, predator weight must be provided. Correct values for predator weight and length are critical for the analyses. This option is used for GRP, Potential Consumption, and  $G_{\max}$  analysis.

foraging		
20	predator length	450.0
21	predator weight	1110.
22	target l-w a	1.038e-06
23	target l-w b	3.400
24	hours of foraging	10.00
25	Cmax available	1.000
26	forage efficiency	0.1000
27	swim speed	1.000
28	target size class	0.000
29	surface light (lux)	1000.
30	Epar (lux extinction	0.07000
31	RD vs lux eqn	10.00
32	prey energy density	1800.
33		0.000

enter id of parameter to change or  
97: reprint menu options values  
99: finish, save new defaults

**Text Box 5.** Foraging parameters menu with values set from the demo data.



*Target length-weight (options 22 & 23):* To compute prey biomass, GRP Map Maker converts the length of the acoustic targets to a weight, then multiplies the weight by the absolute density of targets. Thus, a length-weight relationship is required for targets in the acoustic data. GRP Map Maker uses a simple equation for weight calculations:

$$W = a L^b \quad (3)$$

The parameters, *target l-w a* and *target l-w b* are the *a* and *b* values used in this equation. Users may select from a few predefined values for specified species or may enter their own values. Used for GRP and Potential Consumption analysis.

*Hours of foraging (option 24):* To compute encounter rate of predator and prey, the number of hours that the forager is assumed to be actively foraging must be provided. In doing this, the user is tacitly assuming that the environment being modeled is essentially constant during that period. For foragers, this assumption is generally valid for both nighttime and daytime periods. However, prey fish distributions commonly differ appreciably during these periods, so assuming that the prey environment is constant for a full 24-hr day is unlikely. Prey fish distributions can change drastically and quickly when modeling crepuscular periods. In these situations the hours spent foraging should be small to make the assumption of a constant environment valid. Used for GRP analysis.

*C<sub>max</sub> available (option 25):* Bioenergetics models assume a 24-h day for computation of C<sub>max</sub> and energetic costs. However, the number of hours spent foraging when computing GRP is typically less than 24 h. Some predators may achieve their entire daily consumption in less than 24 h, while others may need the full 24 h period to achieve C<sub>max</sub>. The user must decide the foraging characteristics of the species being modeled and select an appropriate fraction of C<sub>max</sub> to allow the modeled forager to achieve. C<sub>max</sub> is a fraction with a range of 0-1.0. Used for GRP and Potential Consumption analysis.

*Foraging efficiency (option 26):* Capture efficiency determines the fraction of encountered prey items that are captured by the predator and has a range of 0-1. It reflects both the predator's ability to effectively strike at prey, and the prey's ability to avoid a predator. Capture efficiency is commonly set to 1.0 for planktivores because zooplankton are ineffective at avoiding planktivorous fish. For piscivorous fish, capture efficiency is typically much lower than 1.0. Capture efficiency can have a strong effect on the predicted growth of the fish. This parameter is often calibrated to produce average values of GRP in the environment that are reflective of growth rates measured in the field. Values of this parameter can greatly affect GRP calculations (Mason and Brandt 1996). Used for GRP analysis.

*Swim speed (option 27):* Swimming speed is measured in body lengths/s and is another key variable in calculating predator encounter rates with prey. Predator swimming speed values generally range between 0.5 and 1.5 body lengths/s and will vary by predator depending on its foraging mode. A cruising predator will often be assigned a swimming speed of 1.0-1.5 body lengths/s, while a sit-and-wait predator may be assigned a swimming speed of 0.5 body lengths/s or lower. (Of course, a sit-and-wait predator would not be feeding in the pelagic zone, which would invalidate the GRP map as a measure of the fish's foraging/growth environment.) Used for GRP analysis.

*Prey size class (option 28):* When processing acoustic data with DEVIS, the size range of targets can be specified for size classification. The arrays of target length and density are dimensioned by NRPT, NSTR, and the number of size classes. GRP Map Maker allows the user to define which of the size class arrays

defines the prey fish available to the predator for GRP analysis or the foraging fish in Potential Consumption analysis. In addition, options are available that allow multiple size classes to define the fish population. For example, acoustic data may be grouped into three size classes of fish targets: small (12-50 mm), medium (50-200 mm), and large (200-1000 mm). GRP Map Maker allows users to select any one of these size classes to be used in an analysis, or users may select combinations of size classes. Users may want to group small and medium fish into a single prey population for GRP analysis. Alternatively, users may want to group medium and large fish into a single predator population for Potential Consumption analysis. When defining multiple size classes as the fish population, the program assumes that the length-weight relationship used to convert target length to fish weight is valid for both size classes. If this is not the case, then the user should not choose an option that defines more than one size class of fish as the fish population. Used for GRP and Potential Consumption analysis.

*Surface light (option 29):* Light intensity (lux) at the water surface and an extinction coefficient must be supplied ( $E_{par}$ , option 30) to compute a light array for the foraging model. The light array is critical for examining the effect of light intensity and water clarity on fish foraging and growth. Setting surface light intensity to 0 causes the light array to have 0 for all values. In this case, the fish reactive distance is set to the length of the predator and is assumed constant at all depths. When no light data are available, surface light is commonly set to 0. Used for some GRP analysis.

*$E_{par}$  light extinction coefficient (option 30):* To compute the light array for GRP Map Maker both surface light and an extinction coefficient,  $E_{par}$ , are required.  $E_{par}$  accounts for the amount of light lost as depth increases. Low values of  $E_{par}$  represent clear water, while high values represent turbid water. For example, the invasion of zebra mussels into Lake Erie caused a considerable clearing of the water column, and values of  $E_{par}$  measured in the lake changed from near 2.0 to near 0.5. Used for some GRP analysis.

*RD vs. Lux equation (option 31):* GRP Map Maker includes four menu options under the RD vs. Lux equation. The user may select one of two methods for computing prey length (Appendix III, eqn 23) and one of two equations. The first prey length option uses a prey length computed from the average length across all cells in the transect. The second prey length option uses the average length of prey in each cell to compute the predator reactive distance in that cell. The prey length may vary significantly across a transect. If the user wants to focus on the effects of light intensity on predator foraging, they may use the first method for including prey length in the predator reactive distance calculation. Including all of the cell-to-cell variability in prey length in the reactive distance calculation may overwhelm the light intensity variability and make an assessment of the importance of light intensity difficult.

The effect of light intensity (lux) on forager reactive distance may be described using one of two different equations (Appendix III, eqns 23, 24). The first equation is a simple sigmoid curve in which reactive distance decreases monotonically with decreased light intensity. This is the most common option. The second equation is a specialized intermediate-peak equation that shows a peak in predator reactive distance at intermediate light intensities and then decreases as light intensity continues to increase (Figure 6). Used for some GRP analysis.

*Prey energy density (option 32):* Users adjust the energy density value of prey (fish targets in the transect) with this option. The energetic density of prey often varies between species and between seasons. In bioenergetics models of fish growth the ratio of prey to predator energy density is a critical value. Used for GRP analysis.

### 4.3 Plots Menu

The Plots Menu contains a set of standard plots for users to explore their data.

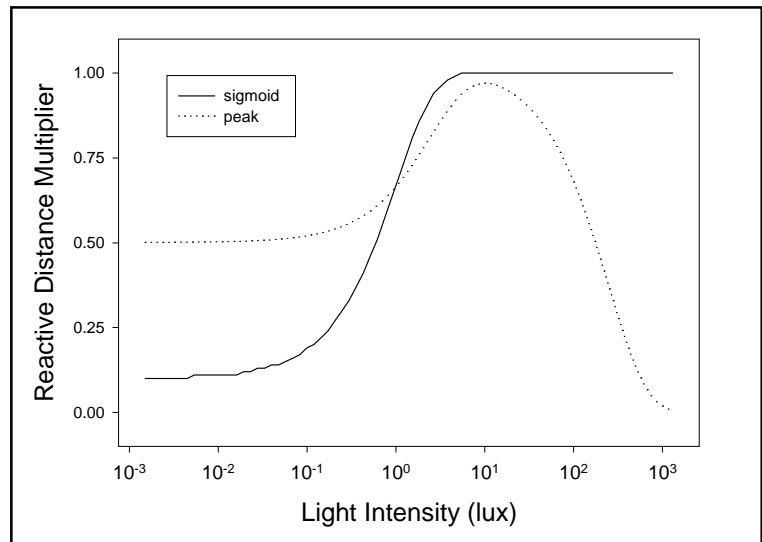
*Bioenergetics and length-weight (option 1):* Two plots are created here, one with two important bioenergetics measures and one with the length-weight measures of the target fish. The purpose of the plots is to help identify commonly made errors in parameter values. The bioenergetics plot shows the change in  $C_{max}$  and in respiration in relation to temperature for the selected forager species, and plot values of  $C_{max}$  and respiration for all cells in which fish targets are found. The temperature range covers only the range occupied by fish targets. *Note: this plot will not operate properly for Potential Consumption analysis.* The length-weight plot presents the length and weight for all fish targets found and provides an easy way to check the correctness of the length-weight parameters input into the Foraging Parameter Menu.

*Frequency histograms (option 2):* Three plots are generated here: frequency distributions of fish length, fish biomass, and GRP. Users are prompted to provide a length interval for the frequency distribution of lengths and to provide the number of bins in the biomass and GRP histograms.

*Fish length and density vs. depth (option 3):* Three plots are created from the length and density of fish targets with depth. The first plot is a simple cloud of points showing the mean fish length and depth of all cells with fish targets in the acoustic data transect. The second plot shows the mean length of fish found at each depth, and the third plot shows the total number of fish found at each depth in the acoustic data.

*Fish length and density vs. temperature (option 4):* Three plots are created from the length and density of fish in relation to water temperature. The first plot is a cloud of points showing the mean fish length and the water temperature in all cells with fish targets in the acoustic transect. The second plot shows a histogram of the mean fish length at each observed water temperature in the data set. The third plot shows a histogram of the total number of fish found at each water temperature in the acoustic data.

*RD vs. light intensity (option 5):* The relationship between fish reactive distance (RD) and light intensity is plotted so that users may check their equation selection. Relatively clean plots like those shown in Figure 6 will result only if the user chooses to use the average length of fish in the transect to compute predator RD. If the average length of fish within each cell is used for this computation, this plot will



**Figure 6.** Reactive distance modifiers in GRP Map Maker, foraging parameter option 31.

2D plot menu

- 1) bioenergetics and length-weight
- 2) frequency histograms
- 3) fish length and density vs depth
- 4) fish length and density vs temp
- 5) RD vs Light intensity
- 6) GRP vs prey biomass and temp

99) exit

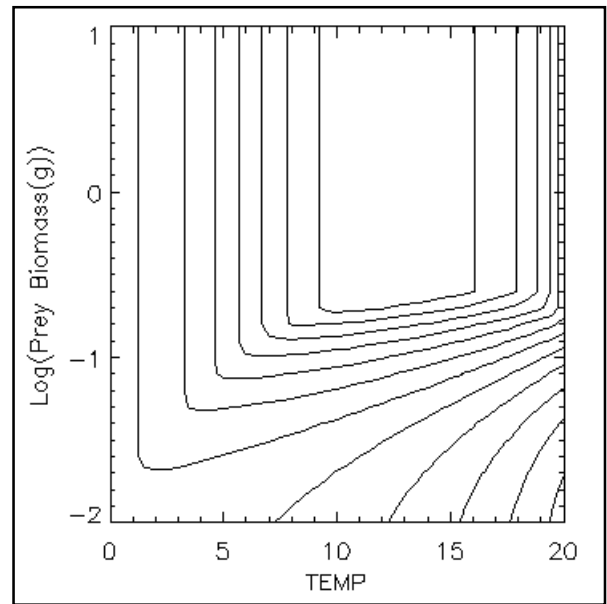
enter plot menu selection:

show considerable variability in RD for each value of light intensity because of the variation in fish length.

*GRP vs. prey biomass and temperature (option 6):*

This option produces a contour plot of the change in fish GRP as biomass density of fish and water temperature change (Figure 7). Users are prompted to define the water temperature range and prey biomass values for computing the contour plot. The plot clearly shows any variation that may occur in GRP over the temperature and prey density range shown. From the text outputs and the summary results file users can find the range of values present in their data.

Changes in the foraging model parameters will greatly affect this plot. The most important parameter is the foraging efficiency (parameter 26). GRP will not vary with prey biomass due to high foraging efficiency values. Users must exercise their best judgement in selecting values for this parameter. In addition, this plot will show that GRP will not vary across the transect with a narrow temperature range.



**Figure 7.** Contour plot of GRP vs water temperature and prey density. Data from Lake Ontario (D.W. Hondorp).

## 5.0 ACKNOWLEDGEMENTS

The programming code used in GRP Map Maker is the original work of Jeffrey A. Tyler, but the majority of equations and algorithms result from the efforts of others. Of note, a number of graduates students, technicians, and researchers have contributed to the overall development of growth rate potential (GRP) spatial modeling. Stephen Brandt played a seminal role in the conceptual development of GRP spatial models (Brandt et al. 1992; Brandt and Kirsch 1993; Goyke and Brandt 1993). Other key contributors include Andrew Goyke, Kyle Hartman, John Horne, Mike Jech, Jay Kirsch, Jiangang Luo, and Doran Mason. Eric Demers provided important assistance by checking the computer code for accuracy, uncovering coding errors, and providing ideas for user operation and model understanding. Maria E. Terra helped develop some of the functions for describing light intensity-reactive distance relationships.

All published applications of GRP spatial modeling to date have used acoustic data to describe prey fish abundance and distribution. The acoustic processing software that GRP Map Maker is designed to use was developed through the combined efforts of J. Michael Jech, Jiangang Luo, and Doran Mason, although their efforts were not always done in collaboration. GRP Map Maker was specifically designed to use the Digital Echo Visualization and Information System (DEVIS) acoustic processing software by Jech and Luo.

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## **APPENDIX I. Bioenergetics Equations**



The equations for bioenergetics models have been published in a variety of manuscripts, manuals, and reports. They are repeated here for users who are particularly interested in the details of GRP Map Maker. The presentation here is nearly identical to that of the Fish Bioenergetics Model v. 2.0 by Hewett and Johnson (1992). For a more complete discussion of bioenergetic models, see Hewett and Johnson (1992) or references cited therein.

Maximum Consumption ( $C_{max}$ ):

A limit on the total maximum daily consumption is given by the  $C_{max}$  equation. Experiments have found that  $C_{max}$  ( $g \cdot g^{-1} \cdot d^{-1}$ ) varies with fish weight (W) and with water temperature (T).

$$C_{max} = a W^b f(T) \quad (4)$$

The function that modifies  $C_{max}$  as water temperature changes [ $f(T)$ ] can take three different forms.

$f(T)$  version 1:

$$f(T) = e^{(\theta T)} \quad (5)$$

$f(T)$  version 2:

$$f(T) = V^X e^{(X(1-V))} \quad (6)$$

Where

$$V = \frac{T_m - T}{T_m - T_o}$$

$$X = \frac{(Z^2 (1 + (40/Y)^{0.5})^2}{400} \quad (7)$$

$$Z = \ln(\theta) (T_m - T_o)$$

$$Y = \ln(\theta) (T_m - T_o + 2)$$

$f(T)$  version 3:

$$f(T) = K_A K_B \quad (8)$$

Where

$$K_A = \frac{K1 L1}{1 + K1 (L1 - 1)} \quad (9)$$

$$L1 = e^{G1 (T - \theta)}$$

$$G1 = (1 / (T_o - \theta)) \ln\left(\frac{0.98 (1 - K1)}{0.02 K1}\right)$$

$$K_B = \frac{K4 L2}{1 + K4 (L2 - 1)}$$

$$L2 = e^{G2 (T_L - T)}$$

$$G2 = (1 / (T_L - T_m)) \ln\left(\frac{0.98 (1 - K4)}{0.02 K4}\right)$$

Consumption (C) by the predator is then computed as:

$$C = \begin{cases} C_{predict} & \text{if } C_{predict} > C_{max} \\ C_{max} & \text{if } C_{predict} \leq C_{max} \end{cases} \quad (10)$$

$C_{predict}$  = predicted consumption from the foraging model.

### Respiration:

Respiration is the amount of energy lost to metabolism by the fish. Total metabolic losses include both respiration and specific dynamic action. Fish Bioenergetics v. 2 (Hewett and Johnson 1992) deals with both respiration and specific dynamic action together because they combine to compute total metabolism. Here, I deal only with respiration and include specific dynamic action in the computation of other losses including egestion and excretion. This is done for computing reasons. Specifically, respiration is independent of consumption, but all other losses require consumption for their computation. The only time when this is important to the user is if they dig into the computer code that runs GRP Map Maker.

As with  $C_{max}$ , Respiration ( $R$ ) is a function of both fish weight ( $W$ ) and water temperature ( $T$ ). It follows the equation:

$$R = \alpha W^\beta f(T) ACTIVITY \quad (11)$$

There are two sets of equations with  $f(T)$  and  $ACTIVITY$  differing between the two sets.

$f(T)$  and  $ACTIVITY$  set 1:

$$f(T) = e^{(\theta T)} \quad (12)$$

$$ACTIVITY = e^{((T_o - (T_m T)) V)} \quad (13)$$

Where

$$V = \begin{cases} KI W^{K4} & \text{if } T > T_L \\ ACT e^{BACT \cdot T} W^{K4} & \text{if } T \leq T_L \end{cases} \quad (14)$$

$f(T)$  and  $ACTIVITY$  set 2:

$$f(T) = V^x e^{(x(1-V))} \quad (15)$$

Where

$$\begin{aligned}
V &= \frac{T_m - T}{T_m - T_o} \\
X &= \frac{(Z^2 (1 + (1 + 40 / Y)^{0.5}))^2}{400} \\
Z &= \ln(\theta) (T_m - T_o) \\
Y &= \ln(\theta) (T_m - T_o + 2)
\end{aligned}
\tag{16}$$

$$ACTIVITY = ACT \tag{17}$$

Other Losses: Specific Dynamic Action, Egestion and Excretion:

The equations used to compute losses other than respiration are generally simple equations. Losses resulting from specific dynamic action ( $S$ ) are largely a fraction of consumption ( $C$ ):

$$S = SDA (C - F) \tag{18}$$

Where  $SDA$  = species-specific fraction of energy not assimilated and  $F$  = species-specific rate of egestion.  $C$  is computed through the foraging model and calculation of  $C_{max}$  and  $F$  is computed as described immediately below.

Two sets of equations may be used to describe egestion ( $F$ ) and excretion ( $U$ ), although the first set is most commonly used.

Egestion/Excretion set 1:

$$\begin{aligned}
F &= FA C \\
U &= UA (C - F)
\end{aligned}
\tag{19}$$

In the two more complicated versions of egestion and excretion equations, the variable  $P$  is used.  $P = C_{predict} / C_{max}$  and is bounded 0-1.

Egestion/Excretion set 2:

$$\begin{aligned}
F &= \alpha_F T^{\beta_f} e^{\gamma_f P} C \\
U &= \alpha_U T^{\beta_U} e^{\gamma_U P} (C - F)
\end{aligned}
\tag{20}$$

There are, in fact, three sets of equations that have been used to describe egestion and excretion in fishes and are implemented in Fish Bioenergetics v. 2 (Hewett and Johnson 1992) and in v. 3 (Hanson et al. 1997). The third set of equations requires knowledge of diet composition and the fraction of indigestible

material in each prey type. Because this diet information is often unknown, the third set of equations has not been implemented in GRP Map Maker.

### Energy density

The model presented by Hewett & Johnson (1992) and implemented in GRP Map Maker uses the energy density of predators and prey to convert grams of prey consumed into grams of growth in the predator. Predator energy density is computed two ways, the first is a simple constant entered by the user. The second method of calculating predator energy density ( $ED_{predator}$ ) uses a simple linear equation:

$$ED_{predator} = \alpha + \beta W \quad (21)$$

The value of parameters a and b change at a prescribed weight “cutoff”.

## **APPENDIX II. Parameters for GRPPARAM.PRO**

**Table A.II.1.** Bioenergetics model parameter values used in GRP Map Maker that are created with GRPPARAM.PRO.

parameter	variable name & equation number	description
spname	none	name of the species
$C_{max}$ eq#	none	$C_{max}$ equation number, Hewett and Johnson
CA	a, eqn 4	constant on W
CB	b, eqn 4	exponent on W
CQ	q, eqn 5	constant on T
CTO	$T_o$ , eqns 7, 9	$C_{max}$ optimal temperature
CTM	$T_m$ , eqns 7, 9	$C_{max}$ maximum temperature
CTL	$T_L$ , eqns 7, 9	$C_{max}$ lower temperature
CK1	K1, eqn 9	$C_{max}^1$
CK4	K4, eqn 10	$C_{max}^1$
Resp eq#	none	Respiration equation number, Hewett and Johnson
RA	$\alpha$ , eqn 11	constant on W
RB	$\beta$ , eqn 11	exponent on W
RQ	$\theta$ , eqn 12	constant on T
RTO	$T_o$ , eqns 13, 16	Respiration optimal temperature
RTM	$T_m$ , eqns 13, 16	Respiration maximum temperature
RTL	$T_L$ , eqn 14	Respiration lower temperature
RK1	K1, eqn 14	constant on W
RK4	K4, eqn 14	exponent on W
ACT	ACT, eqns 14, 17	activity multiplier
BACT	BACT, eqn 14	exponent on activity multiplier
SDA	SDA, eqn 18	fraction of consumption lost to SDA

**Table A.II.1.** continued

parameter	variable name & equation number	description
Egest/Excr eq#	none	egestion/excretion equation number
FA	FA, eqn 19, $\alpha_F$ eqn 20	constant: consumption (16), T (17)
FB	$\beta_F$ , eqn 20	exponent on T
FG	$\gamma_F$ , eqn 20	constant on P
UA	UA, eqn 19, $\alpha_U$ eqn 20	constant: consumption (16), T (17)
UB	$\beta_U$ , eqn 20	exponent on T
UG	$\gamma_U$ , eqn 20	constant on P
Cal Den eq#	none	predator caloric density equation
caloric den	$ED_{\text{predator}}$ , eqn 22	predator energy density
Alpha 1	$\alpha$ , eqn 21	$\alpha$ for $W < \text{cutoff}$
Beta 1	$\beta$ , eqn 21	$\beta$ for $W < \text{cutoff}$
cutoff	none	value of W for switching between a and b
Alpha 2	$\alpha$ , eqn 21	$\alpha$ for $W > \text{cutoff}$
Beta 2	$\beta$ , eqn 22	$\beta$ for $W > \text{cutoff}$
prey cal den	$ED_{\text{prey}}$ , eqn 22	prey energy density
<sup>1</sup> See Hewett and Johnson (1992) or Thornten and Lessem (1978) for description.		

### **APPENDIX III. Foraging Equations**



The foraging model used in GRP Map Maker v. 2.8 is based on the model originally derived by Gerritsen and Strickler (1997) and subsequently used in a variety of models (DeAngelis et al. 1991, Brandt et al. 1992, Aksness and Giske 1993, Rose and Cowan 1993, Giske et al. 1994, Rose et al. 1996, Tyler and Rose 1997). The model is derived for a planktivorous fish, but here we apply it to all fishes.

The foraging model assumes that fish may search all of the volume that they see and that they then capture some fraction of the food in that volume. Predicted consumption is, thus, computed as:

$$C_{predict} = VS PD C_{eff} \left( \frac{ED_{prey}}{ED_{predator}} \right) \quad (22)$$

$VS$  = volume searched ( $m^3$ ),  $PD$  = prey density ( $g/m^3$ ),  $C_{eff}$  = capture efficiency, the fraction of encountered prey that are consumed by the foraging fish,  $ED$  = energy density of prey and predator.  $C_{predict}$  is in units of  $g$  and must be converted to ( $g \cdot g^{-1} \cdot d^{-1}$ ) by dividing out predator weight. The encounter rate of predators with prey is simply the volume searched times prey density ( $VS \cdot PD$ ). Multiplying by  $C_{eff}$  converts encounter rate to capture rate, and multiplying by the ratio of prey and predator energy densities accounts for the fact that prey and predator energy densities generally differ. Differences in energy density between predator and prey can have a strong effect on fish growth and need to be accounted for (Stewart and Binkowski 1986, Hartman and Brandt 1995).

The volume searched ( $VS$ ) is defined as that of a cylinder with a radius equal to the reactive distance ( $RD$ ) of the fish and a length equal to the distance swum in the modeled foraging period.

$$VS = \frac{2 \pi RD^2 SS L TF}{10^9} \quad (23)$$

$SS$  = swimming speed of foraging fish in body lengths/s,  $L$  = length of the fish (mm),  $TF$  = time spent foraging (sec), dividing by  $10^6$  converts volume units from  $mm^3$  to L.

The forager's reactive distance is computed one of two ways. If night data are used, then the model assumes that no light data are available for visual foraging. In this case the model assumes that  $RD = L$  and that all prey detection is done simply by use of the lateral line. If light data are available, the model assumes that the foraging fish is a visual feeder and that  $RD$  follows the formulation of Breck and Gitter (1983):

$$RD = \frac{L_{prey}}{2 \tan(\alpha / 2)} \quad (24)$$

$L_{prey}$  = length of the prey,  $\alpha$  = visual acuity (min) of the predator and is based on Guma'a (1982):

$$\alpha = \begin{cases} 168.8 - 0.94 (L / 10) & \text{if } L < 1265 \\ 50.0 & \text{if } L \geq 1265 \end{cases} \quad (25)$$

For use in computing  $RD$ ,  $\alpha$  must be converted to radians, multiplying by  $(\pi / 180 * 1/60)$  converts to radians.

To account for the effect of light intensity on fish reactive distance, GRP Map Maker modifies the reactive distance calculation by a factor with range 0-1. Thus, when light intensity is assumed to affect fish foraging:

$$RD = RD LI_{fac} \quad (26)$$

Two light intensity factors ( $LI_{FAC}$ ) have been implemented in GRP Map Maker, the first is a simple sigmoid relationship based on data from Howick and O'Brien (1983).

$$LI_{fac} = 1.0 - 0.8994 e^{-1 LI} \quad (27)$$

$LI$  = light intensity (lux). The second version of  $LI_{FAC}$  is based on data from Ali and Anctil (1977):

$$LI_{fac} = \frac{(w + x) (e^{-x(LI - z)} - e^{-y(LI - z)})}{y - x} \quad (28)$$

where  $w$ ,  $x$ ,  $y$ , and  $z$  are parameters with values:  $w = 1.0184$ ,  $x = 0.3936$ ,  $y = 0.0041$ ,  $z = -1.7306$ .

**APPENDIX IV. TEMP\_FILL.PRO**

The program `TEMP_FILL.PRO` was written by Darryl Hondorp and Mike Jech to take temperature data from either cast profiles or tow-yoed profiles from an undulating sampler and create the array `MEANTEMP` that is used by GRP Map Maker. Below is the memo from D.W. Hondorp describing `TEMP_FILL.PRO`.

#### Memorandum

To: All current and would-be spatial modelers  
From: dwh  
Re: Temperature Interpolation Program

#### Modeling Group:

A while back, Mike J. and I wrote a little program that allowed you to use `interp3.pro` with CTD cast data (as opposed to tow-yow CTD data). I promised several of you that I would combine the new program with `interp3.pro`, so that we would have one program that met all of our needs for temperature interpolation. Over the past couple of days, I have written that program.

The new program is called `temp_fill.pro`. This program calls three procedures: `stackfiles.pro`, `countlines.pro` and `telev.pro`. Most of you already have the path to `telev.pro` in your Sun account start-up files so you will probably only need to copy `temp_fill.pro`, `stackfiles.pro` and `countlines.pro`. `Stackfiles.pro` and `countlines.pro` are needed to handle CTD data in cast form.

Regardless of what form your temperature data is in (cast or tow-yow), you will need to know the following information in order to run `temp_fill.pro`:

1. The temperature data file must be some sort of space or tab-delimited text file where column 1 is a relative or absolute measure of horizontal distance (x), column 2 is the depth (z), and column 3 is the temperature at the specified x,z coordinate.
2. You must know the dimensions of the acoustic array you wish to fill with temperature values (i.e., **nrpt** and **nstr**).
3. You must know the path and filename of the `.idldat` file that contains `>wc=` for the transect you're interested in.
4. You must know the vertical bin size of the acoustic data (the value is usually between 0.5 m and 2.5 m).
5. You must know the depth at which the acoustic data starts. Remember: you may have temperature data starting at the surface, but you do not have acoustic data until depth = 2.0-4.0 m. The sum of the x-ducer depth and the blanking distance should give you the appropriate value.
6. Do not give the output filename an extension; the extension `.idldat` is added at the end of the program.

### For tow-yow (or OPC) data:

In addition to the above information, you need to know the path and filename of the OPC data file.

### For cast data:

1. You must make sure that the columns in the data file contain the appropriate information.

- Using Excel or your favorite spreadsheet, you will have to add a column that contains horizontal distance information to the Sea-Bird ascii files. I determine which column the cast occurred in and use the column numbers as my measure of horizontal distance. Suppose your Sea-Bird file looks like:

```
0.5 23.0
1.2 22.9
2.5 21.0
4.0 20.7
```

- Suppose this cast occurred in column 43 of the acoustic data array. You would then have to add a third column such that the new file looked like:

```
43 0.5    23.0
43 1.2    22.9
43 2.5    21.0
43 4.0    20.7
```

- Now, the data file contains horizontal distance in the first column, depth in the second column and temperature in the third column. The last correction you may have to make concerns temperature values at depths for which you have no acoustic data. Suppose x-ducer depth = 0.5 m and blanking distance = 0.5 m. This means you do not have acoustic data from the surface to depth =  $0.5 + 0.5 = 1.0$  m. Temperature values from the surface to a depth of 1m are invalid and must be eliminated. The final, corrected text file should look like:

```
43 1.2    22.9
43 2.5    21.0
43 4.0    20.7
```

- Once you've got a set of properly-formatted temperature files, you'll have to create a list-file containing the path and filename for each cast. The order of the casts in the list-file doesn't matter as long as you gave a cast the appropriate horizontal distance marker. The list-file filename should have the extension *.list*.

### Output:

Believe it or not, only one variable is saved after all this. The variable, **meantemp**, is a 2-dimensional array that contains the temperature of each cell in an acoustic array. Hopefully, this is the information you were after!

## **APPENDIX V. Demonstration**

A set of acoustics data, temperature data, menu and .GRPLIST files is available in a directory named DEMO for users to work with while getting familiar with GRP Map Maker. The files that need to be present to run the demo are:

DEMOACOUSTX.IDLDAT	:	acoustics file
DEMOTEMP.IDLDAT	:	water temperature file
DEMOMENU.DAT	:	menu file
DEMO.GRPLIST	:	.GRPLIST file

Users are welcome to copy these files for their own uses or use them in the directory that they exist. Any uncertainty about the format of files, particularly the .GRPLIST file, may be cleared up by taking a look at the demo file. To examine the format of the data in the acoustics and temperature files, simply enter:

```
IDL> restore, "demoacoustix.idldat"  
IDL> restore, "demotemp.idldat"
```

and use IDL's help to view the data arrays contained in the files.

Users will need to have the name of the directory containing GRP Map Maker v. 2.8 in their path to run the program. I suggest organizing your files such that GRP Map Maker has its own directory that includes only the program files needed to run the program. Data and outputs should be kept separate from the program files. For users on UNIX computers, the IDLPATH in the .CSHRC will need to include the GRP Map Maker directory to operate.

To run the demonstration, run GRP Map Maker v 2.8 enter:

```
IDL> .run grpmap28
```

Enter demo for the .GRPLIST file name. GRP Map Maker will then present the Operations and Foraging menus (Tables 2 and 3). Change menu options at will and view the results that are presented in the display window and on the text output. Working with the demo data set will allow users to become comfortable with GRP Map Maker before having to use their own data.

A few options may cause problems for users working with the demonstration dataset. This dataset only includes one set of acoustics and temperature data and is really designed to be used in GRP Map Maker under Single map mode. However, users can select Batch mode for this data set, and it will process the file and save it automatically as described in the users guide for Batch mode.

## **APPENDIX VI. Creating figures with data from GRP Map Maker**



Although the display of GRP Map Maker can be tailored to users' desires, the program is not designed to produce figures of GRP maps. However, the data stored in the .IDLGRP file can be easily used to create a figure for presentation. The main tool for creating a figure is the TELEV command (by J. Kirsch) and for saving output to a .GIF file the WRITE\_MAC command (J. Kirsch). Syntax for these two commands is:

```
TELEV, VAR, WC, XPOS, YPOS, MIN, MAX, XZOOM, YZOOM, SCALE
    var:          array to be displayed
    wc:           array of cells used to identify water column
    xpos:         horizontal position of lower left corner of map
    ypos:         vertical position of lower left corner of map
    min:          minimum value for display range of var
    max:          minimum value for display range of var
    xzoom:        horizontal magnification factor of map display (integer value only)
    yzoom:        vertical magnification factor of map display (integer value only)
    scale:        linear (0) or log (1) scale of map display
```

```
WRITE_MAC, 'OUTPUT.GIF', WINDOWNUM
    output.gif:   name of output file, must be inside ' '.
    windownum:   number of the IDL display window with figure.
```

Below is a program (in the demo directory) that will produce a .GIF file.

```
; demopic.pro

!order=1                ; orients the maps correctly
loadct,25               ; selects color table
white0                  ; sets background to white
window,0,xsize=500,ysize=600 ; opens and sizes display window
yinc1=100               ; used in telev to place maps on display window
ypos0=100               ; set origin for first map

restore,'demoacoustx.idlgrp' ; read data file

telev,grp,wc,50,ypos0 + 3*yinc1,-0.0022,0.004,3,2,0 ; display GRP
telev,biodens,wc,50,ypos0 + 2*yinc1,.002,.005,3,2,1 ; display biodens
telev,lightarr,wc,50,ypos0 + yinc1,0.001,200.,3,2,1 ; display light array
telev,meantemp,wc,50,ypos0,min(meantemp),max(meantemp),3,2,0 ; display water temp

scalen,200,scl          ; create scale
tvsc1,scl,100,100      ; display scale

; to write file:
; write_mac,'demopic.gif',0

end
```

## **APPENDIX VII. GRP Map Maker v. 2.8 Upgrade Notes**

### *Changes in the menu*

The menu structure of GRP Map Maker has evolved over the various versions. GRP Map Maker v. 2.8 starts users at the Top Menu from which all data inputs and other menus are reached. Previous versions started by asking users to input a .GRPLIST file and proceeded directly to the Operations and Foraging Menu. From the Top Menu, users are provided more control over data inputs and outputs than in previous versions. Of note is the addition of the Plots Menu where users may create a set of graphs for exploring the data and the GRP analysis.

### *Automatically detecting DEVIS version*

Users will note that in GRP Map Maker v. 2.8 they are no longer required to input the version of DEVIS used to process their acoustics data as was required in previous versions. Also, the Operations Menu is missing option 1 where users once input the DEVIS version used to process the acoustic data. GRP Map Maker v. 2.8 is written so that it can accept input from any of the versions of DEVIS written prior to October 1998. The code in GRPACSTX.PRO restores the acoustics data file and transfers the data stored by DEVIS into standard variables for analysis with GRP Map Maker.

### *Platform notes*

GRP Map Maker was developed on a UNIX workstation, but v. 2.8 has been tested and will run effectively on personal computers as well. Users will notice that the tables and menus may not line up properly when GRP Map Maker is run on a PC. For GRP Map Maker to produce clear tables on the PC, users should select a non-proportional font (e.g. Courier 10 pt) to use for their output in IDL. Proportional fonts cause the tables to be misaligned when written to the IDL output window. Formatted text outputs from GRP Map Maker have been modified so that they are readable when the program is run from either a UNIX workstation or PC.