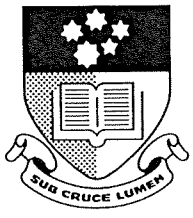
Modelling Prawn Larvae Dispersion and Settlement in Spencer Gulf—Technology Transfer

J.B. Nixon and *B.J. Noye*



FISHERIES
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Project 95/136

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ii Non-Technical Summary

The western king prawn (*Penaeus latisulcatus*) is a commercially trawled pelagic species in Spencer Gulf, South Australia. On a world-wide basis, this fishery is the major producer of western king prawns. It has been valued at approximately $AUD40 million per annum and approximately 90% of the catch is exported.

Trawlers manned by members of the Spencer Gulf & West Coast Prawn Fishermen's Association (SGWCPFA) operate on days of the year predetermined by fisheries management officers at the South Australian Research and Development Institute (SARDI) and are restricted in their efforts in terms of periods open to fishing, numbers of vessels trawling, haul sizes taken, ship and equipment types used, and individual prawn lengths allowed, etc. In order to set these restrictions so as to successfully manage such an economically significant resource, management needs an in-depth understanding of the factors which structure recruitment to nurseries and the fishery. Larval dispersion and the level of reproductive depletion of key spawning areas by fishing are considered by SARDI to be important factors which affect recruitment to the fishery.

At some point in each prawn's life, it will reach a maximum biovalue. The regime developed by SARDI of sampling and stock harvesting at key areas in Spencer Gulf and during key times of the year has aimed at achieving as close to this maximum as possible. The management of a fish resource becomes in this sense closer to crop or forest husbandry, whereby the producer waits for the best biological and economic conditions to reap the benefits. Strategies can be designed to target best market periods providing that an understanding of the fundamental processes which structure recruitment to the fishery are better understood. Significant economic benefits can thus accrue by allowing prawns to grow to a more valued size, but there is a need to develop a harvesting strategy which has a stronger biological basis.

The coupling of modelling studies of larval dispersion with empirical field testing will provide a better understanding of the importance of dispersion and other factors which structure recruitment to fisheries. In this project, rather than attempt a near impossible statistical analysis of expensive field measurements to determine the spread of larvae from known sources to possible destinations, a deterministic mathematical modelling approach was taken.

A tidal model solves the mathematical equations governing shallow sea motion, using highly specialised numerical techniques, to determine the tidal currents. The model predictions are at much greater spatial and temporal resolution than is economically feasible—and physically possible—by field measurement using moored current meters. The larval dispersion model solves the mathematical equations governing larval dispersion based on transport in currents produced by tides and winds, diffusion due to small-scale eddy turbulence, and mortality due to predation, etc. It does this using specialised numerical techniques, to determine larval concentrations to a spatial and temporal scale chiefly limited only by the accuracy in specification of program inputs parameterising larval biological factors such as the initial patch of fertilised prawn eggs, and the capacities of the computer on which the model is executed.

These models were ported from Sun Microsystems SPARC computers in the Department of Applied Mathematics ("the Department") at the city campus of The University of Adelaide to a Digital Equipment Corporation ALPHA computer at the Roseworthy campus. They were then transferred to an ALPHA computer at the South Australian Aquatic Sciences Centre (SAASC) laboratories of SARDI. The models were also documented for the first time, and many improvements were made, particularly in user-computer interaction and error handling. Many examples were also constructed to aid new users of the model.

iii Background

Section iii.1 summarises the background provided in the original application (Noye and Nixon 1995). Section iii.2 includes changes which emerged during the research.

iii.1 Original Background

The background to this application was defined by the project

> **"91/004: Prawn Larvae Dispersion and Settlement in Spencer Gulf–Management Implications"**

undertaken by the Applicant previously, and funded by the Fisheries Research and Development Corporation (FRDC) for 01/07/92–30/06/95 (Noye and Nixon 1993).

The proposal was to modify the existing prawn larvae dispersion modelling computer software and to document it. This would effectively transform a sophisticated numerical modelling suite of programs from a form serviceable for use by technicians conversant with it's workings and underlying algorithms/mathematical concepts to explore the dynamics of the modelled processes, into a more user-friendly form appropriate for use by fisheries research officers and industry personnel more concerned with management/decision making. The specific needs of the end users would be determined through extensive consultation, implemented by the Applicant and tested on-site to the satisfaction of the Direct Beneficiaries.

iii.2 Background Changes

The specific needs of the end users were unable to be determined since extensive consultation did not eventuate during the Project period, for reasons outlined below. More general needs of any end user, however, were determined through consultation with the existing user base of the modelling suite. Changes to the modelling suite to incorporate these needs were not able to be tested on-site to the satisfaction of the Direct Beneficiaries, for reasons outlined below. These changes were, however, implemented by the Applicant and tested on-site to the satisfaction of the existing user base.

The reasons why extensive consultation and on-site testing were not possible are compound. It was not determined until late into the project that telecommunication between the Department and the SAASC of SARDI sites was not possible—the original application assumed telecommunication *would* be possible. It was also not determined until late into the project that procurement of a suitable computer language compiler at the SAASC site was well beyond budget—the original application assumed a low cost compiler *would* be available within budget. Although adequate solutions to these problems were found, and some end user consultation and subsequent testing were carried out, extensive consultation with and on-site testing specifically for SARDI personnel were not possible.

iv Need

Section iv.1 summarises the need as defined in the original application (Noye and Nixon 1995). There were no changes which emerged during the research.

iv.1 Original Need

Computer models simulating advection, diffusion, and mortality processes affecting the dispersion of penaeid prawn species in the egg and larval life-cycle stages have been developed by the Applicant to determine the proportion of prawn larvae which successfully travel, via sea currents, from off-shore spawning grounds to settle in near-shore nursery grounds. These models have been deemed qualitatively accurate in their predictions by SARDI research officers (Nixon 1996).

The models incorporate user defined parameters and input options in the computer software which result in a number of values to be set and choices to be made by the modeller from a number of possibilities. Model input derived from field data concerning initial larvae concentrations for particular spawning events influence the effective choice of preferred input options and values. The options taken and values used effect model output. Comparison of model prediction data with that derived from field measurements of larvae concentrations for particular spawning events influence the effective choice for optimal input options and values.

There is thus a need for fisheries management and research officers themselves to play an interactive role in adjusting parameters used in the model, utilising their experience and appropriate field data as it becomes available, to continually calibrate the model ensuring that simulations are as close to reality as the basic concepts of the mathematical framework of the model allow. Such an interactive information exchange between model and modeller also allows scenarios and "what if" analyses to be undertaken as well as specific larval dispersion events to be simulated, enabling fisheries management and research officers to obtain valuable insight into the physical processes at work. This information would be less efficiently communicated if results for only a few pre-determined characteristically representative and/or unique events or single past specific events were presented, as were produced in the final stages of **Project 91/004** (Nixon and Noye 1996). It is in this way that fisheries management and research officers will make the best use of the many man-years of effort that the Applicant has put into the mathematical and numerical modelling and software development associated with the tide and dispersion modelling programs which are the basis of this project.

The Applicant is of the opinion that an enthusiastic appreciation by the Direct Beneficiaries of the applied usefulness of the results of the computer models is advantageous to industry and fisheries management, and that this can best be engendered through interactive participation in the modelling process itself by SARDI research officers and industry personnel. The Applicant is also of the opinion that as new field data is collected, processed and analysed by fisheries management and research officers in the future, it should be able to be used to further improve both their understanding of the physical processes modelled and the intrinsic accuracy of the model itself, and that this can only be accomplished if continued "hands-on" access to the computer model is provided to them.

v Objectives

The objectives were achieved to an extent commensurate with the quantity and quality of data available by which to make such an assessment.

v.1 Original Objectives

The objectives as they appeared in the original application were stated as:

> To provide a useful fisheries management tool which is suitable to the specific purposes of the Direct Beneficiaries. This tool will utilise existing and forthcoming field data and other biological information and will combine this with mathematical modelling methods developed during **Project 91/004** to produce a representation of the processes and results of larval dispersion that can be more easily interpreted than historical statistical data on its own. Forecasting, hindcasting, and "what if" analyses will all be possible.

and there were no changes to these original objectives.

vi Methods

In the following, the word "port" (standard computer software terminology) is used to mean "the transfer of software source code listings from one computer hardware platform to another [in this case SPARC to ALPHA] and the re-writing of this code to run on the new platform".

Section vi.1 describes the methods used in the research. Section vi.2 highlights changes made during the research from those described in the original application.

vi.1 Method Description

The existing prawn larvae dispersion model (`prawn`, Nixon 1997), three-dimensional tidal model (`ted`, Nixon and Bills 1997) and many other support applications (too many to list here) exist in the form of computer programs. The original programs were written in the FORTRAN 90 computer language (`f90`) on Sun Microsystems SPARCstation workstation computers (SPARCs) running the BSD UNIX 4.3.1 operating system (OS), installed at the Department of Applied Mathematics of The University of Adelaide. The models were required to be at least partially re-written in `f90` in order to execute on Digital Equipment Corporation (DEC) Alpha workstation computers (ALPHAS) running the Open Software Foundation (OSF) UNIX OS, installed at the Roseworthy campus of The University of Adelaide. This required a `f90` compiler for ALPHA machines and, as was envisaged, changes to the existing program source code.

Modification to these programs in terms of user-computer interaction and input/output and, within limitations, in terms of the underlying features were carried out to provide a user-friendly interface to the satisfaction of the Applicant. This aspect of the project required UNIX shell scripting using the `tcsh` scripting language.

Graphics output was implemented in two forms. Black and white PostScript stills output may be produced by the `draw` (Beard and Nixon 1997) program, a `f90` SPARC to ALPHA port of which was required. This necessitated the `f90` SPARC to ALPHA porting and modification of the existing `ted2draw` (three-dimensional tidal model *and* prawn larvae dispersion model) static graphics post-processing program. Colour computer animated output may be produced by the Grid Analysis and Display System (GrADS) program (Doty 1995), an ALPHA executable of which is available to the Direct Beneficiaries. This necessitated the `f90` SPARC to ALPHA porting and modification of the existing `prawn2grads` (prawn larvae dispersion model) and `ted2GrADS` (three-dimensional tidal model) dynamic graphics post-processing programs.

Documentation for the models and the support programs have been provided as hardcopy, and as PostScript files for viewing online. These documents were produced using a combination of the $\mathcal{AMS}$-LaTeX (Anonymous 1995), `xdvi` (Cooper et al. 1990), TeX (Knuth 1986), LaTeX (Lamport 1994), BibTeX (Patashnik 1988), `dvips` (Rokicki 1993), and `ghostview` (Theisen 1992) systems and the model and support programs themselves. The existing documentation for the `draw` and `ted` programs was updated, as required. Documentation for the `prawn`, `ted2draw`, `prawn2grads`, `ted2GrADS`, and other programs was also written.

vi.2 Method Changes

Since it was not possible to telecommunicate between The University of Adelaide's Department of Applied Mathematics and SARDI's SAASC, the SPARC to ALPHA port was instead carried out remotely at The University of Adelaide's Roseworthy campus. The final executable models and documentation were then transferred by tape from the Department to the SAASC by post.

Since procurement of a suitable computer language compiler at the SARDI site was determined to be well beyond budget, program modifications were generally carried out to the satisfaction of the Applicant rather than the Direct Beneficiaries specifically. This aspect of the project required UNIX shell scripting using the `tcsh`—and not the `sh`, `csh`, or `perl`—scripting languages.

The `f90` SPARC to ALPHA porting and modification of the existing `prawn2draw` (prawn larvae dispersion model) static graphics post-processing program was not required. The capabilities of that program were, instead, incorporated into the modified and generalised `ted2draw` (three-dimensional tidal model *and* prawn larvae dispersion model) static graphics post-processing program.

The hardcopy documents were produced without the use of the $\mathcal{A}_{\mathcal{M}}\mathcal{S}$-TEX (Spivak 1986) and PICTEX (Wichura 1987) systems.

Documentation for the `prawn2draw` program was not written because, since the capabilities of that program were incorporated into the `ted2draw` program, for which full documentation was produced.

vii Detailed Results

Detailed results of the research follow. No statistical analyses were undertaken during the research.

vii.1 Form of Results

Results are exclusively in the form of a compiled suite of user-friendly computer programs, complete with extensive examples, and thorough documentation in hardcopy and electronic form. One or more SARDI research officers may be self-trained in the use of the program suite and, to a lesser extent in their internal workings, by executing and modifying the examples supplied, and studying the user-guide and technical background documentation forwarded.

viii Benefits

SARDI research officers and the Spencer Gulf prawn fishing industry will benefit directly from the research. Differences in terms of prices, costs, and/or catch that the adoption of the research results will make to fisheries management and industry profitability are to be quantified by fisheries officers at SARDI responsible for managing the fishery as a sustainable resource. Section viii.1 quantifies non-market benefits of the adoption of the research results.

The benefits and beneficiaries are exactly those identified in the original application.

viii.1 Non-Market Benefits

One non-market benefit of this project is that computer models of larvae dispersion are available to SARDI research officers. On running these models, officers will be in a better position to manage the Spencer Gulf prawn fishery as a sustainable resource, given the detailed knowledge of larval movements during the early stages in the prawn life cycle that the models provide.

The mathematical model of prawn larvae dispersion is considered to be an important aid to developing an increased understanding of the processes which determine recruitment to nurseries and of the population dynamics of the prawn fishery. The Direct Beneficiaries will gain improved theoretical and practical insight into prawn larvae dispersion processes. Thus benefits are both academic and applied in nature.

It is hoped that, through the efforts of SARDI research officers, other Australian and international fisheries management and research officers will be made aware of the benefits of numerical modelling as a supplement to the more traditional statistical and process modelling approaches practised in many fisheries management organisations worldwide.

ix Intellectual Property

Intellectual property arising from the research is identified by the larval dispersion model itself and is quantified by the computer code describing this model. The FRDC and Applicant agreed that the Applicant would not supply source code for any of the developed software, excepting shell script language texts. Support after the Completion Date will not exist and, subsequently, software at the end of the development period has been supplied on a strictly "as is" basis only.

All other intellectual property will be realised on the adoption of the research results by fisheries management officers at SARDI. Commercially significant developments are also to be quantified by fisheries officers at SARDI responsible for managing the fishery as a sustainable resource. Patents applied for or granted, and licences, etc. total zero.

x Further Development

This entire project was one primarily concerning transfer of technologies which existed at the time of the completion date of the **Project 91/004**. Thus, recommended steps that may be taken to further develop, disseminate, or to exploit commercially the results of the research involve further calibration and validation of the model and/or require comparison of simulation results with field measurements undertaken by SARDI fisheries research officers.

Partly due to the lack of consensus in the literature concerning many biological phenomena associated with prawn species larvae in general—and lack of appropriately conclusive information pertaining to *Penaeus latisulcatus* larvae in Spencer Gulf in particular—calibration of model inputs parameterising such biologically based behaviour should be carried out by SARDI research officers. Simulation results should also be validated by comparison with experimental data. It should be pointed out once again, however, that the underlying algorithms of the dispersion model have been proven to be *theoretically* at least as accurate as those of the tidal model—the *practical* accuracy of which is well established.

Only after comparison with SARDI larval dispersion and postlarval settlement data can an accurate assessment of the prawn larvae dispersion model results be made, from which management implications can then be inferred.

xi Staff

The following staff have been employed on the project.

Staff Employed	
Project Supervisor:	B.J. Noye, Ph.D., B.Sc., A.U.A., Dip.Ed.(Sec)
(Principal Investigator)	Associate Professor of Applied Mathematics
Computer Programmer/Modeller:	J.B. Nixon, Ph.D., B.Sc.(Hons)
(Co-Investigator)	Research Officer
Prawn Biologist:	M. Kangas, Hons. B.Sc.(M.Bio.)
(Co-Investigator)	SARDI Research Officer

Table xi.1: Staff employed.

xii Final Cost

The FRDC Statement of Receipts and Expenditure, and details of other contributions made to the Project, follow.

STATEMENT OF RECEIPTS AND EXPENDITURE
Fisheries Research and Development Corporation
Statement of Receipts and Expenditure for the period ending 31 December 1996

Name of Research Organisation	FRDC Project Number	Title of Project
The University of Adelaide	95/136	Modelling prawn larvae dispersion and settlement in Spencer Gulf - technology transfer

Budget Summary	1996/97			
Original Budget	21,472.00			
Current Budget (2)				

Summary Receipts and Expenditure for the Project since commencement

B/F	-			
FRDC Funds (Plus)	-			
Expenditure (Minus)	-			
Refunds (3)	-			
Balance C/F	-			

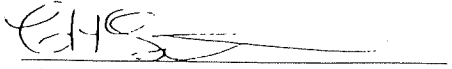
Details to 30 September 1996

Funds Available		
	Balance brought forward from previous year	
	Total funds received from FRDC	
	Funds Available for 1996/97	
Allocation FY (5)	Less Expenditure	
21,172.00	Salaries	19,883.30
100.00	Travel	
200.00	Capital	
Total $21,472.00	**Balance as at 31 December 1996**	(19,883.30)

Notes
(1) Use this column for the final year ONLY regardless of the length of the project.
(2) Total current budget shall not exceed Total original budget without approval, in writing, from the FRDC.
(3) Refunds should only be paid at completion of the project together with the final audited statement.
(4) ACTUAL EXPENDITURE (whether cash or accrual) ONLY. Commitments shall not be included.
(5) Show allocation for the current financial year. Transfers between budget heads allowed under 9(f) of the Project Agreement, or approved, in writing by the FRDC, shall be listed in the comments.

Comments:

Certified by:



(Signature)

CH Gilmour
(Print Name)

3210-4501
CHG:JAFS:6/6/97

Table xii.1: Statement of receipts and expenditure.

xiii Distribution

Distribution lists of the Final Report follow.

xiii.1 Fisheries Research and Development Corporation

The Research Organisation herewith provides 10 copies of the Final Report to the FRDC.

- Mr Peter Dundas–Smith
  Executive Director
  Fisheries Research and Development Corporation
  PO Box 222
  Deakin West ACT 2600

One copy is unbound.

xiii.2 Beneficiaries

A copy of the Final report has been distributed to each of the following beneficiaries, as identified in B7 Flow of Benefits, Part B of the Project Description forming part of the original application.

- Dr John Keesing
  Chief Scientist
  South Australian Research and Development Institute
  South Australian Aquatic Sciences Centre
  PO Box 120
  Henley Beach SA 5022

- Ms Mervi Kangas
  Senior Prawn Biologist
  South Australian Research and Development Institute
  South Australian Aquatic Sciences Centre
  PO Box 120
  Henley Beach SA 5022

- Mr Mick Puglisi
  Chairman
  Spencer Gulf & West Coast Prawn Fishermen's Association
  PO Box 8
  Port Lincoln SA 5606

- Dr John Noye
  Associate Professor
  Department of Applied Mathematics
  Faculty of Mathematical and Computer Sciences
  Division of Engineering and Mathematical Sciences
  The University of Adelaide
  Adelaide SA 5005

xiii.3 Additional Distribution

The Research Organisation has also distributed a copy of the Final Report to:

- National Fishing Industry Council
  Unit 1, 6 Phipps Place
  Deakin ACT 2600
- National Fishing Industry Training Council
  GPO Box 2851AA
  Melbourne VIC 3001
- CSIRO Division of Fisheries
  GPO Box 1538
  Hobart TAS 7001
- CSIRO Division of Fisheries
  PO Box 12
  Cleveland QLD 4163

References

Anonymous (1995, Jan). *AMS-LaTeX Version 1.2: User's Guide.* Providence, Rhode Island: American Mathematical Society.

Beard, D. A. and J. B. Nixon (1997, Mar). *DRAW: Programs for `vis603` Terminal Graphics and PostScript File Output* (Version 4.0 ed.). South Australia: Department of Applied Mathematics, The University of Adelaide.

Cooper, E., B. Scheifler, and M. Eichin (1990, Mar 27). *`xdvi`—DVI Previewer for the X Window System.* Massachusetts: Massachusetts Institute of Technology. This is but a Unix `man` page.

Doty, B. E. (1995, Sep 10). *The Grid Analysis and Display System: GrADS* (V1.5.1.12 ed.). Department of Meteorology, University of Maryland: Centre for Ocean–Land–Atmosphere Interactions. doty@cola.iges.org.

Knuth, D. E. (1986, Jan). *The TeX book.* Reading, Massachusetts: Addison-Wesley Publishing Co., Inc.

Lamport, L. (1994, May). *LaTeX—A Document Preparation System—User's Guide and Reference Manual* (Second ed.). Reading, Massachusetts: Addison-Wesley Publishing Co., Inc.

Nixon, J. B. (1996, Mar 29). *Dispersion Modelling using Finite-Difference Methods with Application to Larval Western King Prawn (*Penaeus latisulcatus*) in Spencer Gulf, South Australia.* Ph. D. thesis, The University of Adelaide, South Australia. Department of Applied Mathematics.

Nixon, J. B. (1997, May). *`prawn`: A Layered Two-Dimensional Advection–Diffusion–Mortality Prawn Larvae Dispersion Model* (Version 4.0 ed.). South Australia: Department of Applied Mathematics, The University of Adelaide. A User's Guide.

Nixon, J. B. and P. J. Bills (1997, May). *`ted`: A Three-Dimensional Eddy Viscosity Tidal Model* (Version 4.0 ed.). South Australia: Department of Applied Mathematics, The University of Adelaide. A User's Guide.

Nixon, J. B. and B. J. Noye (1996, Feb 29). Modelling prawn larvae dispersion and settlement in Spencer Gulf—Management implications. Final Report for period: 22/6/92–30/6/95, Department of Applied Mathematics, The University of Adelaide, South Australia. Funded by the Fisheries Research and Development Corporation.

Noye, B. J. and J. B. Nixon (1993, Jan 7). Modelling prawn larvae dispersion and settlement in Spencer Gulf—Management implications. Application Renewal for Project 91/004, Department of Applied Mathematics, The University of Adelaide, South Australia. Funded by the Fisheries Research and Development Corporation. Completed.

Noye, B. J. and J. B. Nixon (1995, Feb 21). Modelling prawn larvae dispersion and settlement in Spencer Gulf—Technology transfer. Application for State Trust Fund support for Project 95/136, Department of Applied Mathematics, The University of Adelaide, South Australia. Funded by the Fisheries Research and Development Corporation. Completed.

Patashnik, O. (1988, 8 Feb). *BibTeXing.* Stanford University. Documentation for general BibTeX users.

Rokicki, T. (1993). *DVIPS: A TeX Driver* (5.495 ed.). Stanford University. FAX: (415) 327-3329, e-mail: `rokiki@cs.stanford.edu`.

Spivak, M. D. (1986). *The Joy of TeX.* Providence, Rhode Island: American Mathematical Society.

Theisen, T. O. (1992). *ghostview—View PostScript documents using ghostscript* (1.4.1 ed.). Madison, Wisconsin: Department of Computer Sciences, University of Wisconsin-Madison. This is but a Unix man page.

Wichura, M. J. (1987, Sep). *The PiCTeX Manual* (1.1 ed.). Chicago, Illinois: The University of Chicago.