NORTH WEST SHELF
JOINT ENVIRONMENTAL
MANAGEMENT STUDY

The spatial distribution of commercial fishery production on Australia's North West Shelf

NWSJEMS

TECHNICAL REPORT No. 10

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June 2006

CSIRO

Government of Western Australia
Department of Environment

National Library of Australia Cataloguing-in-Publication data:

The spatial distribution of commercial fishery production on Australia's North West Shelf.

Bibliography.
Includes index.
ISBN 1 921061 62 6 (pbk.).

1. Trawls and trawling - Western Australia - North West Shelf - Catch effort. 2. Fisheries - Western Australia - North West Shelf - Catch effort. I. Althaus, Franziska. II. CSIRO. Marine and Atmospheric Research. North West Shelf Joint Environmental Management Study. III. Western Australia. (Series : Technical report (CSIRO. Marine and Atmospheric Research. North West Shelf Joint Environmental Management Study) ; no. 10).

639.22099413

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Bibliography.
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639.22099413

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Final report

North West Shelf Joint Environmental Management Study Final Report.

List of technical reports

NWSJEMS Technical Report No. 1
Review of research and data relevant to marine environmental management of Australia's North West Shelf.
A. Heyward, A. Revill and C. Sherwood

NWSJEMS Technical Report No. 2
Bibliography of research and data relevant to marine environmental management of Australia's North West Shelf.
P. Jernakoff, L. Scott, A. Heyward, A. Revill and C. Sherwood

NWSJEMS Technical Report No. 3
Summary of international conventions, Commonwealth and State legislation and other instruments affecting marine resource allocation, use, conservation and environmental protection on the North West Shelf of Australia.
D. Gordon

NWSJEMS Technical Report No. 4
Information access and inquiry.
P. Brodie and M. Fuller

NWSJEMS Technical Report No. 5
Data warehouse and metadata holdings relevant to Australia's North West Shelf.
P. Brodie, M. Fuller, T. Rees and L. Wilkes

NWSJEMS Technical Report No. 6
Modelling circulation and connectivity on Australia's North West Shelf.
S. Condie, J. Andrewartha, J. Mansbridge and J. Waring

NWSJEMS Technical Report No. 7
Modelling suspended sediment transport on Australia's North West Shelf.
N. Margvelashvili, J. Andrewartha, S. Condie, M. Herzfeld, J. Parslow, P. Sakov and J. Waring

NWSJEMS Technical Report No. 8
Biogeochemical modelling on Australia's North West Shelf.
M. Herzfeld, J. Parslow, P. Sakov and J. Andrewartha

NWSJEMS Technical Report No. 9
Trophic webs and modelling of Australia's North West Shelf.
C. Bulman

NWSJEMS Technical Report No. 10
The spatial distribution of commercial fishery production on Australia's North West Shelf.
F. Althaus, K. Woolley, X. He, P. Stephenson and R. Little

NWSJEMS Technical Report No. 11
Benthic habitat dynamics and models on Australia's North West Shelf.
E. Fulton, B. Hatfield, F. Althaus and K. Sainsbury

NWSJEMS Technical Report No. 12
Ecosystem characterisation of Australia's North West Shelf.
V. Lyne, M. Fuller, P. Last, A. Butler, M. Martin and R. Scott

NWSJEMS Technical Report No. 13
Contaminants on Australia's North West Shelf: sources, impacts, pathways and effects.
C. Fandry, A. Revill, K. Wenziker, K. McAlpine, S. Apte, R. Masini and K. Hillman

NWSJEMS Technical Report No. 14
Management strategy evaluation results and discussion for Australia's North West Shelf.
R. Little, E. Fulton, R. Gray, D. Hayes, V. Lyne, R. Scott, K. Sainsbury and D. McDonald

NWSJEMS Technical Report No. 15
Management strategy evaluation specification for Australia's North West Shelf.
E. Fulton, K. Sainsbury, D. Hayes, V. Lyne, R. Little, M. Fuller, S. Condie, R. Gray, R. Scott, H. Webb, B. Hatfield, M. Martin, and D. McDonald

NWSJEMS Technical Report No. 16
Ecosystem model specification within an agent based framework.
R. Gray, E. Fulton, R. Little and R. Scott

NWSJEMS Technical Report No. 17
Management strategy evaluations for multiple use management of Australia's North West Shelf – Visualisation software and user guide.
B. Hatfield, L. Thomas and R. Scott

NWSJEMS Technical Report No. 18
Background quality for coastal marine waters of the North West Shelf, Western Australia.
K. Wenziker, K. McAlpine, S. Apte, R.Masini

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ACRONYMS

ACOM	Australian Community Ocean Model
AFMA	Australian Fisheries Management Authority
AFZ	Australian Fishing Zone
AGSO	Australian Geological Survey Organisation now Geoscience Australia
AHC	Australian Heritage Commission
AIMS	Australian Institute of Marine Science
AMSA	Australian Maritime Safety Authority
ANCA	Australian Nature Conservation Agency
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZLIC	Australian and New Zealand Land Information Council
APPEA	Australian Petroleum, Production and Exploration Association
AQIA	Australian Quarantine Inspection Service
ARMCANZ	Agricultural Resources Management council of Australia and New Zealand
ASIC	Australian Seafood Industry Council
ASDD	Australian Spatial Data Directory
CAAB	Codes for Australian Aquatic Biota
CAES	Catch and Effort Statistics
CALM	Department of Conservation and Land Management (WA Government)
CAMBA	China Australia Migratory Birds Agreement
CDF	Common data format
CITIES	Convention on International Trade in Endangered Species
CTD	conductivity-temperature-depth
CMAR	CSIRO Marine and Atmospheric Research
CMR	CSIRO Marine Research
COAG	Council of Australian Governments
ConnIe	Connectivity Interface
CPUE	Catch per unit effort
CSIRO	Commonwealth Science and Industrial Research Organisation
DCA	detrended correspondence analysis
DIC	Dissolved inorganic carbon
DISR	Department of Industry, Science and Resources (Commonwealth)
DEP	Department of Environmental Protection (WA Government)
DOM	Dissolved organic matter
DPIE	Department of Primary Industries and Energy
DRD	Department of Resources Development (WA Government)
EA	Environment Australia
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPP	Environmental Protection Policy
ENSO	El Nino Southern Oscillation
EQC	Environmental Quality Criteria (Western Australia)
EQO	Environmental Quality Objective (Western Australia)
ESD	Ecologically Sustainable Development
FRDC	Fisheries Research and Development Corporation
FRMA	Fish Resources Management Act
GA	Geoscience Australia formerly AGSO
GESAMP	Joint Group of Experts on Scientific Aspects of Environmental Protection
GIS	Geographic Information System
ICESD	Intergovernmental Committee on Ecologically Sustainable Development
ICS	International Chamber of Shipping
IOC	International Oceanographic Commission
IGAE	Intergovernmental Agreement on the Environment
ICOMOS	International Council for Monuments and Sites
IMO	International Maritime Organisation

IPCC	Intergovernmental Panel on Climate Change
IUNC	International Union for Conservation of Nature and Natural Resources
IWC	International Whaling Commission
JAMBA	Japan Australian Migratory Birds Agreement
LNG	Liquified natural gas
MarLIN	Marine Laboratories Information Network
MARPOL	International Convention for the Prevention of Pollution from Ships
MECO	Model of Estuaries and Coastal Oceans
MOU	Memorandum of Understanding
MPAs	Marine Protected Areas
MEMS	Marine Environmental Management Study
MSE	Management Strategy Evaluation
NCEP - NCAR	National Centre for Environmental Prediction – National Centre for Atmospheric Research
NEPC	National Environmental Protection Council
NEPM	National Environment Protection Measures
NGOs	Non government organisations
NRSMPA	National Representative System of Marine Protected Areas
NWQMS	National Water Quality Management Strategy
NWS	North West Shelf
NWSJEMS	North West Shelf Joint Environmental Management Study
NWSMEMS	North West Shelf Marine Environmental Management Study
ICIMF	Oil Company International Marine Forum
OCS	Offshore Constitutional Settlement
PFW	Produced formation water
P(SL)A	Petroleum (Submerged Lands) Act
PSU	Practical salinity units
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SOI	Southern Oscillation Index
SMCWS	Southern Metropolitan Coastal Waters Study (Western Australia)
TBT	Tributyl Tin
UNCED	United Nations Conference on Environment and Development
UNCLOS	United Nations Convention of the Law of the Sea
UNEP	United Nations Environment Program
UNESCO	United Nations Environment, Social and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
WADEP	Western Australian Department of Environmental Protection
WADME	Western Australian Department of Minerals and Energy
WAEPA	Western Australian Environmental Protection Authority
WALIS	Western Australian Land Information System
WAPC	Western Australian Planning Commission
WHC	World Heritage Commission
WOD	World Ocean Database
www	world wide web

TECHNICAL SUMMARY

Foreign and domestic commercial fisheries data from three separate sources were used to describe the trawling effort and total catch in the North West Shelf of Australia between 1973 and 1997. These are Taiwanese Logbook data (Anon. 1973-1982), foreign (Taiwanese, Chinese and South Korean) trawl data collated by the Australian Fisheries Management Authority (1979-1989), and domestic catch and effort statistics data collated by Fisheries, Western Australia (1979-1997). Trawling effort and total catch by year are presented in time series plots and in thematic maps describing their spatial distribution over part of the NWS region on a 10 by 10 minute grid scale. Furthermore the data was divided into 22 species categories (mostly family level classifications) and presented as separate time series of the catches for each of these. Yearly distribution maps of the proportion of each species category over the total catch within each 10 by 10 minute grid are also presented.

In addition is the reconstruction and description of what is regarded as the most reasonable and likely record of the historical catch and effort for the commercial fisheries operating on the North West Shelf, by the authors. These interpretations were based mainly on the data sets reviewed here, but also included additional information obtained directly from Taiwan during projects in the mid 1990s. Reconstruction of some historical catches is at a finer taxonomic resolution than is provided in the original data. This reconstruction of the historical catch, and effort data for the fishery, was used in the North West Shelf Joint Environmental Management Study (NWSJEMS) Project 5 to model fish populations and evaluate fishery management strategies.

1. INTRODUCTION

Long-term environmental management and management of fisheries in the North West Shelf (NWS) region, including spatial and temporal zoning of fishing activities, requires information on spatial structures of fisheries and their interactions with other components of the system. In addition, the spatial distribution of fishery production can provide useful information on habitat quality, and on biodiversity at appropriate spatial scales. This project reconstructs the catch history of the North West Shelf fisheries, with the finest space and time resolution that can be consistently applied to each major period in development of the fishery, so as to allow their use in the environmental and fishery management models for Management Strategy Evaluation described in Project 5 of NWSJEMS.

The North West Shelf of Australia has been exploited by five commercial fishing operations: Japanese stern trawlers from 1959 to 1963; Taiwanese pair trawlers from 1972 to 1989; South Korean and Chinese stern trawlers between 1979 and 1989; and a domestic Australian fishery that starting in the early 1980s using traps, and after 1987 using traps and stern trawlers. More or less detailed records of the catches by location were kept by the Demersal Fish Research Center at the National Taiwan University (Anon. 1973-1981), for the Taiwanese fishery between 1973 and 1981; by the Australian Fisheries Management Authority (AFMA) for all foreign fishing operators (Taiwanese, Chinese and South Korean) between 1974 and 1989; and by the Department of Fisheries, Western Australia, for all domestic fishing operations.

These data are first described, and then the historical spatial distribution of the fishery production in the North West Shelf of Australia up to 1997 is described. Finally the most reasonable and likely catch and effort history for the fishery is reconstructed including, for some groups, catches at a finer taxonomic resolution than is available in the historical records (section 3.1).

Data compilation for this project was started 1999, for input into a model evaluating fishery impacts on fish habits. Two sets of domestic fishery data were received:

1. compulsory reporting data at a coarse spatial scale (one degree squares) - CAES; and
2. voluntary reporting shot-by-shot logbook data – Logbook Program.

Although the domestic fishery data set included data up to and including 2000, only data up to 1997 is included in the first part of this report. Fishers' participation in the Logbook Program was only reliable for the period between 1993 and 1997.

The reconstructed catch and effort history for the North West Shelf was used by Project 5 of NWSJEMS to support fishery assessments and management strategy evaluation.

2. DATA SOURCES AND DESCRIPTION

2.1 Foreign fisheries data

2.1.1 Taiwanese logbook data (1973-1981)

Summary logbook data from the Taiwanese pair-trawl fishery operating on the North West Shelf of Australia was transcribed into electronic form from annual reports produced by the Demersal Fish Research Center at the National Taiwan University (Anon. 1973-1981), for the years 1973 to 1981 (inclusive). Data in these annual reports are separated into areas of fishing, with the two main fishing regions being in the East and South China Seas, and the waters surrounding Northern Australia. In turn, the Australian area is split up into three regions - the Arafura Sea region, the Timor Sea region, and the north-western Australian region. For this exercise, only the data from the north-western Australian region (R3 – 111ºE to 125ºE; 12ºS to 25.5ºS) were entered. The data transcribed consisted of the reference area (in half-degree square blocks), total catch, number of hauls, catch per unit of fishing effort (CPUE) and columns for each species grouping.

Catch was given as the number of 30 kg cases, so the catch data were transformed to a catch weight in tonnes.

$$\text{Catch (t)} = \frac{(\text{number of cases} \times 30)}{1000} \tag{2.1}$$

The logbook summaries provided in the annual reports give the catch and effort recorded in logbooks that were returned from the fishery. The fraction of logbooks returned from the fishery varied from year to year and was reported in the annual reports. A correction factor was applied to correct for the recovery rate of fishing logbooks for each year:

$$\text{Corrected catch (t)} = \text{catch}(t) * \frac{1}{\text{recovery}} \tag{2.2}$$

The fishing effort is listed in the reports as a number of hauls. Liu (1976) states that one haul in this data set is approximately 2.5 hours. The number of hauls was converted into the number of hours spent fishing on this basis. We also corrected the reported effort according to the recovery rate of fishing logbooks for each year in the same manner as described above for the catch.

Species listed in the data tables of the annual reports are given numbers which relate to catch reporting categories table in the front of the reports. These categories were used consistently throughout the years and were:

- 5 family, 2 genus and 12 species level categories of fish;
- 3 general groups and 1 species level category of invertebrates;
- ‘other’ retained catch; and
- ‘dumped’ catch.

2.1.2 AFMA logbook data (1974-1989)

The Australian Fisheries Management Authorities (AFMA) provided 'shot-by-shot' fishing data of the foreign (Taiwanese, Chinese and South Korean) trawlers operating in the NWS region between 1974 and 1989. Overall, records of 125 525 trawls were received; however, the data that AFMA had collated prior to 1980 were rather incomplete and poorly documented. That data set was exclusively from Taiwanese vessels, but in comparison to the Taiwanese logbook data mentioned above, underestimated both the effort and total catch in the NWS region. Thus the Taiwanese logbook data for these early years was chosen.

Besides catch by taxonomic grouping and fishing effort (hours trawling), additional information about the trawling conditions and gears were more or less consistently recorded (table 2.1.1).

Species were graded and each grade weighed and recorded separately. The grading however was not done in a consistent fashion, and the grading methods were poorly described; thus the data was summarised by taxonomic groups only. The organisms identified and their taxonomic resolution in the AFMA data can be summarised as follows:

- 5 groups of cephalopods: 2 species, 2 families, 1 order;
- 2 families of euphausiids;
- 1 group of lobsters; and
- 109 groups of fish: 56 species, 45 families, 5 genus groups, 3 groups above family level (e.g. sharks).

Table 2.1.1: Data variables recorded in the logbook entries submitted to AFMA, including the percentage frequency with which the variable was recorded, and comments on range and type/state of the data.

Variable	% records (125525 total)	Comments
Vessel identification	100	
Operation date	100	
Operation number	100	
Year	100	Range: 1974 to 1989
Nationality	94.18	Taiwanese, Chinese and South Korean
Fishing time (hrs)	14.67	Range: 0.67 to 7.83
Search time (hrs)	11.36	Range: 0.16 to 80
Effort (hrs trawling)	94.90	Range: 0.08 to 20.5
Start latitude	100	Range: 12.35°S to 22.25°S
Start longitude	100	Range: 114°E to 123°E
End latitude	80.16	
End longitude	80.17	
Position precision	100	Range: 0.008 to 0.25
Bottom depth, max (m)	79.03	Range: 11 to 925
Bottom depth, min (m)	79.04	Range: 1 to 890
Surface temperature (°C)	7.57	Range: 9 to 34.5
Net temperature (°C)	1.30	Range: 11 to 35
Gear code	76.99	Code detailing the trawl gear — unfortunately the related table describing trawl gear is lost; mostly pair-trawls
Activity code	100	Code giving indication of operation and conditions (99% 'normal fishing')

2.2 Domestic fisheries data

2.2.1 CAES data (1979-2000)

The catch and effort statistics (CAES) data set is a comprehensive set of fish and invertebrate catches, by 1 degree latitude/longitude blocks (24 blocks total) and month, compiled by the Fisheries WA from compulsory submissions from both commercial and recreational fishers in the Pilbara (NWS) region. The data used here were collected from 390 vessels between 1979 and 2000, inclusive; 23 fishing methods were detailed (table 2.2.1), and the catch weight of a range of organisms was recorded. Effort by 1 degree square was recorded as boat days (99.9% recorded) and one boat day is approximately equivalent to 16 hours trawling (P. Stephenson, pers. obs.). Unfortunately, the effort often was not broken down by method. Only the effort distribution of fish trawls was considered over the NWS study region (figure 2.2.1) to make the data comparable to the AFMA and Taiwanese data. Where effort was not recorded separately for each method it was corrected for the simultaneous occurrence of fish trawl and fish traps by apportioning the effort according to the relative catch weight by method. The simultaneous occurrence of fish trawls and prawn trawls was corrected for by dividing the effort evenly between the two methods, since catch weights are not comparable between fish and prawns.

The range of organisms recorded and their taxonomic resolution can be summarised as follows:

- 1 group of sea cucumbers;
- 1 group of urchins;
- 3 orders of cephalopods;
- 7 groups of gastropods: 5 species, 1 family and 1 undifferentiated group;
- 8 groups of bivalves: 6 species, 1 family and 1 undifferentiated group;
- 8 groups of prawns: 6 species, 1 infraorder grouping, 1 family group;
- 14 groups of lobsters, bugs and crabs: 13 species, 1 family group; and
- 162 groups of fish: 118 species, 9 genus groupings, 2 groupings within a family, 29 family groups, 3 groupings of several families (including 'sharks' as a group) and 1 group of unknown fish.

Table 2.2.1: Fishing methods identified and the percentage frequency of each being represented in the total of 104377 records in the CAES data set compiled by the Fisheries WA.

Code	Method	% of records
FG	Fish trawl (approx. 16hrs/day)	32.99
TW	Prawn trawl	28.53
HL	Hand line	12.69
FT	Fish trap (100 pulls/day, 12-13 traps)	11.90
GN	Gill net	3.53
CH	Charter (recreational)	2.88
TL	Trolling	2.74
DL	Drop line	1.69
BH	Beach haul net	1.10
BS	Beach seine	0.65
LL	Long line	0.44
DV	Diving	0.32
SJ	Squid jigging	0.18
PT	Potting	0.09
HN	Haul net	0.07
WD	Wading	0.07
DN	Drop net	0.06
PL	Polling	0.03
PS	Purse seine	0.02
LA	Lampara	0.00
LN	Lift net	0.00
NT	Netting	0.00
OT	Other	0.01

2.2.2 Logbook data (1989-1999)

Logbook trawl catch data on a 'shot-by-shot' basis was voluntarily collected by fishers in the NWS of Australia and submitted to the Fisheries WA as part of a 'Logbook Program'. This data set consists of start and end position (latitude/longitude), shot date and year, trawl time (hrs), total catch weight (kg, not reliably/consistently recorded) and individual catch weight of 10 commercially important species: *Lethrinus sp.*, *L. nebulosus*, *Nemipterus furcosus*, *Pristipomoides multidens*, *Lutjanus vitta*, *L. sebae*, *L. erythropterus*, *L. malabricus*, *Epinephelus multinotatus* and *Argyrops spinifer*.

These data do not comprise additional domestic fisheries data to the CAES data described above, but give a higher spatial resolution of fishers' activities. Although this data set spans the period from 1989 to 1999, reliable data were only collected for the period from 1993 to 1997. The data in 1989 and 1990 were only recorded at a spatial level of 1 degree square, similar to the CAES data; in 1991 no logbook data were collected, and in 1992 and after 1997 fishers' participation in the logbook program was low. Consequently logbook data only for the period from 1993 to 1997 inclusive was used.

2.2.3 CSIRO survey data

Between 1982 and 1997 CSIRO Division of Fisheries (now CSIRO Marine and Atmospheric Research) conducted 15 trawl survey cruises (table 2.2.2) on the continental shelf off the north-west coast of mainland Australia, between North West Cape and Port Hedland. The survey area included the shelf at depths between 20 and 200 m, and was bordered eastwards by the longitude 119°E, and southwards by latitude 21°S. Most biological sampling was done using a Frank and Bryce stern trawl, but long line and prawn nets were also used in 1983, grab and targeted benthic samples were taken in 1987, and a few beam trawl samples were taken in 1990 (table 2.2.2).

Table 2.2.2: CSIRO surveys conducted in the North West Shelf of Australia; body of table shows gear types and number of hauls.

Cruise	Start date	End date	Vessel	Gear Type						
				Stern trawl	Beam trawl	Long line (anchored)	Long line (dragged)	Prawn net	Grabs	Benthic sample
0582	25/09/82	6/10/82	Soela	143						
0682	15/11/82	12/12/82	Soela	133						
0183	20/01/83	19/02/83	Soela	133				6		
0283	6/04/83	28/04/83	Soela	60				2		
0383	1/06/83	22/06/83	Soela	113		9		1		
0483	2/08/83	5/09/83	Soela	138			13			
0583	7/10/83	16/11/83	Soela	155			10			
0686	7/10/86	4/11/86	Soela	145						
0787	17/09/87	13/10/87	Soela	135						
0588	17/09/88	14/10/88	Soela	152					31	12
0489	13/09/89	9/10/89	Pride of Eden	123						
0290	17/09/90	16/10/90	Southern Surveyor	156	6					
0491	12/09/91	29/09/91	Southern Surveyor	110						
0895	19/08/95	9/09/95	Southern Surveyor	114						
0797	7/08/97	1/09/97	Southern Surveyor	108						

In contrast to the commercial fishing, trawl times were limited to 30 minutes and the position of trawl stations were determined using a stratified random sampling design, the stratification factors being depth, seabed sediment type as determined by previous surveys, and location east/west of longitude 117.5°E. Table 2.2.3 lists the additional information that was collected during surveys.

Table 2.2.3: Additional information collected during CSIRO surveys including the percentage frequency with which the variables were recorded.

Variable	% records (2 088 total)
start latitude	100
start longitude	100
end latitude	93.82
end longitude	93.82
tow direction	91.81
time zone	99.90
start time	99.52
duration	94.64
speed	91.24
sea direction	93.63
sea height	79.07
cloud cover	92.82
wind direction	91.33
wind force	97.37
surface temperature	0.91
bottom temperature	13.07
fishing method	93.44
gear type	98.52
location selection method	100
start depth	99.95
end depth	94.40
depth - min.	46.41
depth - max.	51.53
net height	35.49
bottom type	68.97
stratum type	61.21

The catch was sorted to the lowest possible taxonomic level, and the weight (and occasionally the number) of all species caught was recorded. The taxonomic breakdown of all catches by all gears is as follows:

- 19 groups of lobsters bugs and crabs: 13 species, 2 genus groups, 2 family groups, 1 infraorder, 1 undifferentiated lobsters group;
- 2 families euphausiids;
- 6 groups of cephalopods: 1 genus group, 3 families, 1 order, 1 undifferentiated grouping;
- 1 group alcionarians;
- 1group of ascidians;
- 1 group of scallops;
- 1 group of sea slug;
- 1group of sponges;

- 3 groups of starfish;
- 1group of basket stars;
- 1 group of urchins;
- 1 group of sea cucumbers;
- 1 group of bryozoa;
- 1 group of corals;
- 1group of seapens;
- 1 group of burrowing anemones; and
- 1079 groups of fish: 982 species, 88 families and 1 unidentified.

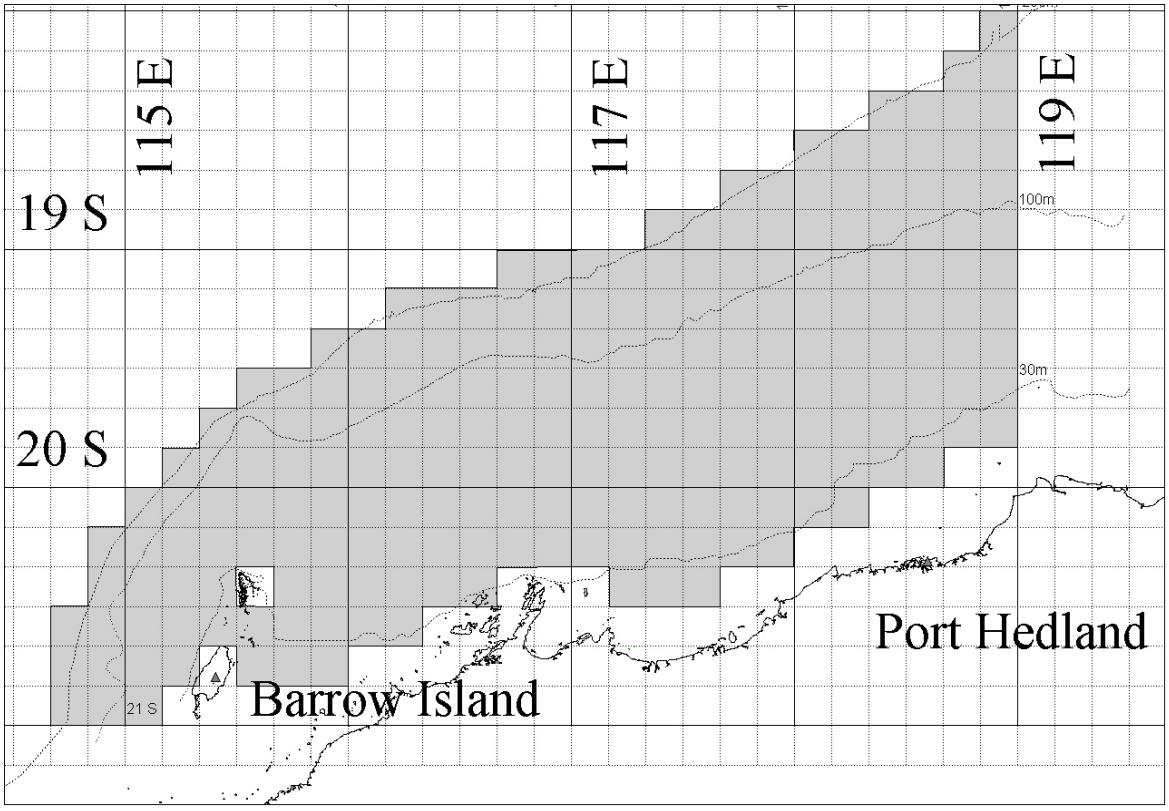

Figure 2.2.1: NWS mapping region (shaded) showing the 10 by 10 minute spatial grid.

2.3 Data summary/treatment

In order to visualise the spatial distribution of total trawling effort and of total catches, as well as catch by species, in the NWS region the data is represented as both a time series of effort and catch by year, and as thematic maps at the scale of 10 by 10 minute grid squares (lower latitude/longitude margins inclusive). For this mapping exercise the NWS region was restricted to the area covered by the CSIRO surveys, since this was the region of consistent overlap of all the data sources. Thus, the mapping region is defined as 218, 10 by 10 minute squares at depths between 20 and 200 m, and bordered eastwards by the longitude 119°E, and southwards by latitude 21°S (figure 2.2.1).

Where 'shot by shot' data were available (AFMA data, domestic Logbook data, and CSIRO survey data) the position of each shot was determined as the mid-point between its start and end latitude/longitude; or where the latter was not recorded, as start latitude/longitude. On the basis of that position each shot was assigned to a grid square and the data were summarised by year and grid square for each data set. As mentioned above, the AFMA data prior to 1980 were sketchy and unrepresentative of the fishing pressure, and so AFMA data from these years were not included in the analyses.

The Taiwanese logbook data were recorded on the basis of 0.5 degree blocks. To provide a simple and general indication of Taiwanese data on a 10 by 10 minute spatial resolution the catch and effort data of each 0.5 degree block, by year, was apportioned evenly over the 10 by 10 minute grid contained within that 0.5 degree block.

For mapping of the domestic fishery data the strengths of the two data sets were combined. CAES data was used for accurate effort and catch records over the entire fishery, and logbook data was used for its detailed spatial scale.

The CAES data were collected at a spatial scale of 1 degree blocks; where no logbook data was available it was treated similarly to the Taiwanese data, by evenly apportioning each block, by year, to the 10 by 10 minute grid contained within that block. This even distribution was used for the data from 1984 (1979 for catch data) to 1992, inclusive.

From 1993 to 1997, reliable ‘shot-by-shot’ logbook data were available covering the same fishery. However, these data only reported on ten species and, because logbook reporting was voluntary, the data did not necessarily encompass the entire effort or catch of the domestic fishery. Thus, for mapping the catch and effort distribution of the domestic fishery, the catch and effort data from the CAES data set and the spatial resolution of the logbook data set was used. First the logbook data was aggregated into the 10 by 10 minute grid cells as described above, then the proportional effort and catch (sum of 10 species) in each grid cell over the 1 degree CAES block was determined. CAES effort (transformed into hours as described above) and catch were apportioned to the grid cells according to the proportions calculated from the logbook data.

The coastal 1 degree block containing Point Samson (117-118°E and 20-21°S) showed very high catches and effort from 1993 onwards. These were not supported by the logbook data, and considering the shallow depth, and proximity to shore of that block, this was probably a result of erroneous block documentation. In order to include these large catches, but minimise their spatial impact, the data of that block for 1993 and subsequent years over the entire study area was apportioned, according to the respective logbook distribution of catches for each year.

2.3.1 Species distribution

Due to differences in the level of identification of species between the data sets available, family or higher taxonomic level groupings of the most commonly recorded species to describe their distribution was used. Table 2.3.1 lists the 22 categories and their abbreviations. Seven commercially important species that were identified consistently in the logbook and in the CAES data sets, five of which were also identified separately in the AFMA data set, are included in these analyses at the species level. The data collated consisted principally of demersal fish trawl data, with the exception of the CAES data that include other fishing methods. Invertebrates and in particular prawns were not targeted or well retained in demersal fish trawls and therefore often not recorded. The prawn fishery forms an important part of the NWS domestic fishery, in particular prior to 1987, so prawns were included as a separate category in the species distribution analyses, even though they were only recorded separately in the Taiwanese logbook and the CAES data sets. The Taiwanese logbook data included two ‘catch-all’ categories, ‘dumped’ and ‘other’ retained catch. These are included in ‘other fish’. Unfortunately, the ‘other’ category was heavily used in the early years of the fishery. The ‘other’ category accounted for 50% of the catch in 1973 and 25% in 1974. For the rest of the 1970s the ‘other’ category accounted for 21% of the total catch, while in 1980 and 1981 it was reduced to 16% and 13% respectively.

The time series plot and the spatial distributions of fishing effort are presented in hours trawling. The time series plots of both total catch and catch by species category are presented in tonnes (t) caught. The spatial distribution of total catch is also presented in tonnes caught, but the spatial distribution of catch by species categories is presented as the proportion of total catch within each 10 by 10 minute grid.

Table 2.3.1: Twenty-two categories of commercially or recreationally important species fished in the North West Shelf of Australia. A tick (✔) indicates the presence of records for that category in the different data sets.

Category	Abbrev.	FOREIGN DATA		DOMESTIC DATA		
		Taiwanese data	AFMA data	CAES data	WA logbook data	CSIRO data
Prawn	Prawn	✔		✔		
Other invertebrates	Iother	✔	✔	✔		✔
Sharks & rays	Sharks	✔	✔	✔		✔
Bathysauridae, Synodontidae	Lizard	✔	✔			✔
Percichthyidae, Serranidae (other)	Rockcod		✔	✔		✔
Epinephelus multinotatus	Epmult			✔	✔	✔
Priacanthidae	Bigeye	✔	✔	✔		✔
Caesionidae, Lizardfishes (other)	Lutjanid		✔	✔	✔	✔
Pristipomoides multidens	Pmult		✔	✔	✔	✔
Lutjanus vitta	Luvitta		✔	✔	✔	✔
Lutjanus sebae	Lusebae		✔	✔	✔	✔
Lutjanus erythropterus	Lueryth		✔	✔	✔	✔
Lutjanus malabaricus	Lumalab	✔		✔	✔	✔
Nemipteridae	Nemip	✔	✔	✔	✔	✔
Haemulidae	Sweetlip	✔	✔	✔		✔
Lethrinidae	Lethrin	✔	✔	✔	✔	✔
Sparidae (other)	Snapper		✔	✔		✔
Argyrops spinifer	Arspinif		✔	✔	✔	✔
Carangidae (Trevallies and Scads)	Trevscad	✔	✔	✔		✔
Mugilidae	Mullet			✔		
Scombridae	Macktuna		✔	✔		✔
Other fish	Fother	✔	✔	✔		✔

2.4 Results

The time series of the commercial trawling effort (figure 2.4.1) shows that the effort by foreign fishers was very high in the early 1970s, although it did fluctuate considerably. It was moderately stable and high (between 25000 and 32000 hours) in the early 1980s and reduced dramatically after 1985, the year when the management closures were first implemented in the region (Sainsbury, 1987). The foreign fishery collapsed entirely in the NWS region after 1989. On the other hand the domestic fishery (figure 2.4.1) started trawl operations in 1987 and, after an initial peak effort in 1990/91, settled at a relatively constant level of between 5 000 and 10 000 hours per year.

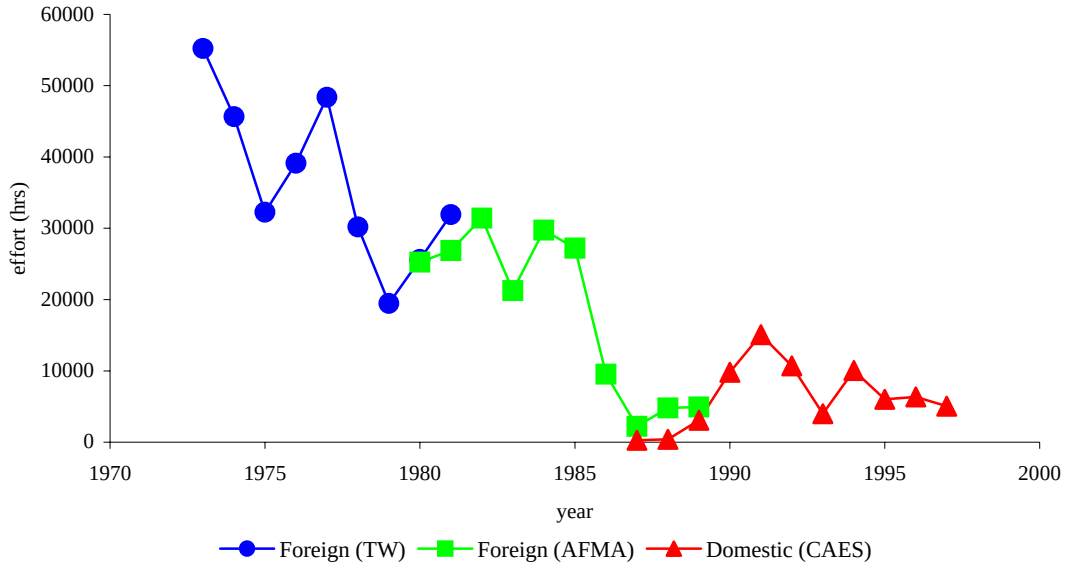

Figure 2.4.1: Time series of trawling effort for three data sets: foreign fisheries (Taiwanese – TW and AFMA data) and for the domestic fishery (CAES data).

The spatial distribution of the effort (figure 2.4.2 (a) to (c)) shows that the foreign fishery, figures 2.4.2 (a) and 2.4.2 (b) concentrated principally on the mid shelf region at depth of 50 to 100 m. Closures of large areas were implemented in two steps; foreign trawl fishing was excluded from all areas west of 116°E after 1985, and all areas west of 117.5°E after 1987 (Sainsbury, 1987). The effect of the second closure is visible in the effort distribution maps of 1988 and 1989 (figure 2.4.2 (b)). The domestic fishery also concentrated its efforts to the mid shelf region and, in addition, trawled mostly between 116°E and 118°E.

Distribution maps depicting ranges of fishing effort (hours trawling) by year on a 10 by 10 minute grid for the foreign fishery ((a) Taiwanese and (b) AFMA), and the domestic fishery ((c) CAES) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive; cells where no effort was recorded are shown as blank.

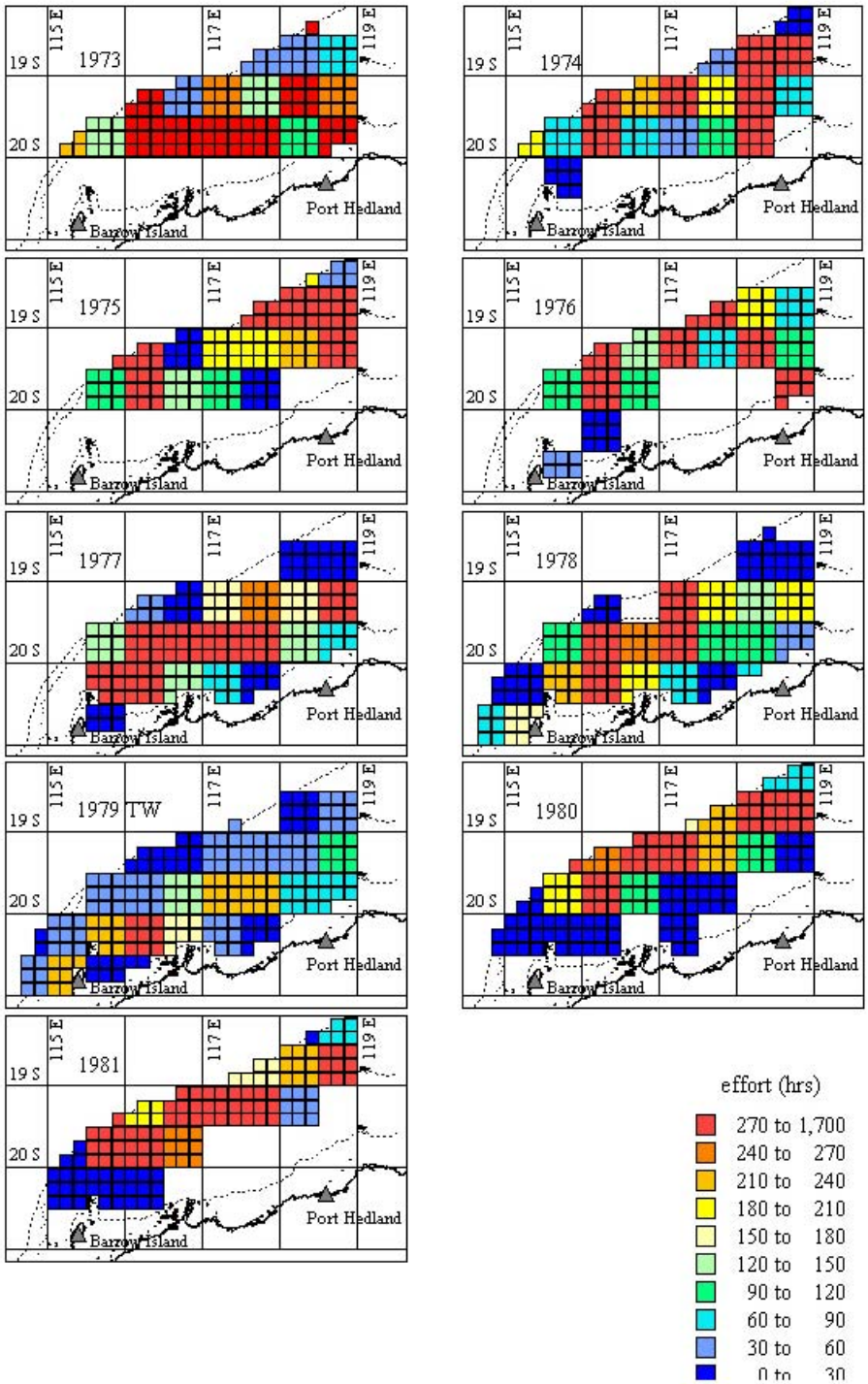

Figure 2.4.2 (a): Foreign trawl effort (Taiwanese logbooks).

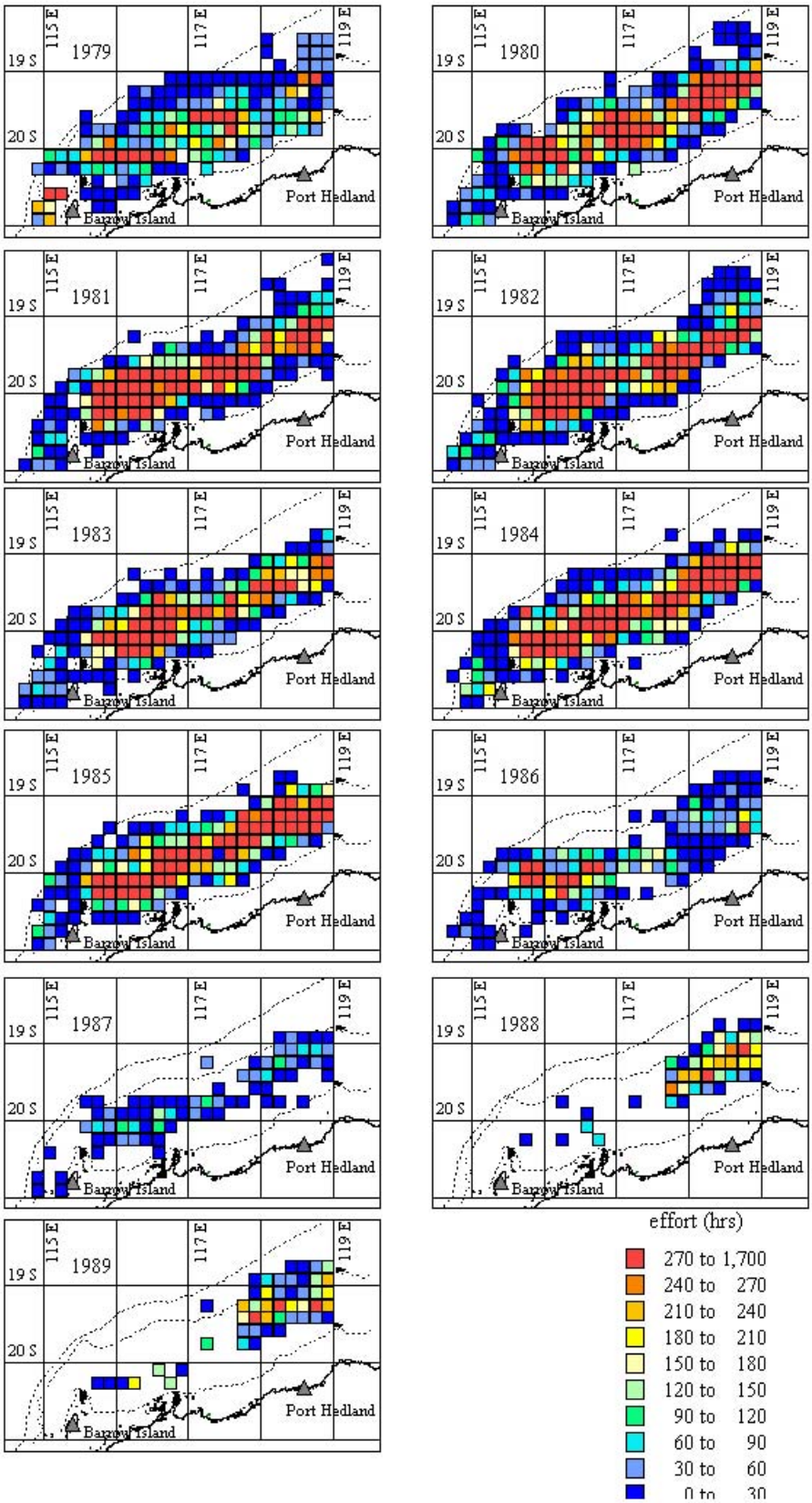

Figure 2.4.2 (b): Foreign trawl effort (AFMA).

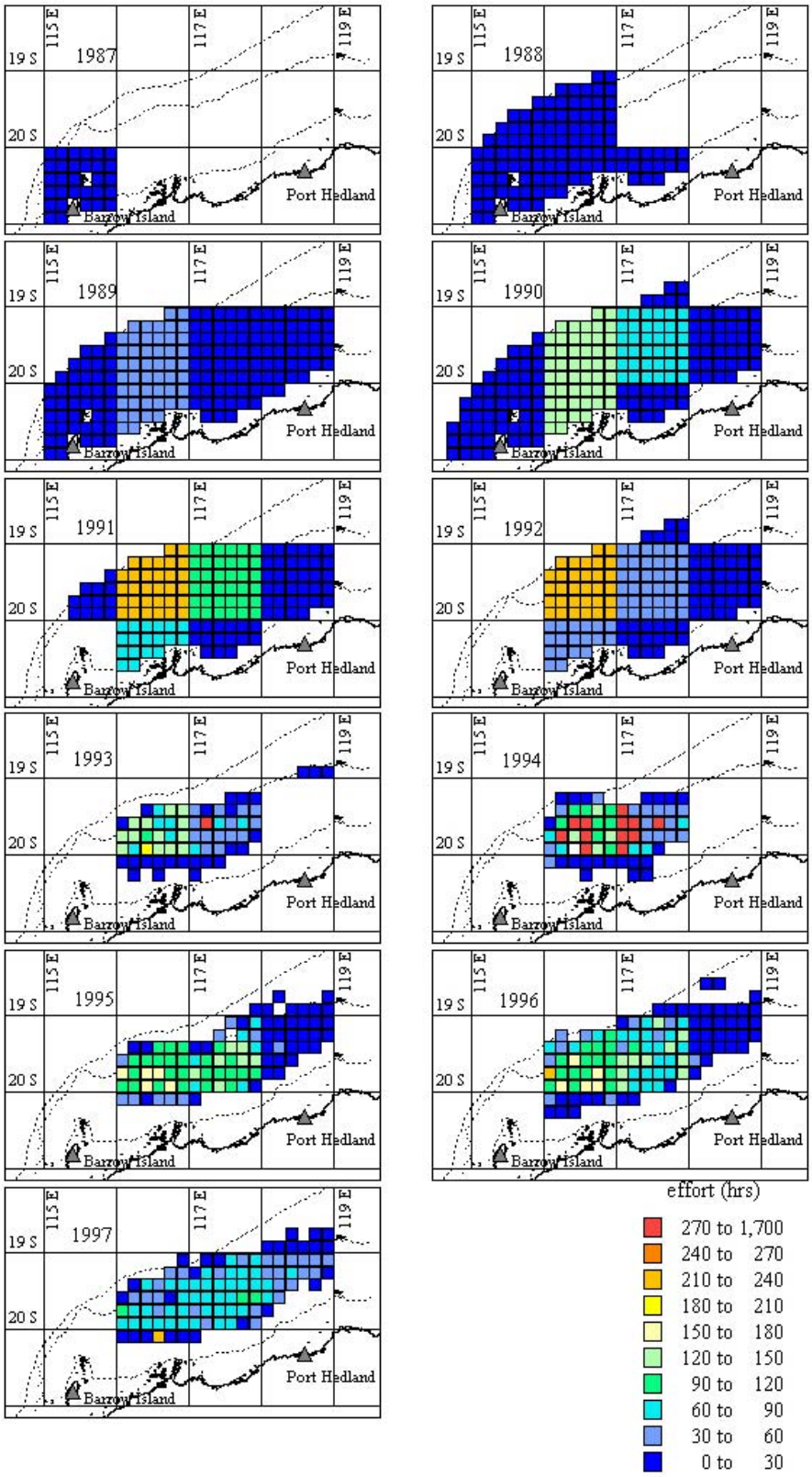

Figure 2.4.2 (c): Domestic trawl effort (CAES).

The total catch decreased rapidly between 1973 and 1979 (figure 2.4.3). It then stabilised at between 8 000 and 10 000 tonnes per year until 1985 (AFMA data), when the foreign fishery in the NWS region started to collapse. The consistently low catches by the domestic fishery prior to 1987 were taken mainly using prawn trawls, traps and other techniques. Once trawling started in 1987, the catches increased gradually.

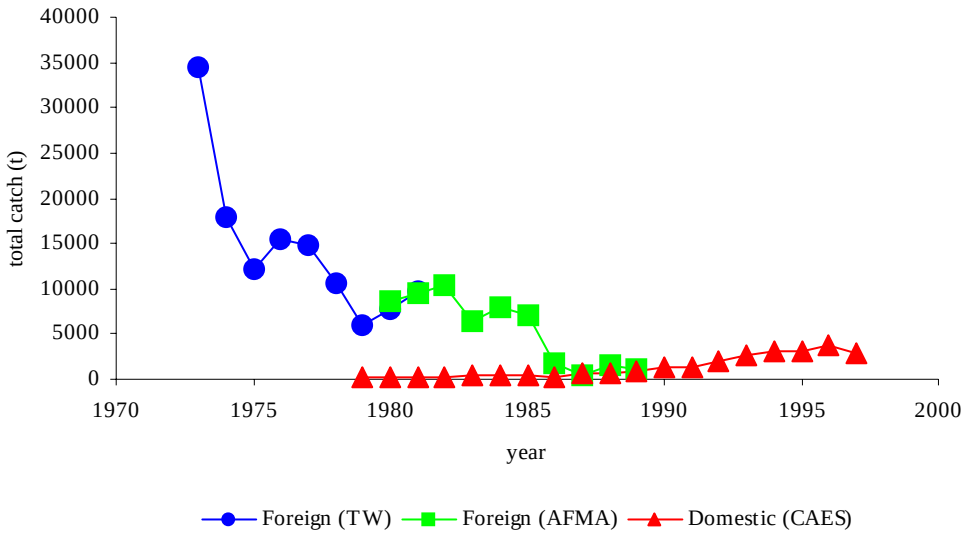

Figure 2.4.3: Time series of total catch for the foreign trawl fishery (Taiwanese – TW and AFMA data), and for the domestic fishery (CAES data, all methods).

The spatial distribution of the total catch (figure 2.4.4 (a) to 2.4.4 (d)) shows that the most fish were caught in the areas where most of the effort was concentrated. Furthermore, slight latitudinal trend of higher catches in the western region of the NWS seems to be apparent. Catches appear rather low, relative to the effort. However, the catch of all methods was mapped, but only trawling effort for the domestic fisheries data (CAES), so the spatial distribution of the catch (figure 2.4.4 (d)) cannot be directly compared to the effort distribution (figure 2.4.2 (c)).

Distribution maps depicting ranges of total catch (t) by year on a 10 by 10 minute grid for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), and the domestic fishery ((c) and (d) CAES, all methods) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

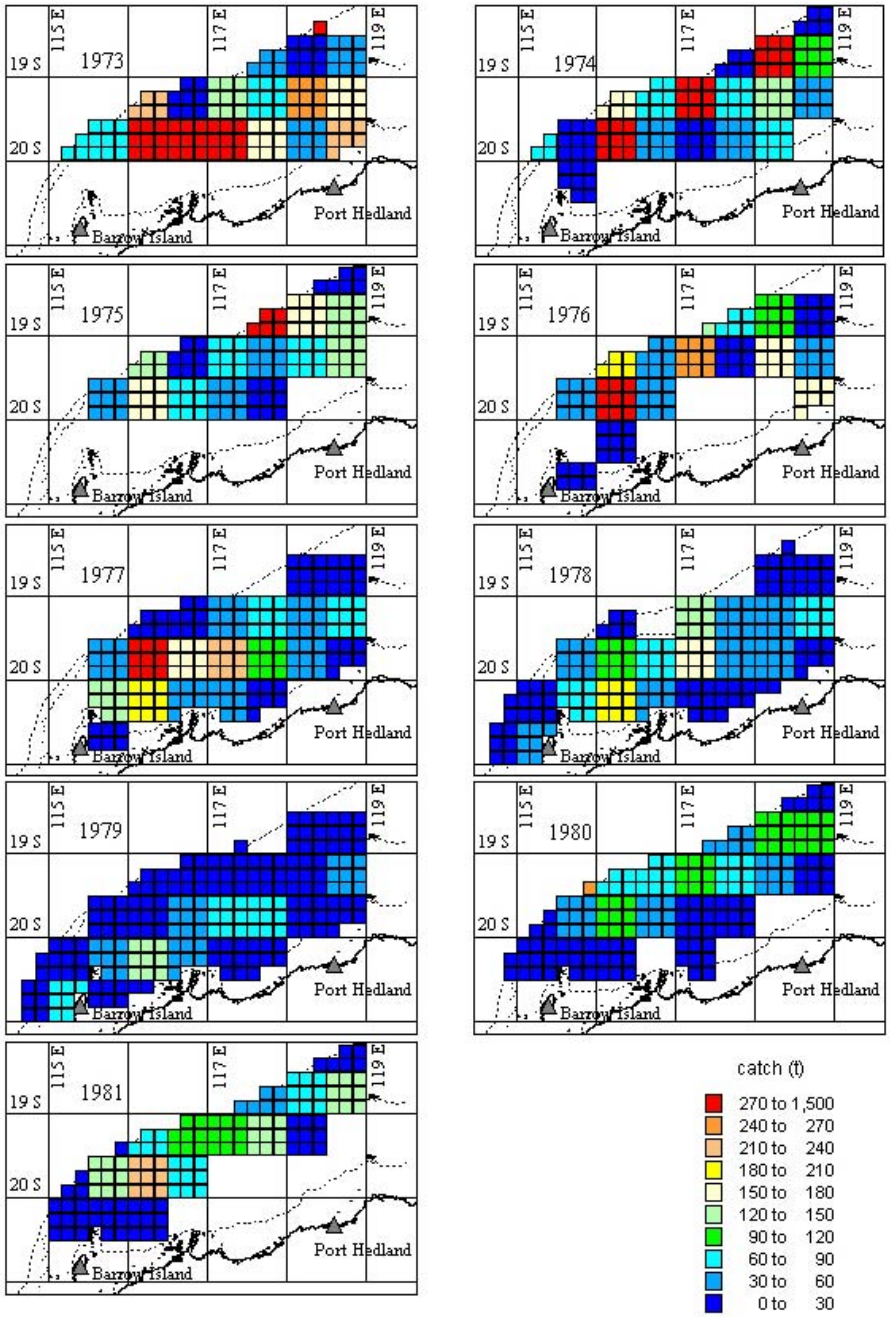

Figure 2.4.4 (a): Foreign total catch (Taiwanese logbooks).

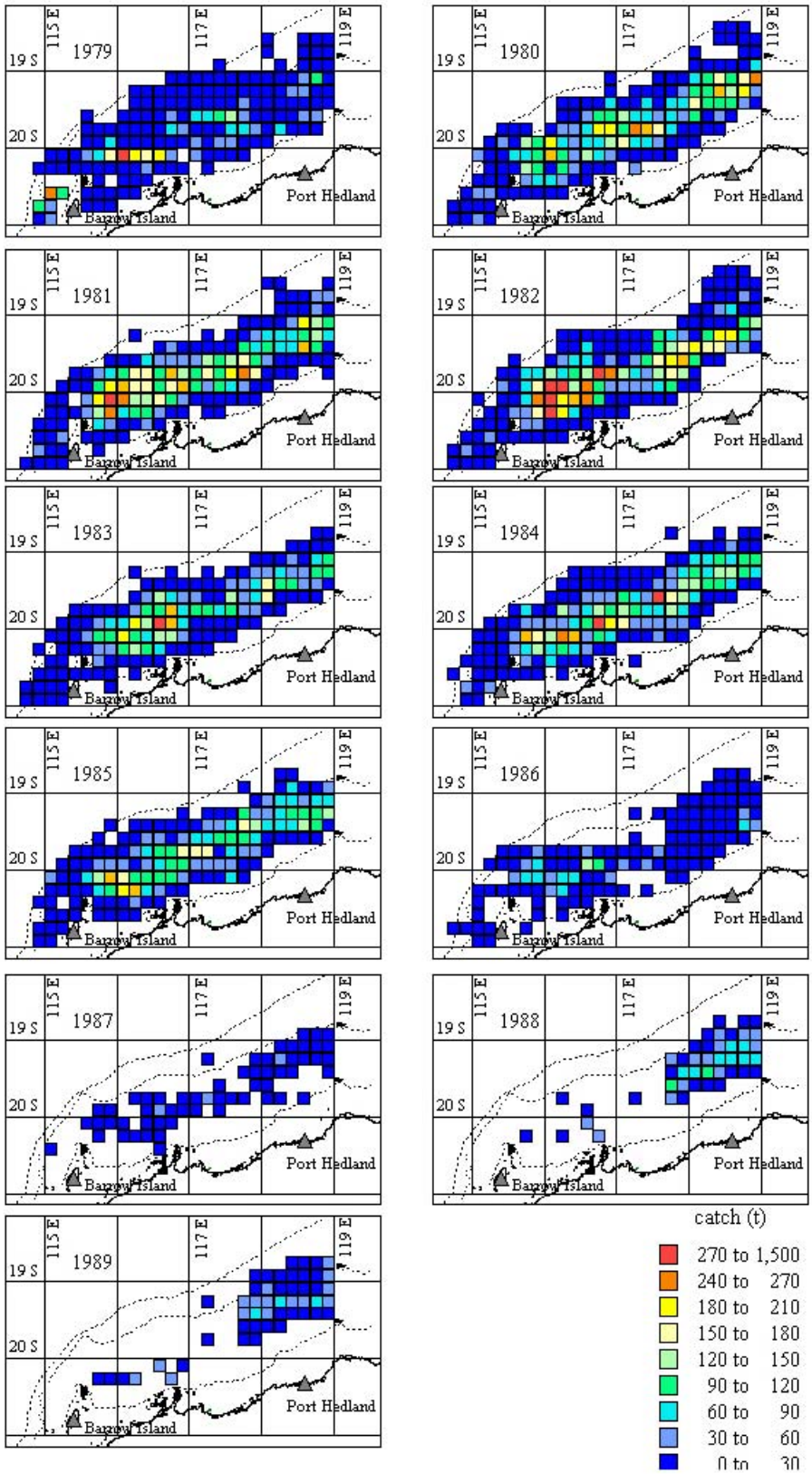

Figure 2.4.4 (b): Foreign total catch (AFMA).

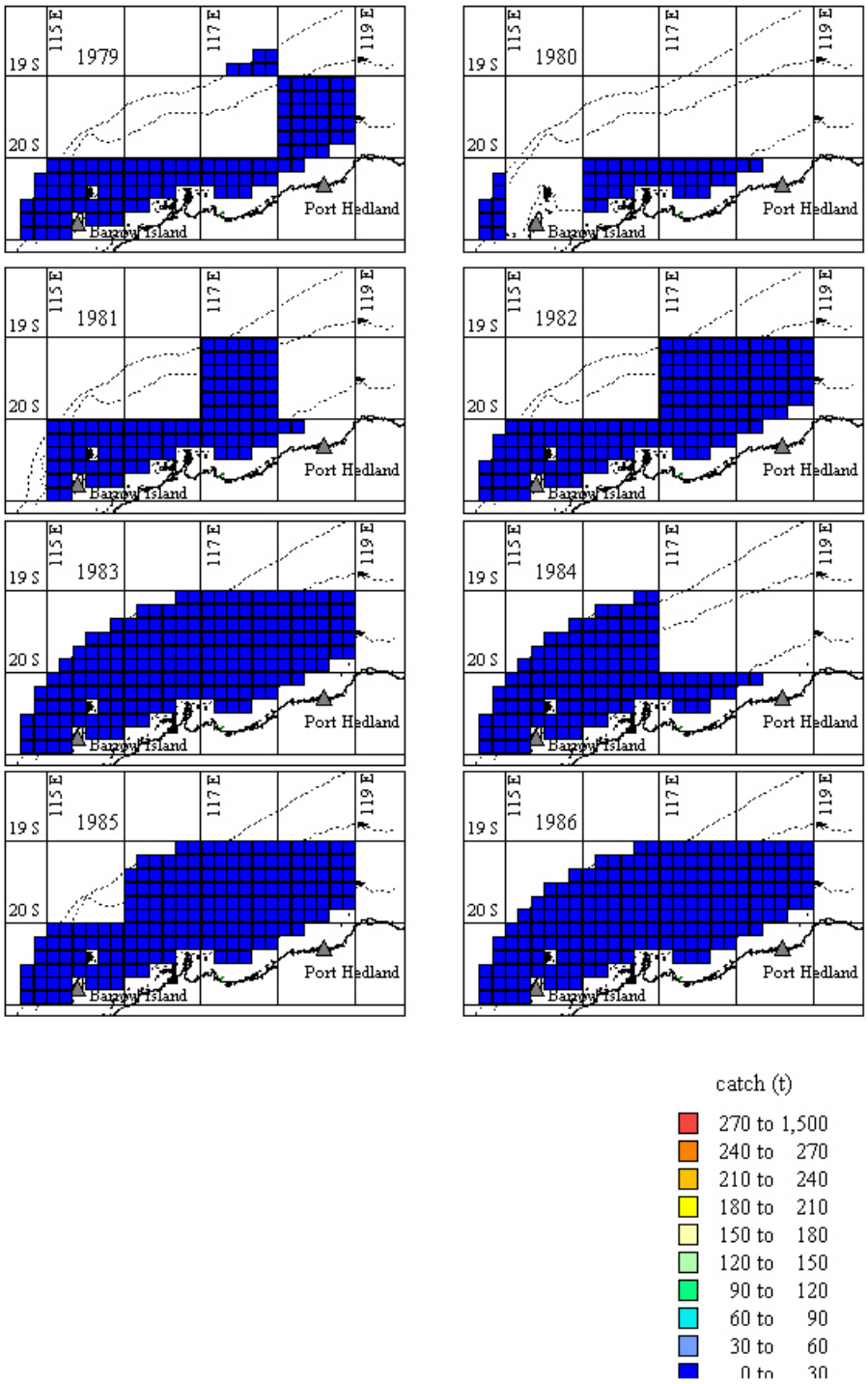

Figure 2.4.4 (c): Domestic total catch, all methods (CAES, 1979-1986).

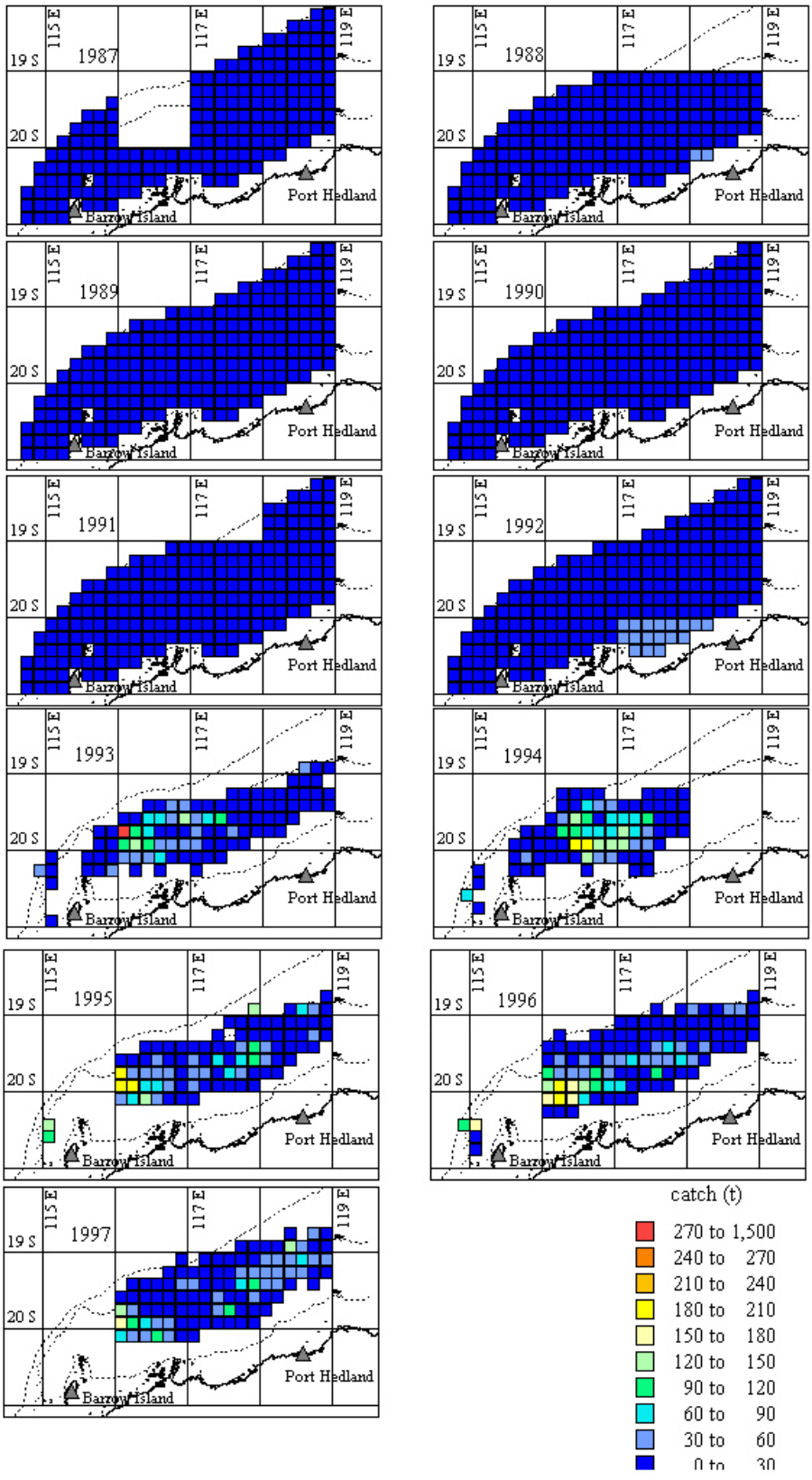

Figure 2.4.4 (d): Domestic total catch, all methods (CAES, 1987-1997).

The time series plots of the catch broken down by species category (figure 2.4.5) partly reflect the trends seen in the total catch of the three different data sets. However they also show the differential preferences of the foreign and domestic fishers for targeting and retaining certain species, probably due to different market demand and to fishing practices. For example, nemipterids and sweetlips catches were high to moderate in both the Taiwanese logbook and in the AFMA data, while catches of these fish were low in the domestic fishing data; similarly, lizardfishes were recorded in the foreign data while they were not distinguished in the domestic data. This pattern is reversed for rockcods, mullets, and mackerels and tunas; although, the latter were probably more prominent in the CAES data because they are not caught by fish trawls. The species from the family Lizardfishes, in particular *Lutjanus vitta*, *L. sebae*, *L. erythropterus*, appear to be highly targeted by the domestic fishery, in comparison to the foreign data; however, these differences could also be due to misidentifications, or due to those species being included in the 'other' category of the Taiwanese data. From these plots, no conclusions can be drawn on the general increase or decline over the time period of any of these species groups; in order to do that, changes in fishing effort, fishing techniques and management closures of regions within the study area would have to be considered.

In order to visualise the spatial distribution of the species categories identified, included is a series of figures in Appendix A (figures A.1 to A.22) where the proportion of each species over total catch within 10 by 10 minute grid square were mapped onto the study area. From these maps an impression can be gained of where the major species were caught. For example, *Pristipomoides multidens* (figure A.9) and *Lutjanus malabaricus* (figure A.13) appear to be more common in the deeper waters of the NWS (around the 100 m isobath). On the other hand the nemipterids (figure A.14) seem to be caught more commonly at shallower depths (between 50 and 100 m); Woolley et al. (2000) confirm the general patterns of these visual interpretations. However, these maps can only be used as an indicator of the catch distribution, and caution has to be applied when comparing distribution maps across data sets, since the species groups are represented as proportions of the total catch, which, as we described above, is broken down differently for each data set.

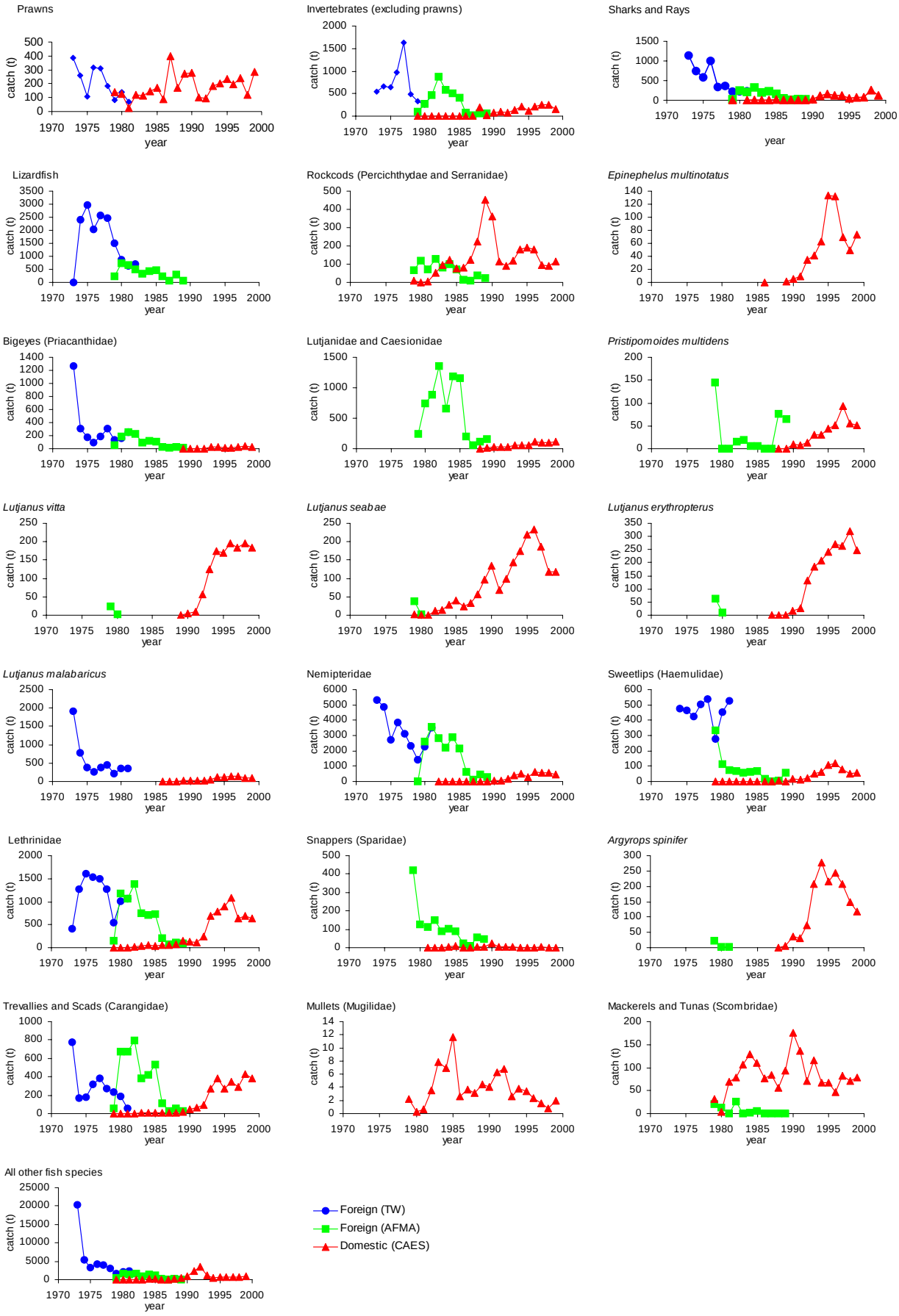

Figure 2.4.5: Time series of catch (t) by species category for the foreign trawl fisheries (Taiwanese – TW, and AFMA data) and for the domestic fishery (CAES data, all methods).

3. GENERAL DISCUSSION

The NWS of Australia has been heavily fished since the early 1970s. The initial catches of the Taiwanese fishery were extremely high, in excess of 35 000 t in 1973. Catches rapidly decreased and somewhat stabilised at around 10 000 t in the early 1980s. The foreign fishery then collapsed, not necessarily as a result of declining fish stocks but more likely due to large-scale closures of the NWS to foreign fishing. These closures were imposed as an experimental management plan in 1985 (Sainsbury, 1991, 1997).

The catches of the domestic fishery are much lower in comparison. Prior to 1987 there was little or no domestic fish trawling, most operators used trapping or trolling to catch fish and trawling was used to target prawns. After the retreat of the foreign fleet, a domestic trawl fishery started to develop, with gradually increasing catches, although never reaching the catch levels of the foreign fleets.

Fishing effort follows a trend that is similar to that of the catch, although it fluctuated more strongly – particularly in the 1970s. No direct comparison of fishing effort from the different data sets was attempted here, since accounting for the different gears employed by different fishing fleets was not possible. Most Taiwanese boats (TW Logbook and AFMA data) used pair trawlers, while the Chinese, South Korean (AFMA data) and domestic fleets (CAES data) used various designs of stern trawlers. Furthermore, the effort invested by each fishery was influenced by a series of managerial interventions, including the closures mentioned above.

In the data presented here lethrinids, lujanids, nemipterids, and lizardfishes (saurids) featured relatively high in the foreign fishing data, while the lizardfishes, in particular *Lutjanus vitta*, *L. sebae*, *L.erythropterus*, appear to be targeted by the domestic fleet. These findings broadly agree with published descriptions of the main target species in the NWS (Young and Sainsbury, 1985; WAFIC, 2002).

3.1 Data used for NWSJEMS Project 5

There are several differences between the data sets reported here with respect to the amount of fishing, the level of catch and the composition of the catch. Reconstructed and described here is what is regarded as the most reasonable and likely record of the historical catch and effort for the commercial fisheries operating on the North West Shelf. This includes reconstructing some catches at a finer spatial resolution than is available in the original data sets. This reconstruction of the historical catch and effort data for the fishery was used in NWSJEMS Project 5 to model fish populations and evaluate fishery management strategies.

3.1.1 Foreign trawl data on the North West Shelf

The foreign catch and effort data used here were derived from two sources:

- for the years prior to the establishment of the Australian Fishing Zone (AFZ) in 1979, foreign catch and effort data came from the Demersal Fish Research Center of the Institute of Oceanography, National Taiwan University; and
- for the years from 1980 onward, foreign catch and effort data came from AFMA.

The species resolution of the Taiwanese logbook data entered from the published reports (Anon 1973-1981; hereafter referred to as the Althaus data) was poor and did not match the species resolution in published accounts of fishing in the NWS (e.g. Ramm, 1994; Sainsbury, 1987). Ramm (1995) had also analysed, compiled and reconciled the various sources of foreign catch and effort fishing data on the North West Shelf. Ramm (1995) had two sources of Taiwanese fishing records spanning the years from 1973 to 1989; the National Taiwan University, and AFMA. The notable difference between these is in the total annual catch recognised by each (figure 3.1.1). Ramm (pers. comm.) recommended using the data obtained from Taiwanese authorities – hereafter referred to as the Ramm (1995) data.

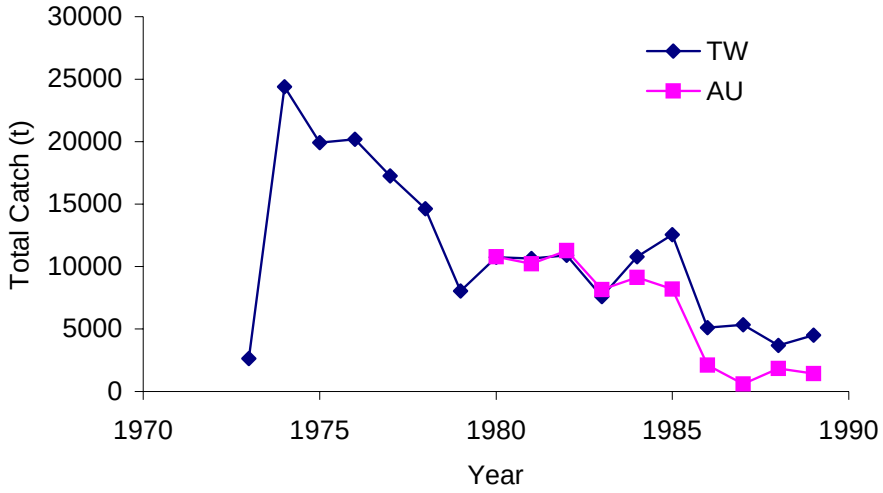

Figure 3.1.1: Comparison of total Taiwanese catch reported by Taiwanese (TW) in by Ramm 1995, and Australian (AU) authorities.

A comparison of the data from Ramm (1995), with the Althaus data and data published by Sainsbury (1987) showed that while there is general agreement in the total catches from the latter two data sets, the Ramm (1995) data differed considerably (figure 3.1.2). For example, there are no data in the Ramm (1995) database for 1972 and catches in 1973 are extremely low compared to the other sources.

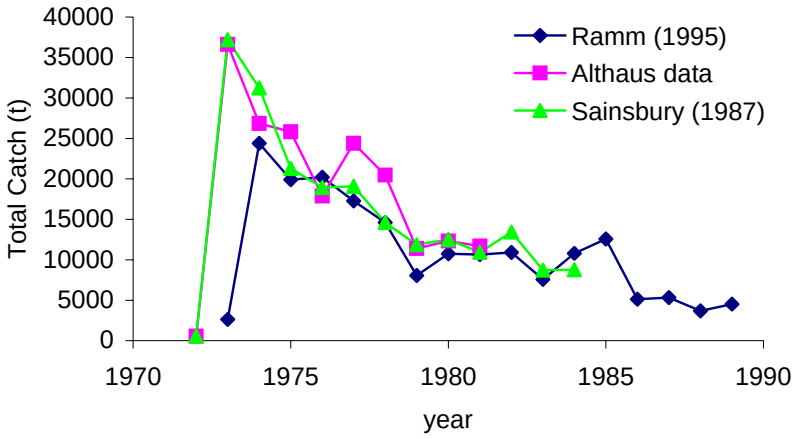

Figure 3.1.2: Taiwanese total annual trawl catch data for the Pilbara region from three sources.

A single 'most reasonable' fisheries data set was required by NWSJEMS Project 5. In particular it required both the total catch accuracy of the Althaus data and the species resolution of Ramm (1995) TW data. The datasets were combined in the following manner. First, the catch and effort data in the Ramm (1995) database were corrected for logbook recovery rate. Then species catches were grouped into categories that could be consistently applied and that were used in Project 5: *L. sebae*, large lutjanids (e.g. *L. malabaricus*, *L. erythropterus*), small lutjanids (e.g. *L. vitta*), lethrinids, nemipterids and saurids. These catch and effort data were recorded and available by 0.5 by 0.5 degree cells by year. For the purpose of Project 5 of interest was the data between 114°E and 123°E inclusive – a slightly larger area than presented in this report. The catches of each species group in each grid cell were scaled to the entire catch (including invertebrates, 'dumped' and 'other') in that cell for a given year. Thus, the Ramm (1995) database gave the annual spatial distribution of species catch scaled to the entire catch. More specifically, the logbook recovery adjusted catch and effort are defined as,

$$C'_{s,x,y,t} = \frac{C_{s,x,y,t}}{L_t}$$

$$E'_{x,y,t} = \frac{E_{x,y,t}}{L_t}$$

where

L_t is the log book recovery rate for year t

$C_{s,x,y,t}$ is the recorded catch of species group s, at location x,y in year t

$E_{x,y,t}$ is the recorded trawl effort at location x,y in year t

The annual spatial distribution of species catch scaled to the entire catch was determined as,

$$\hat{C}_{s,x,y,t} = \frac{C'_{s,x,y,t}}{\sum_{s \in S} C'_{s,x,y,t}}$$

where the summation in the denominator is across the entire species set S of the database.

A spatially aggregated summary of this (figure 3.1.3) shows the annual relative proportions of the different species groupings. Note that the data start in 1973.

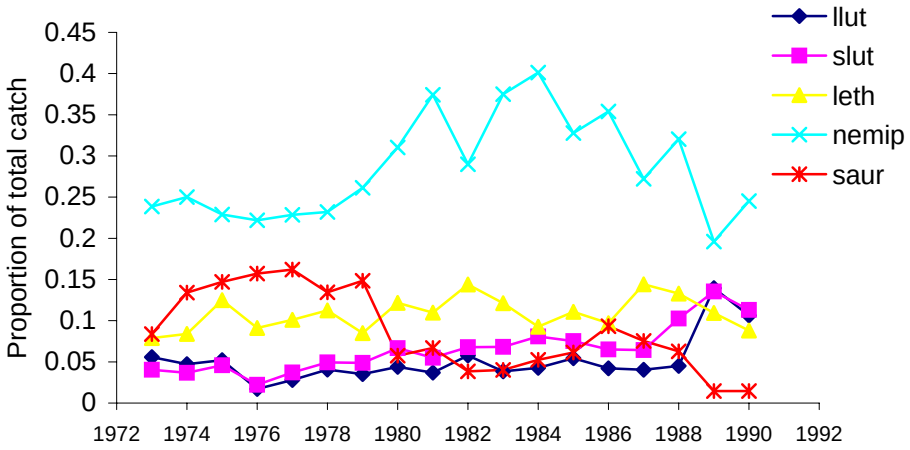

Figure 3.1.3: Annual relative catch of 5 species groupings taken from the Ramm (1995) database: llut: large lutjanids; slut: small lutjanids; leth: lethrinids; nemip: nemipterids; saur: saurids.

These figures agree with Sainsbury (1987) where, for example, large and small lutjanids comprise between roughly 4% and 5% of the total catch, although the proportions of these rise above 10% in the latter years (particularly small lutjanids; figure 3.1.3). Figure 3.1.3 also shows lethrinids (which include *Gymnocranius spp*.) comprise approximately 10% of the total catch, compared to 9.8% given by Sainsbury (1987). Both Nemipterids and saurids in figure 3.1.3 vary substantially over time, but again are close to the 21.1% and 12.3% respectively given by Sainsbury (1987).

The relative species catches derived from the Ramm (1995) dataset were then applied to the annual spatially disaggregated total catch (including invertebrates, 'dumped' and 'other') in the Althaus dataset to give an estimate of the individual species catches making up the Althaus dataset; namely,

$$C''_{s,x,y,t} = \hat{C}_{s,x,y,t}\tilde{\tilde{C}}_{x,y,t}$$

where

$\tilde{\tilde{C}}_{x,y,t}$ is the total catch obtained from the Althaus dataset that includes invertebrates, 'dumped' and 'other' at location x,y in year t

$C''_{s,x,y,t}$ is the estimated catch from the Althaus data of species s, at location x,y at year t

In applying the species catch information from Ramm (1995) to the total catch of the Althaus data, irregularities between the databases invariably occurred – as for example when a datum of catch occurred in the species (Ramm) dataset, but was absent from the total catch (Althaus) dataset. When this happened, the total catch from the Ramm (1995) data was used. Alternatively, when a datum of catch occurred at a particular place and year in the Althaus data, with no corresponding datum of species composition from the Ramm (1995) data, then the datum in the Ramm (1995) database that was closest in space and time was used. So for example, no species composition of catch was available from the Ramm (1995) database for 1972. Therefore for each datum in the Althaus database in 1972, the spatially closest species composition datum for 1973 in the Ramm (1995) database was used, and if such a datum was also absent, the closest in space and time was chosen. The resulting data gave detailed species catches by 0.5 degree grid cells by year, and preserved the total amount of catch taken. Figure 3.1.4 shows the results of this procedure aggregated across spatial grid cells.

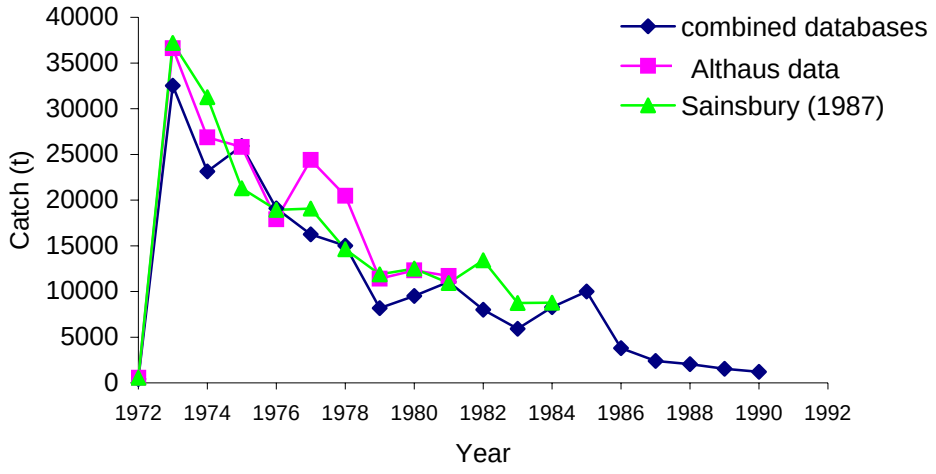

Figure 3.1.4: Comparison of the catch data derived using a combination Ramm (1995) species catch distribution data and Althaus total catch data (combined databases), with total catch data from the Althaus database and Sainsbury (1987).

The resulting catches were generally lower than the other databases (figure 3.1.4), in part because the species that are of interest on the NWS are a subset of the entire catch considered in the present report and by Sainsbury (1987). Also notable is the time period over which the new data extend. The reason for this, as previously stated, is that Ramm (1995) incorporated the catch data reported to the Australian authorities once the 200 nautical mile limit came into effect in 1980. The breakdown of catch by species grouping that resulted is shown in figure 3.1.5.

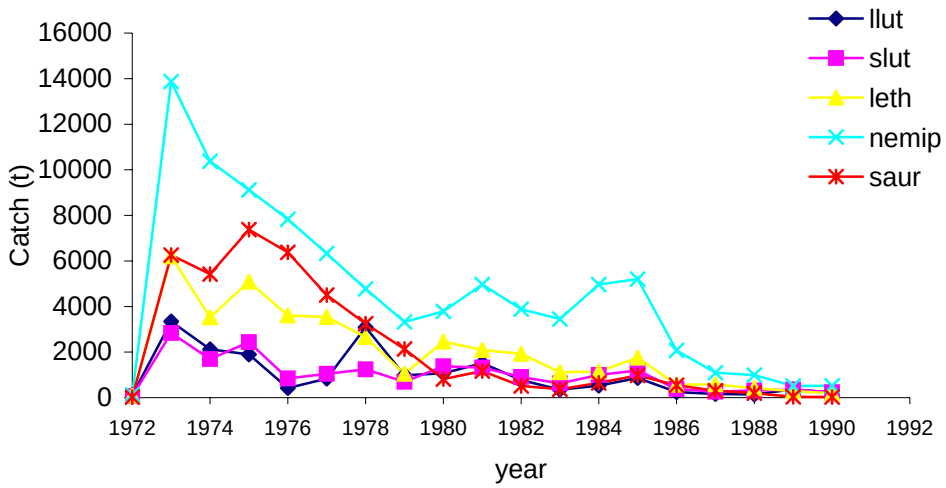

Figure 3.1.5: The annual catch of the different species groups derived from the application of Ramm (1995) species groupings, and the Althaus total catch. llut: large lutjanids; slut: small lutjanids; leth: lethrinids; nemip: nemipterids; saur: saurids.

The results of this analysis (figure 3.1.5) are somewhat different from those derived in figure 2.4.5. For example, the peak catch of saurids in figure 2.4.5 is about 3000 t in 1975, whereas the peak catch of saurids in figure 3.1.5 occurred in 1975 but at approximately 7 000 t. Similarly, the catch of lethrinids in figure 2.4.5 peaked in 1975 at about 1 500 t, whereas figure 3.1.5 indicates that catches of lethrinids were not below this value until the 1980s. These large discrepancies probably occur because, as previously commented, the species resolution in the Althaus data is not accurate. For example, there are no catches recorded for small lutjanids prior to 1979. This inaccuracy was the primary reason for using the data of Ramm (1995) to reconstruct what should be a more reliable catch composition for the foreign fleet.

3.1.2 Australian trawl data on the North West Shelf

Domestic fisheries data come from Fisheries WA in the form of Catch and Effort Statistics (CAES) and a voluntary logbook program, which were used to give a spatial catch distribution, as described above. For the purpose of Project 5, and keeping the same spatial scale as the foreign trawl data, the aggregated data was reconstructed into 0.5 degree grids.

The combined foreign and domestic trawl catch data, aggregated across grids cells is shown in figure 3.1.6. Because saurids were not targeted or retained by the domestic fleet, there is no catch data for this group after 1990. There is also a notable sharp decrease in catch after 1990 caused by the end of the foreign trawl catch data (note the log scale). Most of the trends however resume after 1993, and it is likely the dip in catch data is the result of jurisdictional changes from federal to state managed fisheries in 1990, and associated problems that accompany such institutional changes. For Project 5 we obtained additional data such that the final year of data is 2000.

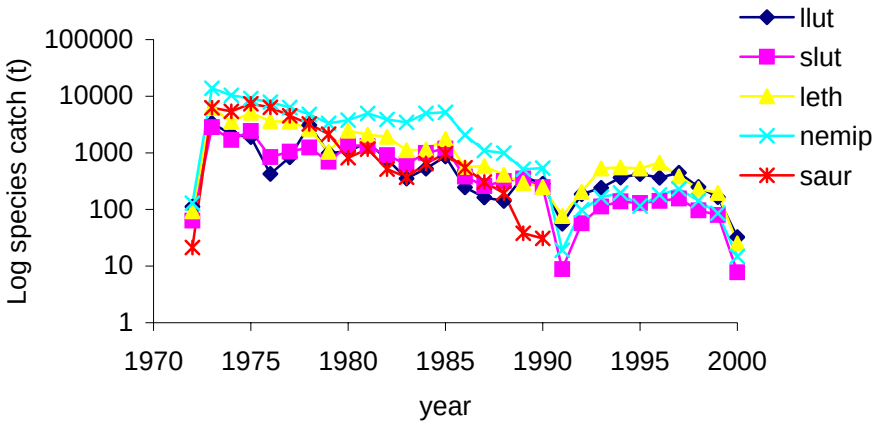

Figure 3.1.6: Total catch of species groups used in the NWS-JEMS Project 5 resulting from data analyses and compilation (llut: large lutjanids, slut: small lutjanids, leth: lethrinids, nemip: nemipterids, saur: saurids).

The relative proportion of the different species caught is show in figure 3.1.7. A substantial change in the species composition of the catch is apparent after 1990. This in part is exaggerated due to the lack of saurids in the catch reported at this time. Nonetheless, it is apparent that the catches of the nemipterids and small lutjanids decreased, and large lutjanids and lethrinids increased as the Taiwanese departed and the domestic fleet continued operations.

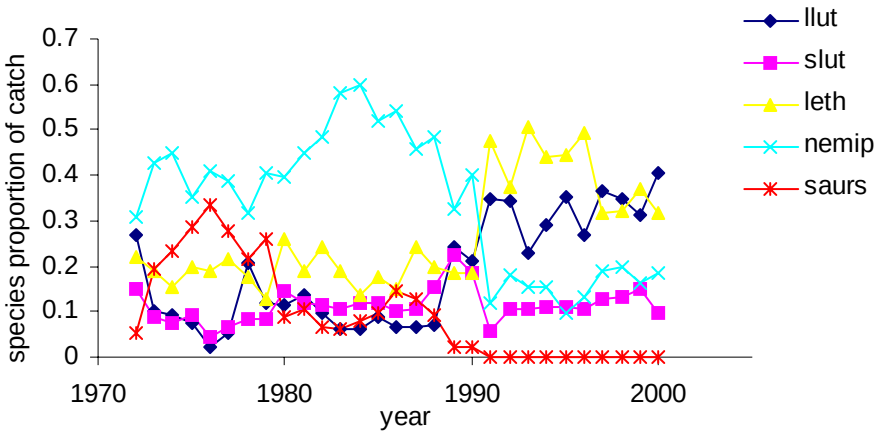

Figure 3.1.7: Relative proportions of species groups caught over the period 1972 to 2000 (llut: large lutjanids; slut: small lutjanids; leth: lethrinids; nemip: nemipterids; saur: saurids).

3.1.3 Foreign and domestic trawl effort data

Foreign effort data were taken as a combination of the Ramm (1995) and Althaus data. In particular, records of effort (in a specific year and 0.5 degree grid cell) from the latter were used exclusively unless there was no matching effort record for a particular catch record. In this circumstance, the effort record was obtained from the Ramm (1995) data. Domestic effort data was taken from the database developed in Project 2.6 of the NWSJEMS. Figure 3.1.8 shows the annual trawls effort for the domestic and foreign operations. Comparing figure 3.1.8 with figure 2.4.1, it is important to remember that the area covered in Project 5 is larger (114°E to 123°E) than the one covered in Project 2.5 (shaded area in figure 2.2.1).

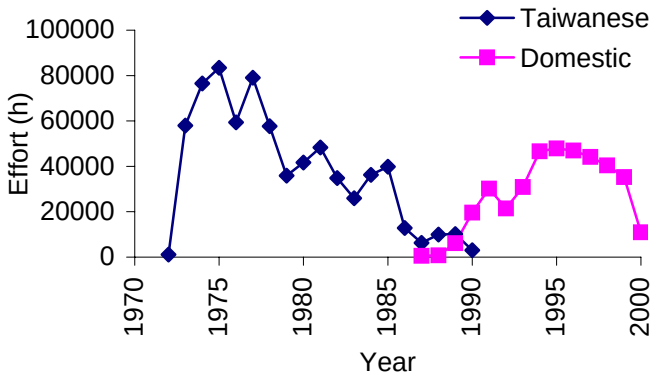

Figure 3.1.8: Spatially aggregated foreign (Taiwanese) and domestic trawl effort data from the North West Shelf derived from the various sources of data available.

3.1.4 North West Shelf trap fishery data

Australian trap fishery data on the North West Shelf is contained in the Fisheries WA CAES database. There is no logbook or other data source that could be used to disaggregate the data to a scale finer than 1 degree blocks so they were simply spread evenly among 0.5 degree grid cells for use in the MSE model. Figure 3.1.9 shows the trap catches for the different species groups (note the log scale). The main species caught by this trap fishery tended to be large lutjanids and lethrinids. The annual trap effort data derived from the databases is summarised in figure 3.1.10. Trap effort has been measured in boat days, where a boat day is equivalent to approximately 100 trap pulls (each boat has about 12 to 13 traps).

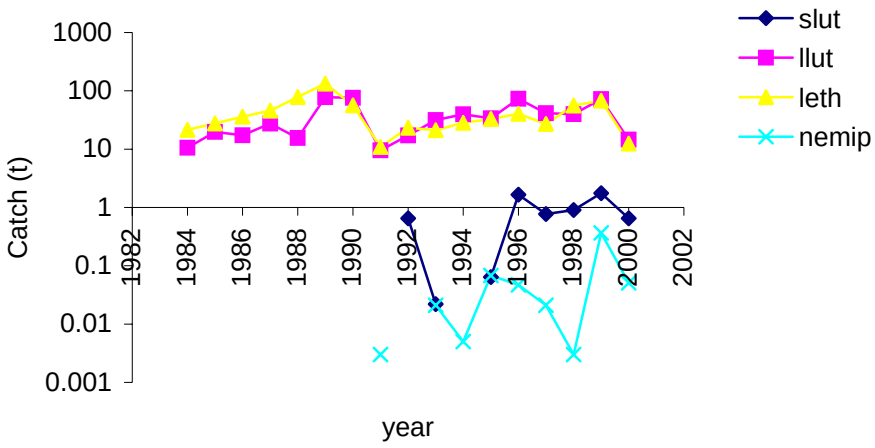

Figure 3.1.9: Annual catch of different species groups caught over the period 1984 to 2000 by the trap fishery on the North West Shelf (llut: large lutjanids; slut: small lutjanids; leth: lethrinids; nemip: nemipterids; saur: saurids).

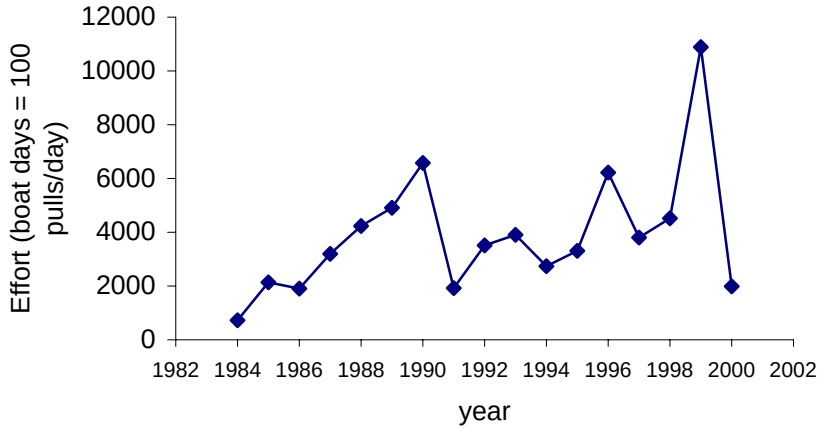

Figure 3.1.10: Annual effort expended by the trap fishery on the North West Shelf.

3.2 Summary

The period 1972 to 1979 was a significant period of development and change for the commercial fisheries on the Pilbara region of North West Shelf, and during this period there was significant fishing pressure and reduction in many fish stocks. The two data sources that are available to provide the fishery catch and effort history both originated from the logbook data provided by the Taiwanese, but differ primarily in the catch recorded in the early years of the fishery – that is 1972 and 1973. Ramm (1995) database, based on work and data held at the National Taiwan University (NTU) tended to have smaller catches than the Althaus database, which transferred the data directly from the annual reports released by the NTU. The former has a much finer species resolution, but the total catch in the latter database is judged to be closest to the actual data based on the commonly held view that 37000 t of fish were caught in 1973 (K. Sainsbury and P. Stephenson pers. comm.). For the purposes of the NWSJEMS Project 5 both desirable attributes of these databases were used to generate an annual spatial distribution of catch for five species groups. The results of the analysis give a realistic portrayal of the spatial distribution of catches for the species groups prior to 1979.

The domestic operators on the North West Shelf increased in importance in the late 1980s and early 1990s. Catch and Effort Statistics (CAES) data record this, but at a coarse spatial scale. A voluntary logbook program from 1993 to 1997 has aided in disaggregating these data to a finer spatial scale. Included in the CAES, but not the logbook data, are trap fishery data. Where the finer-scaled voluntary logbook data are absent a broad-brush approach was taken of evenly distributing catch and effort at the 1 degree grid cells to the 0.5 degree grids used by the MSE model in Project 5.

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APPENDIX A: CATCH DISTRIBUTION MAPS

A.1 Prawn catch

Distribution maps depicting ranges of the proportionate catch of prawns by year on a 10 by 10 minute grid, for the foreign trawl fishery ((a): Taiwanese) and the domestic fishery ((b) and (c): CAES, all methods) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

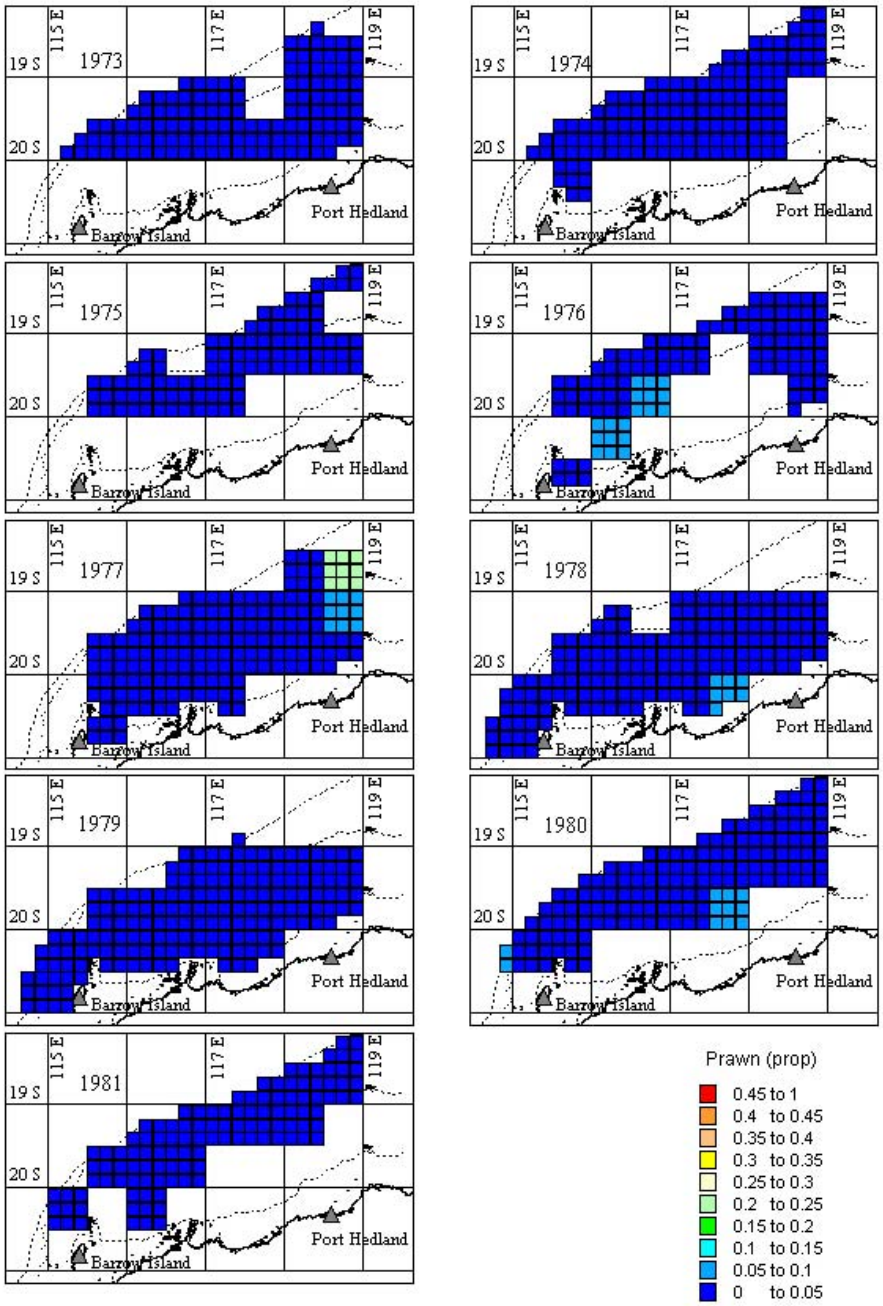

Figure A.1 (a): Proportional catch of prawns (Taiwanese logbooks).

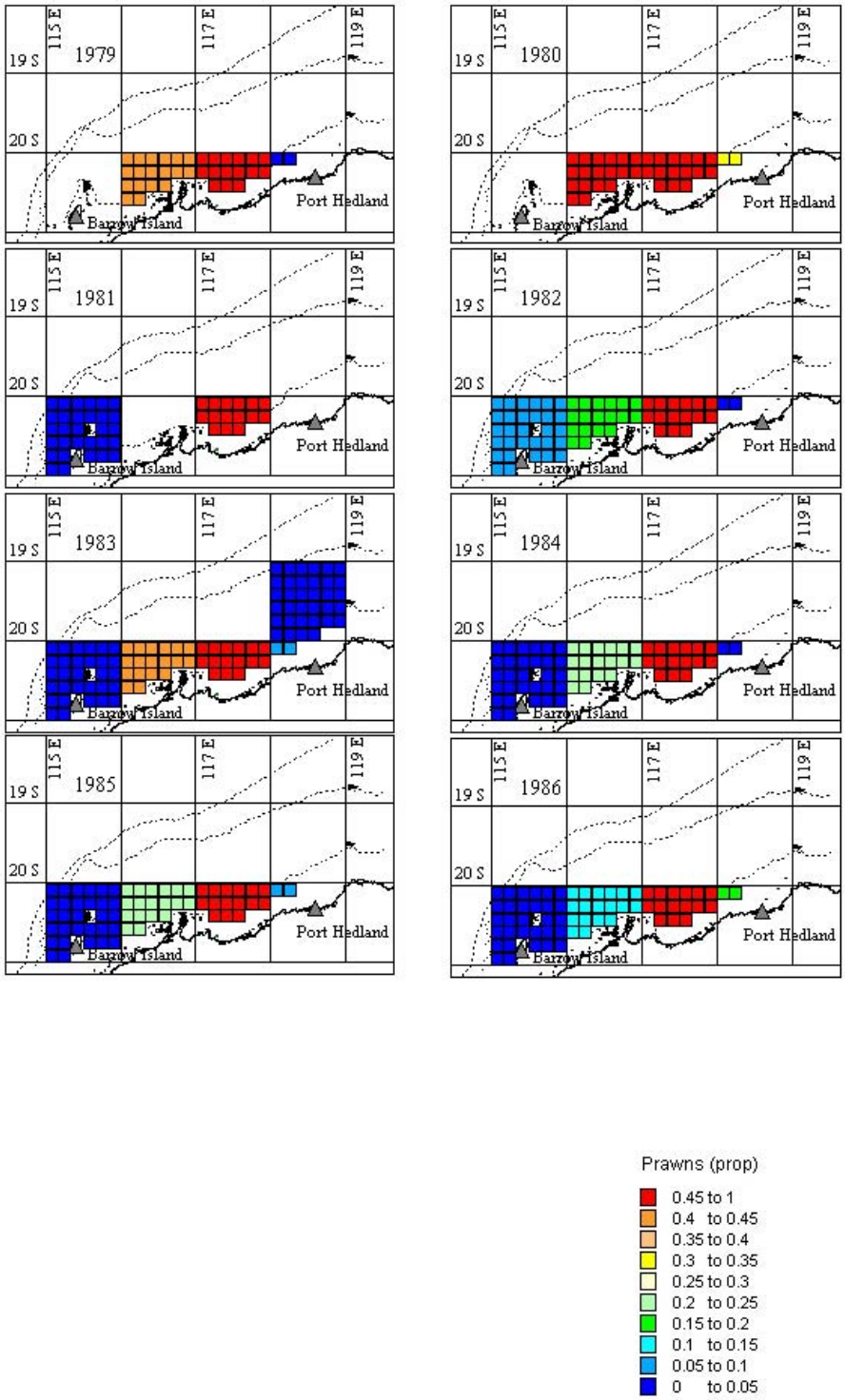

Figure A.1 (b): Proportional catch of prawns (CAES, 1979-1986).

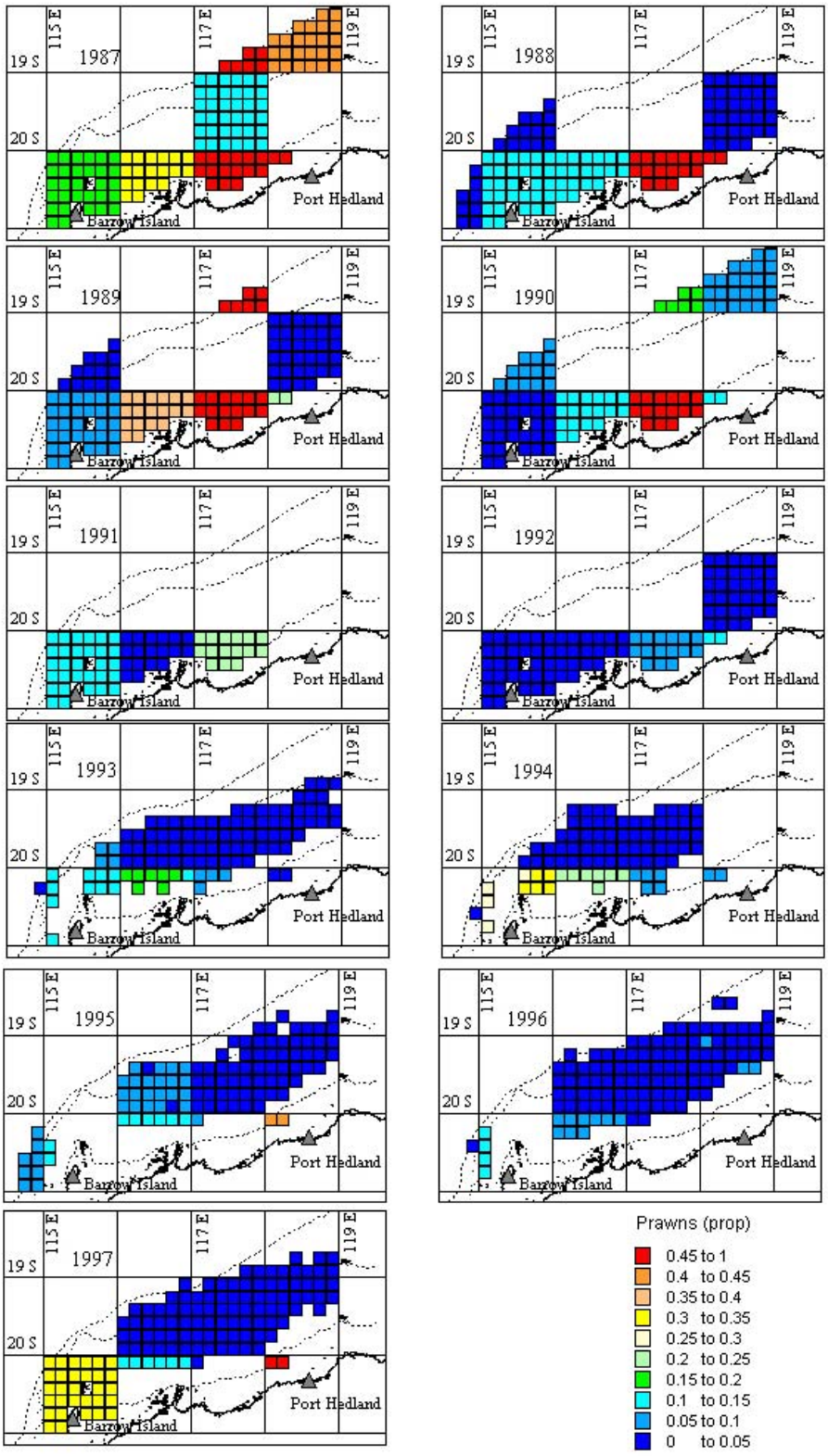

Figure A.1 (c): Proportional catch of prawns (CAES, 1987-1997).

A.2 Other invertebrates

Distribution maps depicting ranges of the proportionate catch of invertebrates (Iother), excluding prawns, by year on a 10 by 10 minute grid, for the foreign trawl fishery ((a) Taiwanese, (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and for the CSIRO research surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

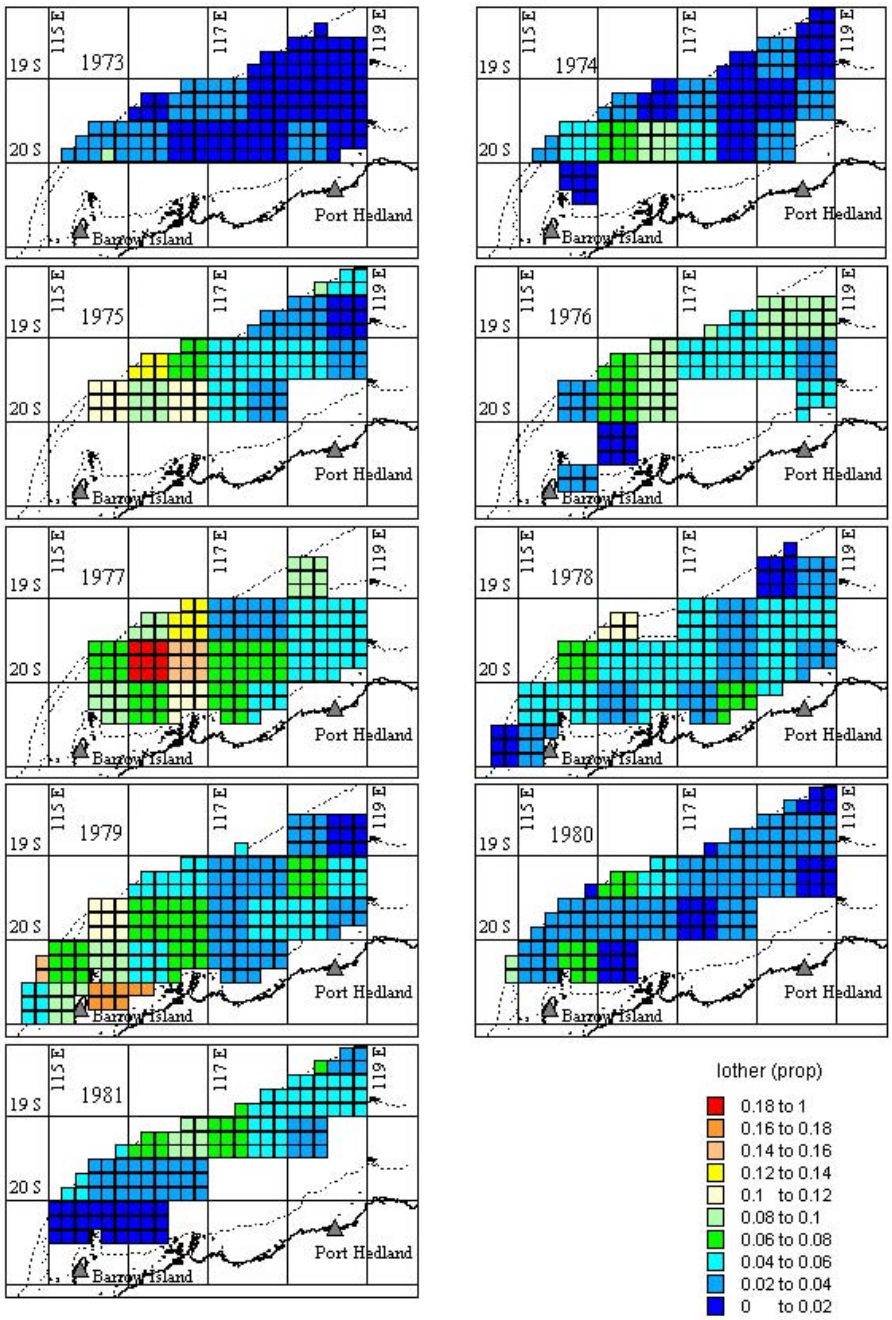

Figure A.2 (a): Proportional catch of other invertebrates (Taiwanese logbooks).

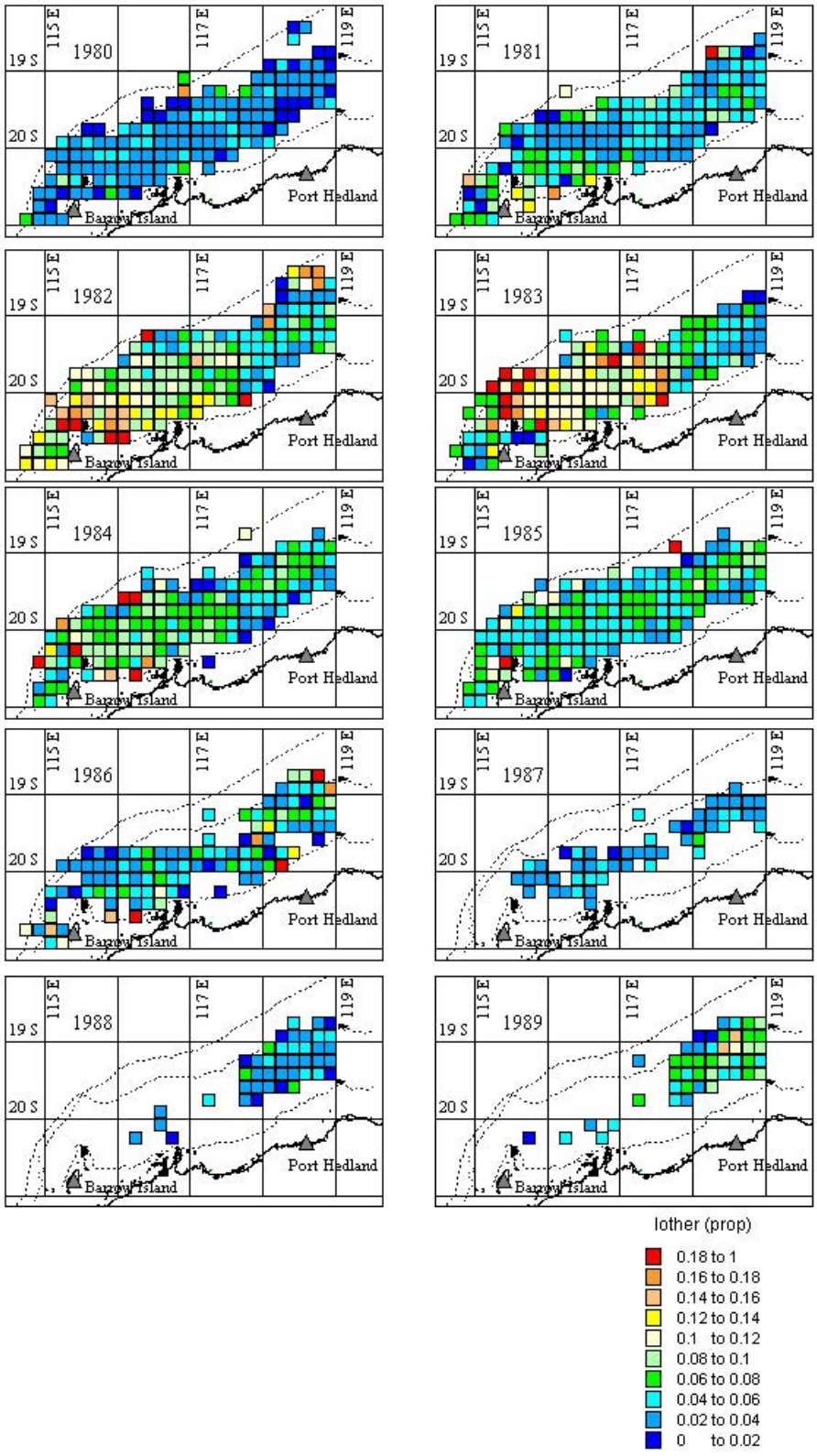

Figure A.2 (b): Proportional catch of other invertebrates (AFMA).

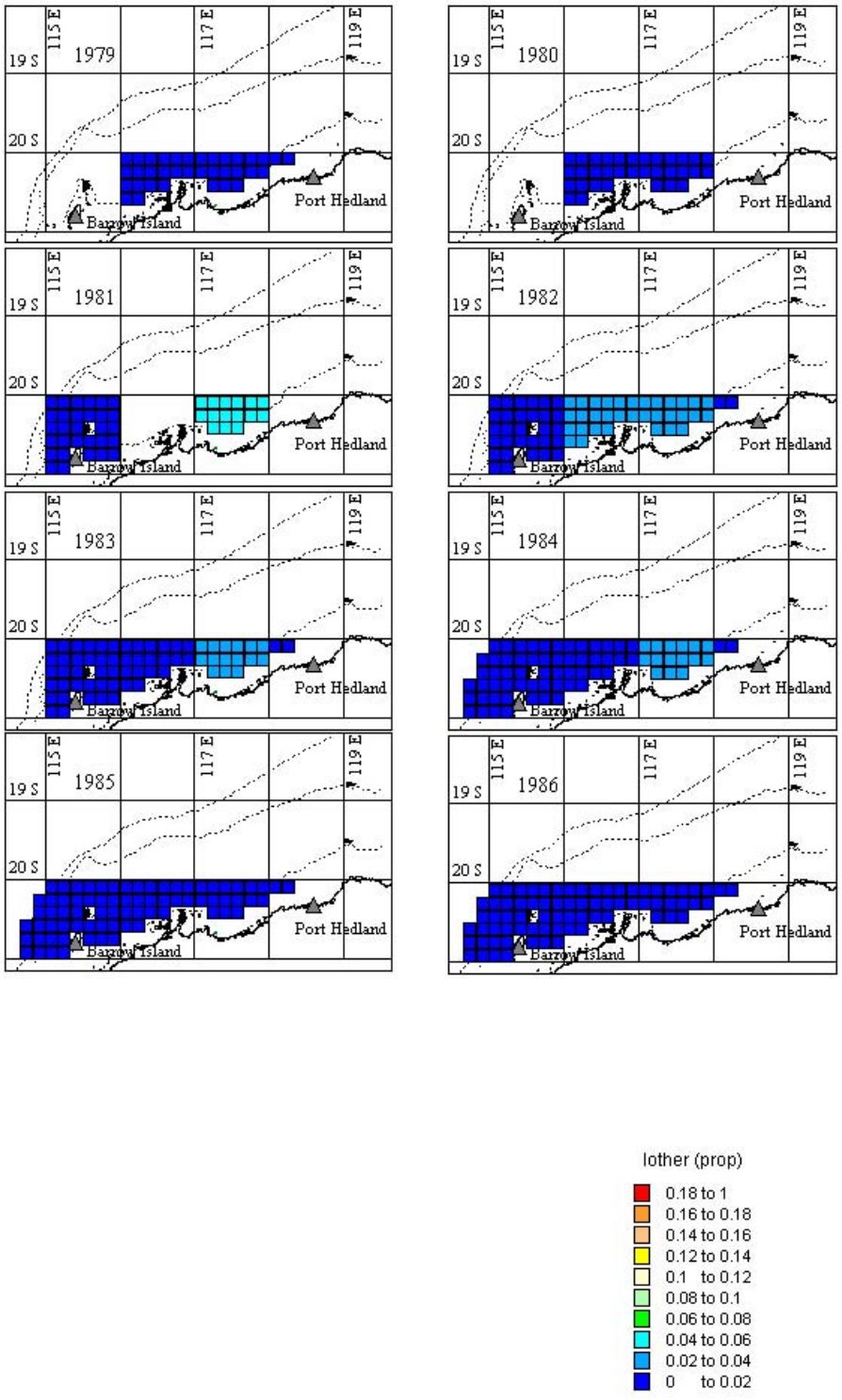

Figure A.2 (c): Proportional catch of other invertebrates (CAES, 1979-1986).

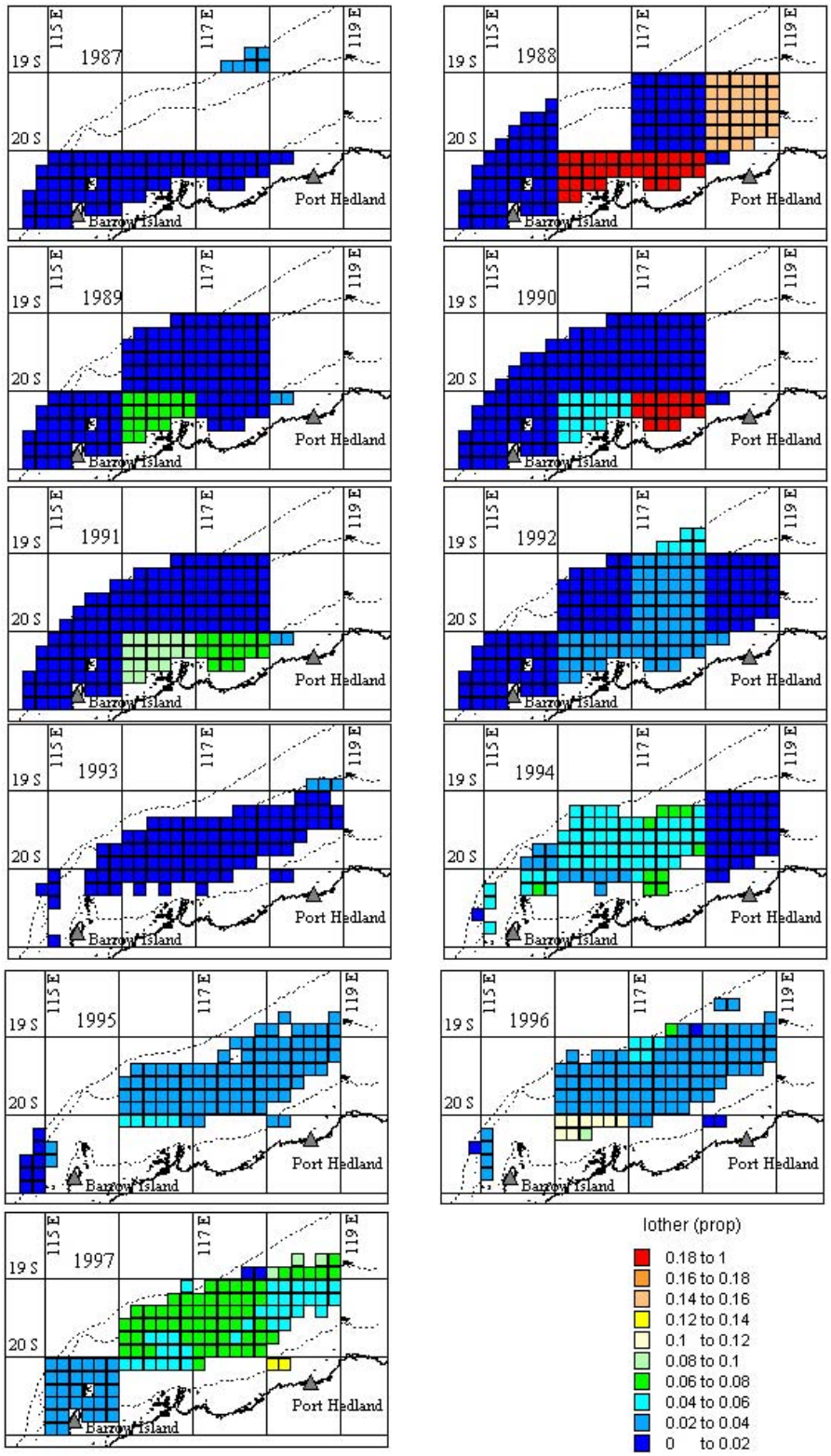

Figure A.2 (d): Proportional catch of other invertebrates (CAES, 1987-1997).

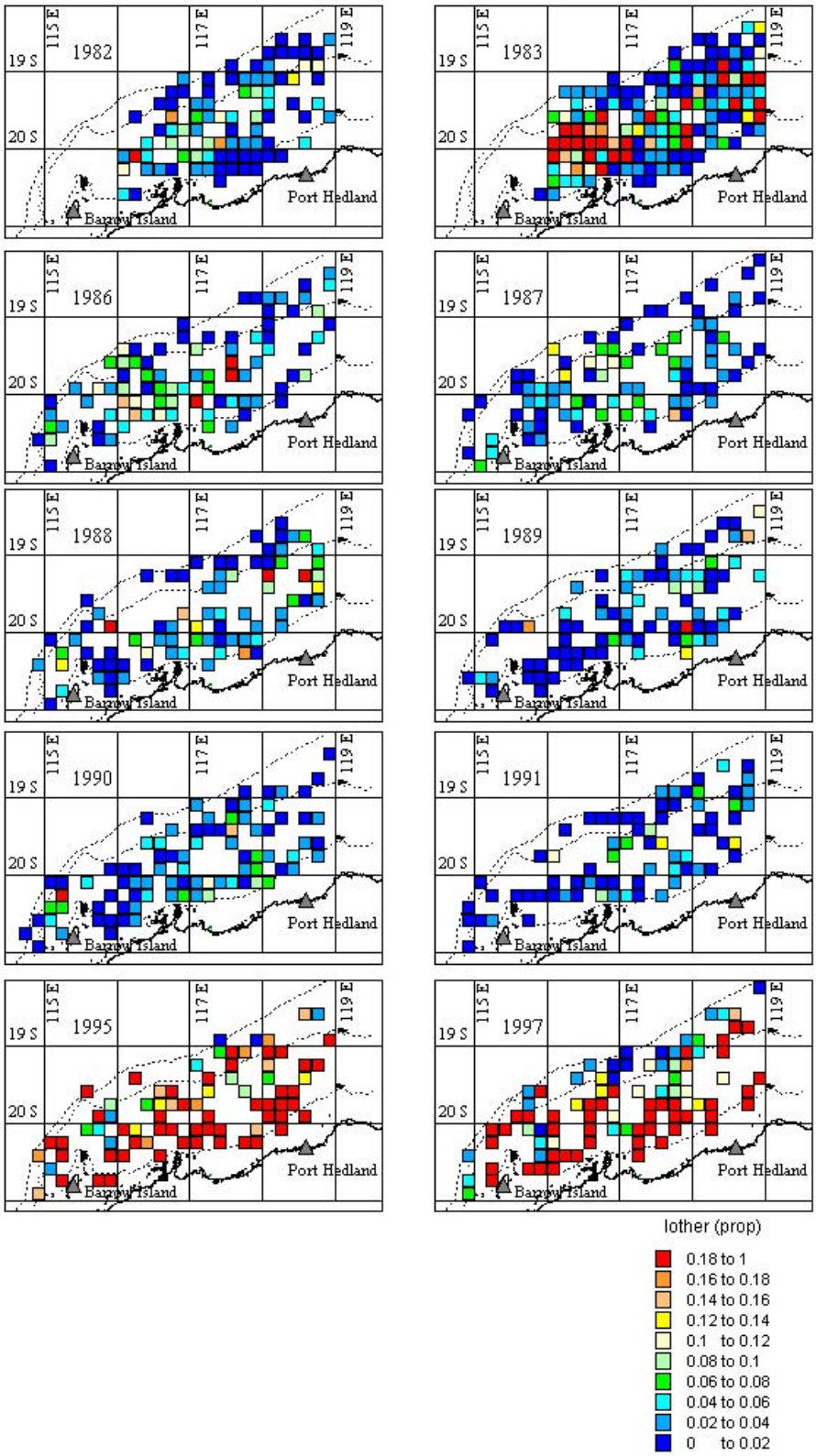

Figure A.2 (e): Proportional catch of other invertebrates (CSIRO surveys).

A.3 Sharks and rays

Distribution maps depicting ranges of the proportionate catch of sharks and rays by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

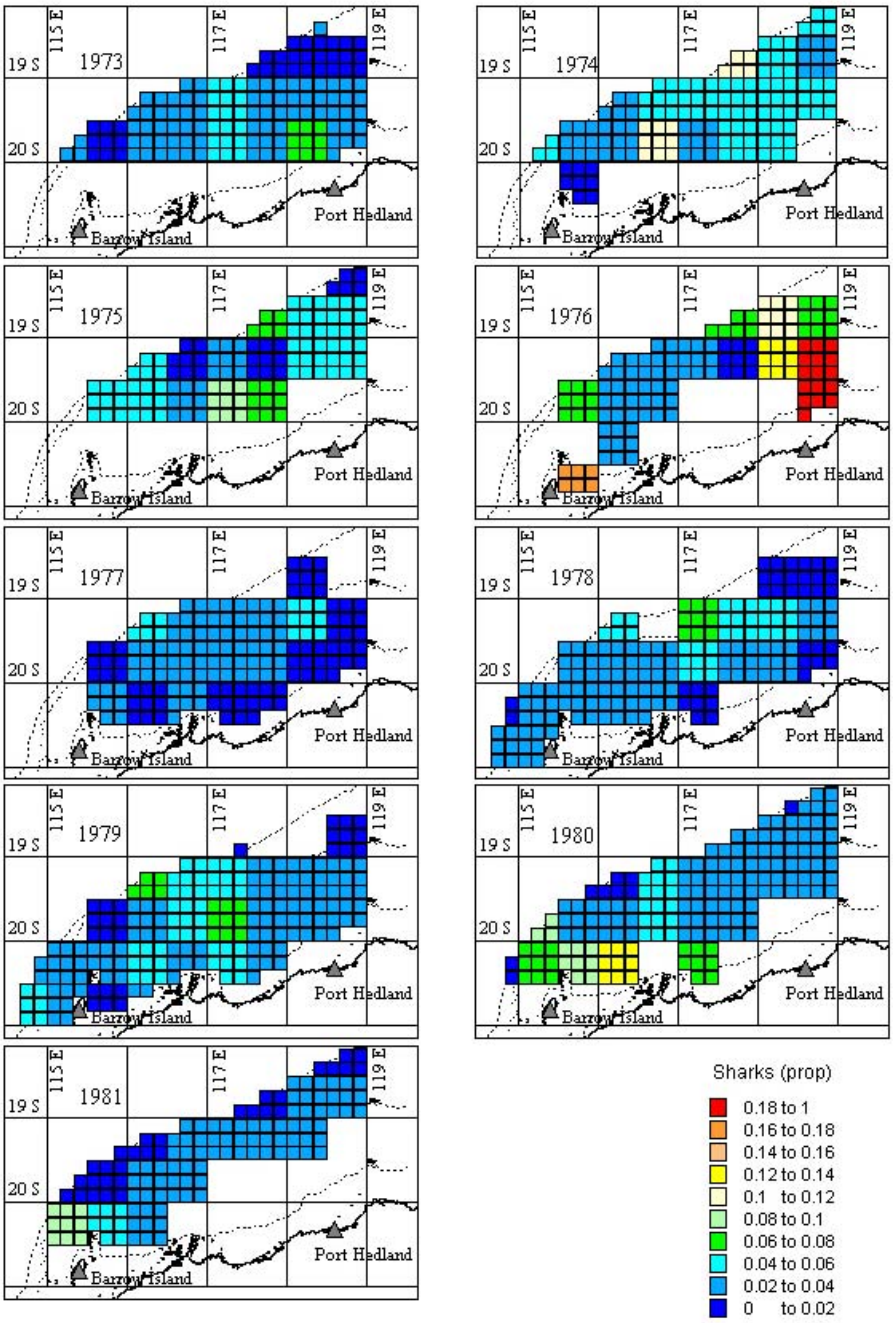

Figure A.3 (a): Proportional catch of sharks and rays (Taiwanese logbooks).

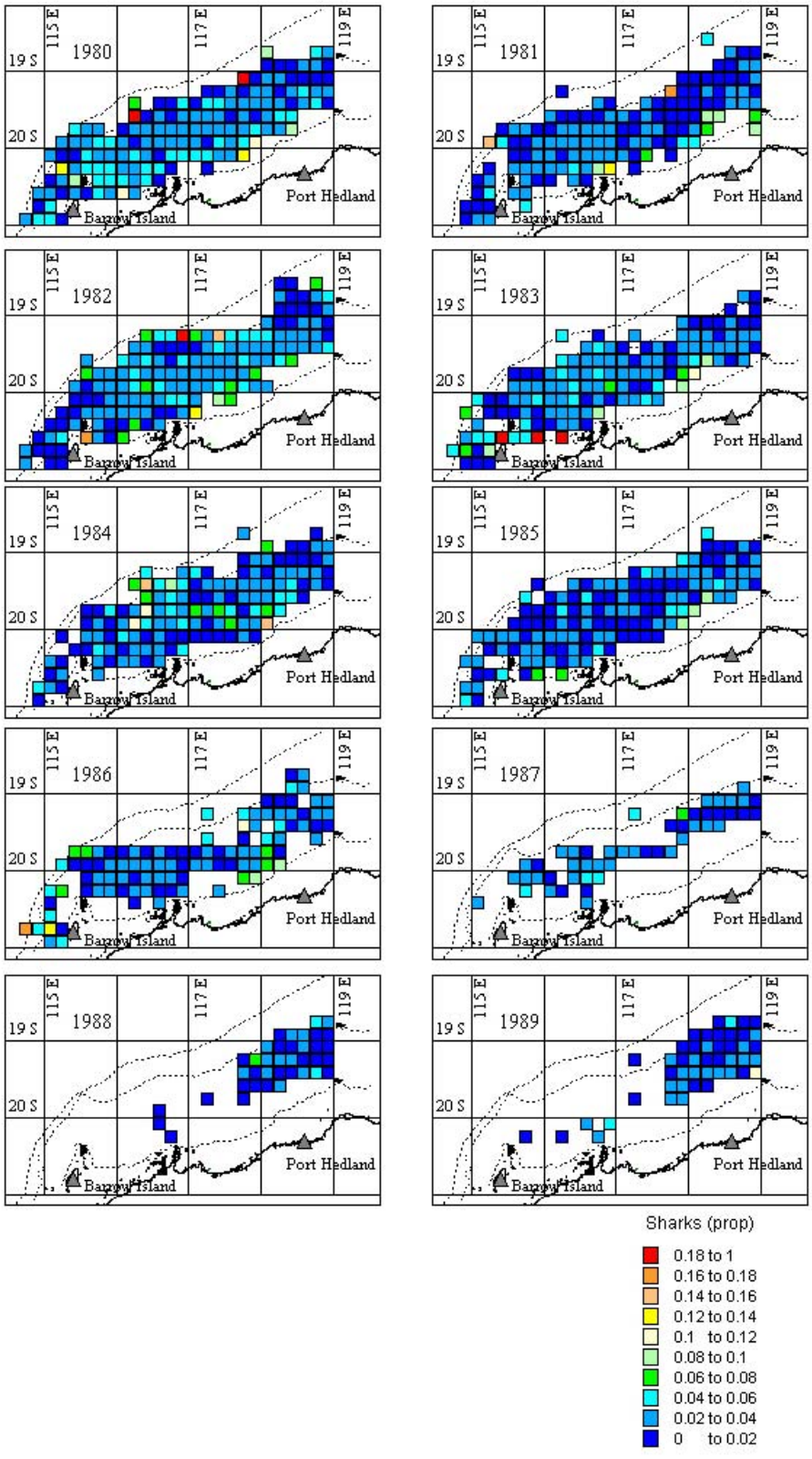

Figure A.3 (b): Proportional catch of sharks and rays (AFMA).

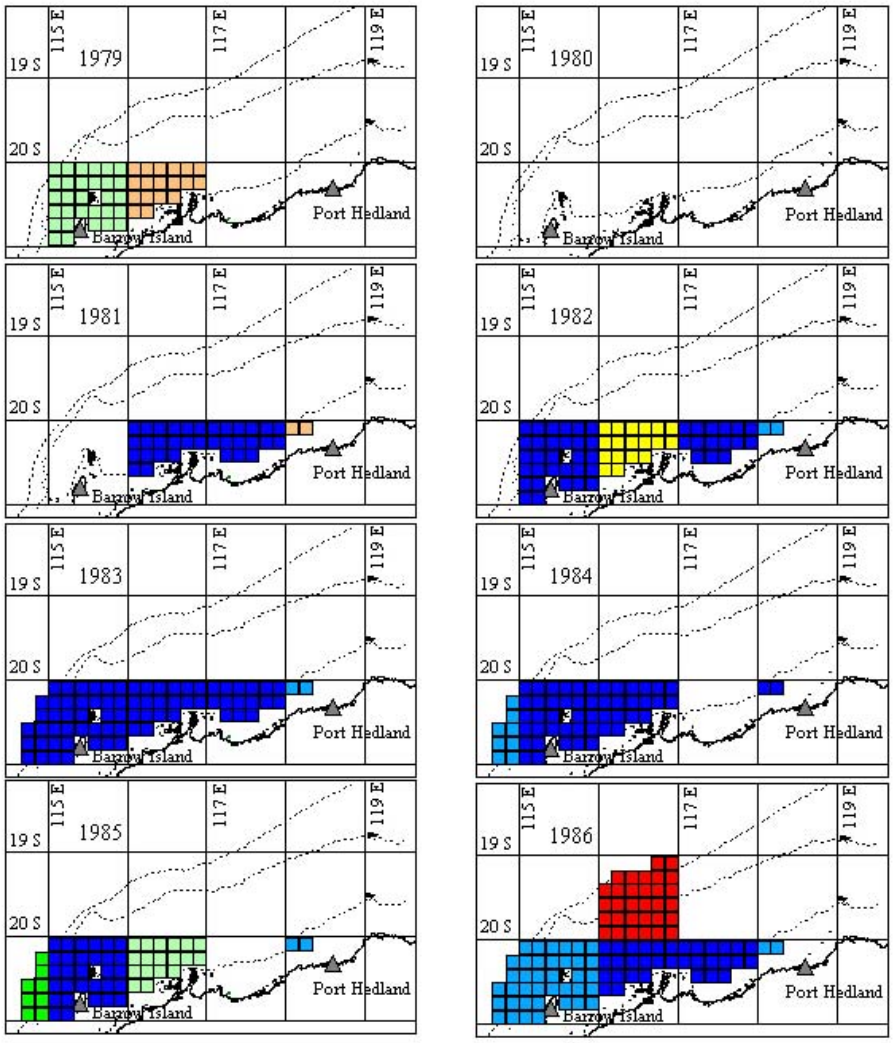

Figure A.3 (c): Proportional catch of sharks and rays (CAES, 1979-1986).

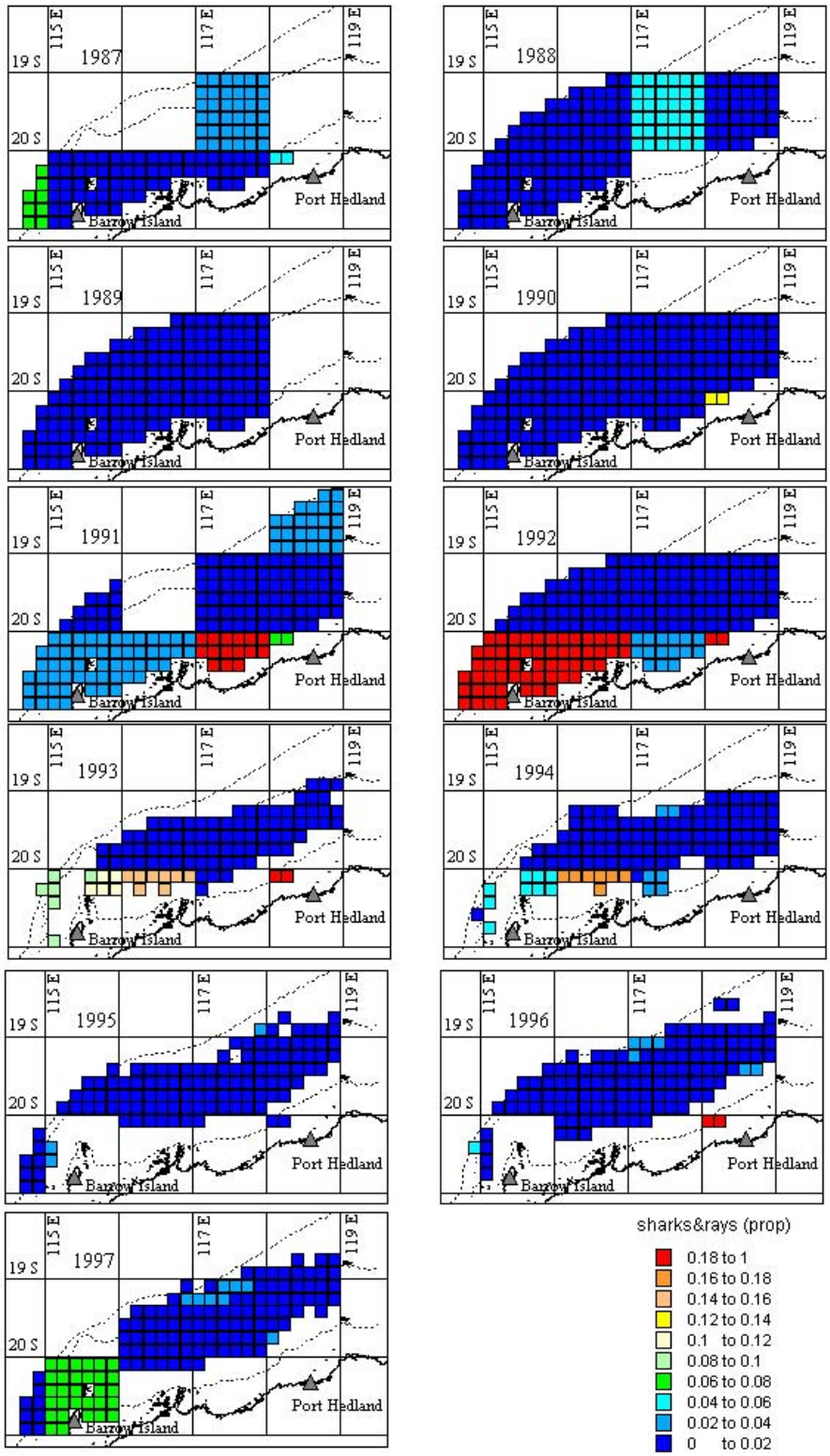

Figure A.3 (d): Proportional catch of sharks and rays (CAES, 1987-1997).

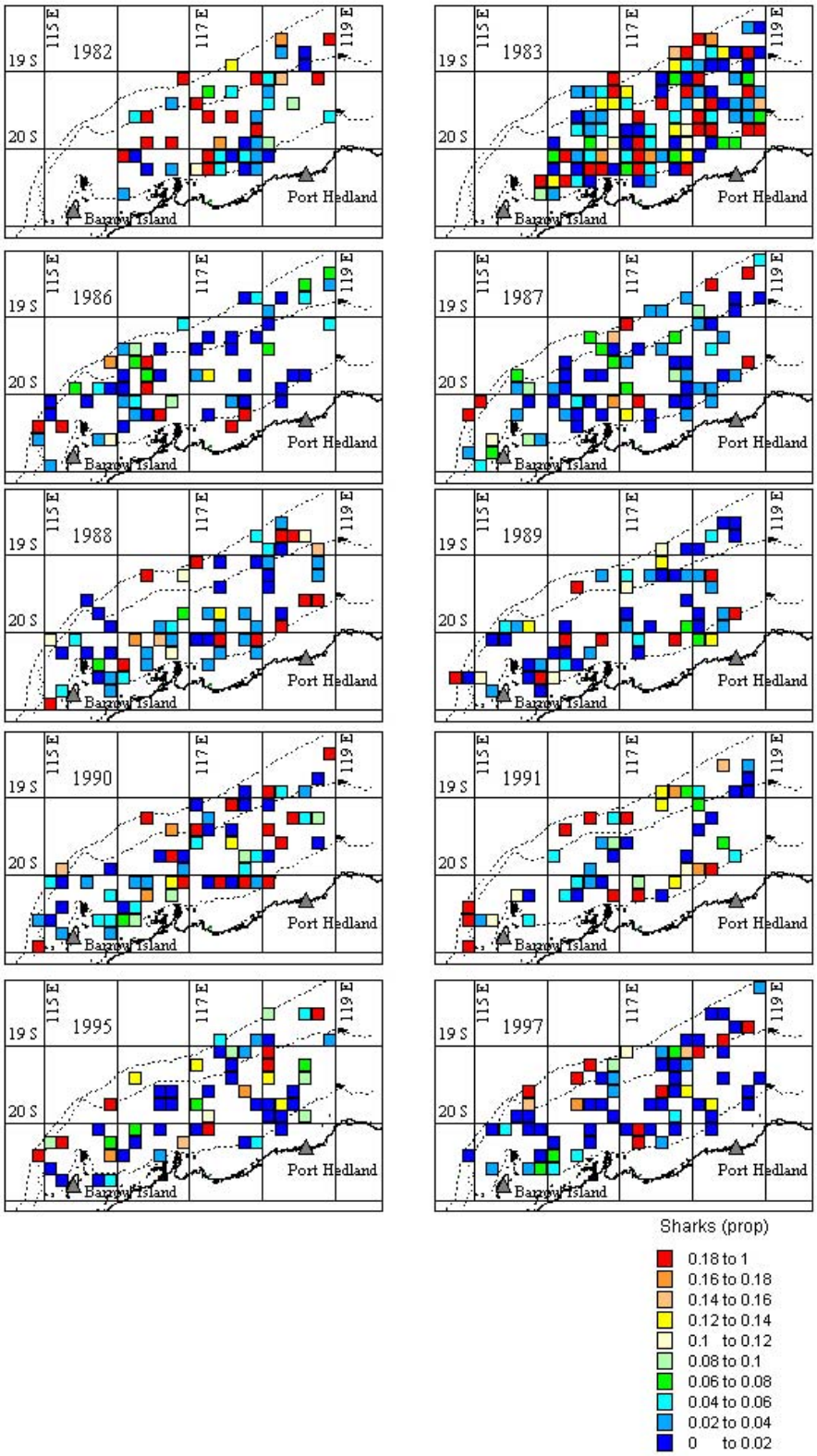

Figure A.3 (e): Proportional catch of sharks and rays (CSIRO surveys).

A.4 Lizardfishes (bathysauridae and synodontidae)

Distribution maps depicting ranges of the proportionate catch of lizardfishes (bathysauridae and synodontidae) by year on a 10 by 10 minute grid, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

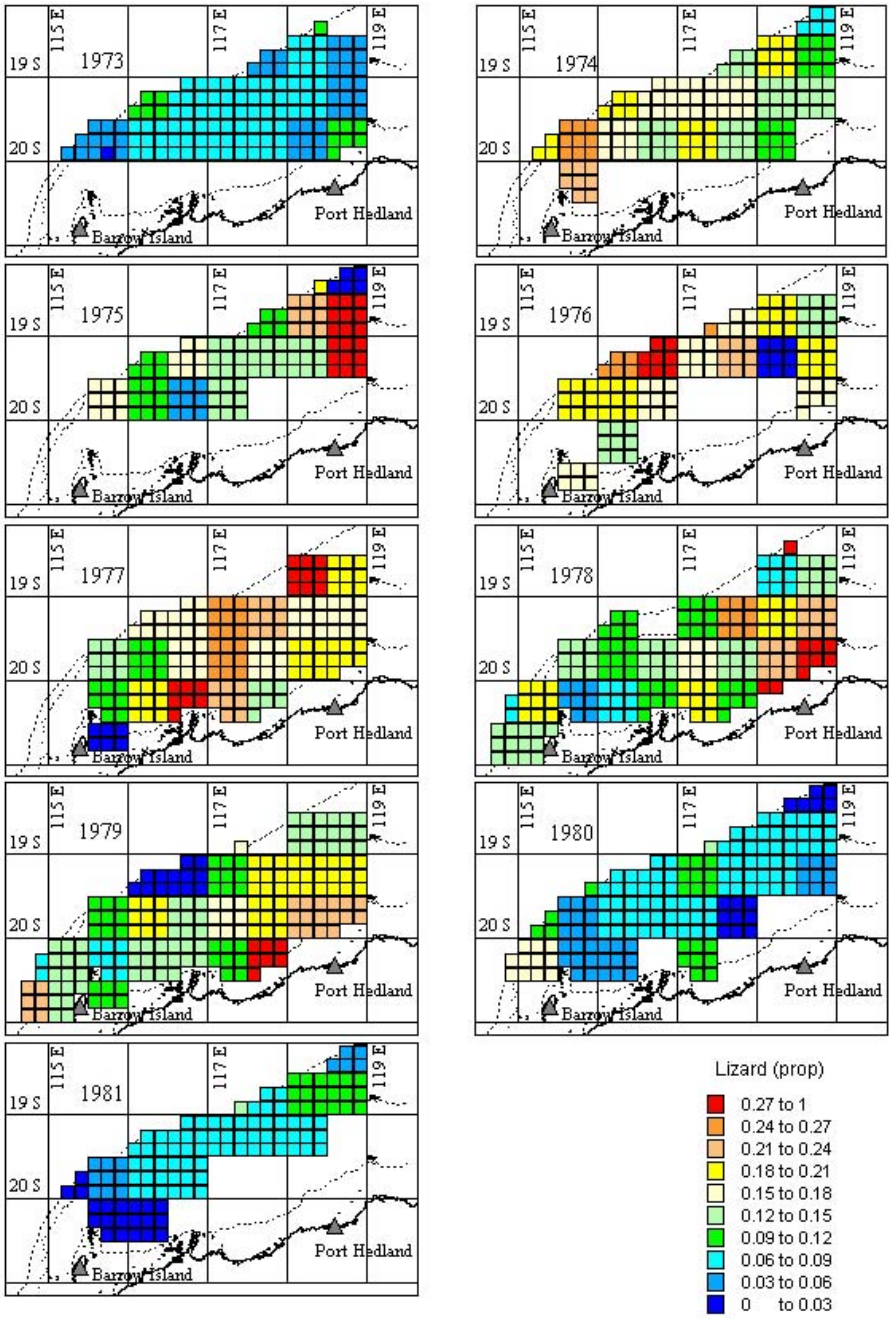

Figure A.4 (a): Proportional catch of lizardfishes (Taiwanese logbooks).

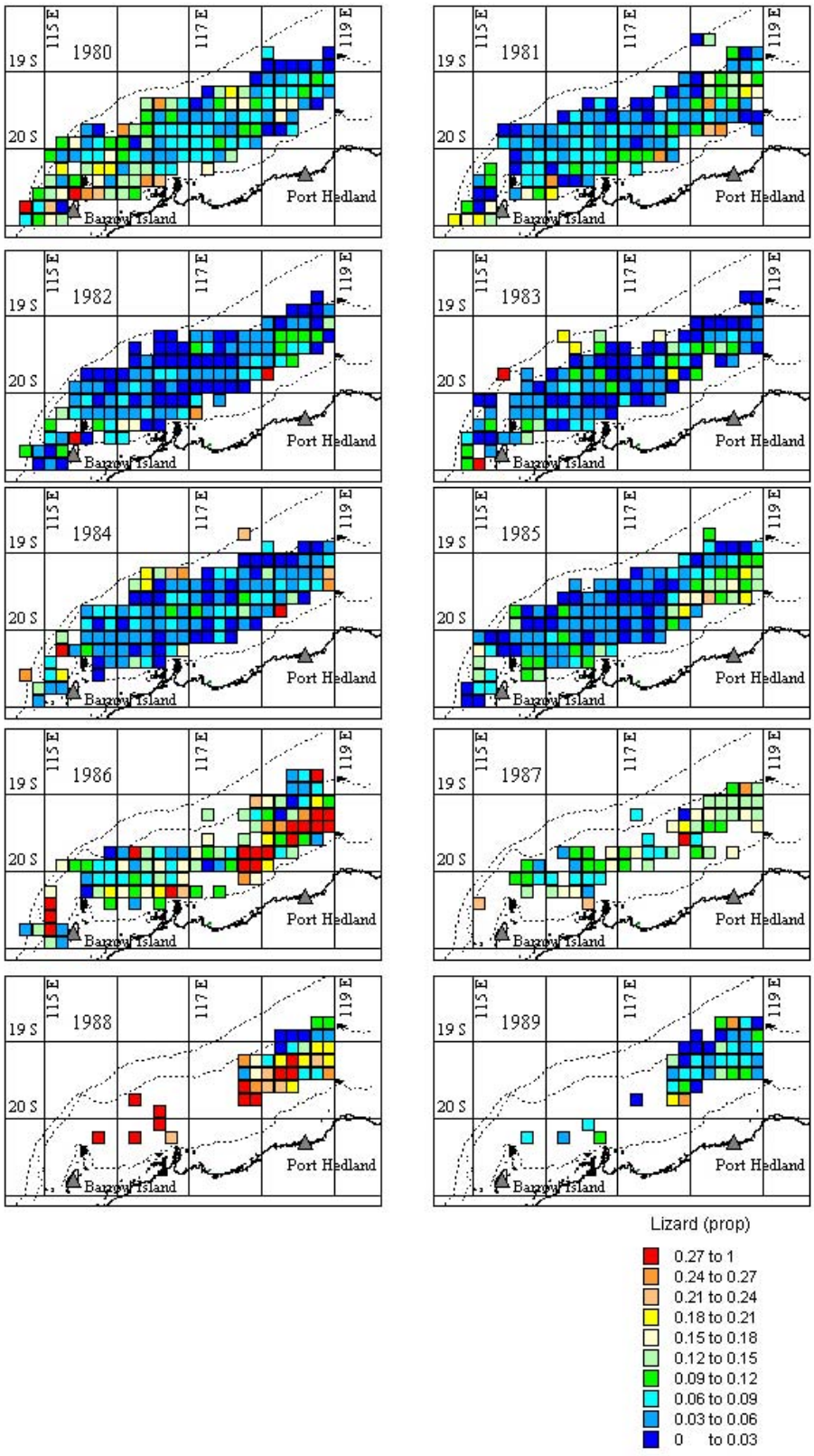

Figure A.4 (b): Proportional catch of lizardfishes (AFMA).

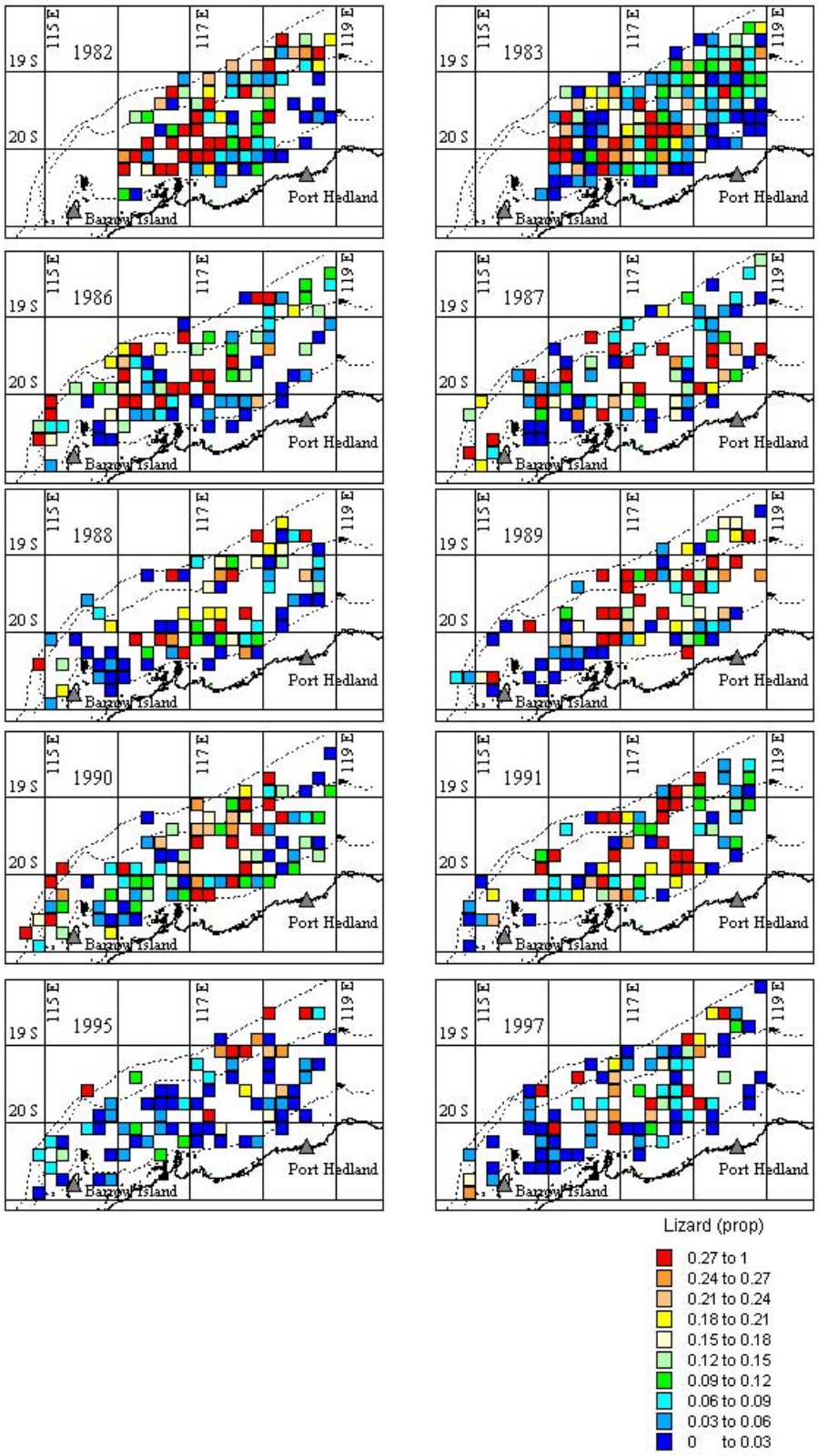

Figure A.4 (c): Proportional catch of lizardfishes (CSIRO surveys).

A.5 Rockcods (percichthyidae and serranidae)

Distribution maps depicting ranges of the proportionate catch of rockcods (percichthyidae and serranidae), excluding Epinephelus multinotatus, by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) and (c) CAES, all methods), and the CSIRO surveys (d) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

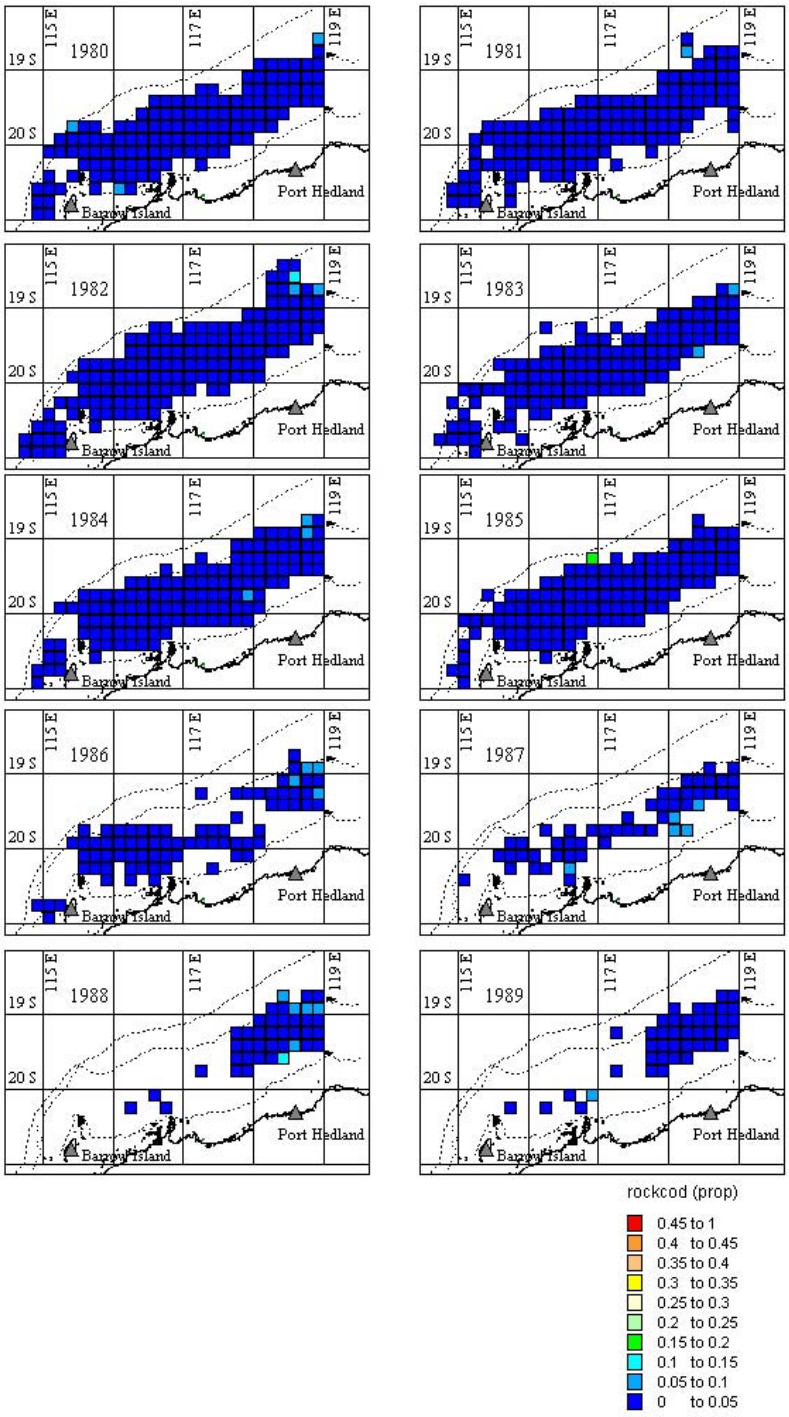

Figure A.5 (a): Proportional catch of rockcods (AFMA).

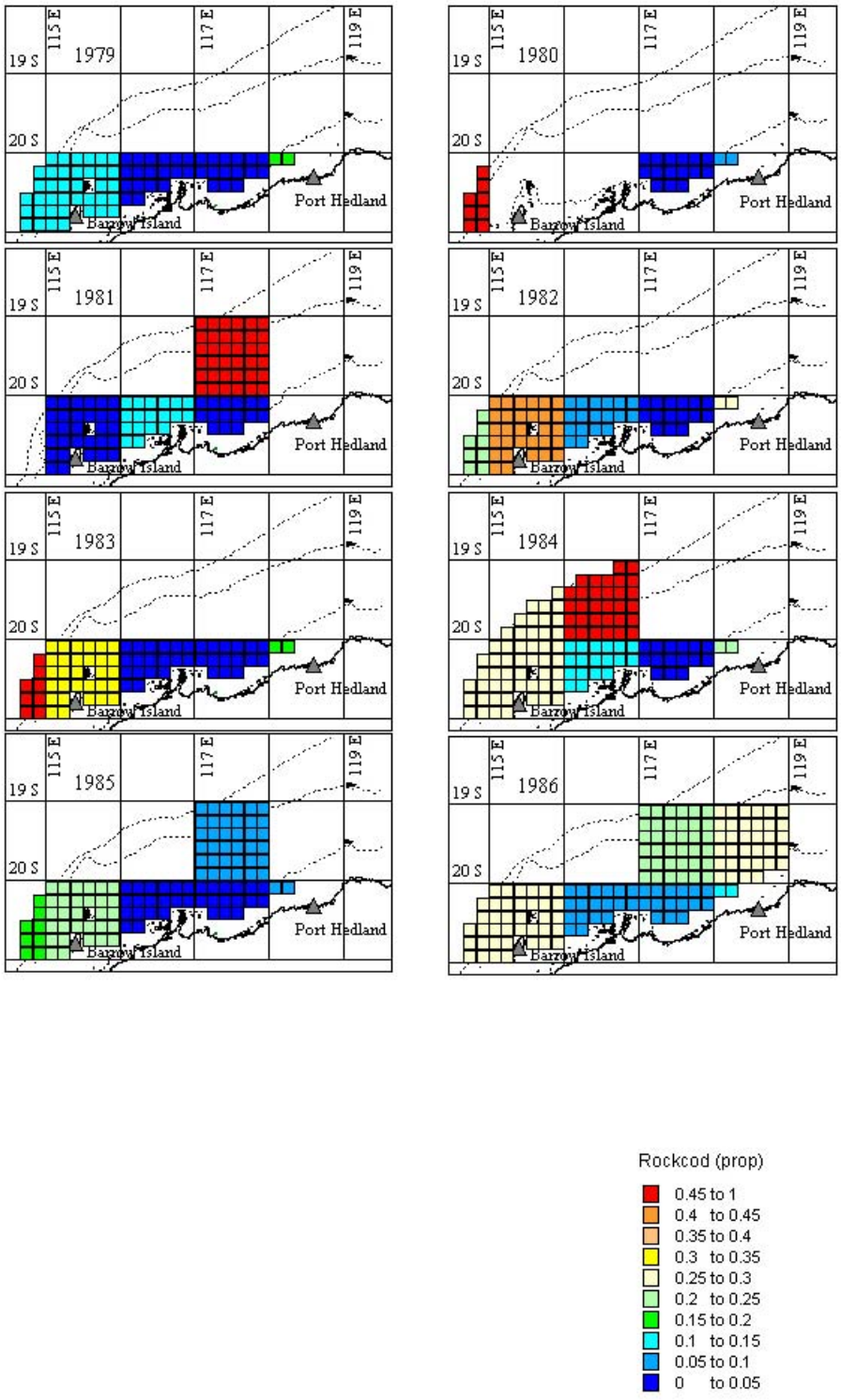

Figure A.5 (b): Proportional catch of rockcods (CAES, 1979-1986).

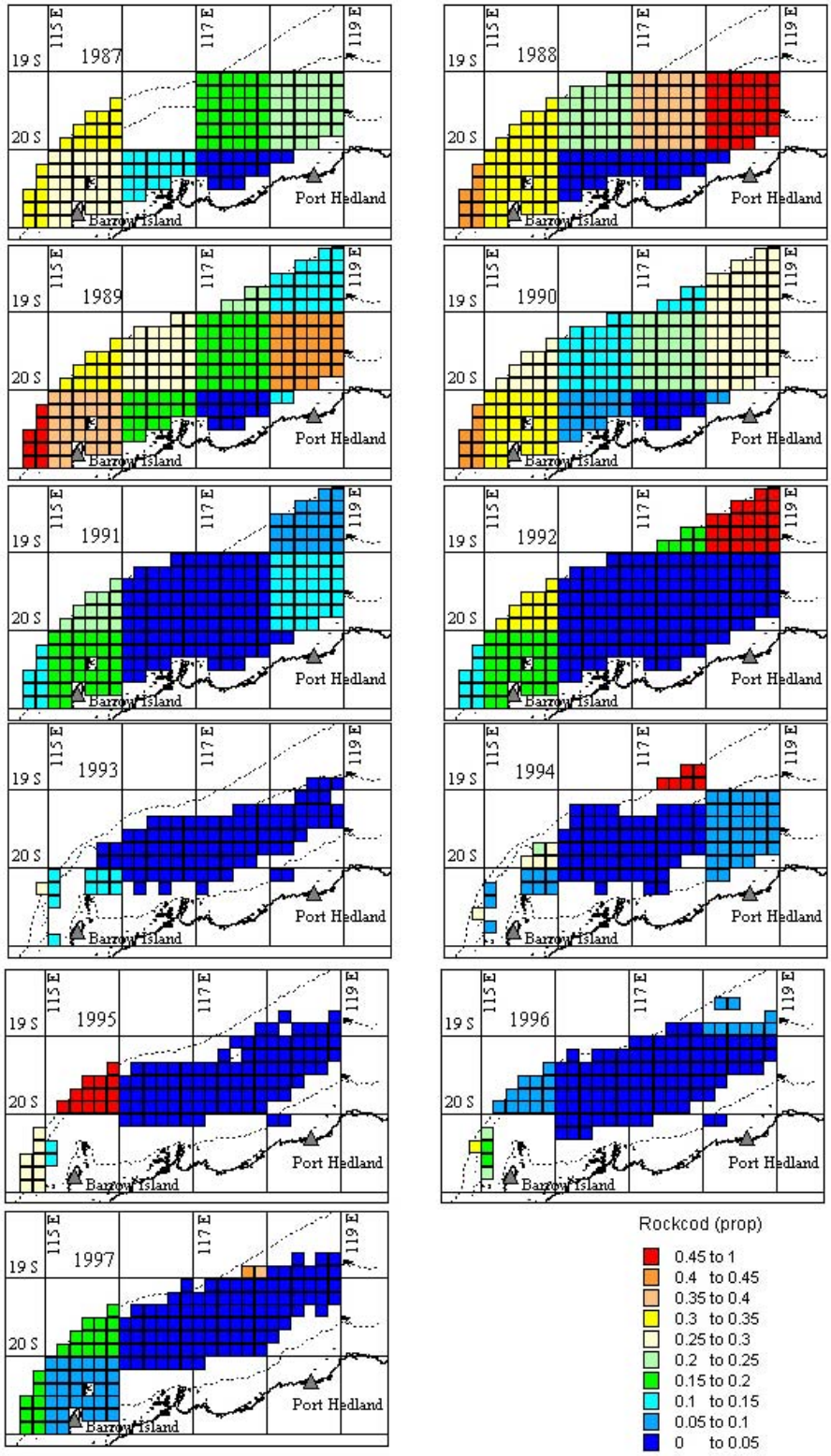

Figure A.5 (c): Proportional catch of rockcods (CAES, 1987-1997).

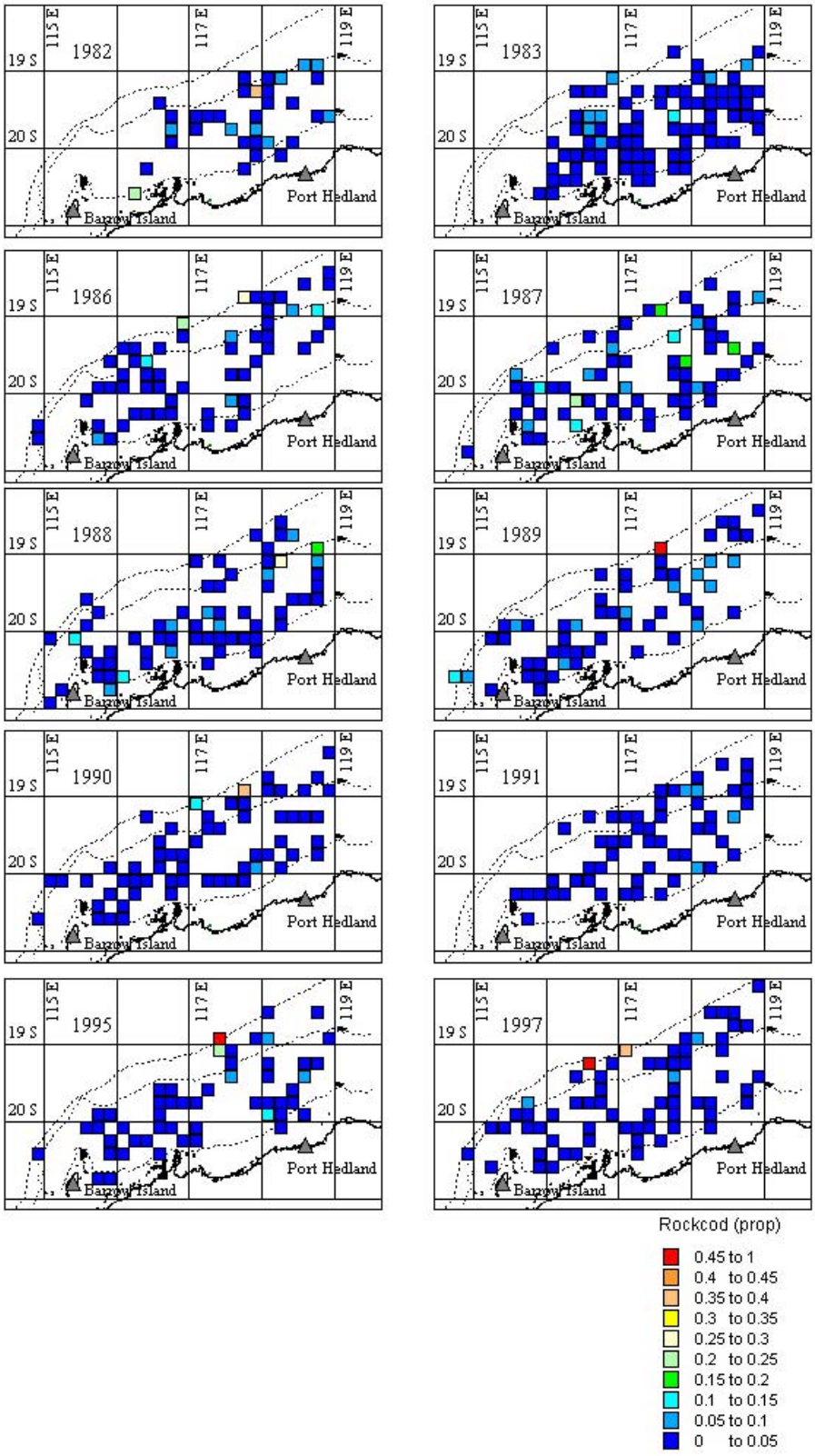

Figure A.5 (d): Proportional catch of rockcods (CSIRO surveys).

A.6 *Epinephelus multinotatus*

Distribution maps depicting ranges of the proportionate catch of *Epinephelus multinotatus* (Epmult) by year on a 10 by 10 minute grid scale, for the domestic fishery ((a) and (b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

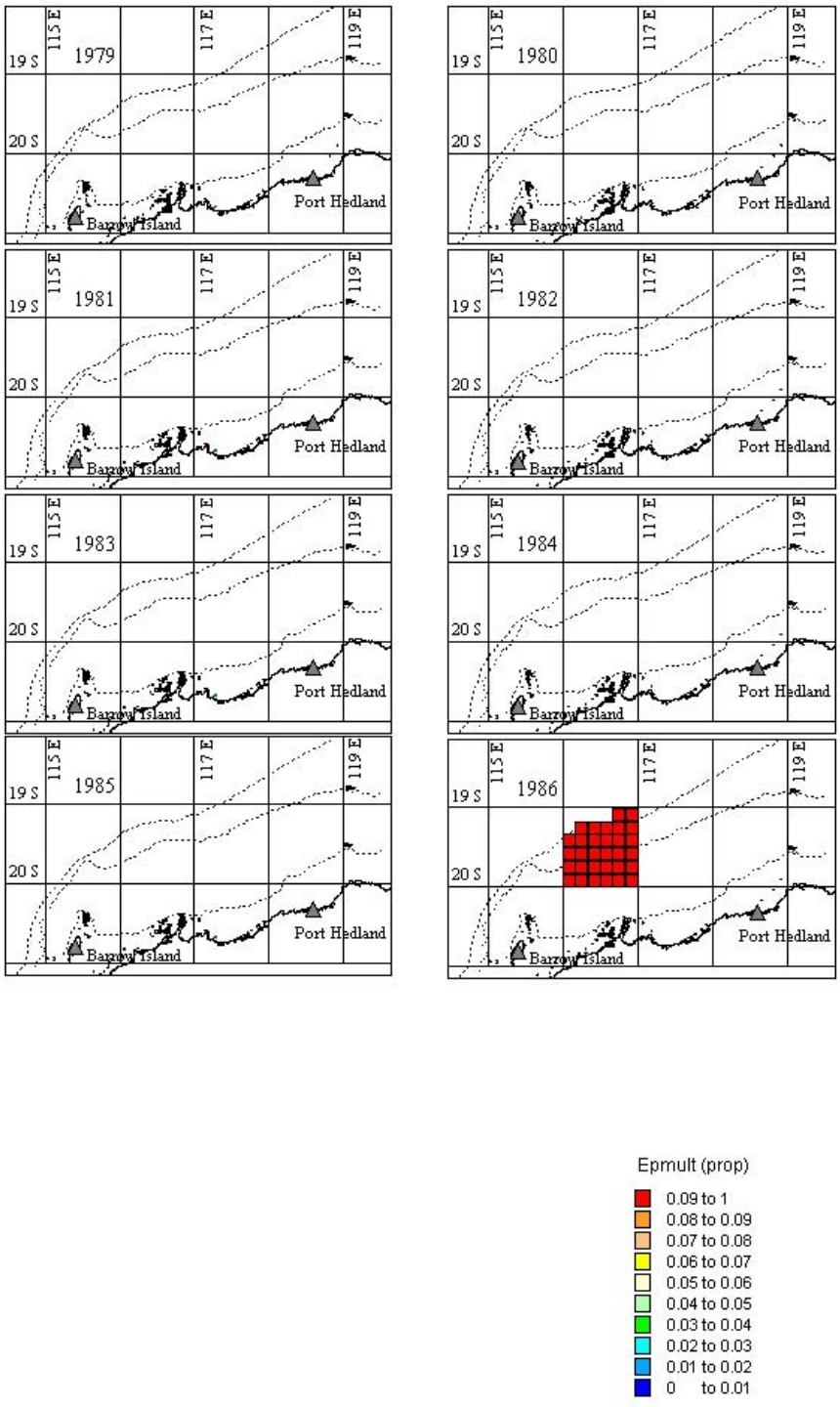

Figure A.6 (a): Proportional catch of *Epinephelus multinotatus* (CAES, 1979-1986).

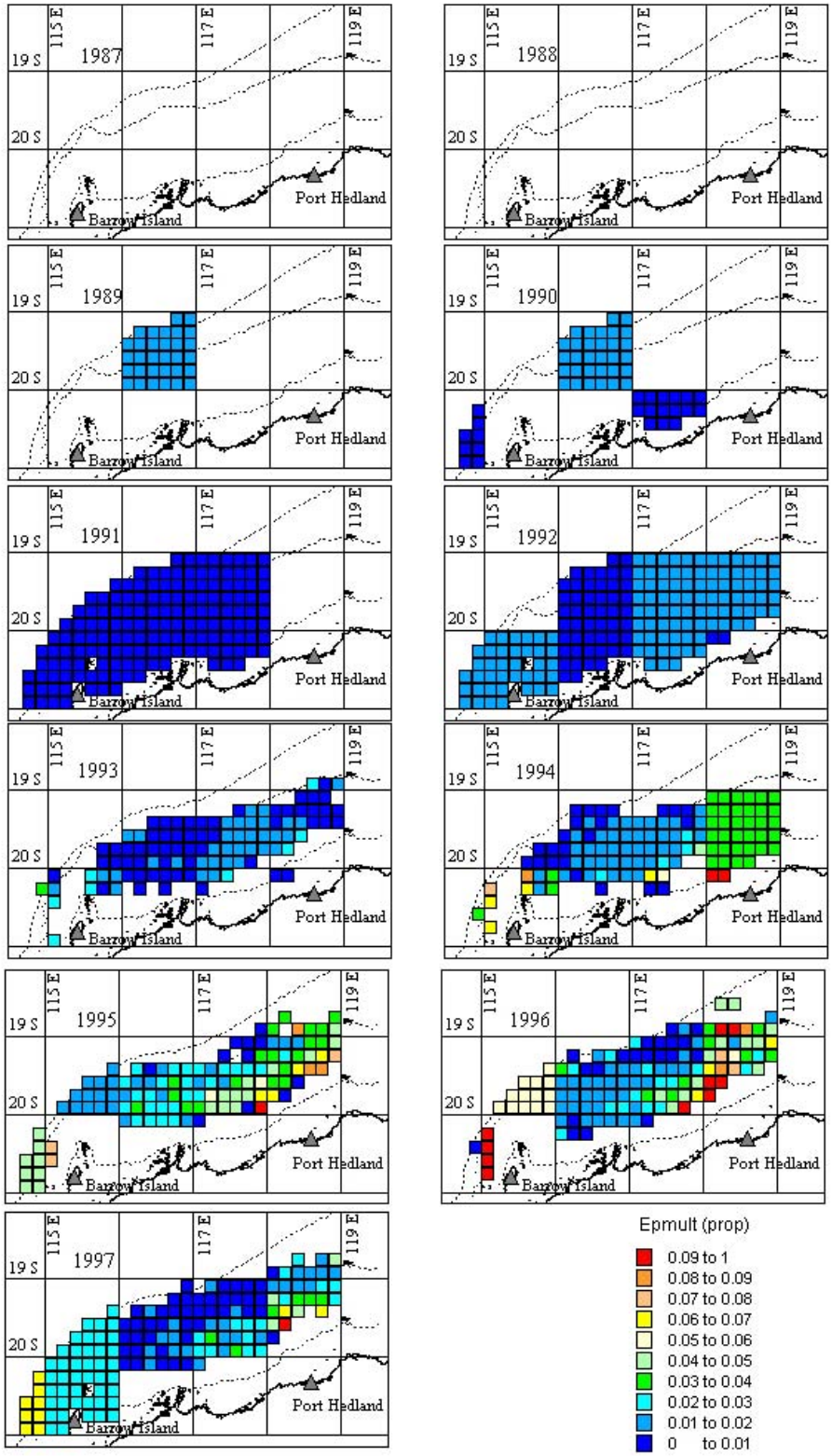

Figure A.6 (b): Proportional catch of Epinephelus multinotatus (CAES, 1987-1997).

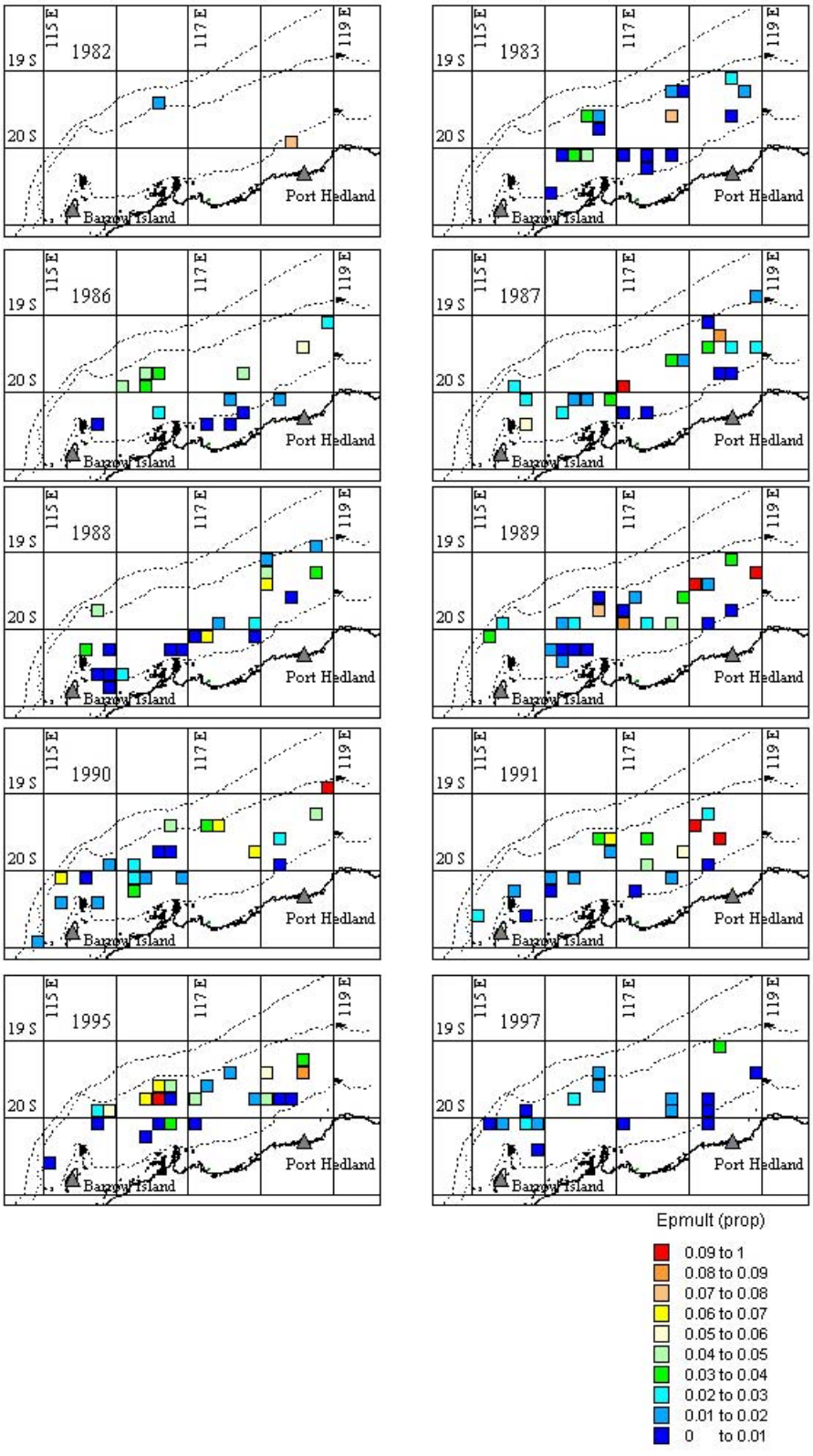

Figure A.6 (c): Proportional catch of *Epinephelus multinotatus* (CSIRO surveys).

A.7 Bigeyes (Priacanthidae)

Distribution maps depicting ranges of the proportionate catch of bigeyes (Priacanthidae) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) CAES, all methods), and the CSIRO surveys (d) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive. Ranges: lower limit exclusive, upper limit inclusive.

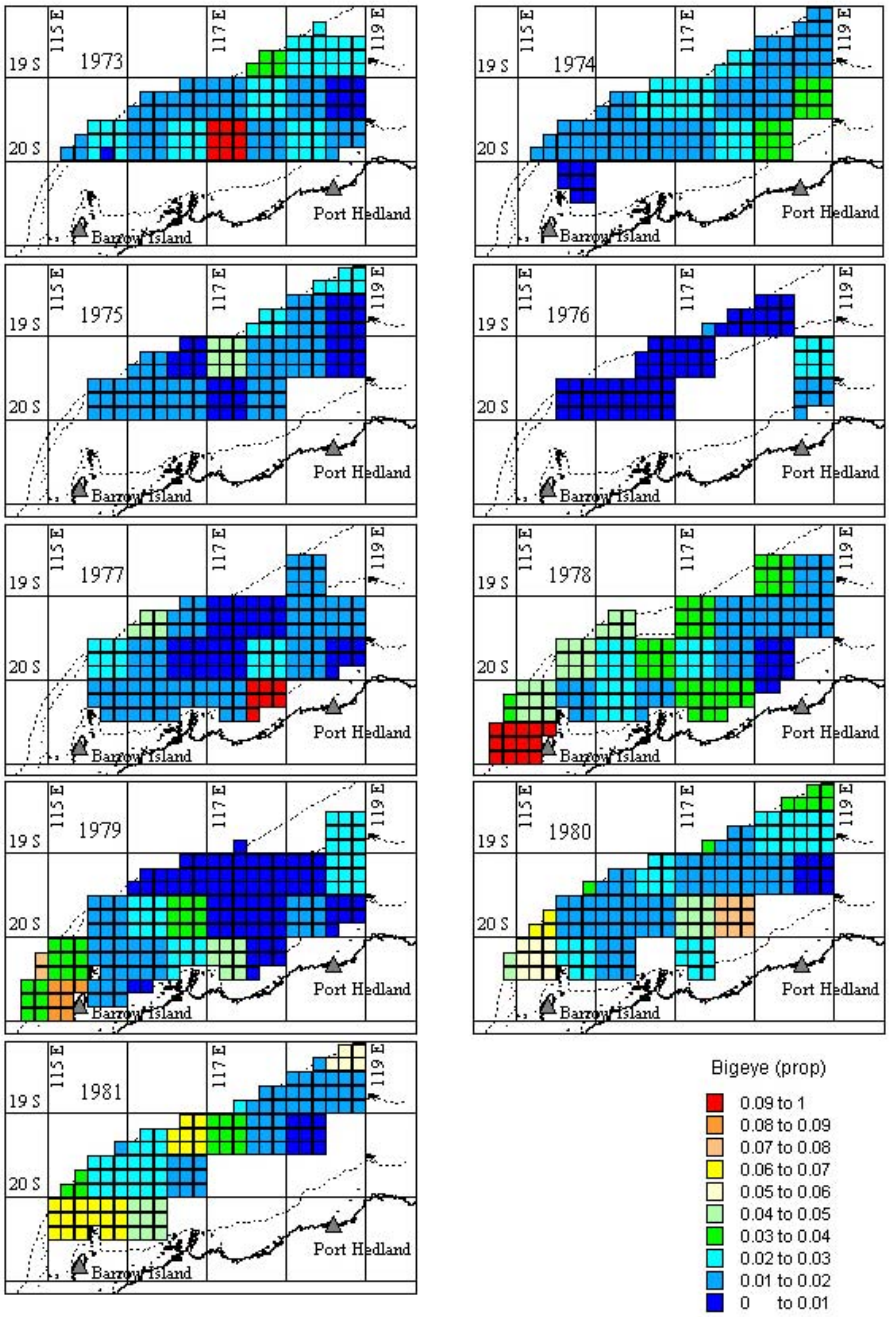

Figure A.7 (a): Proportional catch of bigeyes (Taiwanese logbooks).

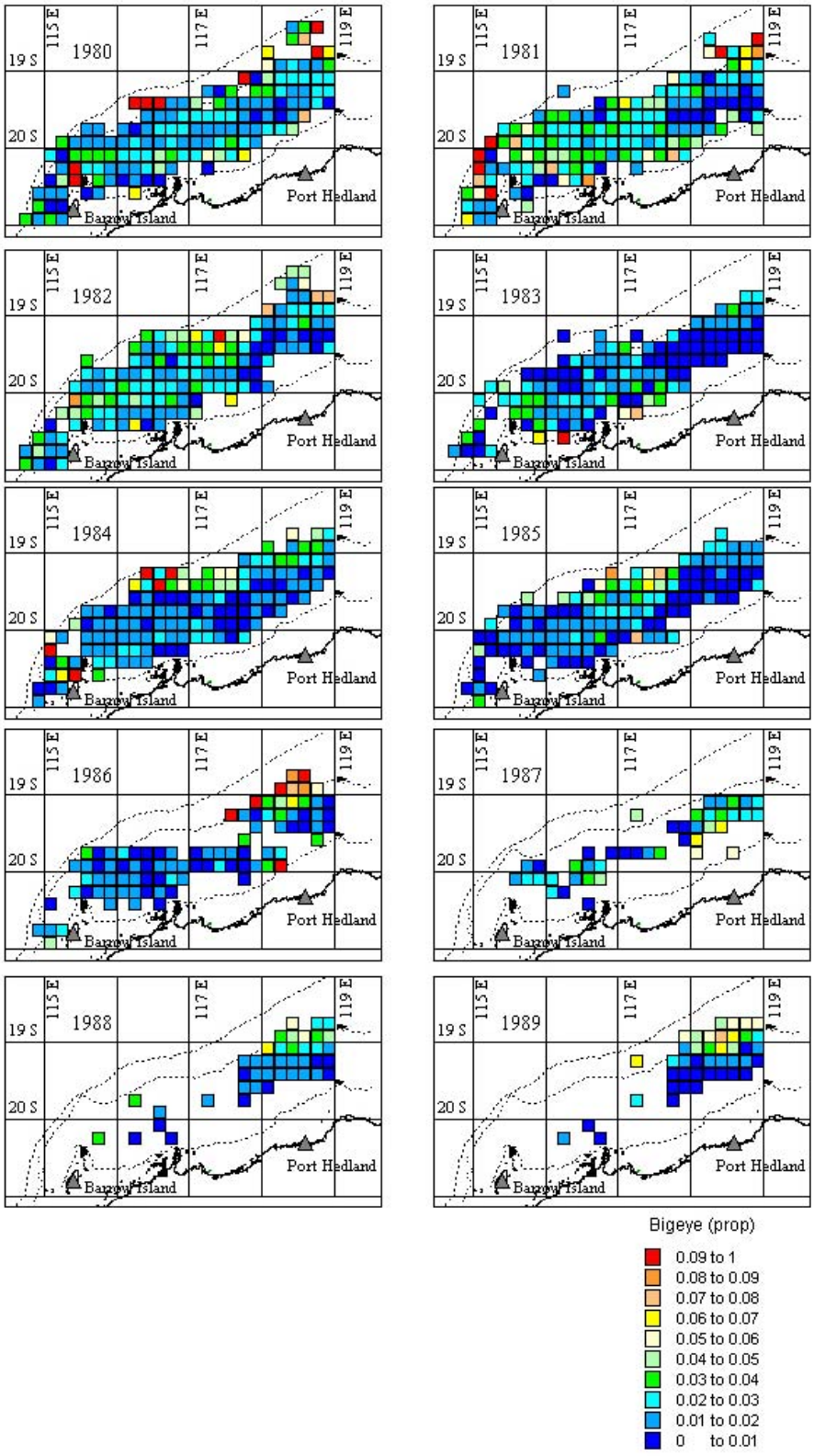

Figure A.7 (b): Proportional catch of bigeyes (AFMA).

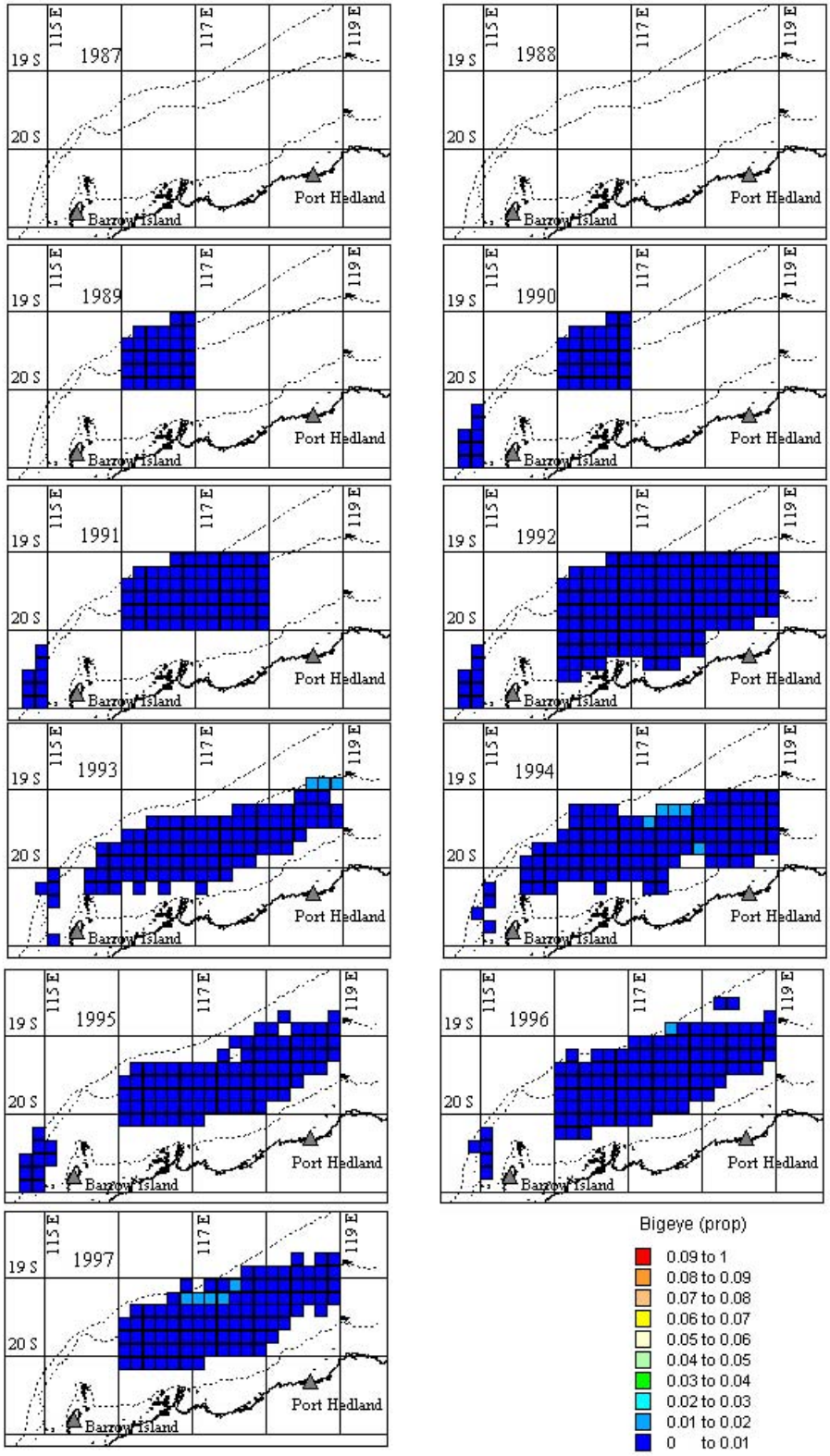

Figure A.7 (c): Proportional catch of bigeyes (CAES, 1987-1997).

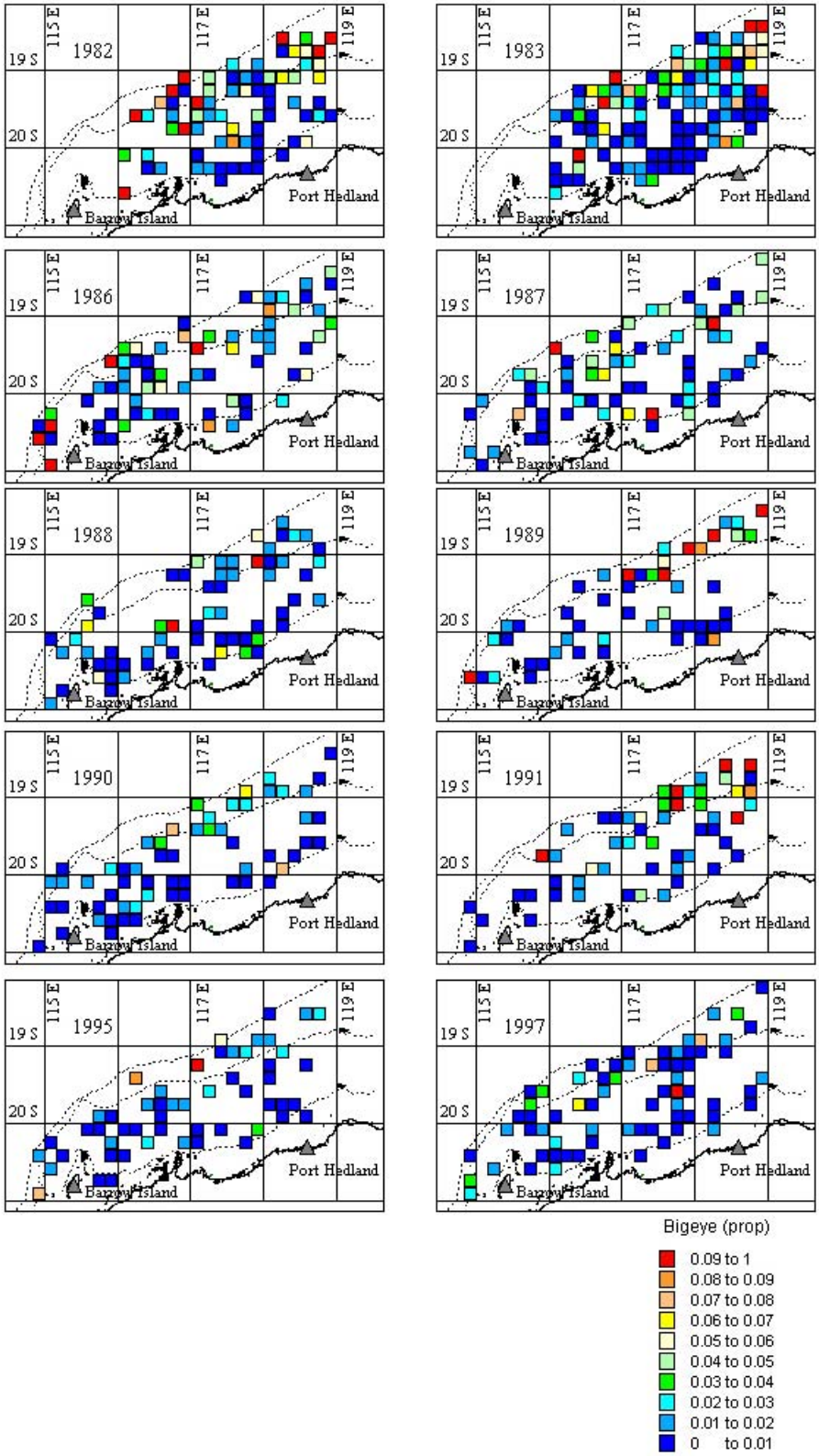

Figure A.7 (d): Proportional catch of bigeyes (CSIRO surveys).

A.8 Lutjanidae and Caesionidae

Distribution maps depicting ranges of the proportionate catch of Lutjanidae and Caesionidae, excluding five species, by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

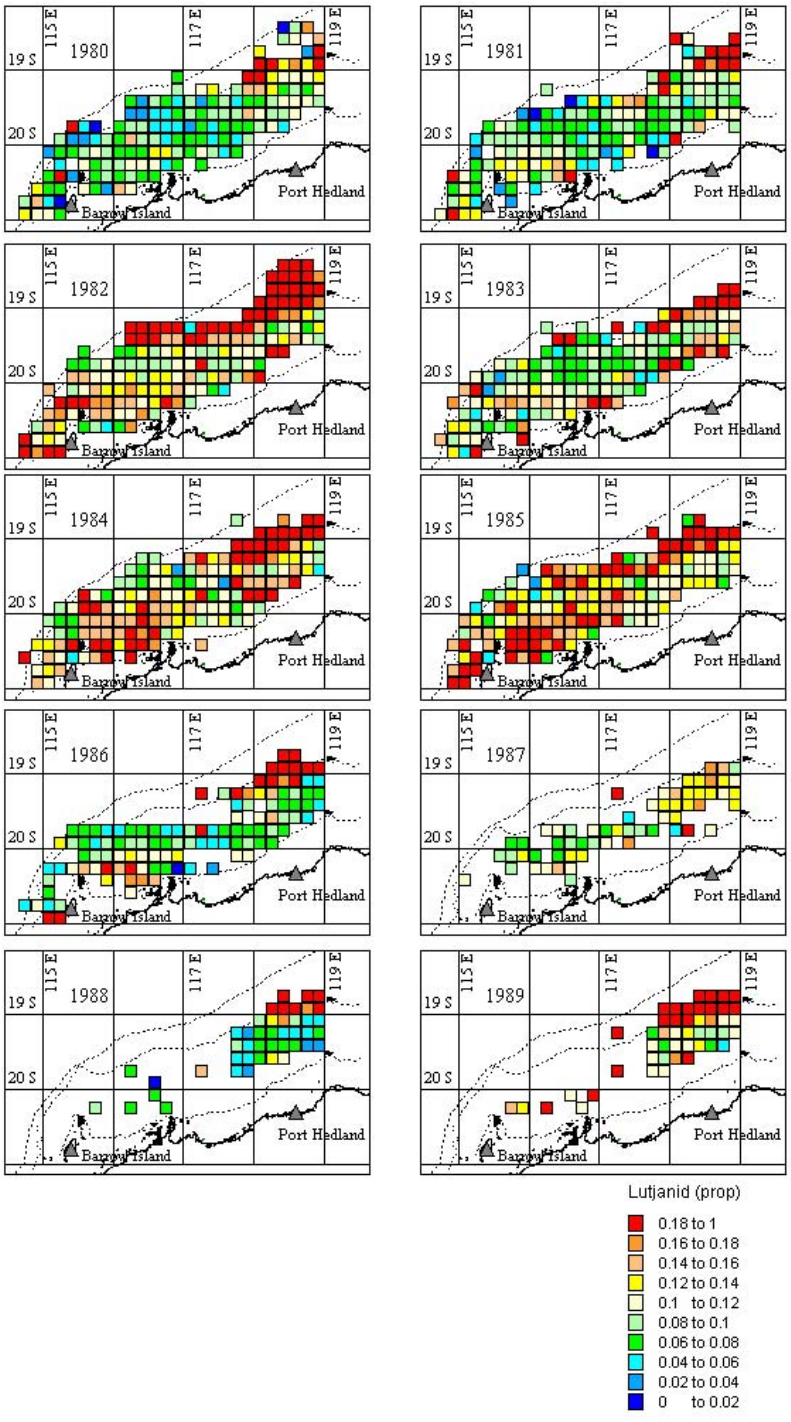

Figure A.8 (a): Proportional catch of Lutjanidae and Caesionidae (AFMA).

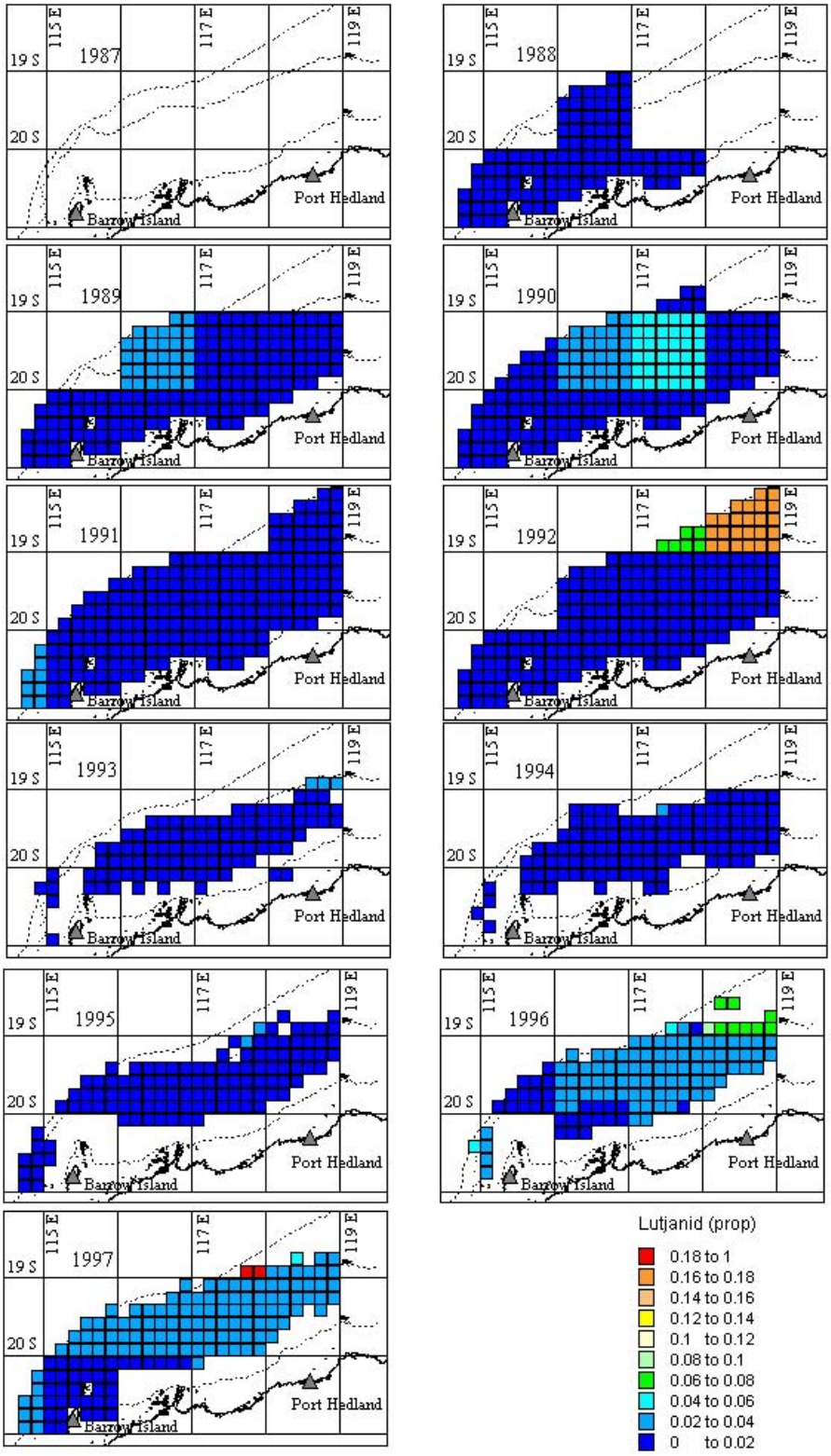

Figure A.8 (b): Proportional catch of Lutjanidae and Caesionidae (CAES, 1987-1997).

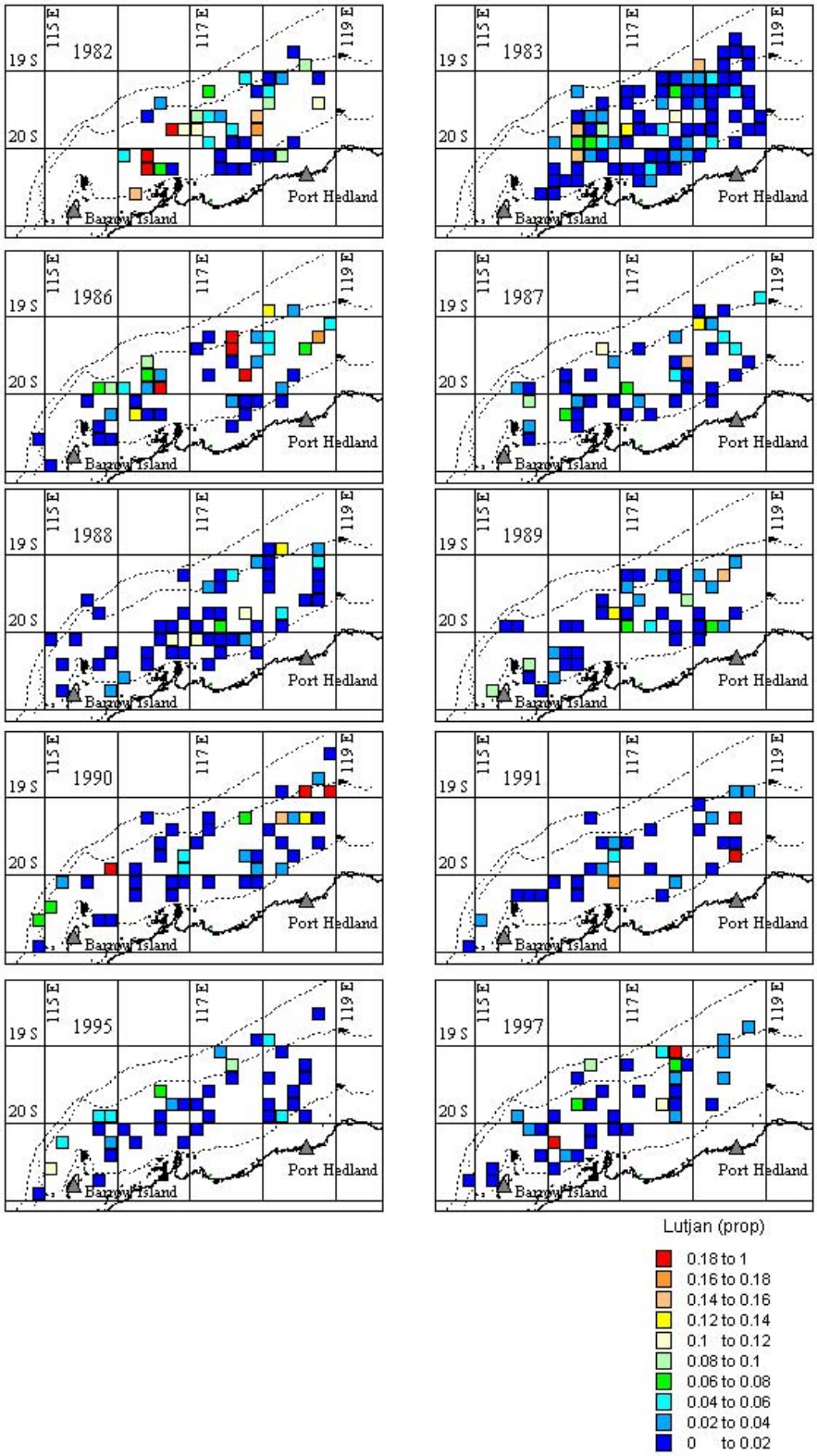

Figure A.8 (c): Proportional catch of Lutjanidae and Caesionidae (CSIRO surveys).

A.9 Pristipomoides multidens

Distribution maps depicting ranges of the proportionate catch of *Pristipomoides multidens* (Pmult) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

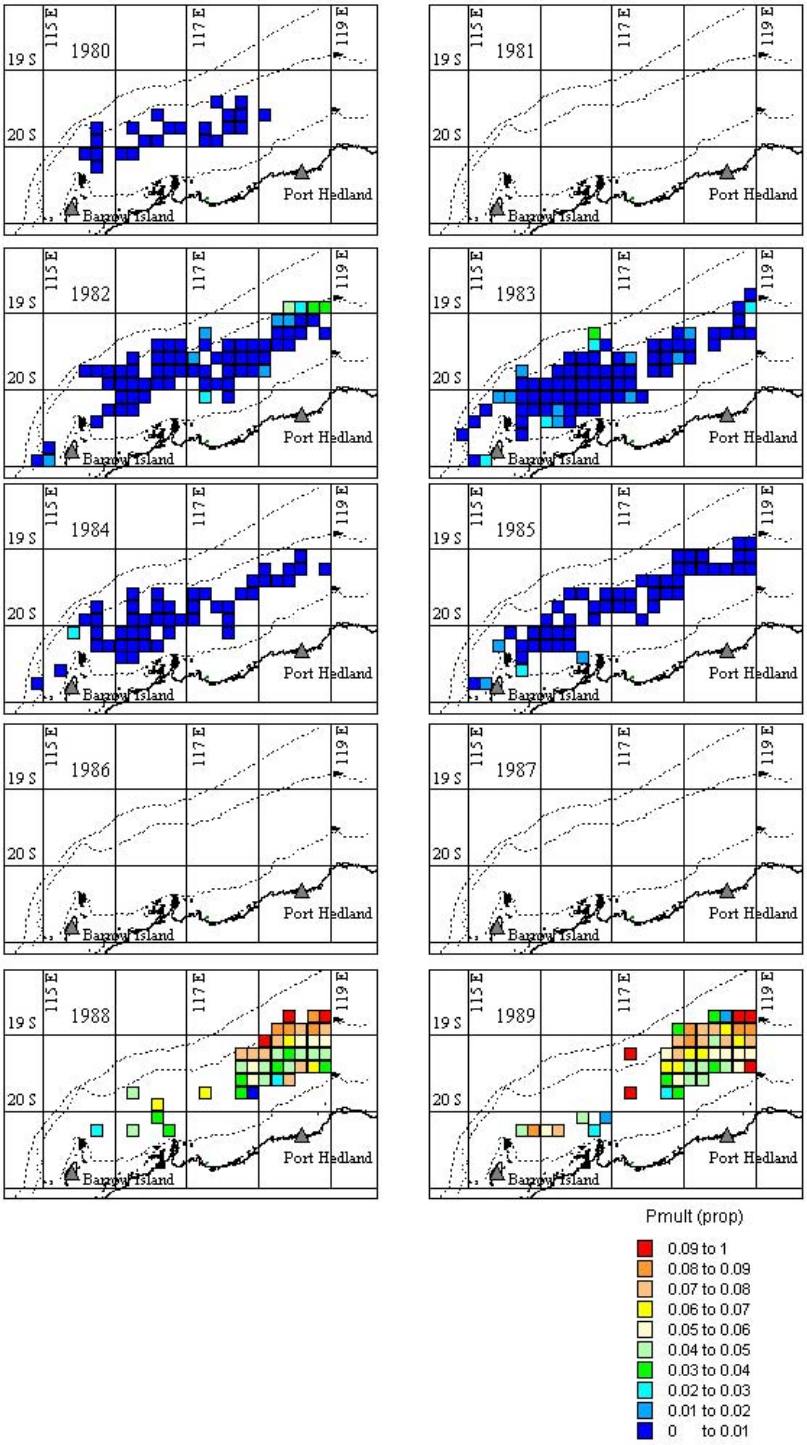

Figure A.9 (a): Proportional catch of *Pristipomoides multidens* (AFMA).

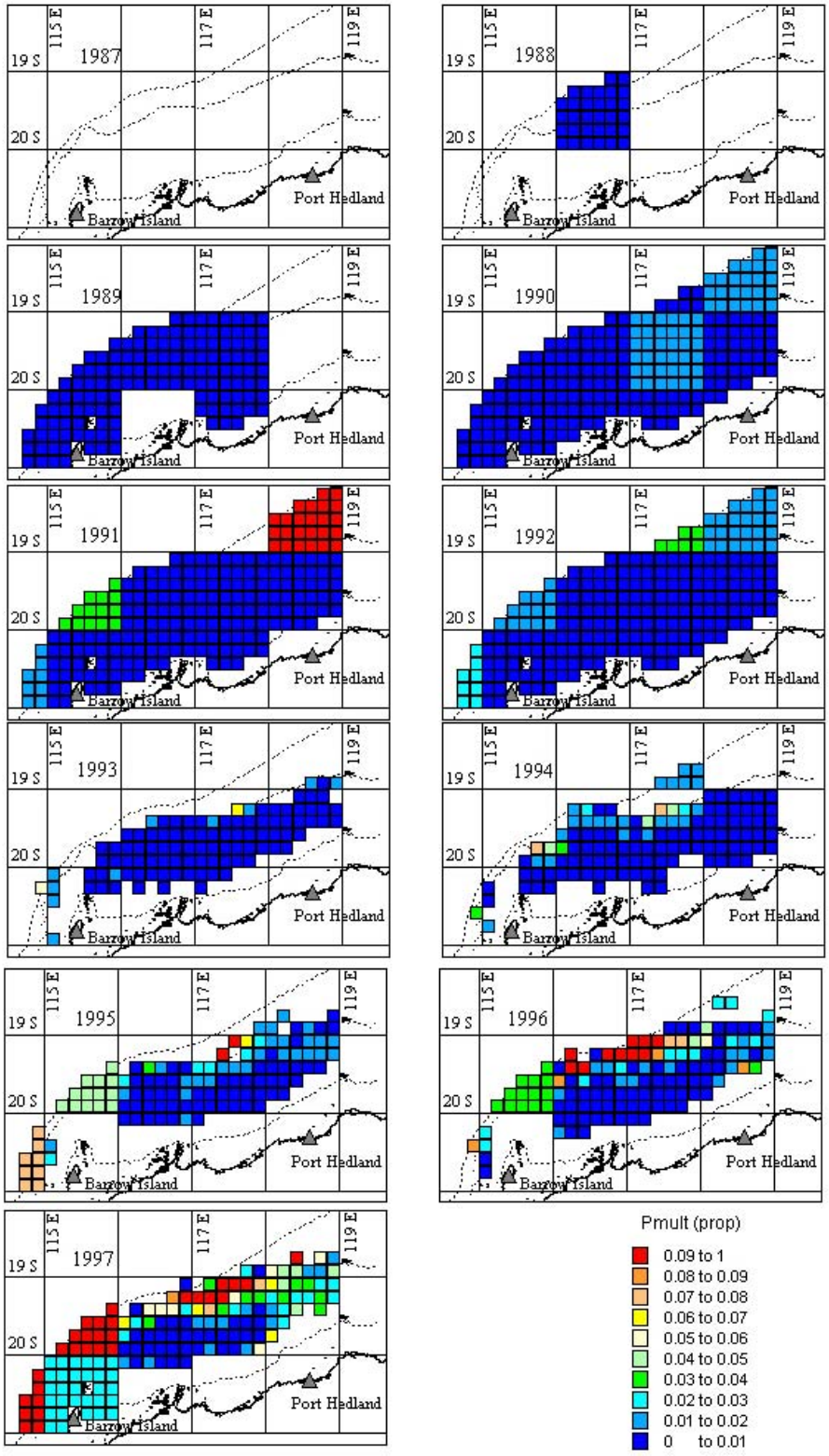

Figure A.9 (b): Proportional catch of *Pristipomoides multidens* (CAES, 1987-1997).

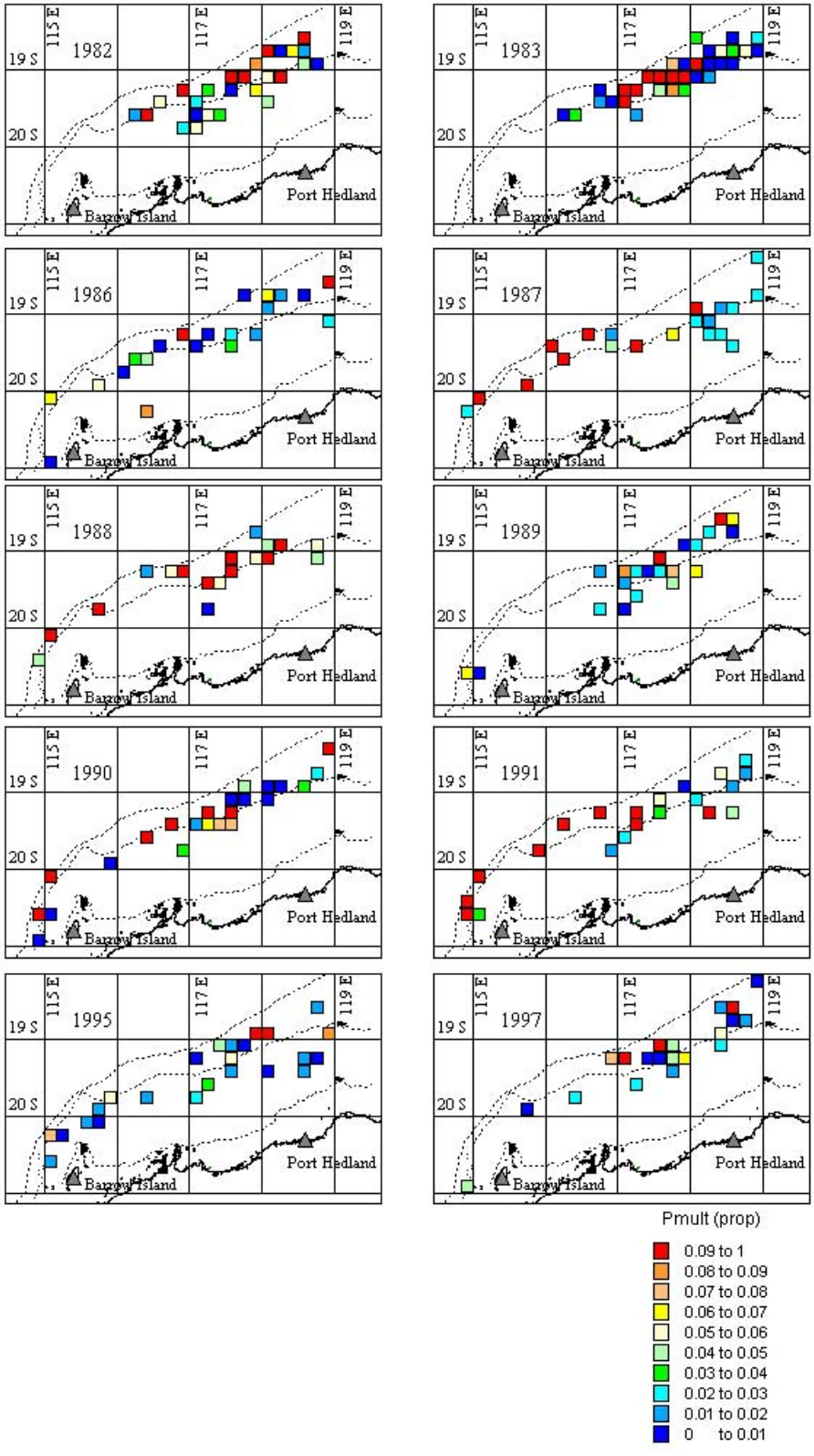

Figure A.9 (c): Proportional catch of *Pristipomoides multidens* (CSIRO surveys).

A.10 *Lutjanus vitta*

Distribution maps depicting ranges of the proportionate catch of *Lutjanus vitta* (Luvitta) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

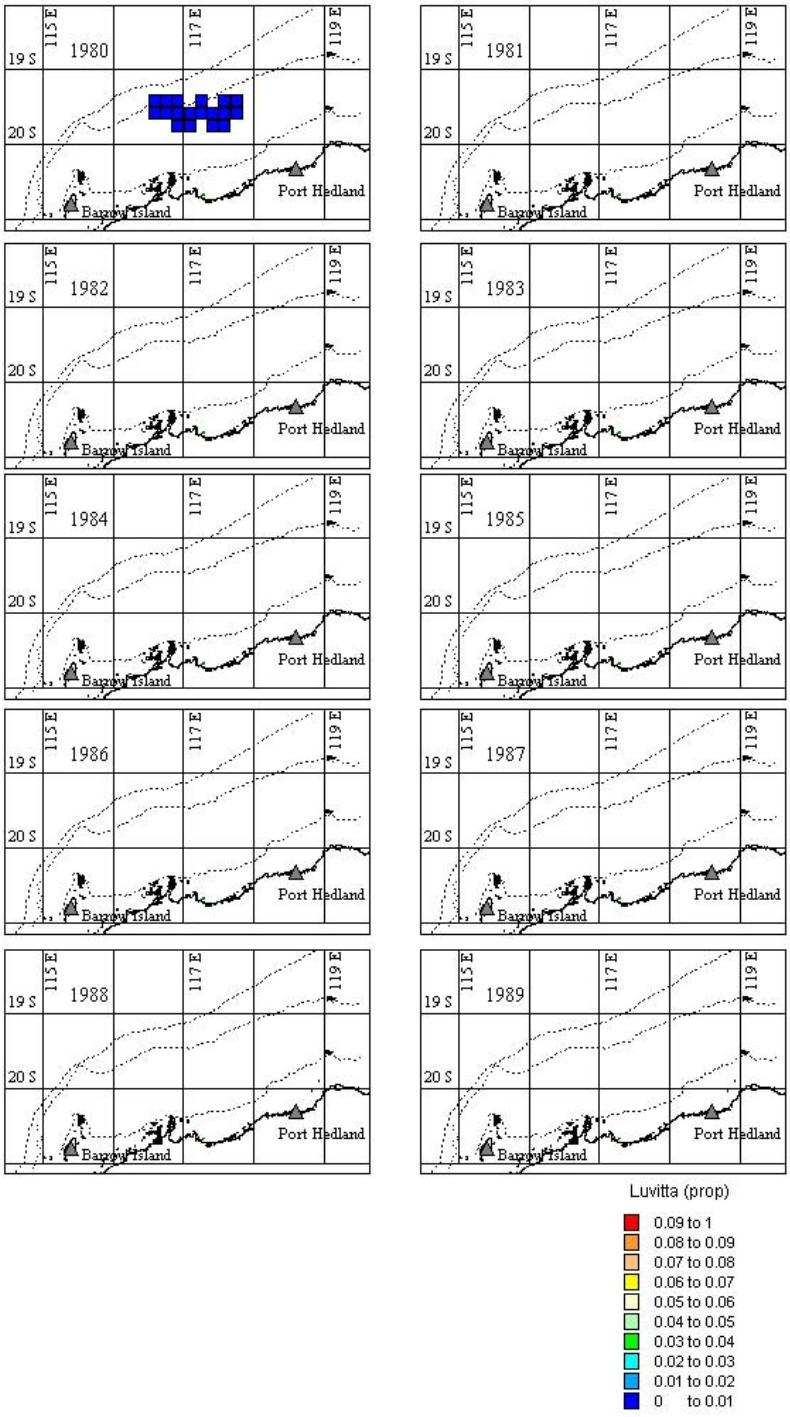

Figure A.10 (a): Proportional catch of *Lutjanus vitta* (AFMA).

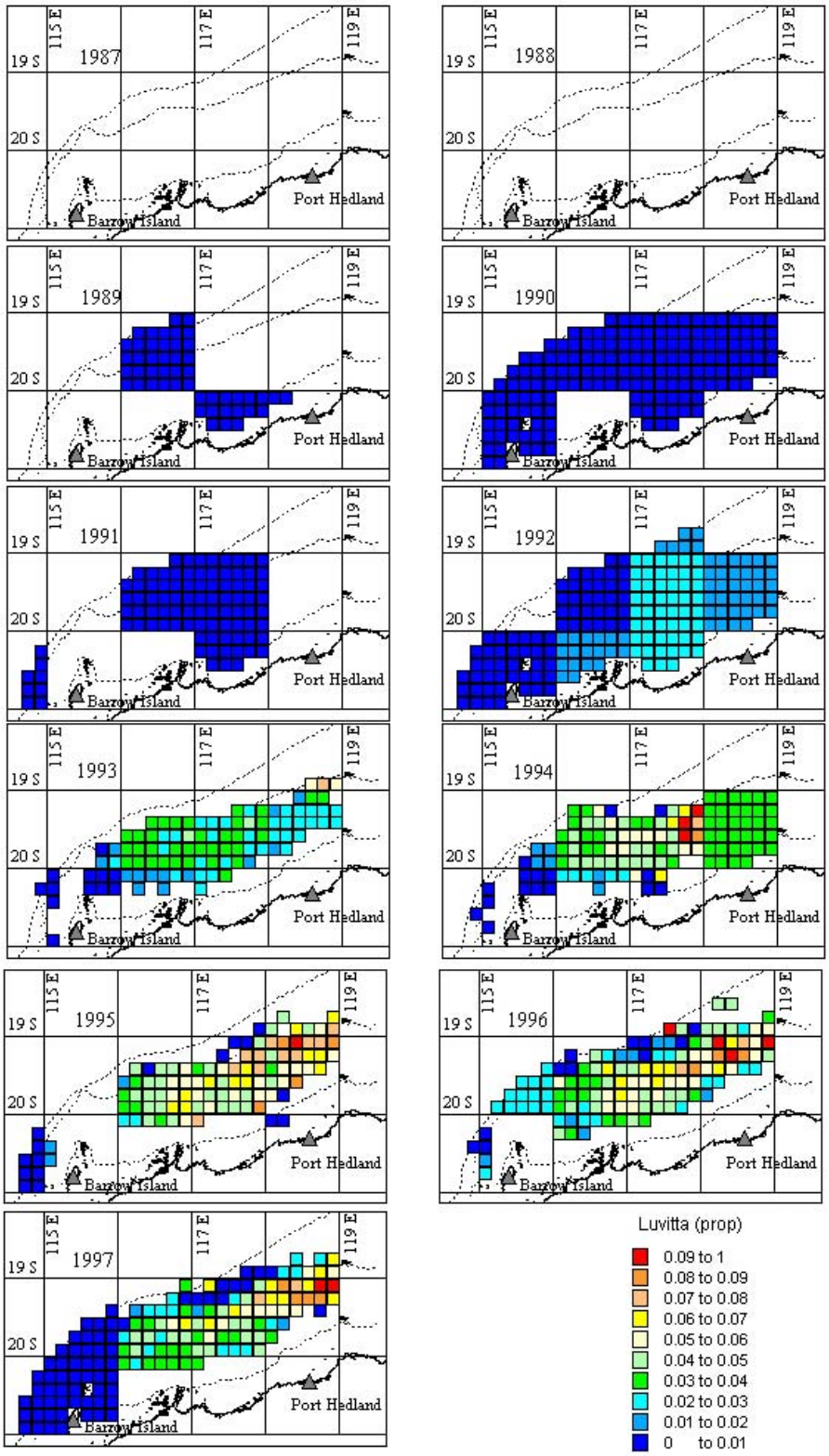

Figure A.10 (b): Proportional catch of *Lutjanus vitta* (CAES, 1987-1997).

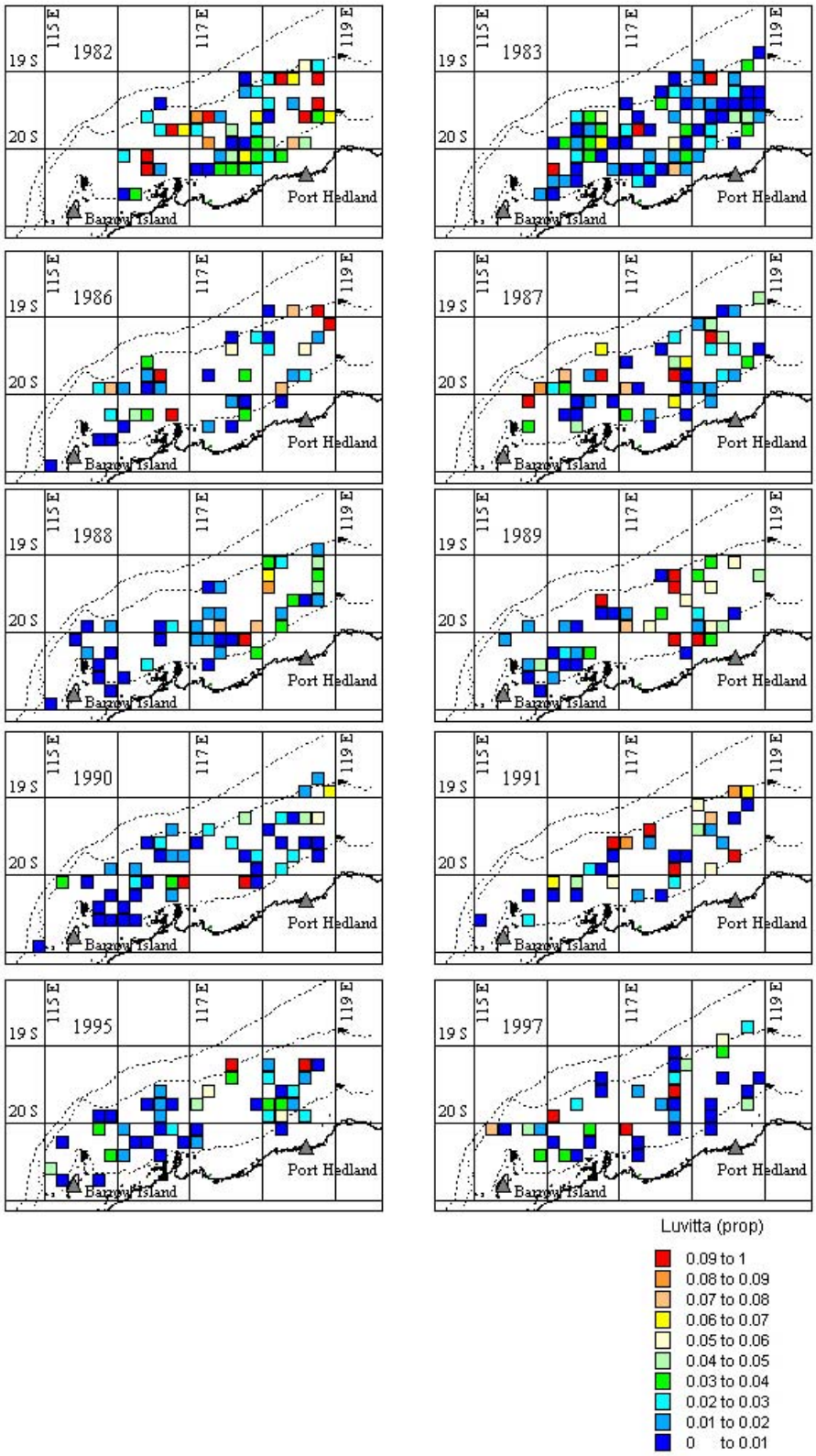

Figure A.10 (c): Proportional catch of *Lutjanus vitta* (CSIRO surveys).

A.11 *Lutjanus sebae*

Distribution maps depicting ranges of the proportionate catch of *Lutjanus sebae* (Lusebae) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) and (c) CAES, all methods), and the CSIRO (d) surveys in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

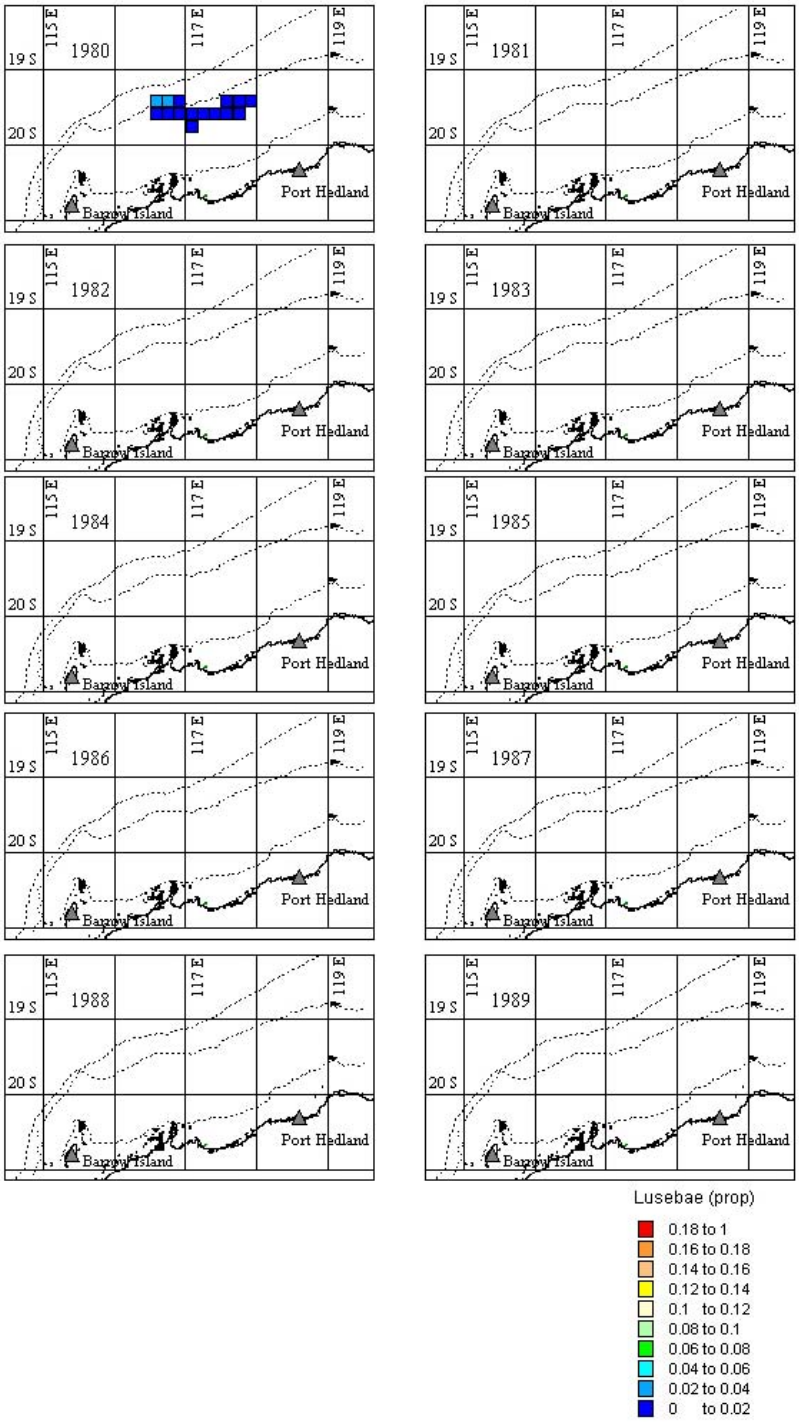

Figure A.11 (a): Proportional catch of *Lutjanus seabae* (AFMA).

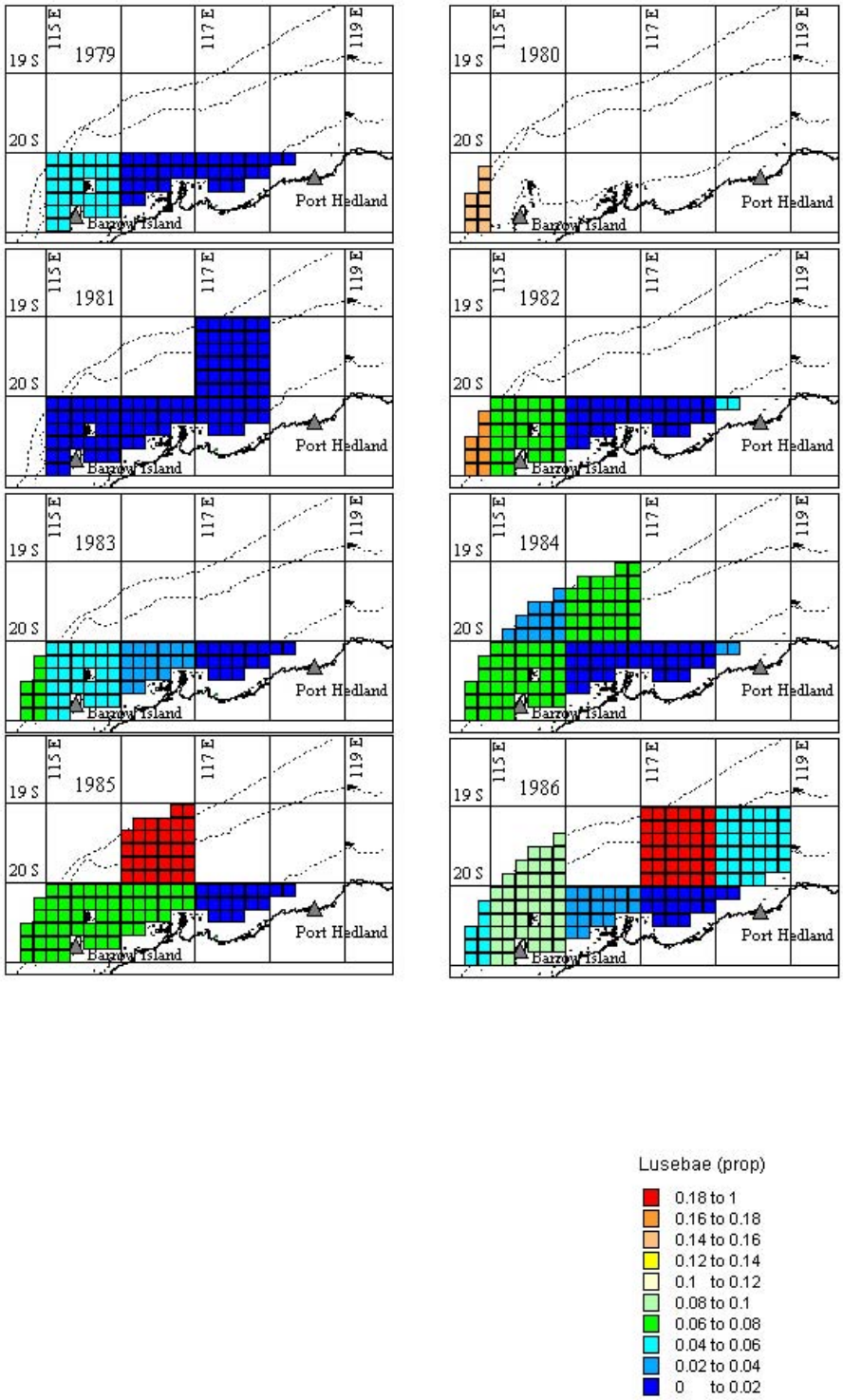

Figure A.11 (b): Proportional catch of *Lutjanus sebae* (CAES, 1979-1986).

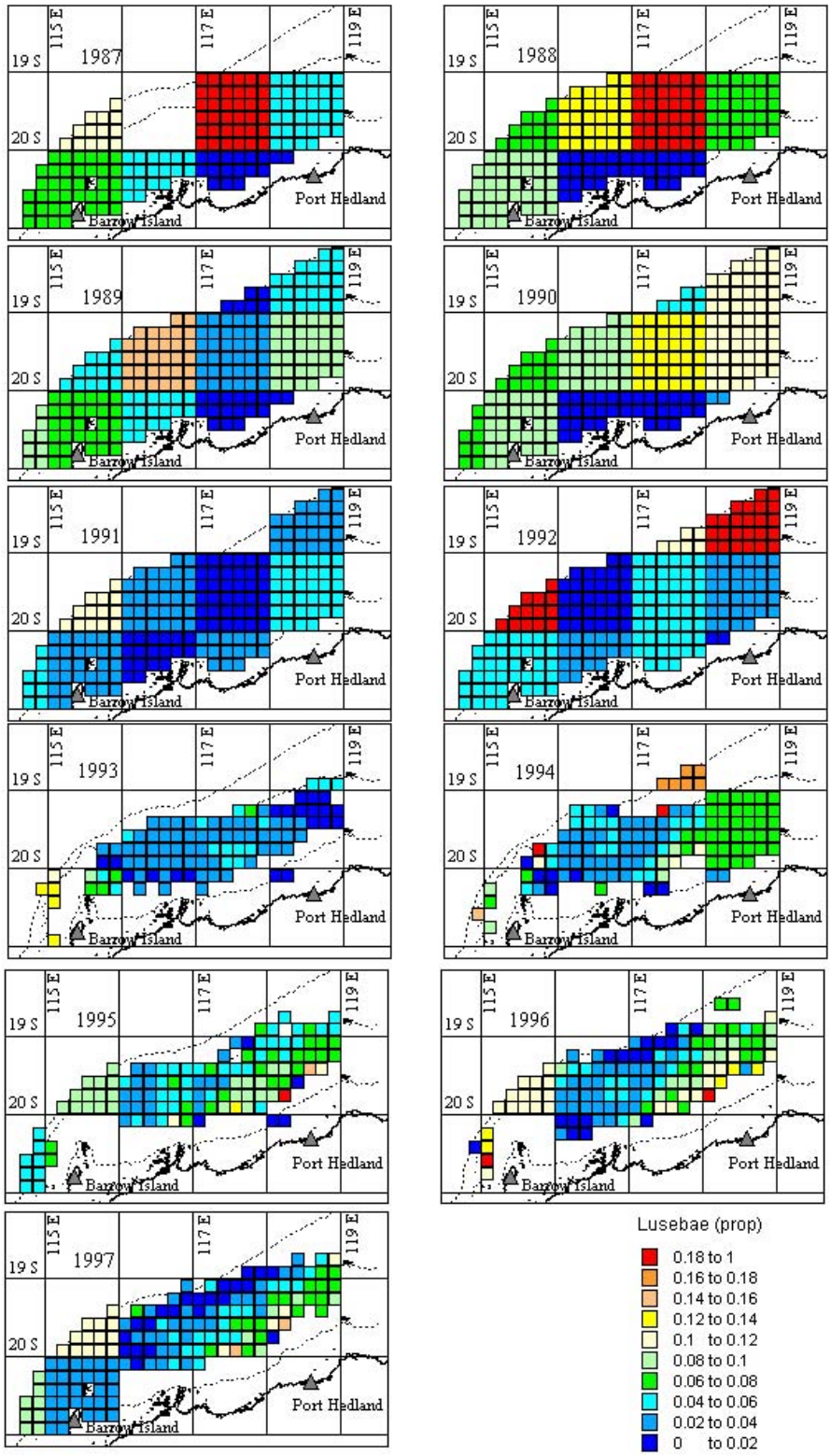

Figure A.11 (c): Proportional catch of *Lutjanus sebae* (CAES, 1987-1997).

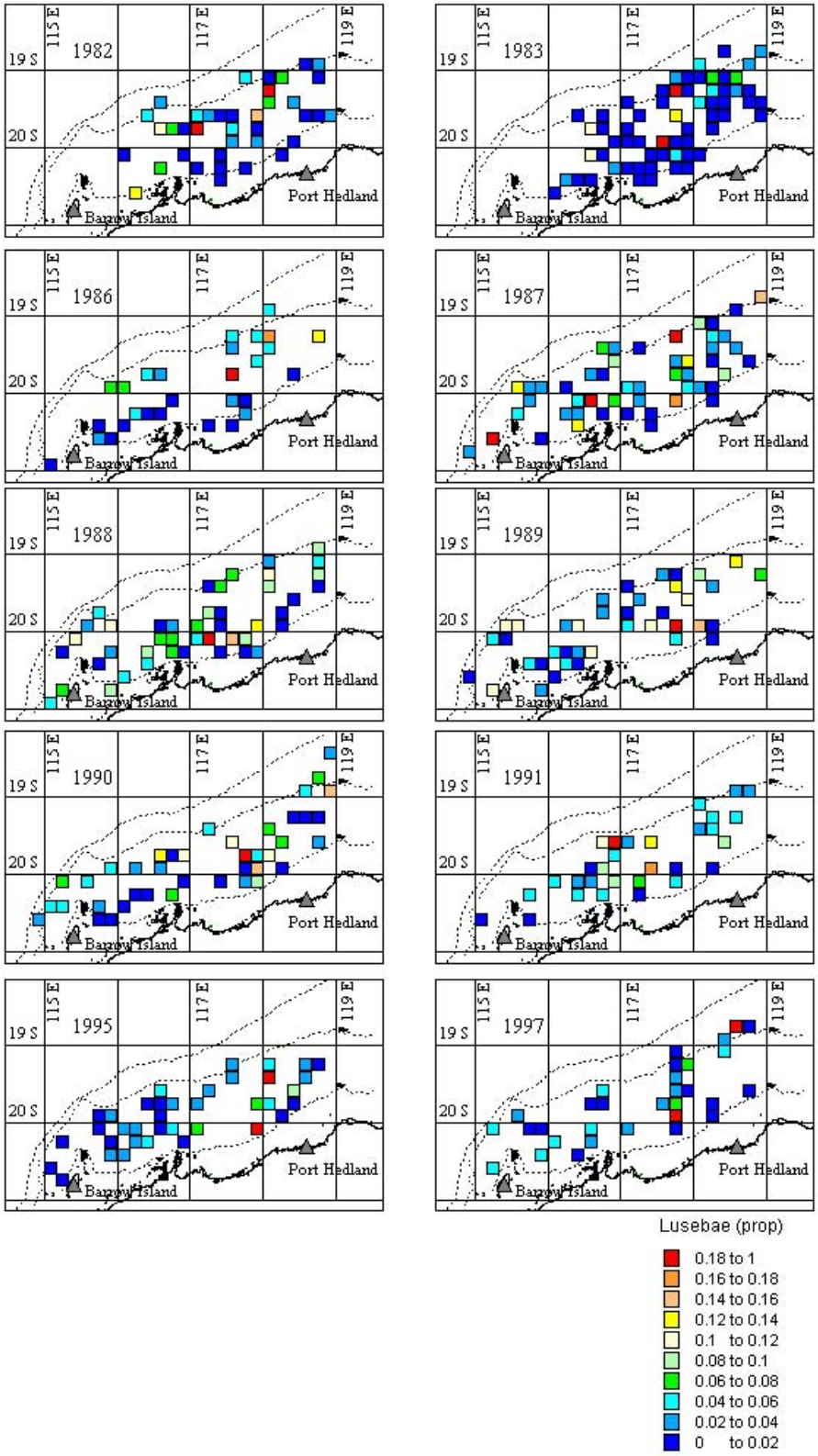

Figure A.11 (d): Proportional catch of *Lutjanus sebae* (CSIRO surveys).

A.12 *Lutjanus erythropterus*

Distribution maps depicting ranges of the proportionate catch of *Lutjanus erythropterus* (Lueryth) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

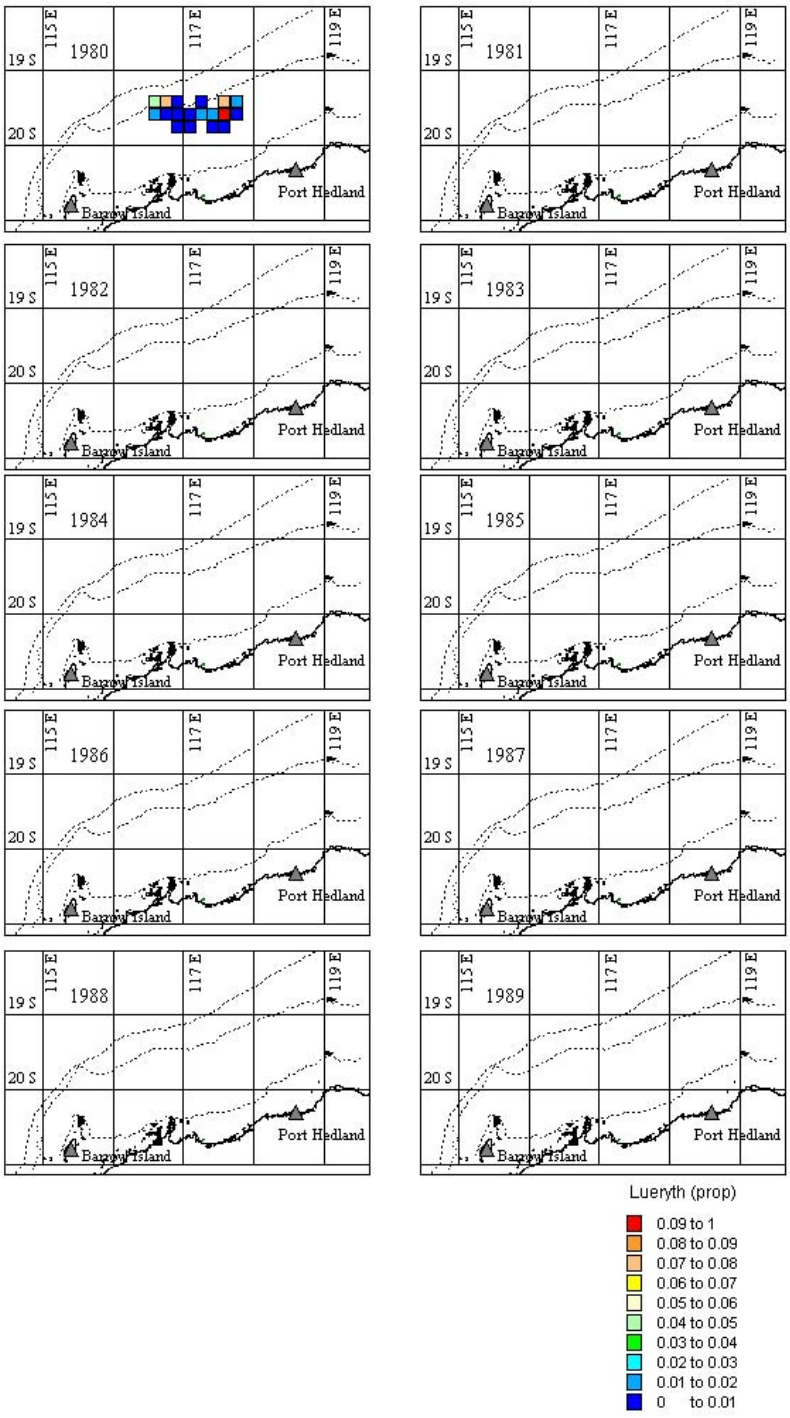

Figure A.12 (a): Proportional catch of *Lutjanus erythrotperus* (AFMA).

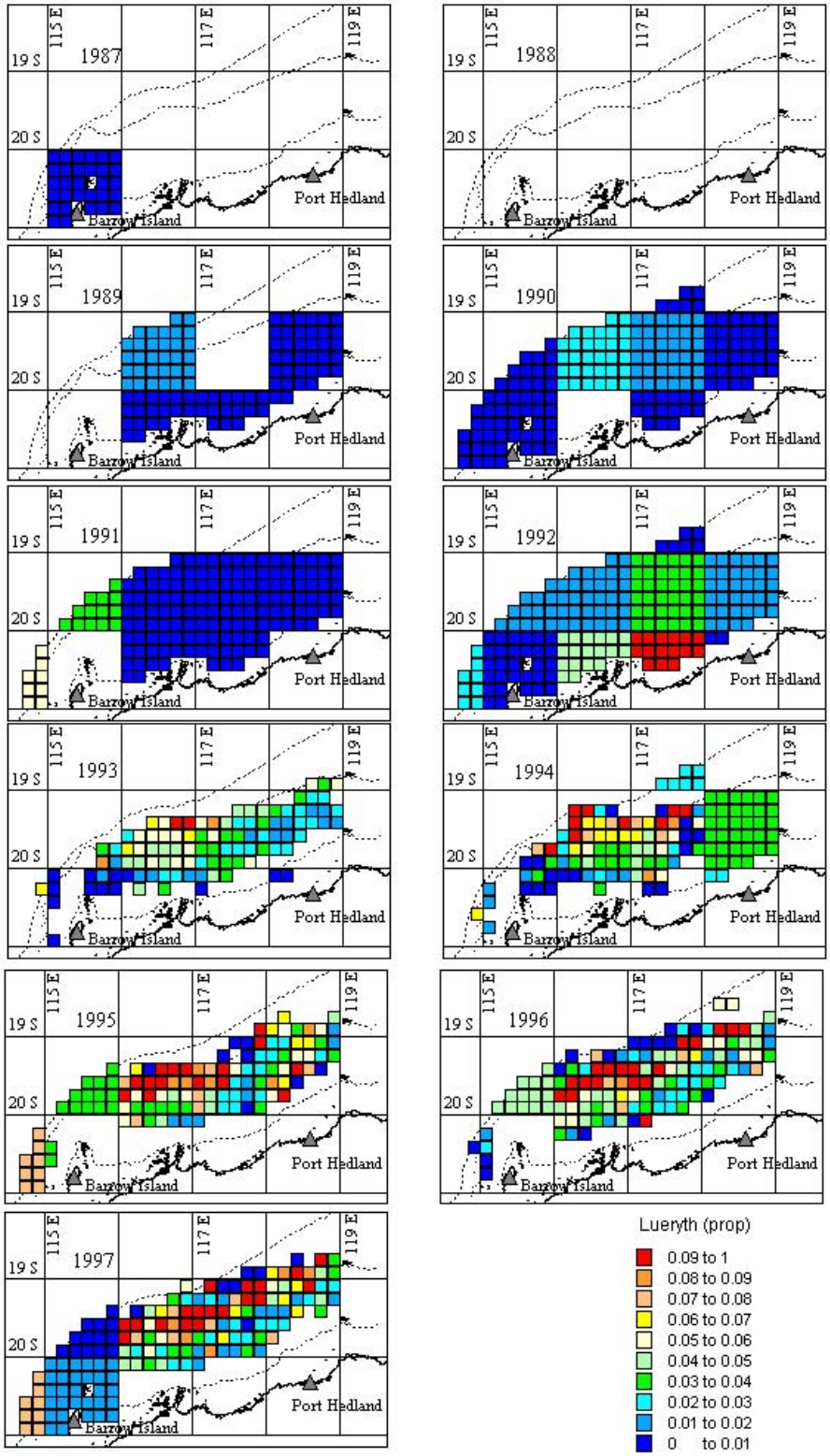

Figure A.12 (b): Proportional catch of *Lutjanus erythrotperus* (CAES, 1987-1997).

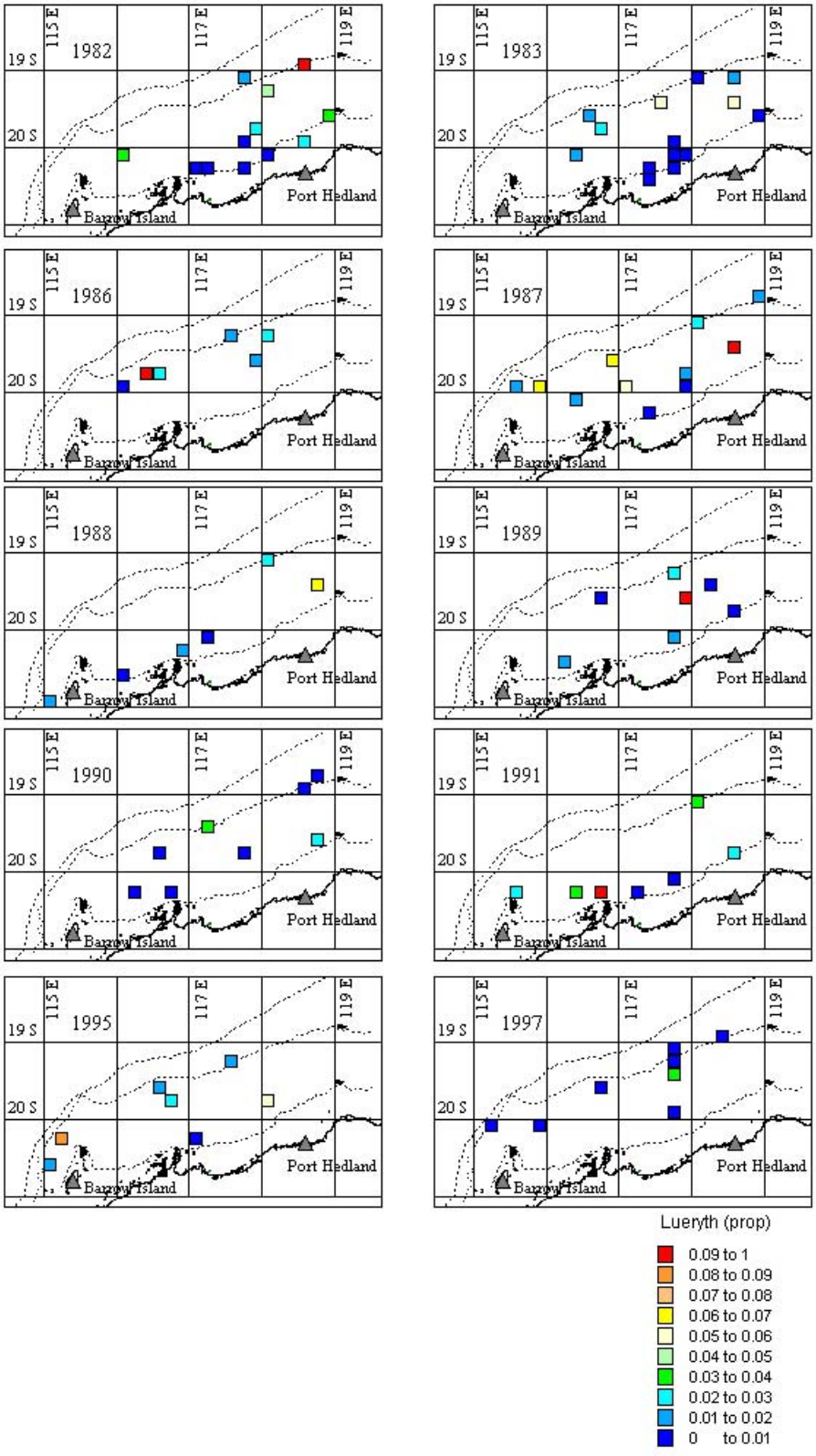

Figure A.12 (c): Proportional catch of *Lutjanus erythrotperus* (CSIRO surveys).

A.13 *Lutjanus malabricus*

Distribution maps depicting ranges of the proportionate catch of *Lutjanus malabricus* (Lumalab) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese), the domestic fishery ((b) and (c) CAES, all methods), and the CSIRO surveys (d) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

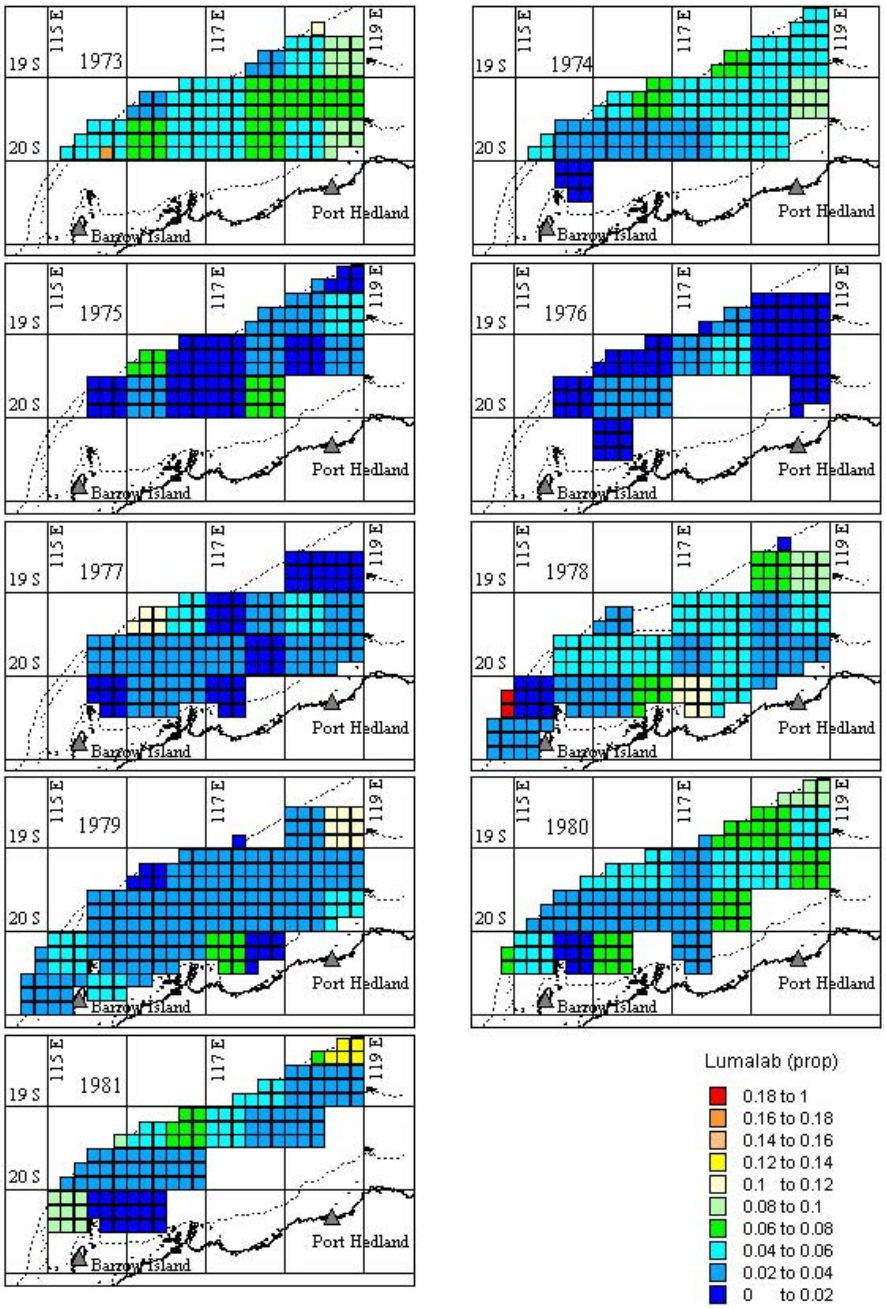

Figure A.13 (a): Proportional catch of *Lutjanus malabricus* (Taiwanese logbooks).

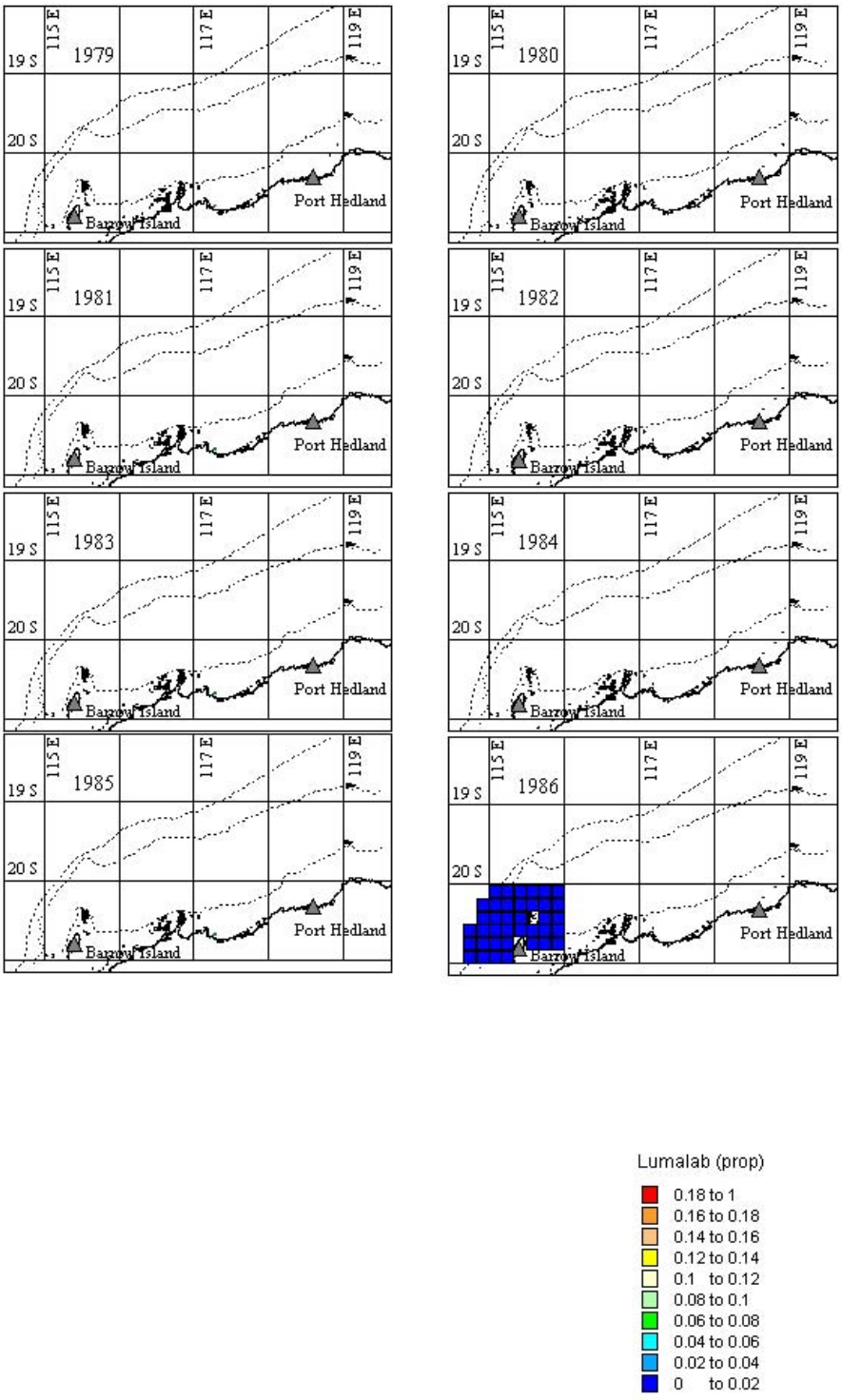

Figure A.13 (b): Proportional catch of *Lutjanus malabricus* (CAES, 1979-1986).

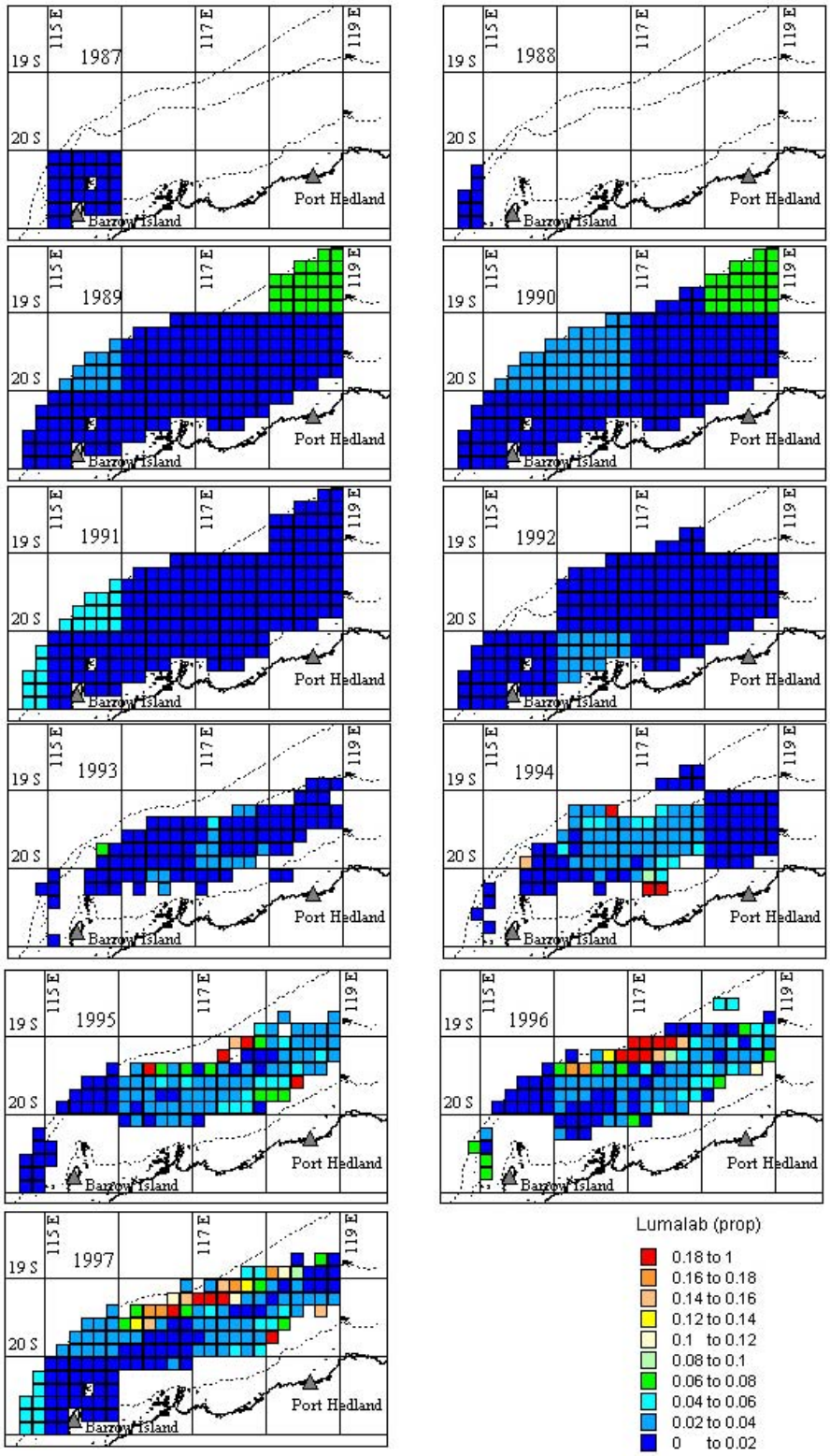

Figure A.13 (c): Proportional catch of *Lutjanus malabricus* (CAES, 1987-1997).

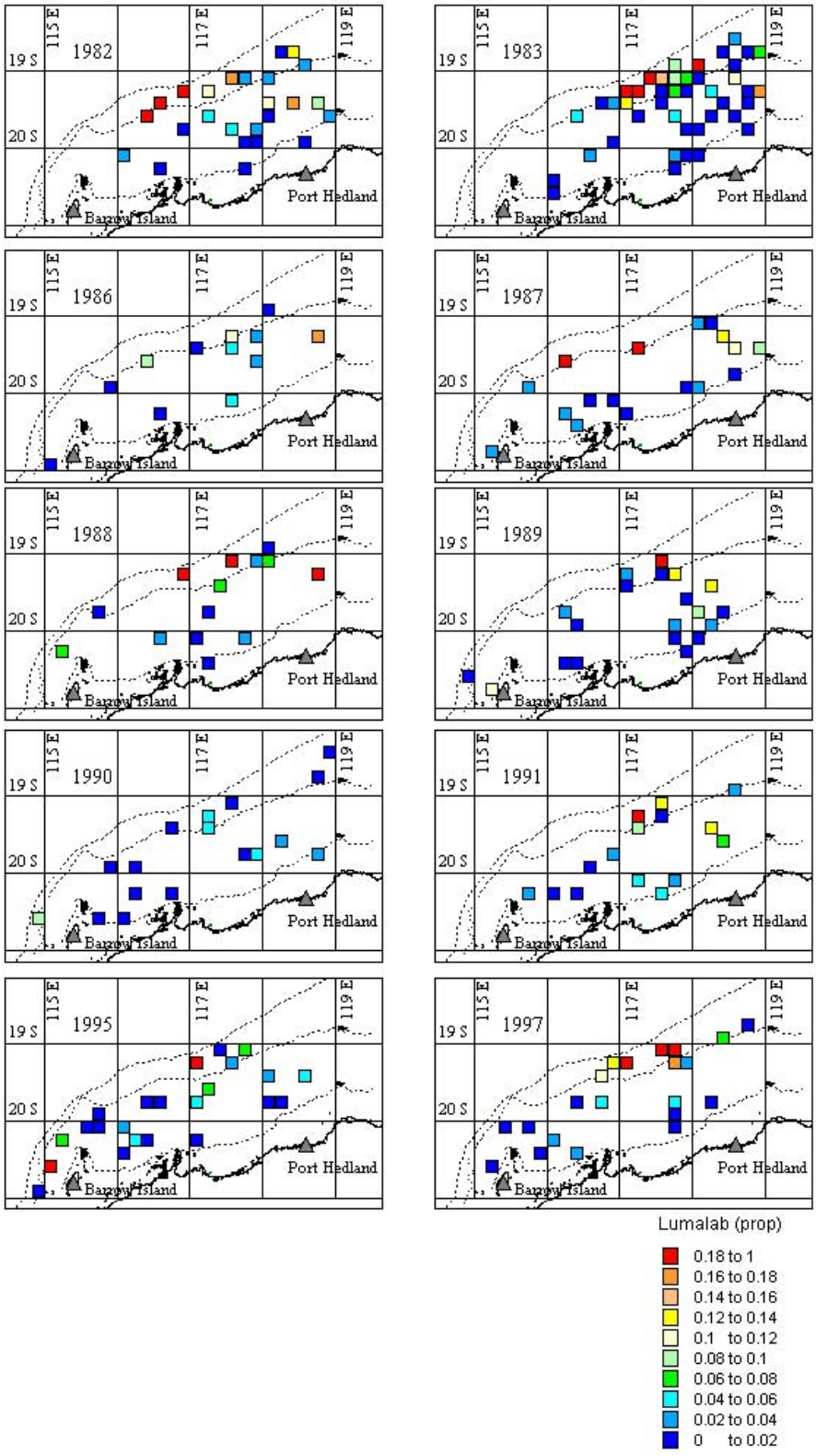

Figure A.13 (d): Proportional catch of *Lutjanus malabricus* (CSIRO surveys).

A.14 Nemipteridae

Distribution maps depicting ranges of the proportionate catch of Nemipteridae (Nemip) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

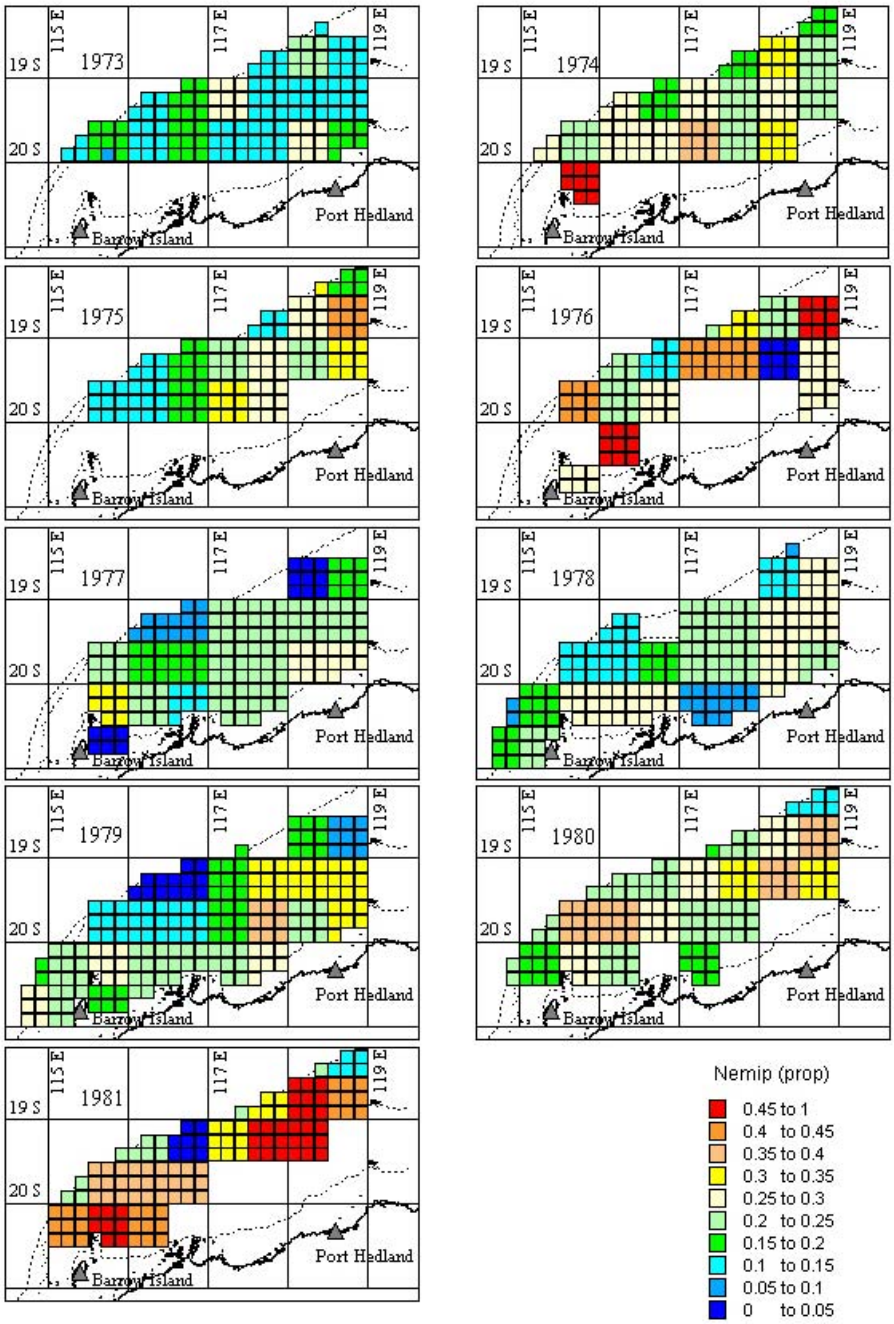

Figure A.14 (a): Proportional catch of Nemipteridae (Taiwanese logbooks).

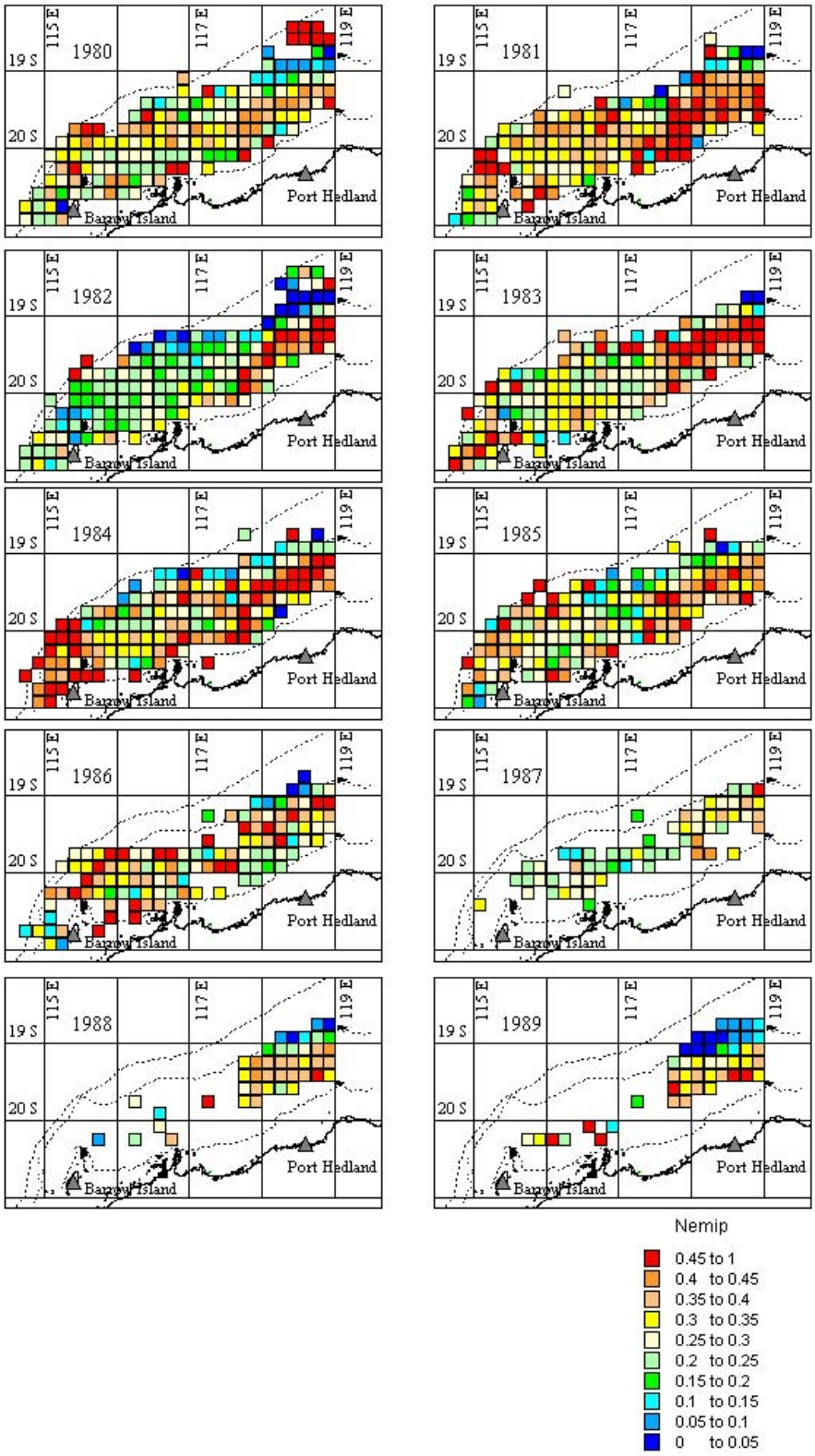

Figure A.14 (b): Proportional catch of Nemipteridae (AFMA).

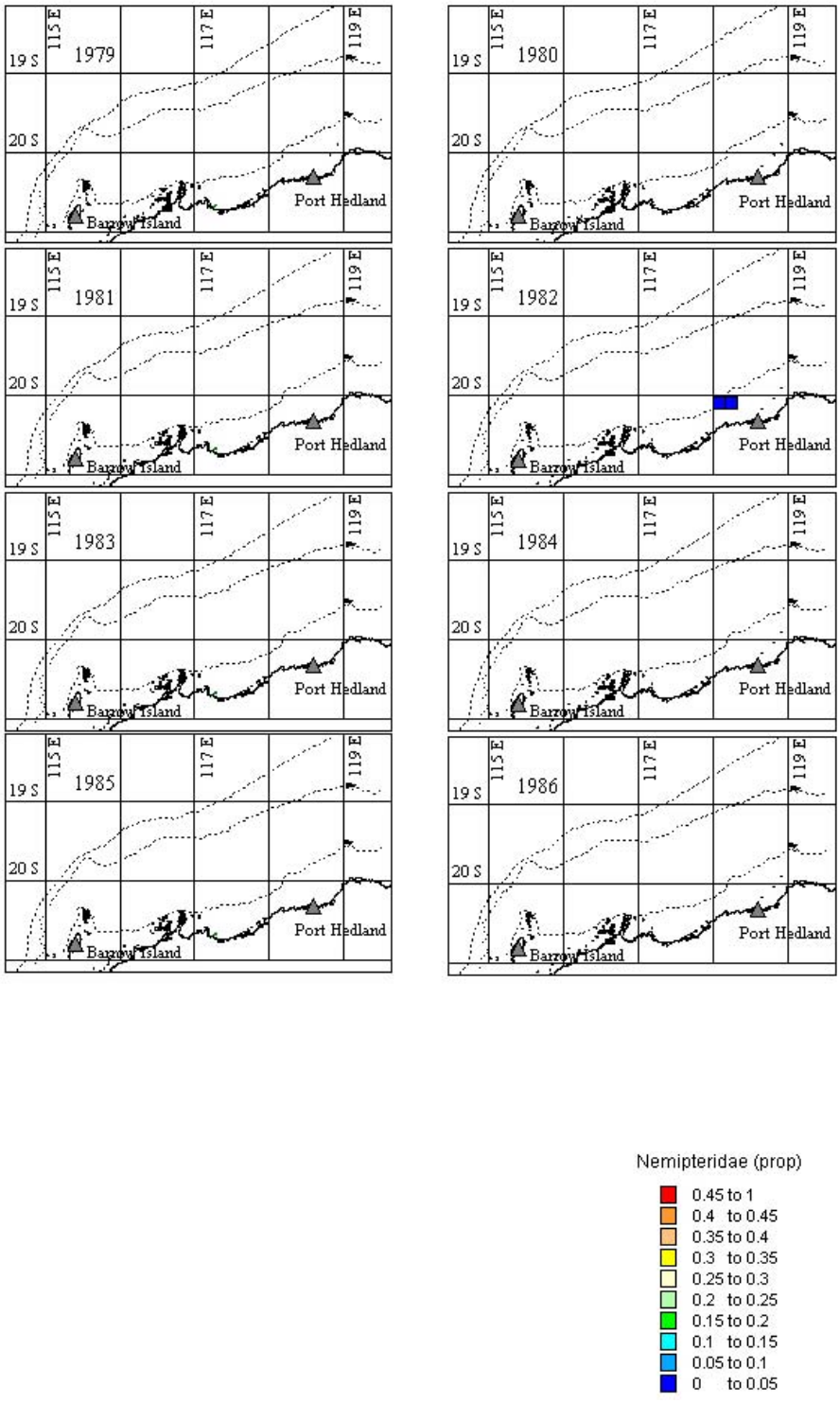

Figure A.14 (c): Proportional catch of Nemipteridae (CAES, 1979-1986).

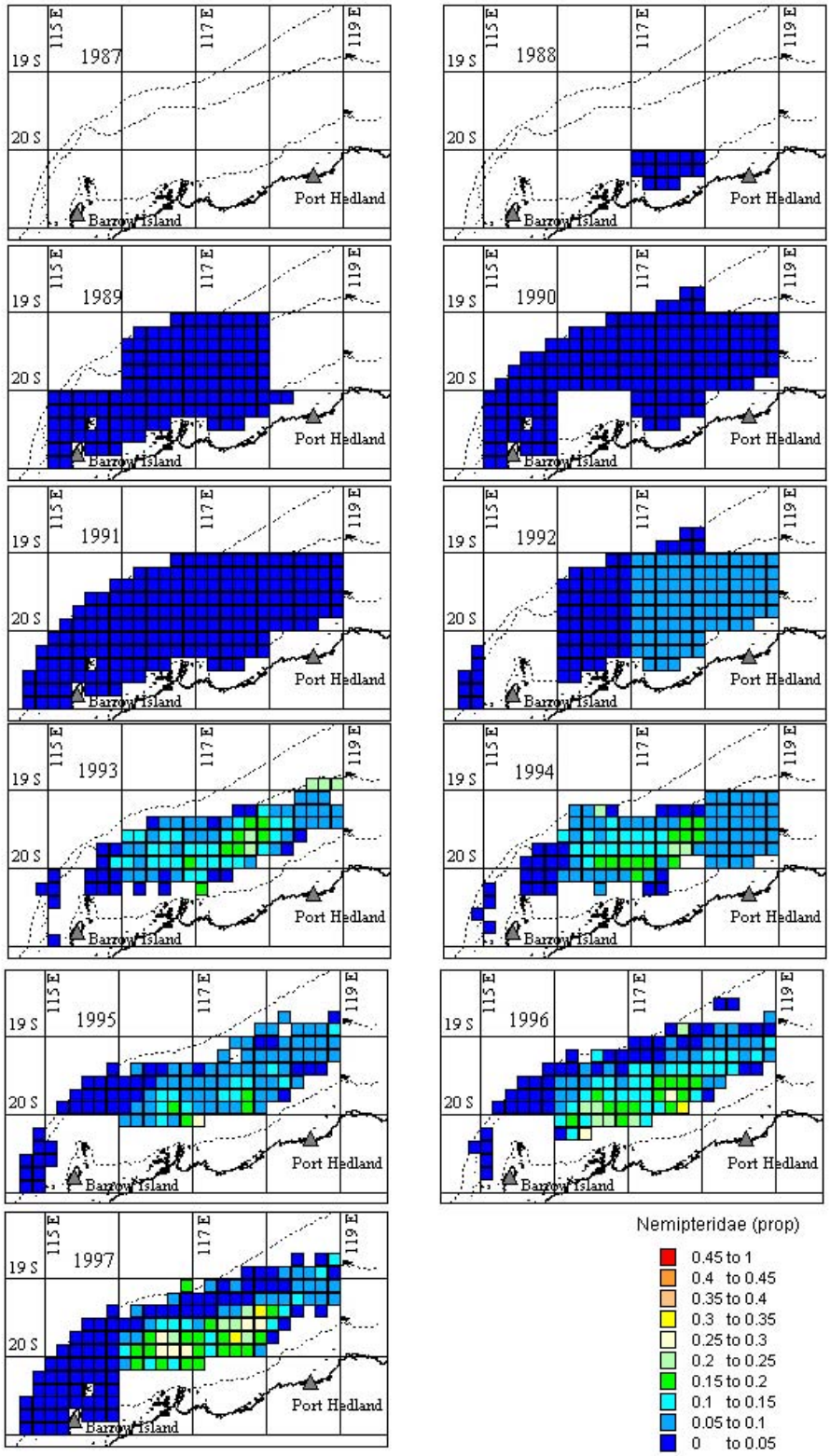

Figure A.14 (d): Proportional catch of Nemipteridae (CAES, 1987-1997).

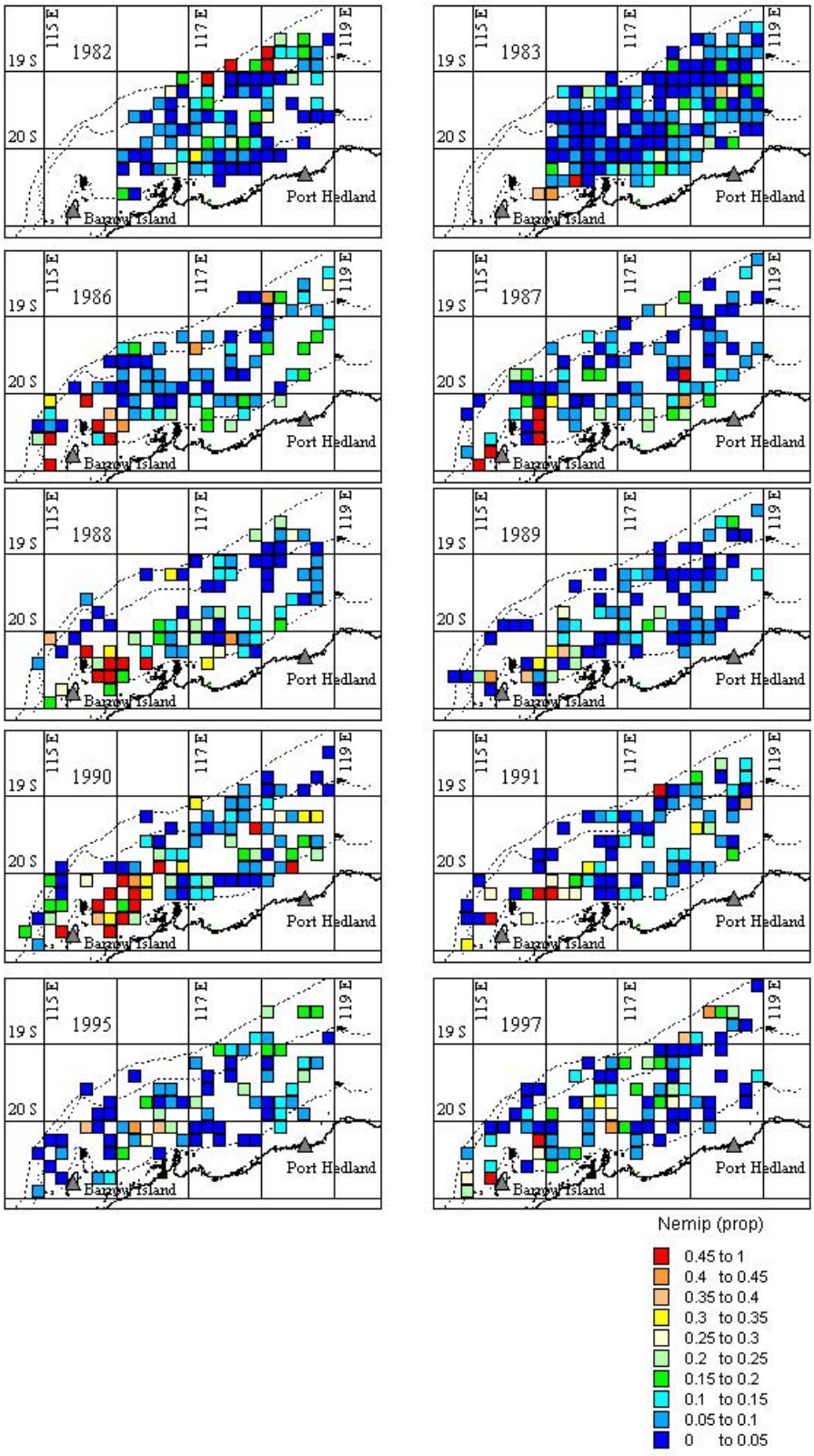

Figure A.14 (e): Proportional catch of Nemipteridae (CSIRO surveys).

A.15 Sweetlips (Haemulidae)

Distribution maps depicting ranges of the proportionate catch of sweetlips (Haemulidae) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

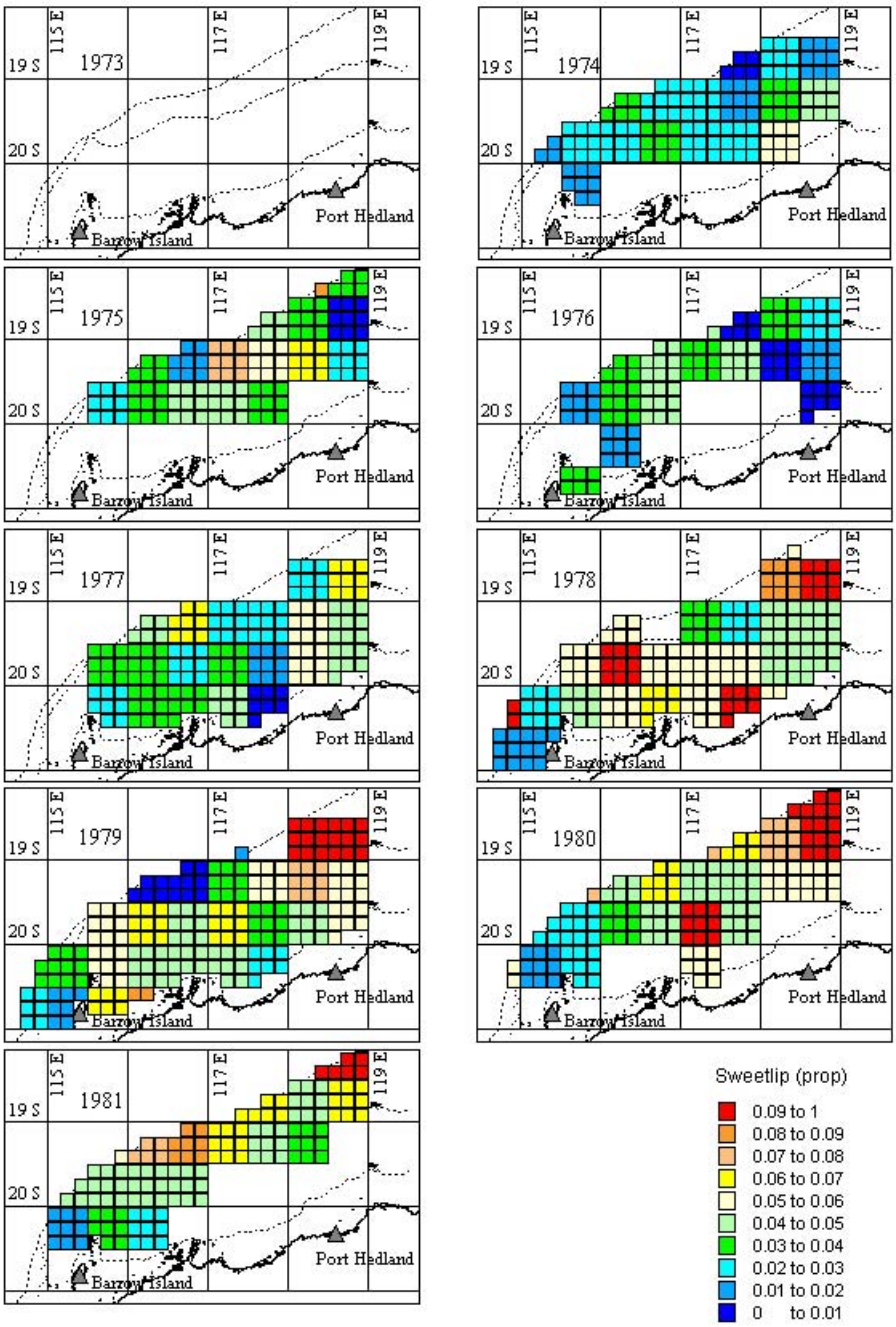

Figure A.15 (a): Proportional catch of sweetlips (Taiwanese logbooks).

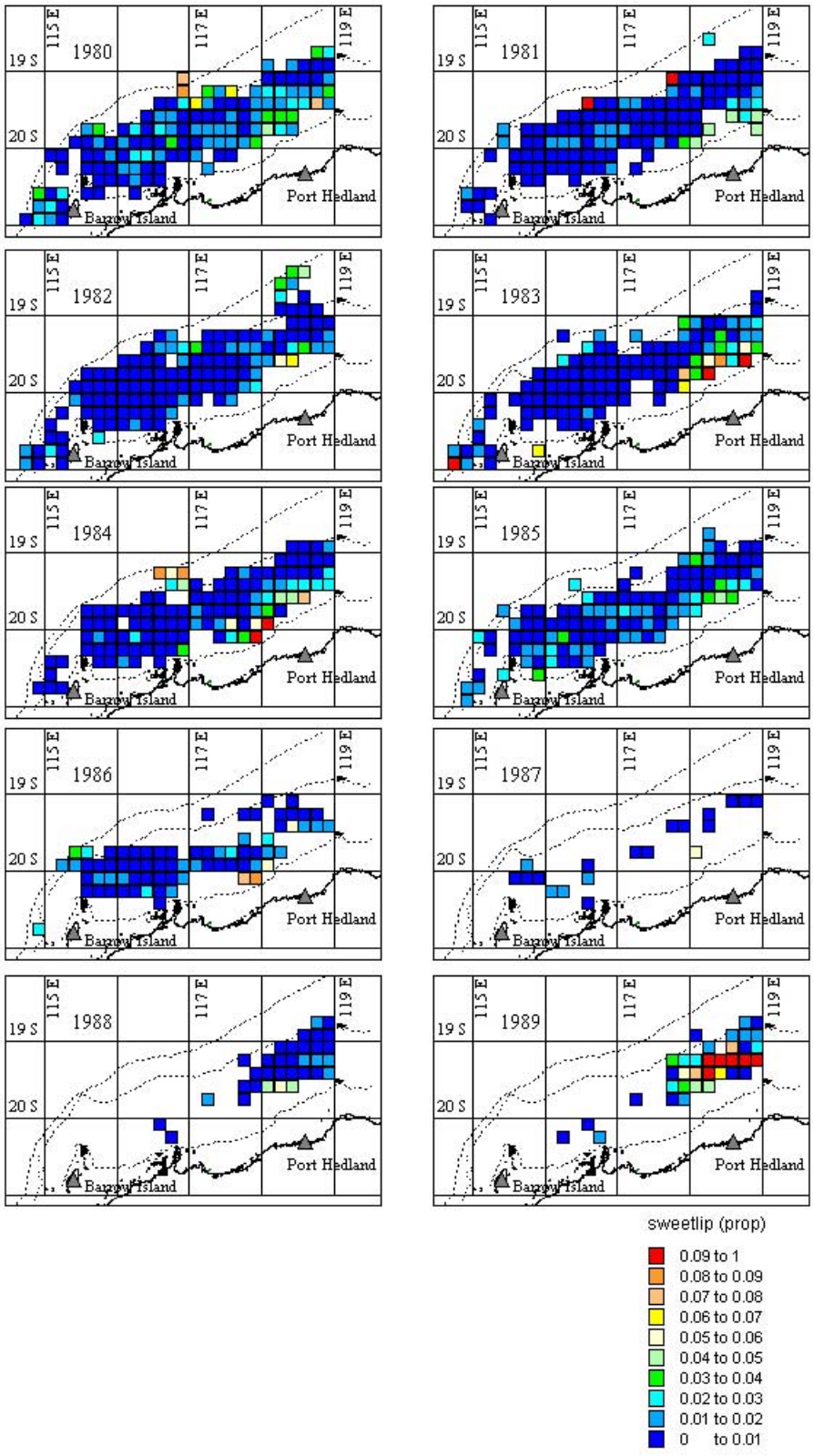

Figure A.15 (b): Proportional catch of sweetlips (AFMA).

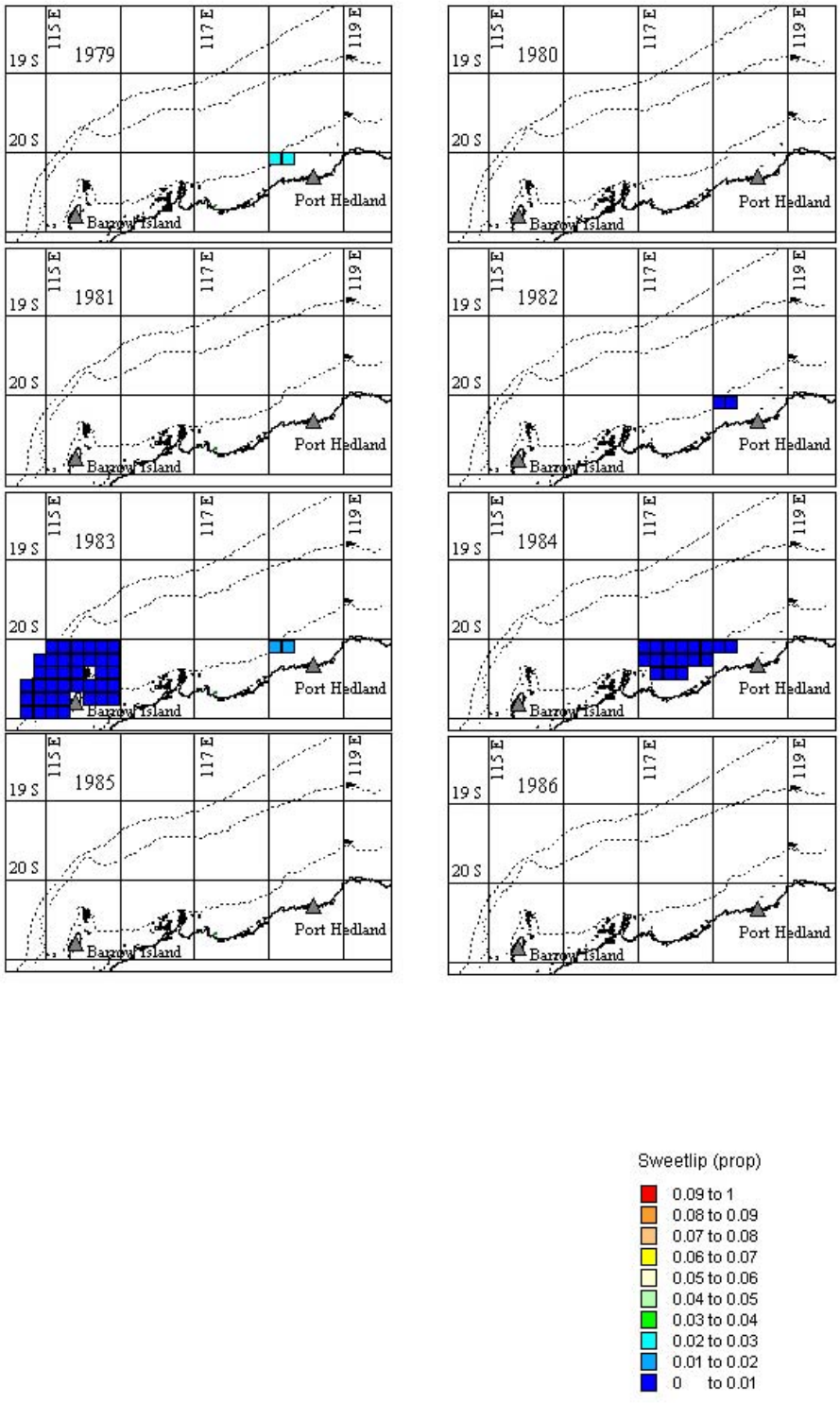

Figure A.15 (c): Proportional catch of sweetlips (CAES, 1979-1986).

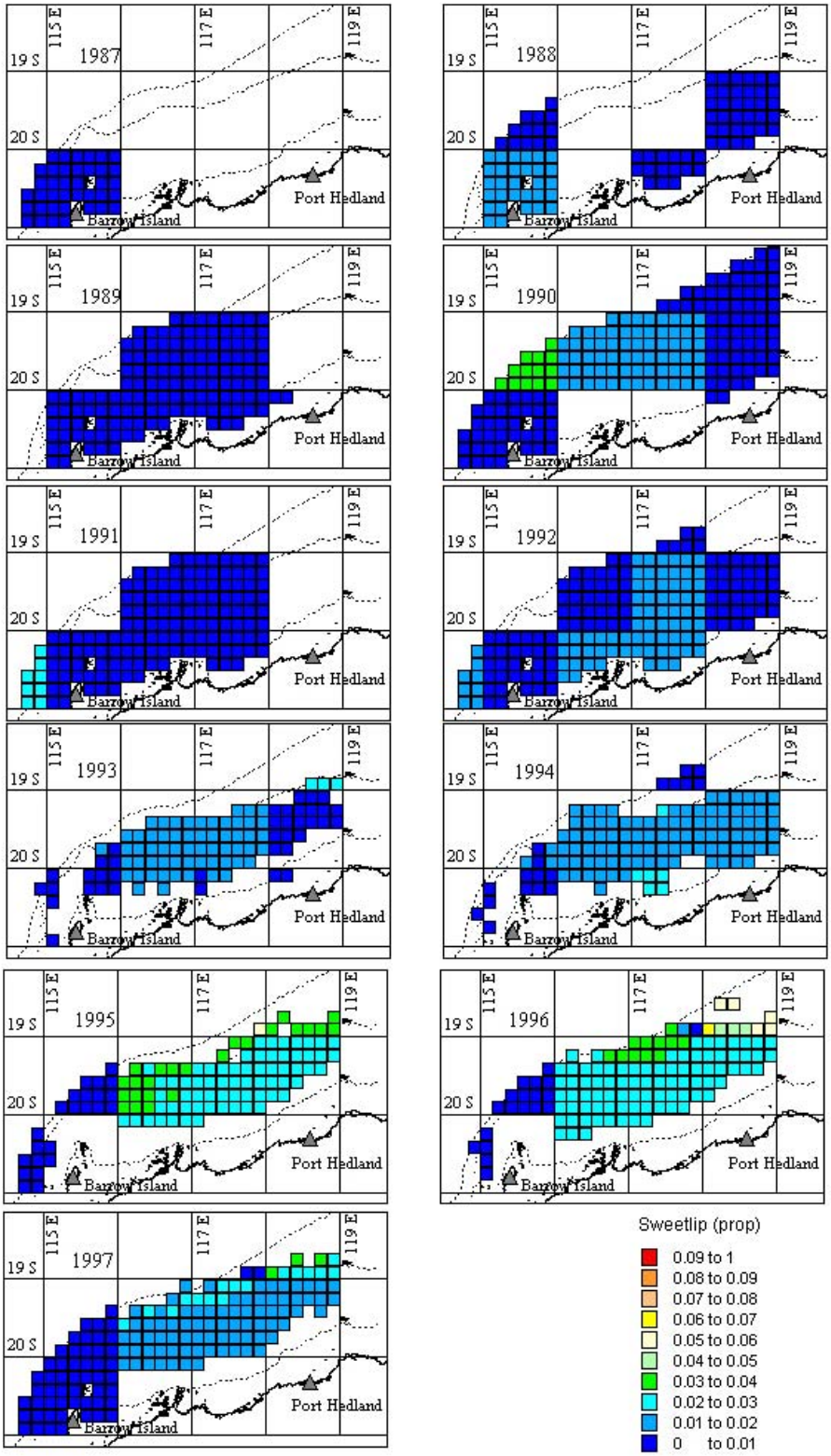

Figure A.15 (d): Proportional catch of sweetlips (CAES, 1987-1997).

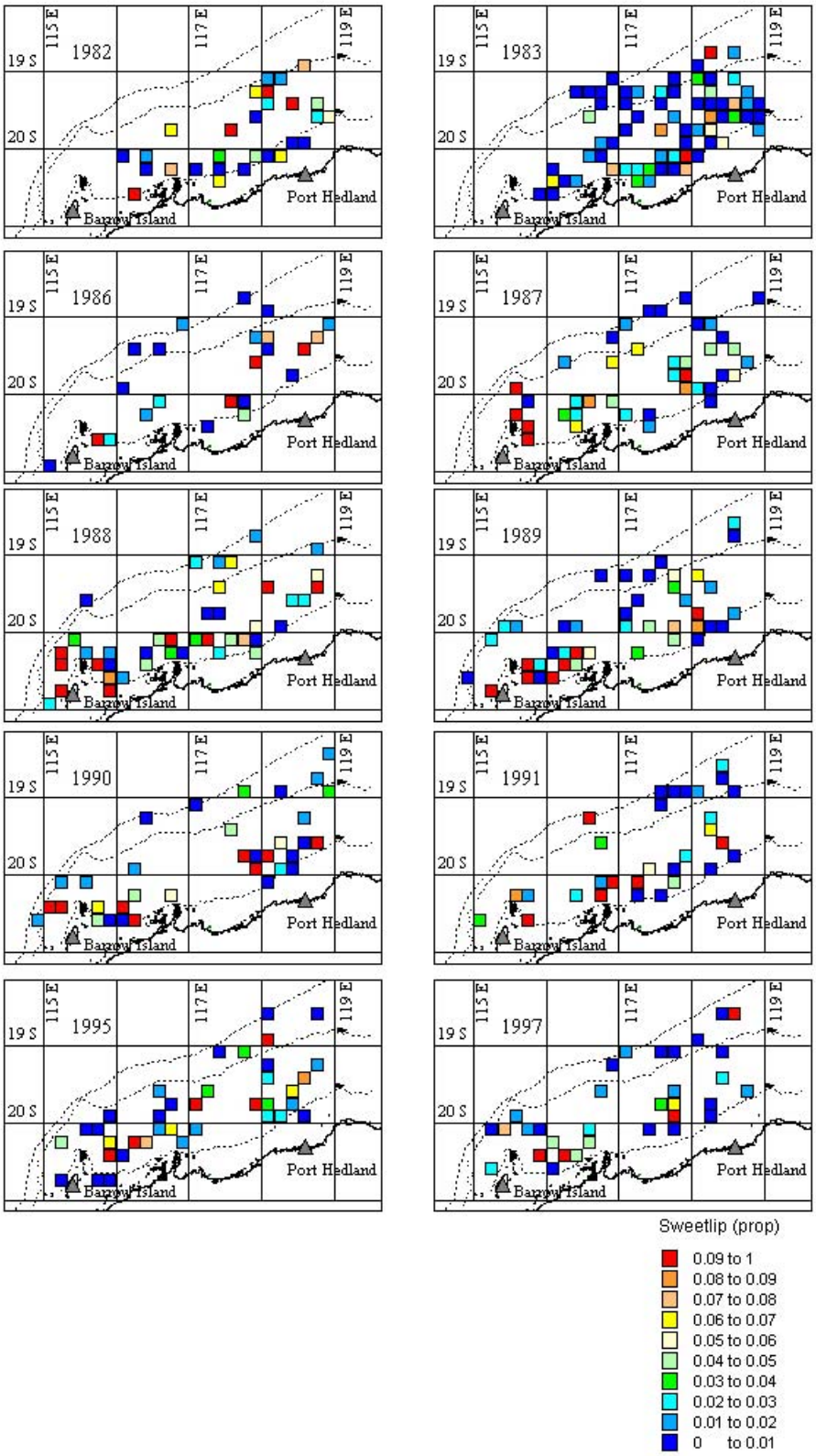

Figure A.15 (e): Proportional catch of sweetlips (CSIRO surveys).

A.16 Lethrinidae

Distribution maps depicting ranges of the proportionate catch of Lethrinidae (Lethrin) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

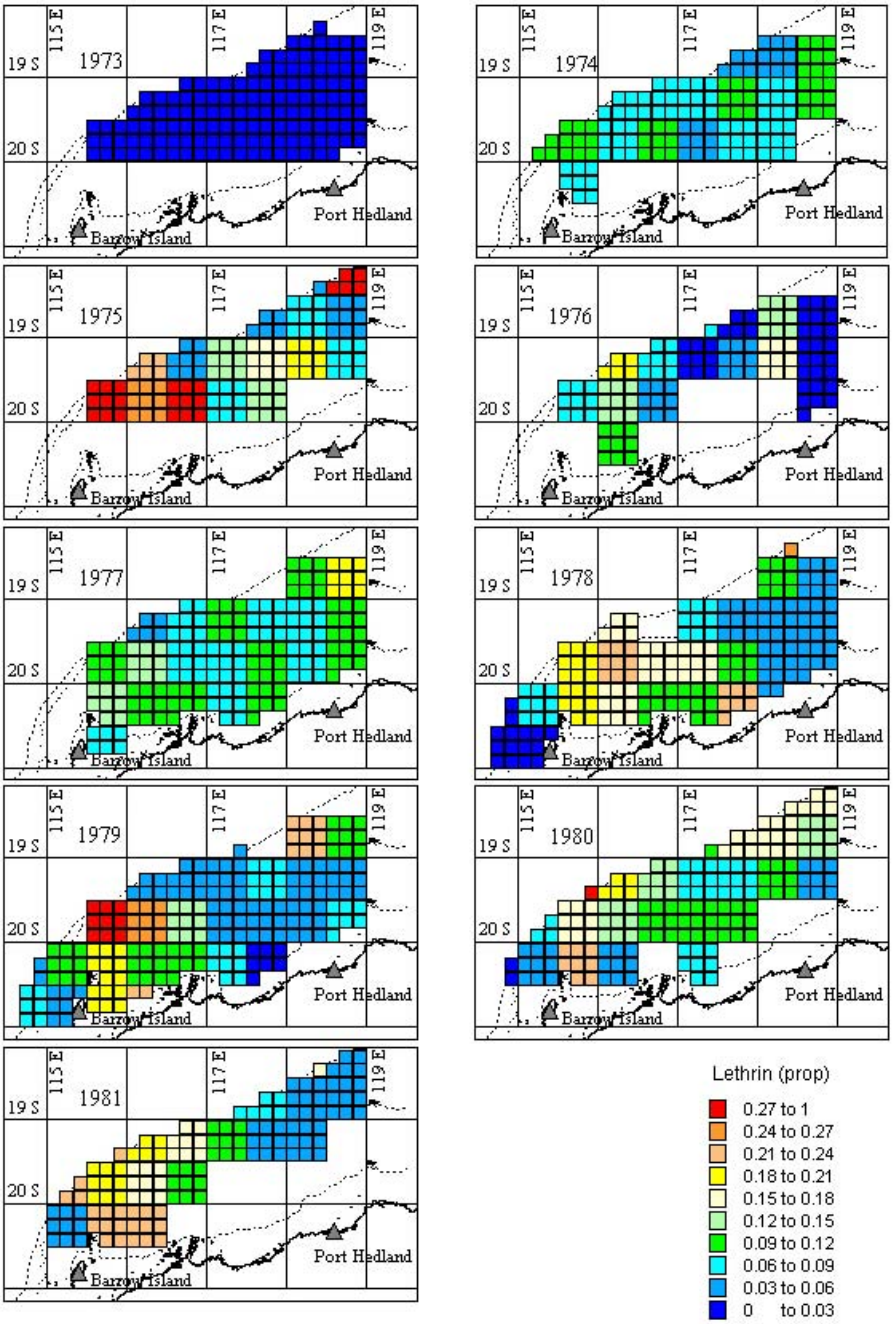

Figure A.16 (a): Proportional catch of Lethrinidae (Taiwanese logbooks).

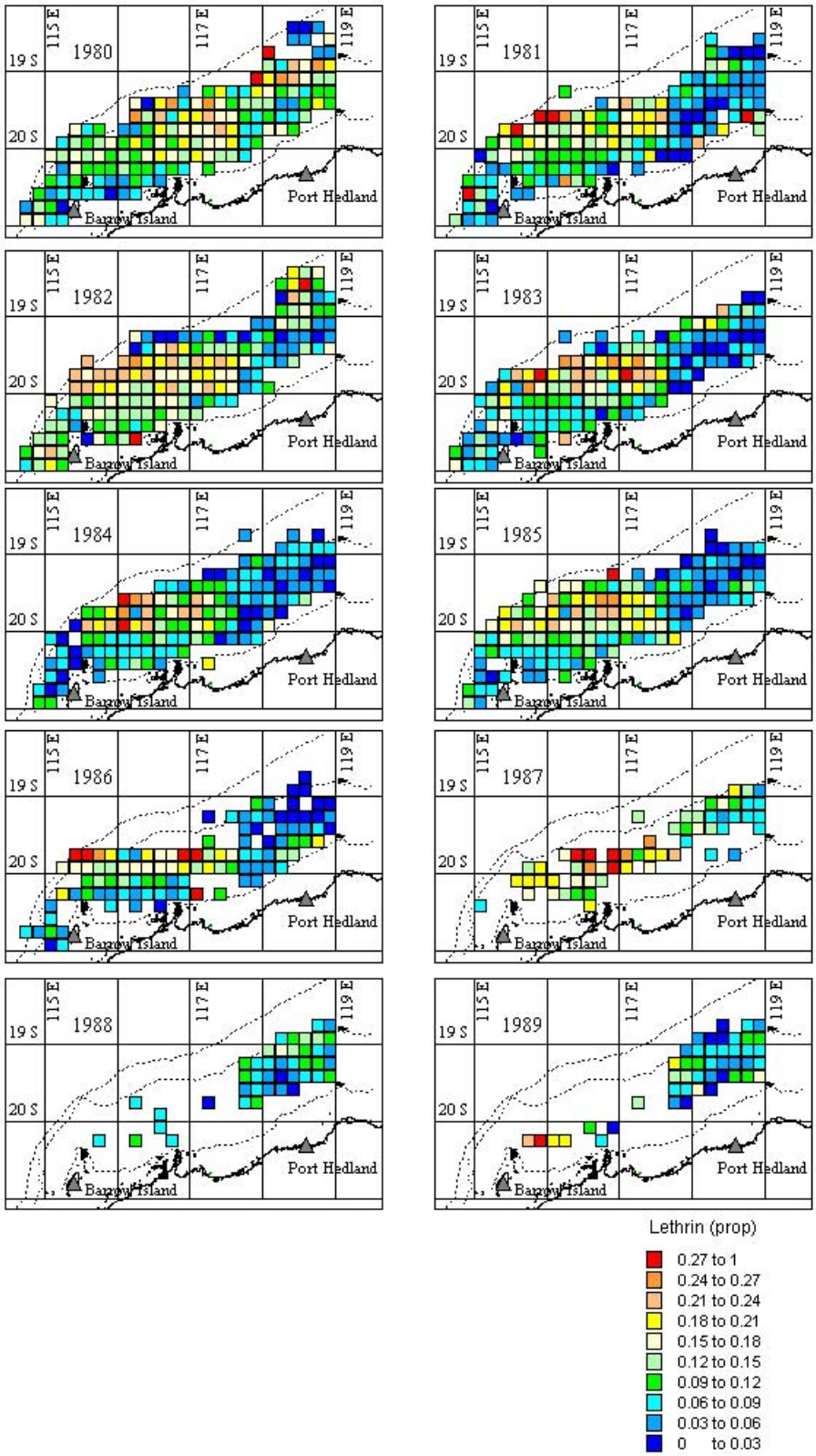

Figure A.16 (b): Proportional catch of Lethrinidae (AFMA).

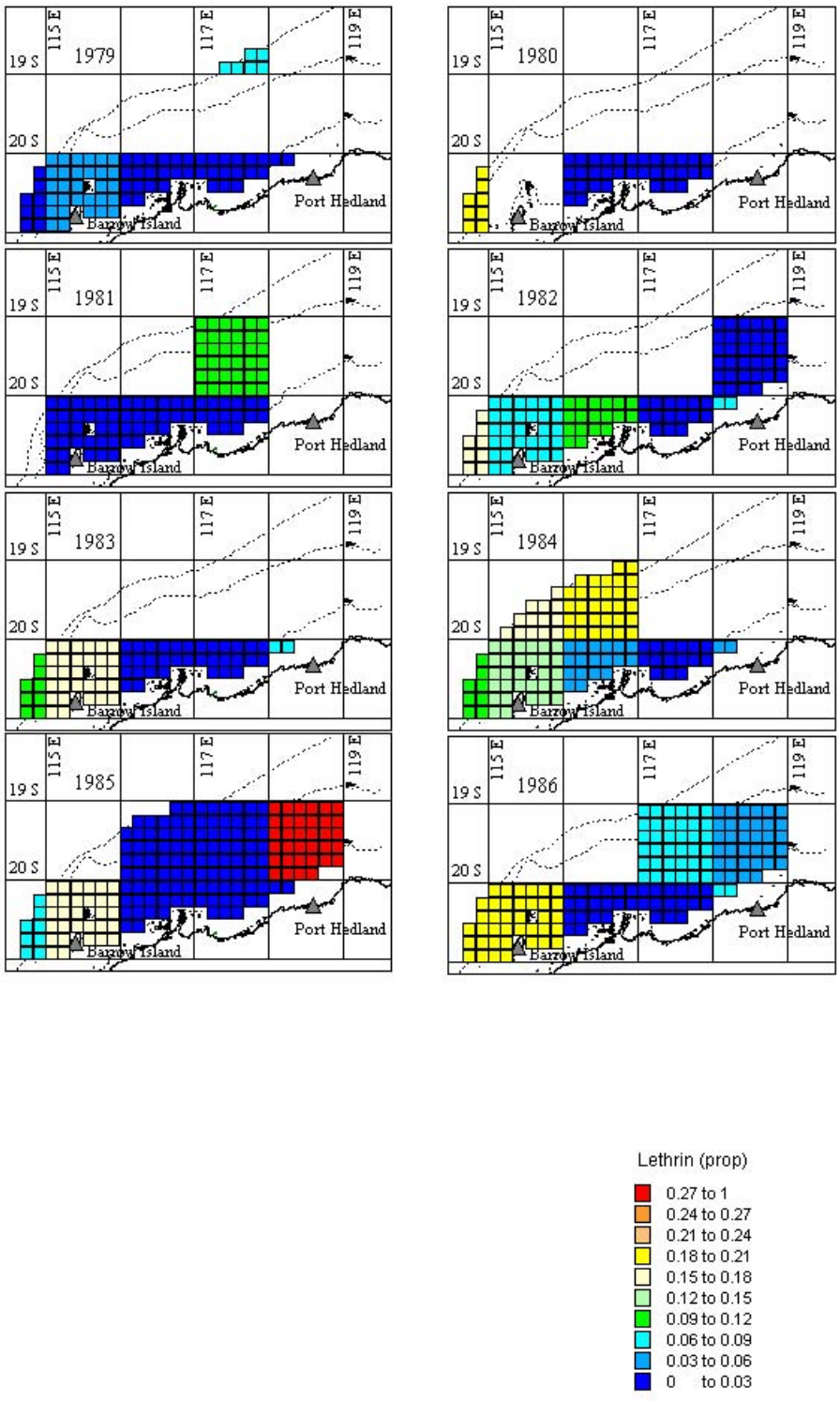

Figure A.16 (c): Proportional catch of Lethrinidae (CAES, 1979-1986).

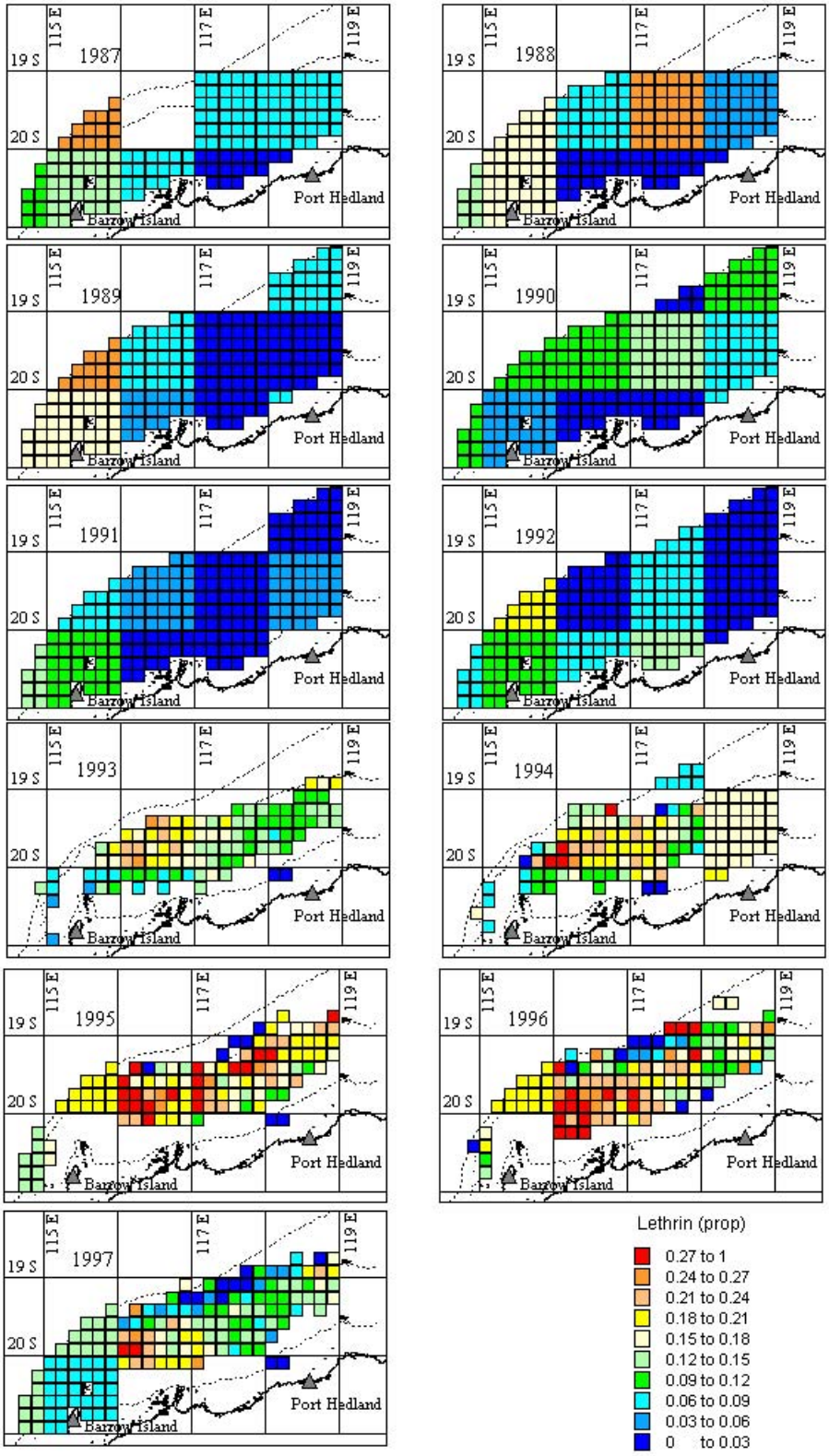

Figure A.16 (d): Proportional catch of Lethrinidae (CAES, 1987-1997)

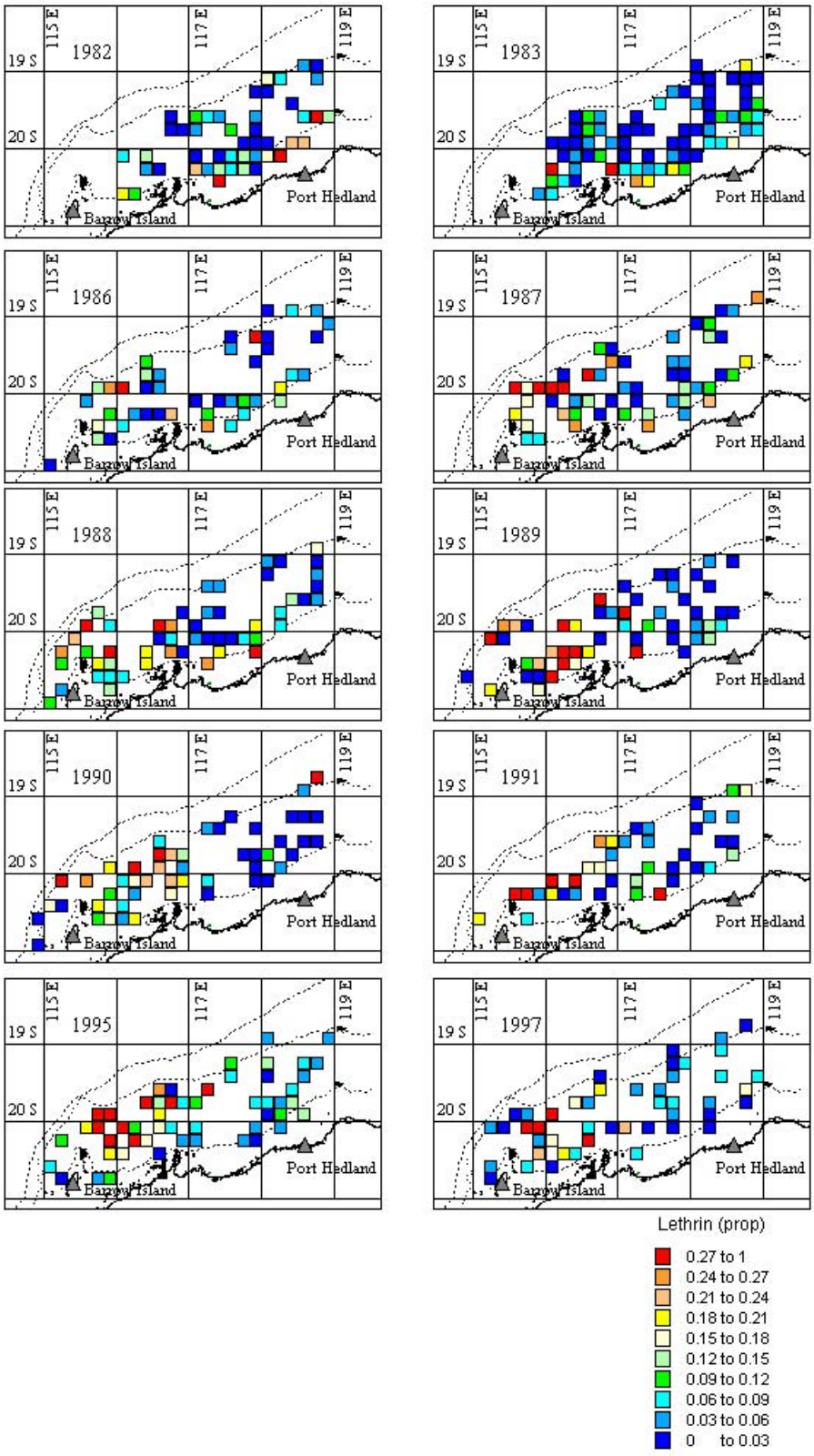

Figure A.16 (e): Proportional catch of Lethrinidae (CSIRO surveys).

A.17 Snappers (Sparidae)

Distribution maps depicting ranges of the proportionate catch of snappers (Sparidae), excluding *Argyrops spinifer*, by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) and (c) CAES, all methods), and the CSIRO surveys (d) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

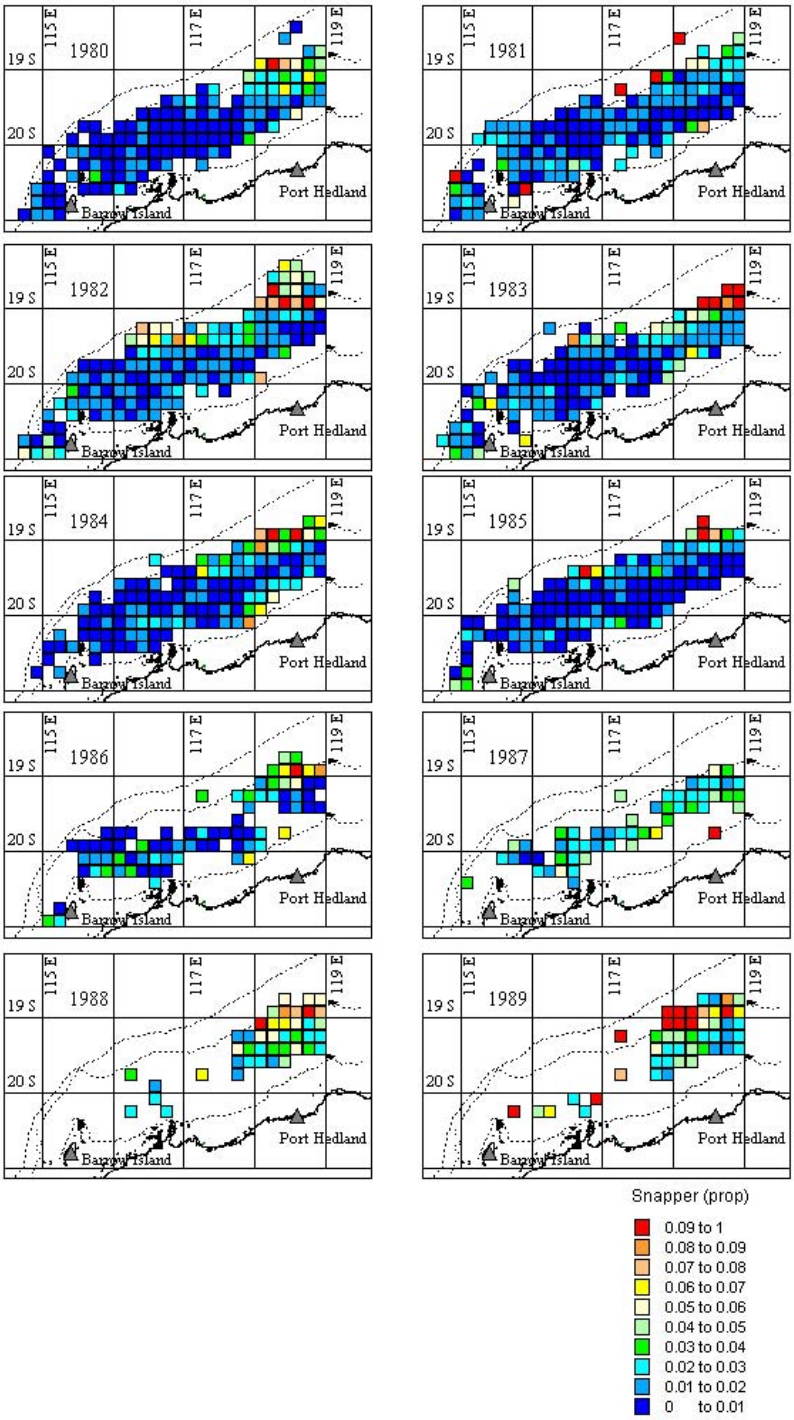

Figure A.17 (a): Proportional catch of snappers (AFMA).

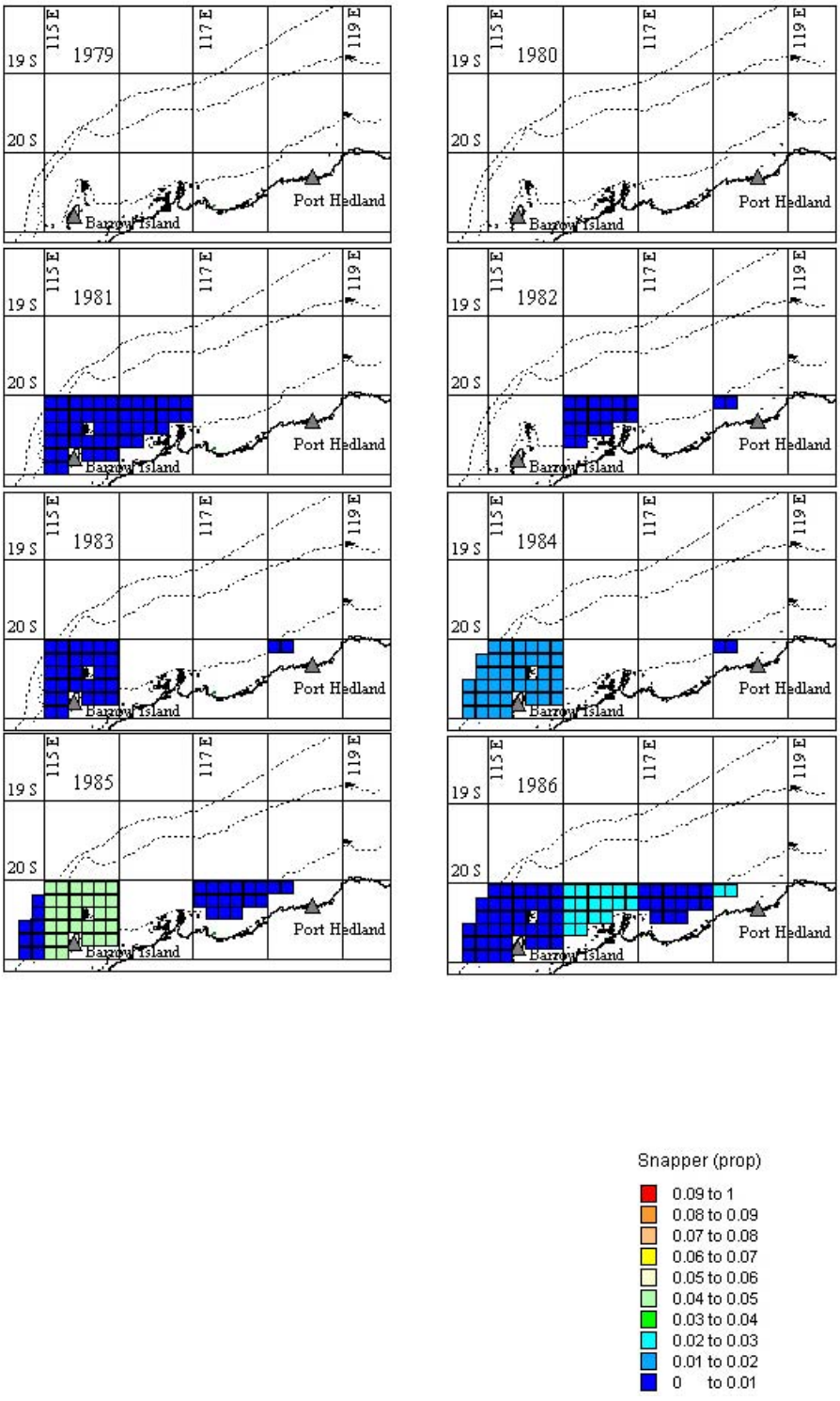

Figure A.17 (b): Proportional catch of snappers (CAES, 1979-1986).

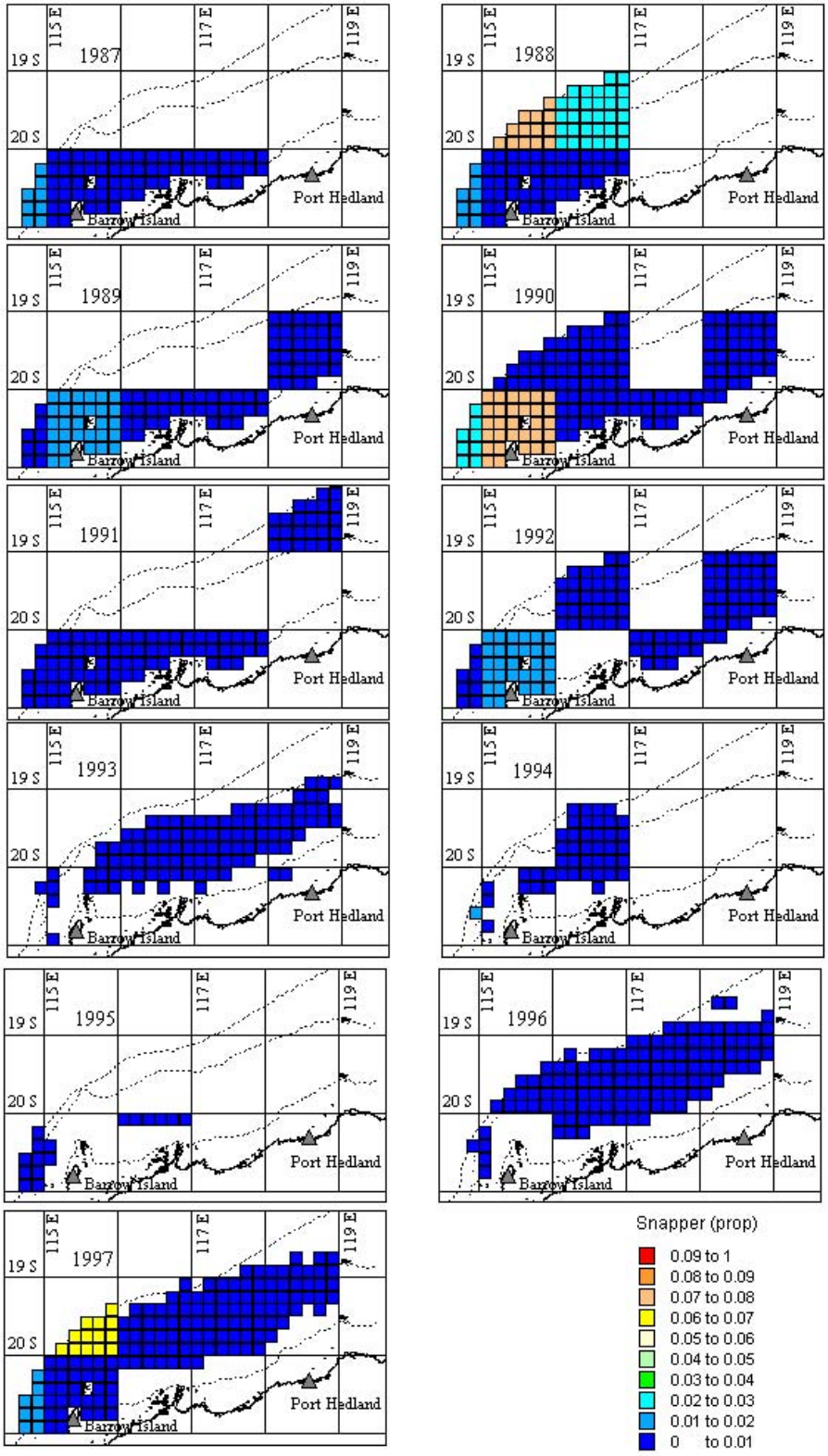

Figure A.17 (c): Proportional catch of snappers (CAES, 1987-1997).

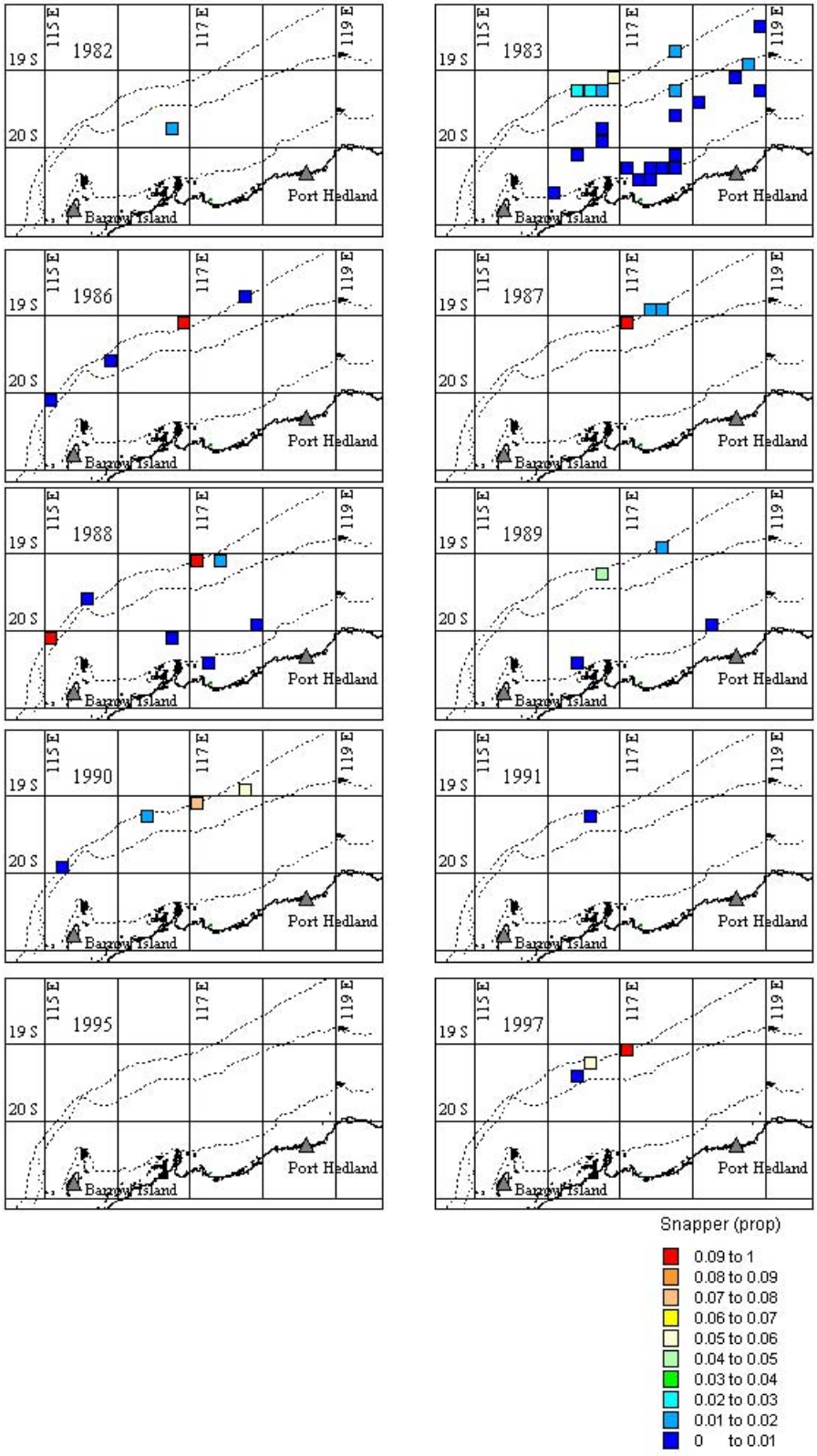

Figure A.17 (d): Proportional catch of snappers (CSIRO surveys).

A.18 *Argyrops spinifer*

Distribution maps depicting ranges of the proportionate catch of *Argyrops spinifer* (Arspinif) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) CAES, all methods), and the CSIRO surveys (c) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

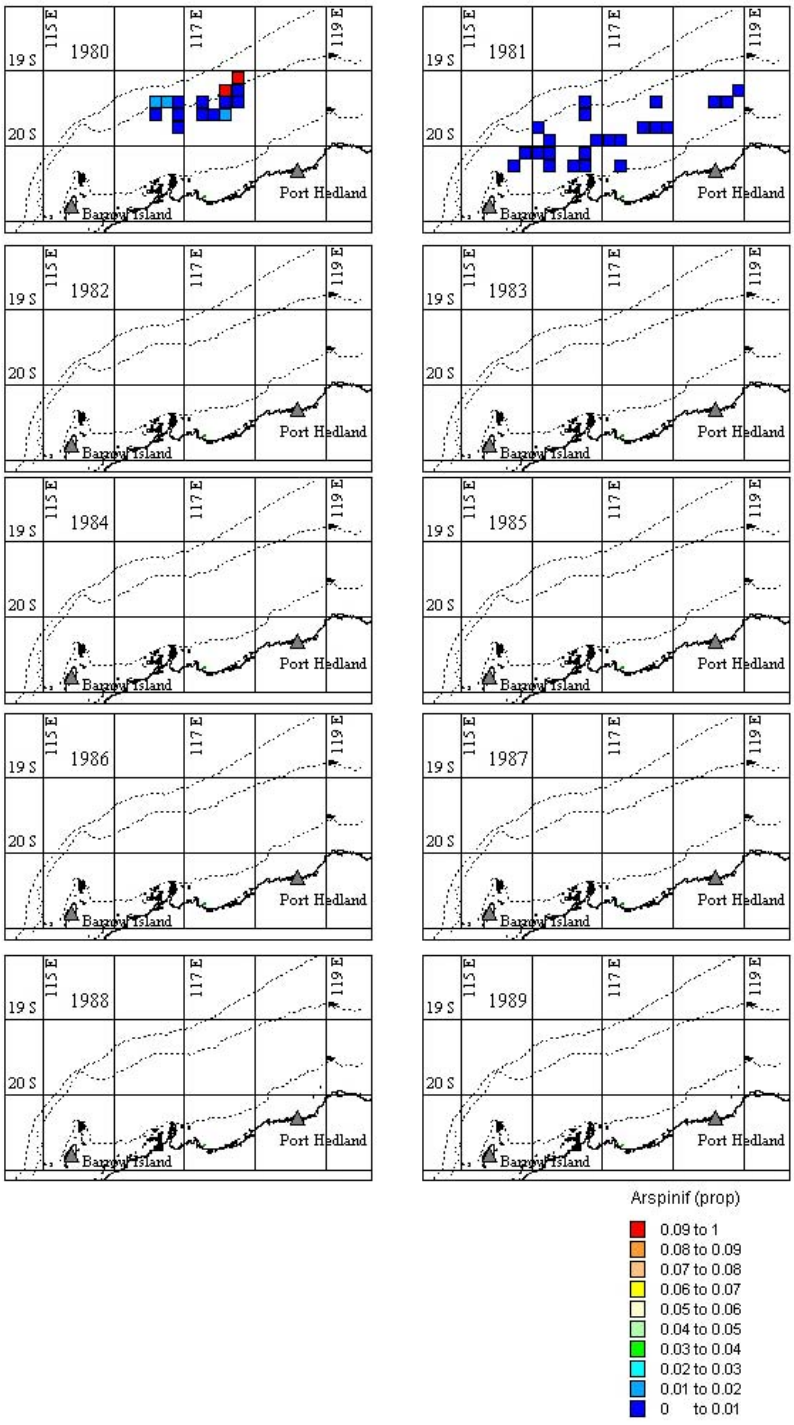

Figure A.18 (a): Proportional catch of *Argyrops spinifer* (AFMA).

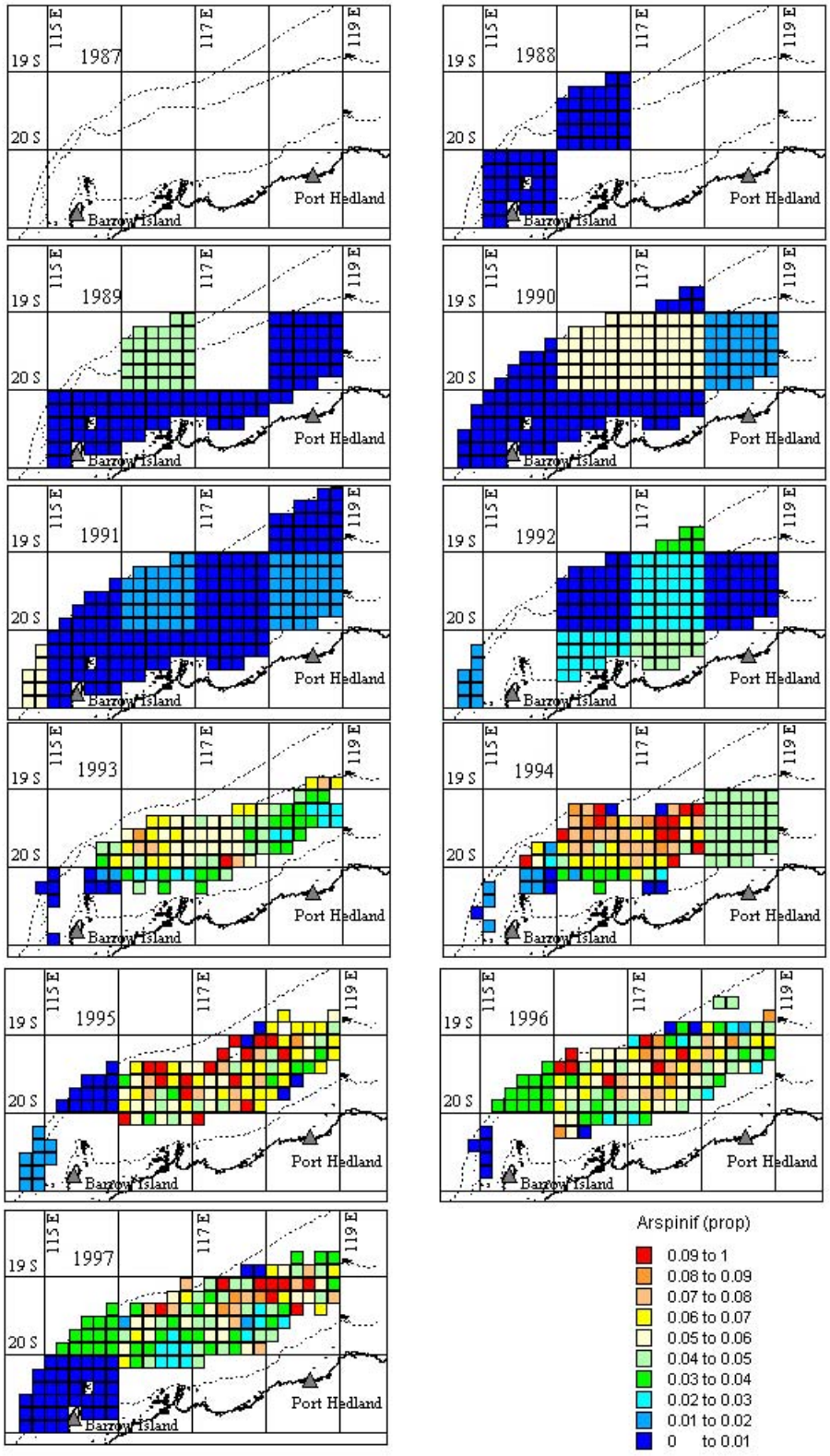

Figure A.18 (b): Proportional catch of *Argyrops spinifer* (CAES, 1987-1997).

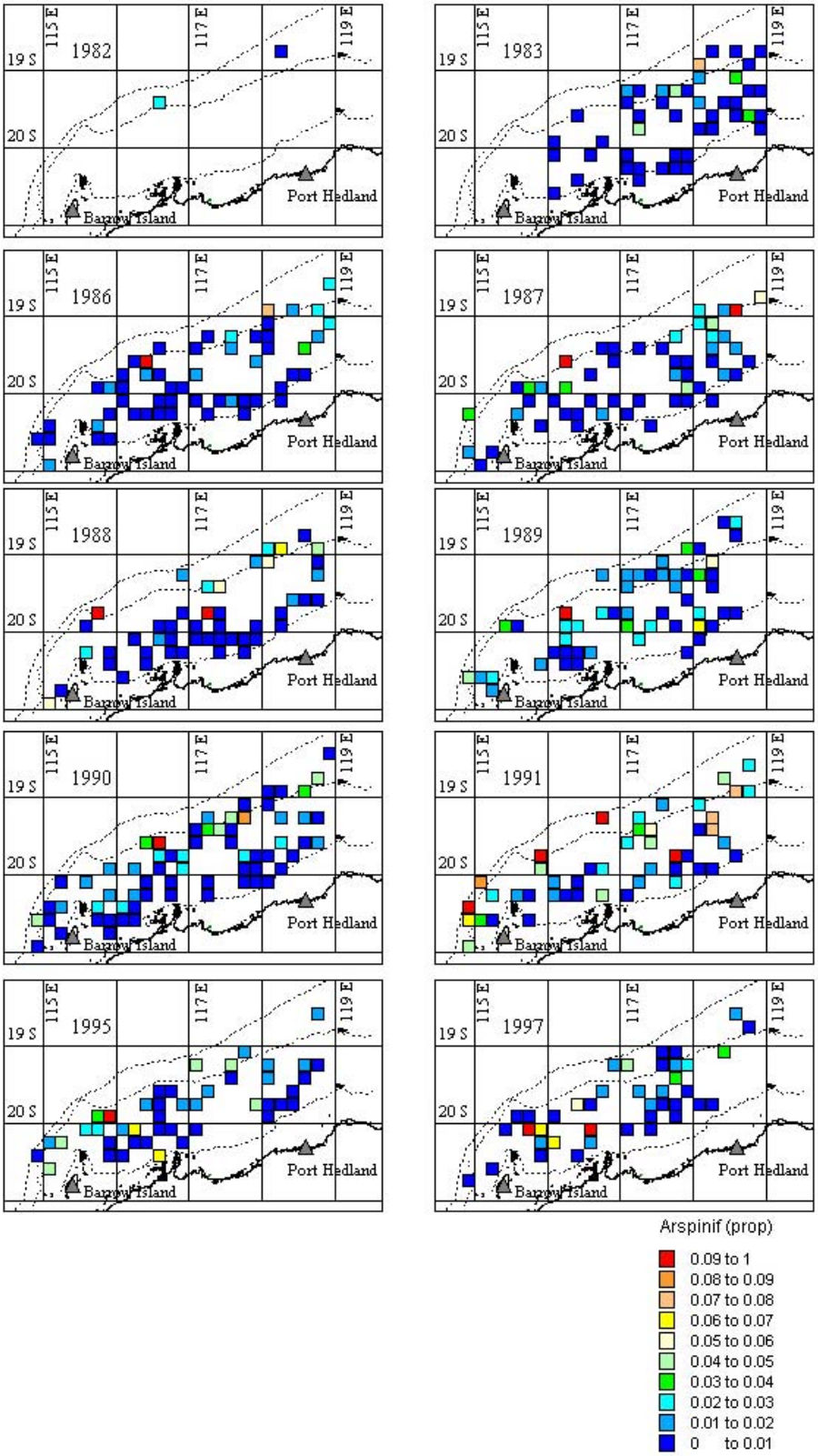

Figure A.18 (c): Proportional catch of *Argyrops spinifer* (CSIRO surveys).

A.19 Trevallies and scads (Trevscad, Carangidae)

Distribution maps depicting ranges of the proportionate catch of trevallies and scads (Trevscad, Carangidae) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

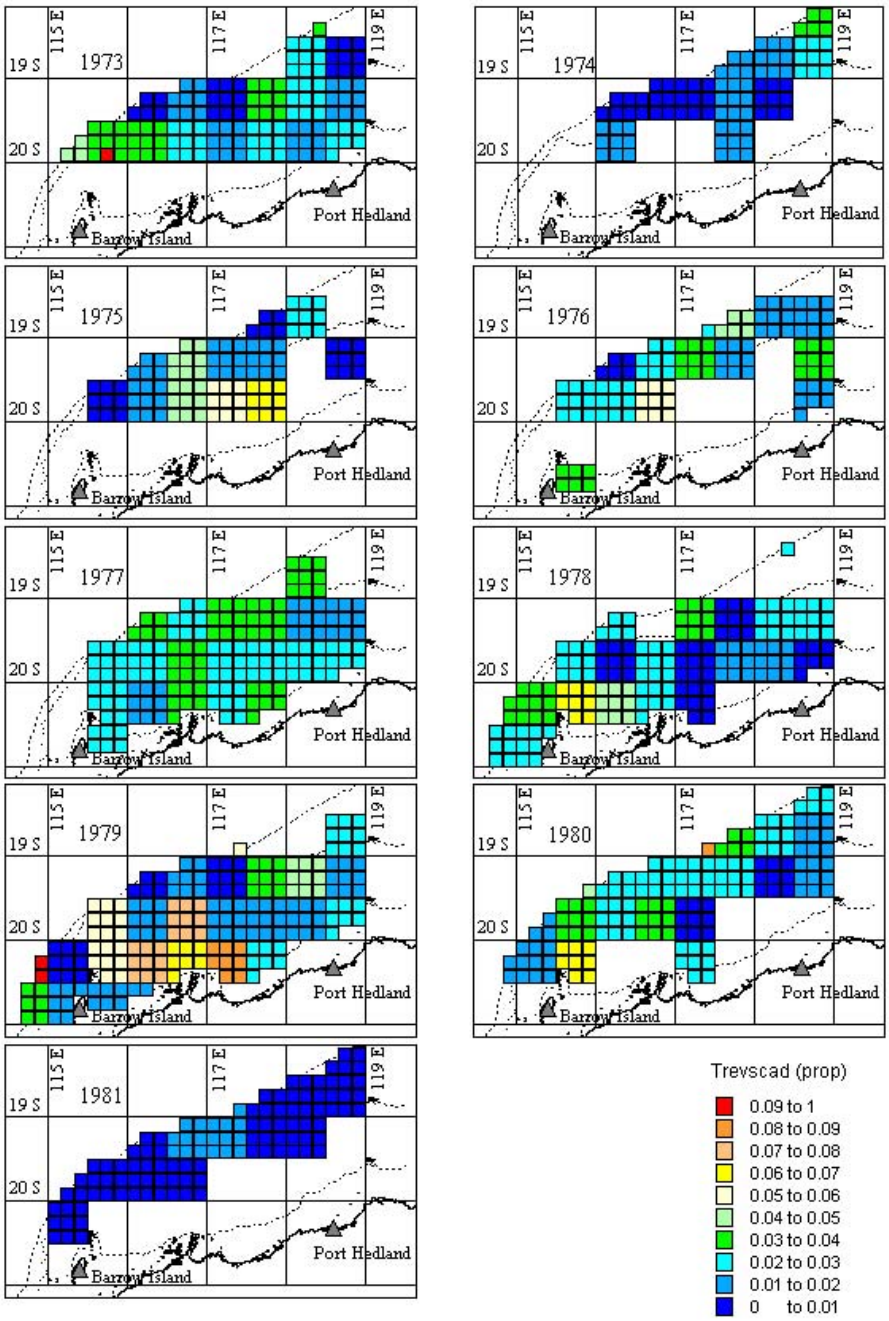

Figure A.19 (a): Proportional catch of trevallies and scads (Taiwanese logbooks).

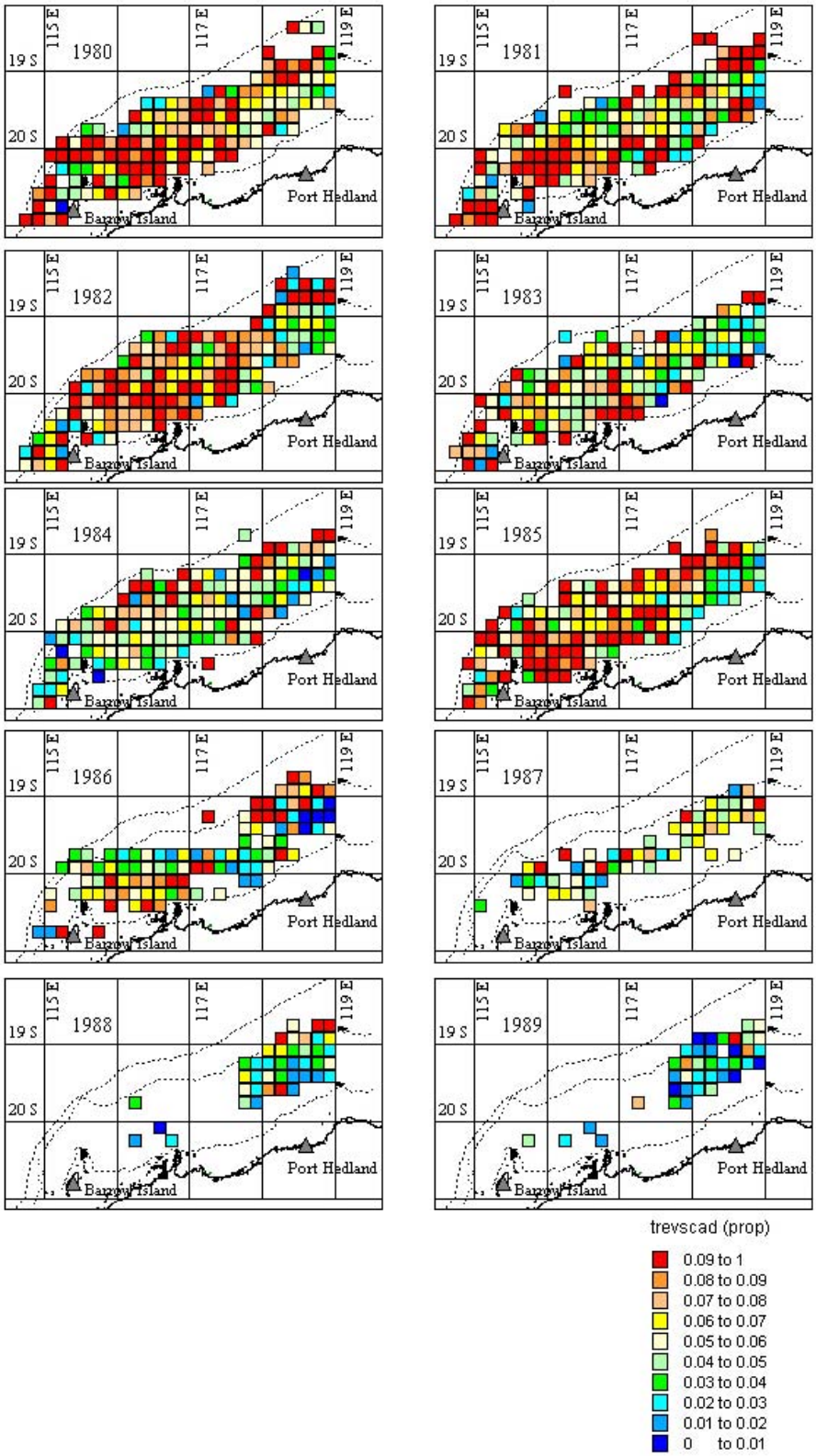

Figure A.19 (b): Proportional catch of trevallies and scads (AFMA).

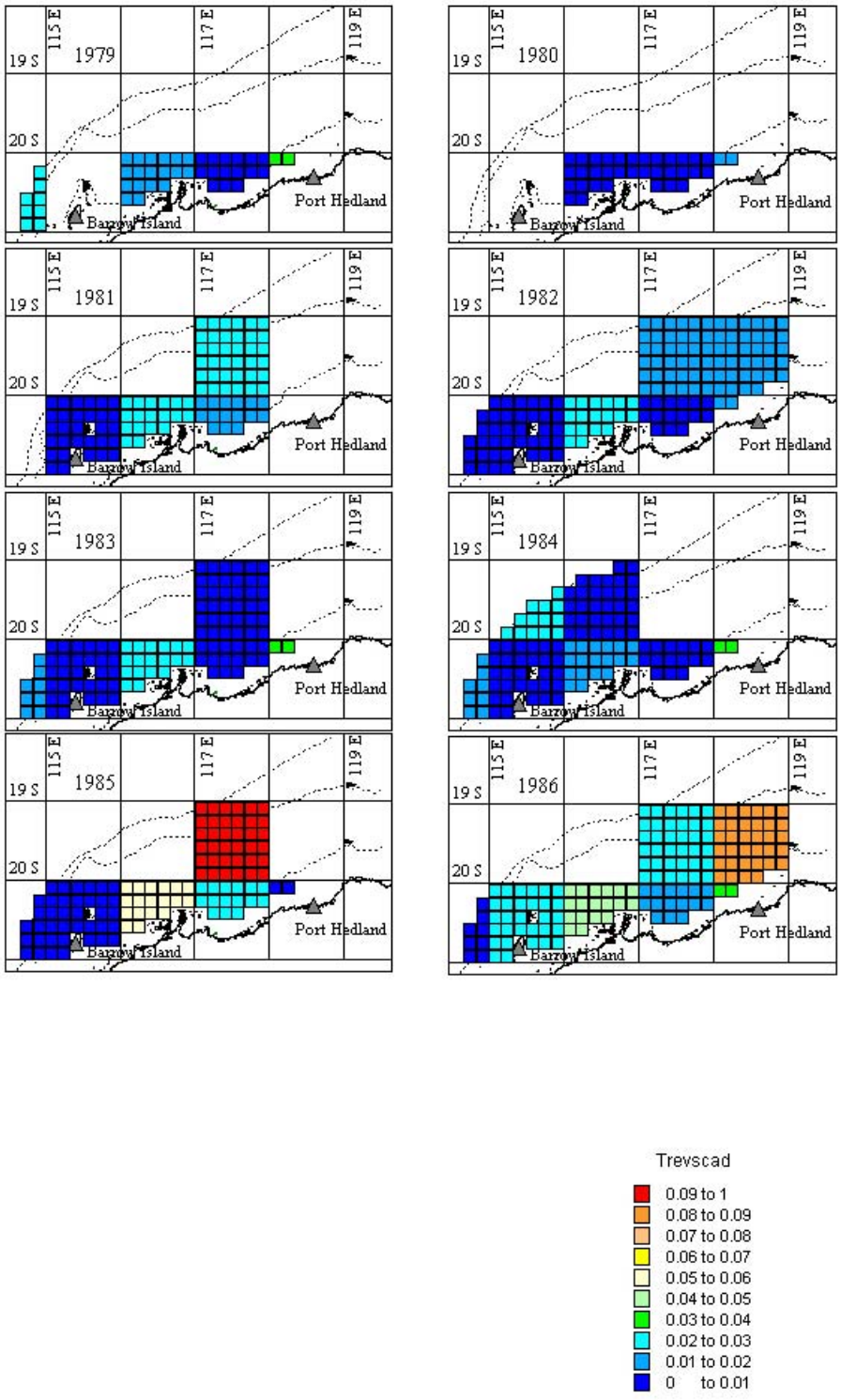

Figure A.19 (c): Proportional catch of trevallies and scads (CAES, 1979-1986).

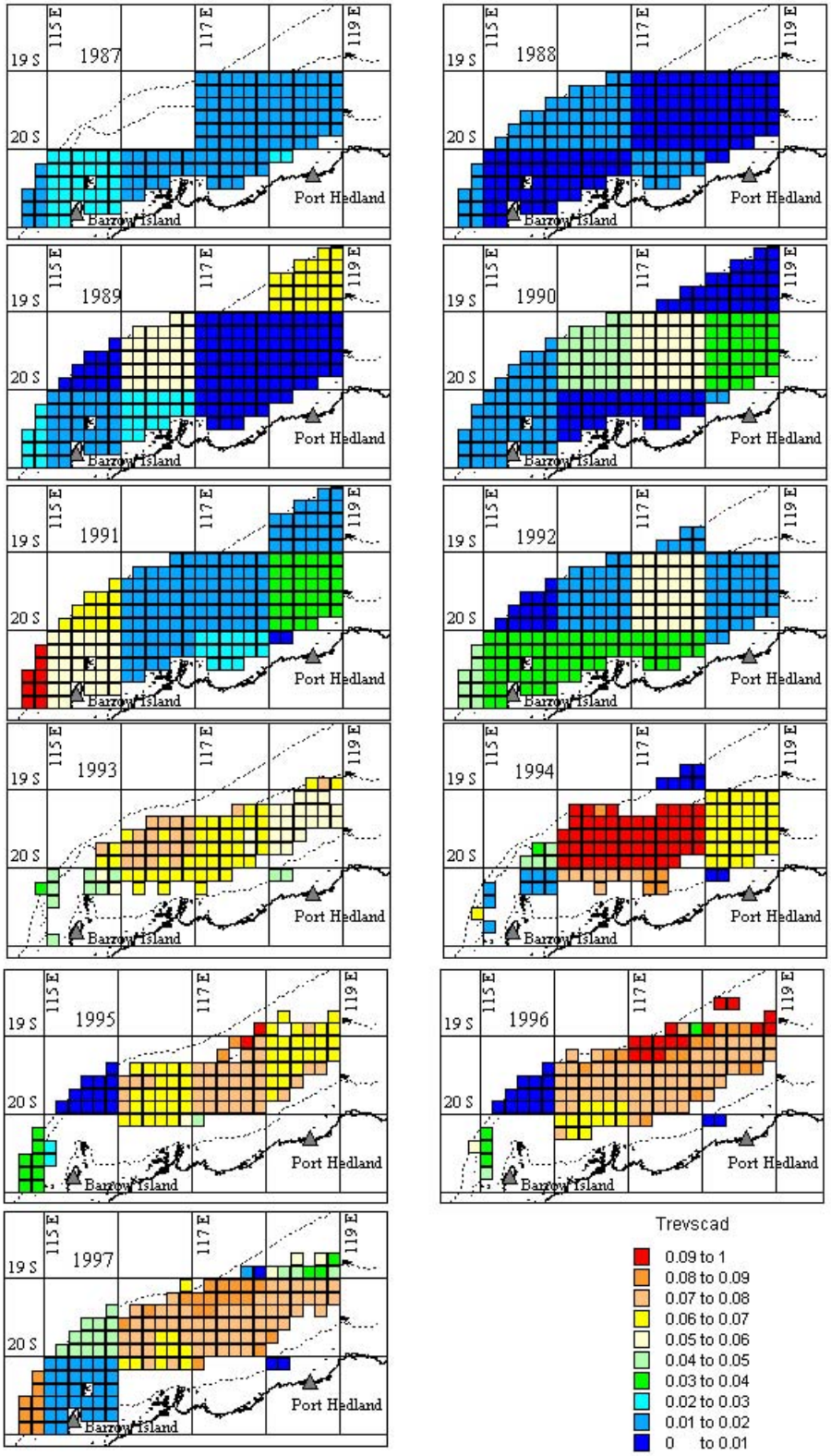

Figure A.19 (d): Proportional catch of trevallies and scads (CAES, 1987-1997).

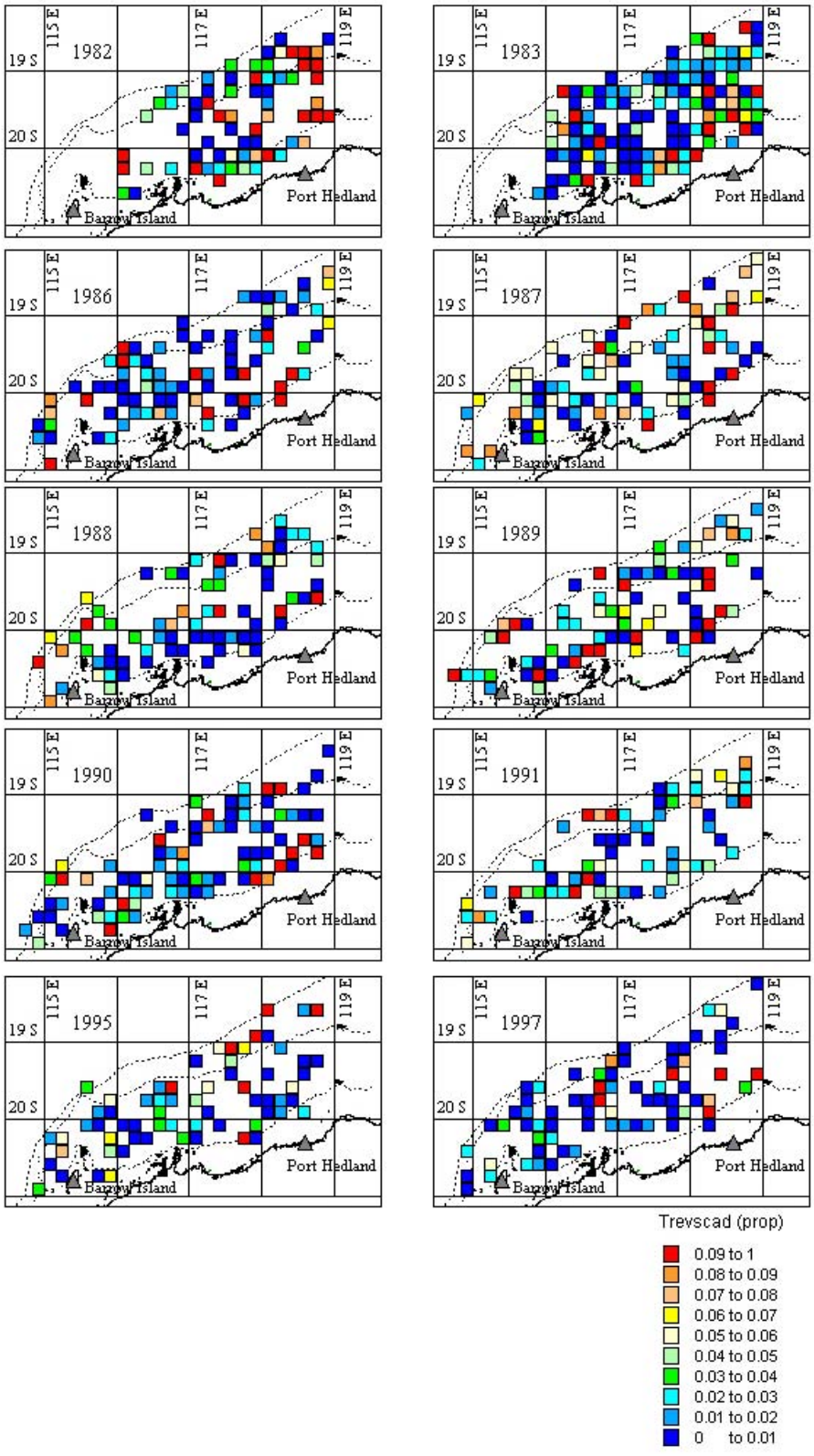

Figure A.19 (e): Proportional catch of trevallies and scads (CSIRO surveys).

A.20 Mullets (Mugilidae)

Distribution maps depicting ranges of the proportionate catch of mullets (Mugilidae) by year on a 10 by 10 minute grid scale, for the domestic fishery ((a) and (b) CAES, all methods) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

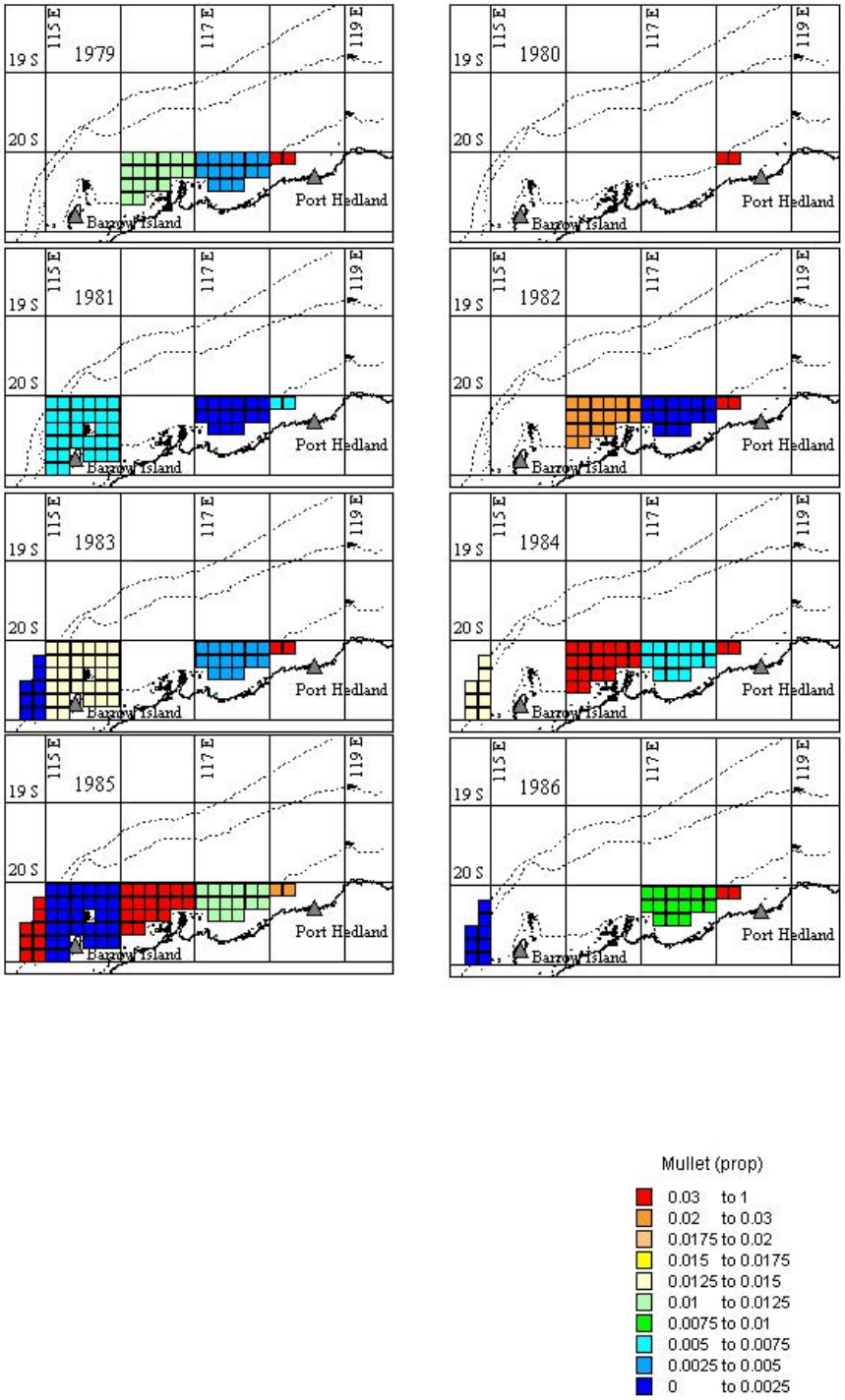

Figure A.20 (a): Proportional catch of mullets (CAES, 1979-1986).

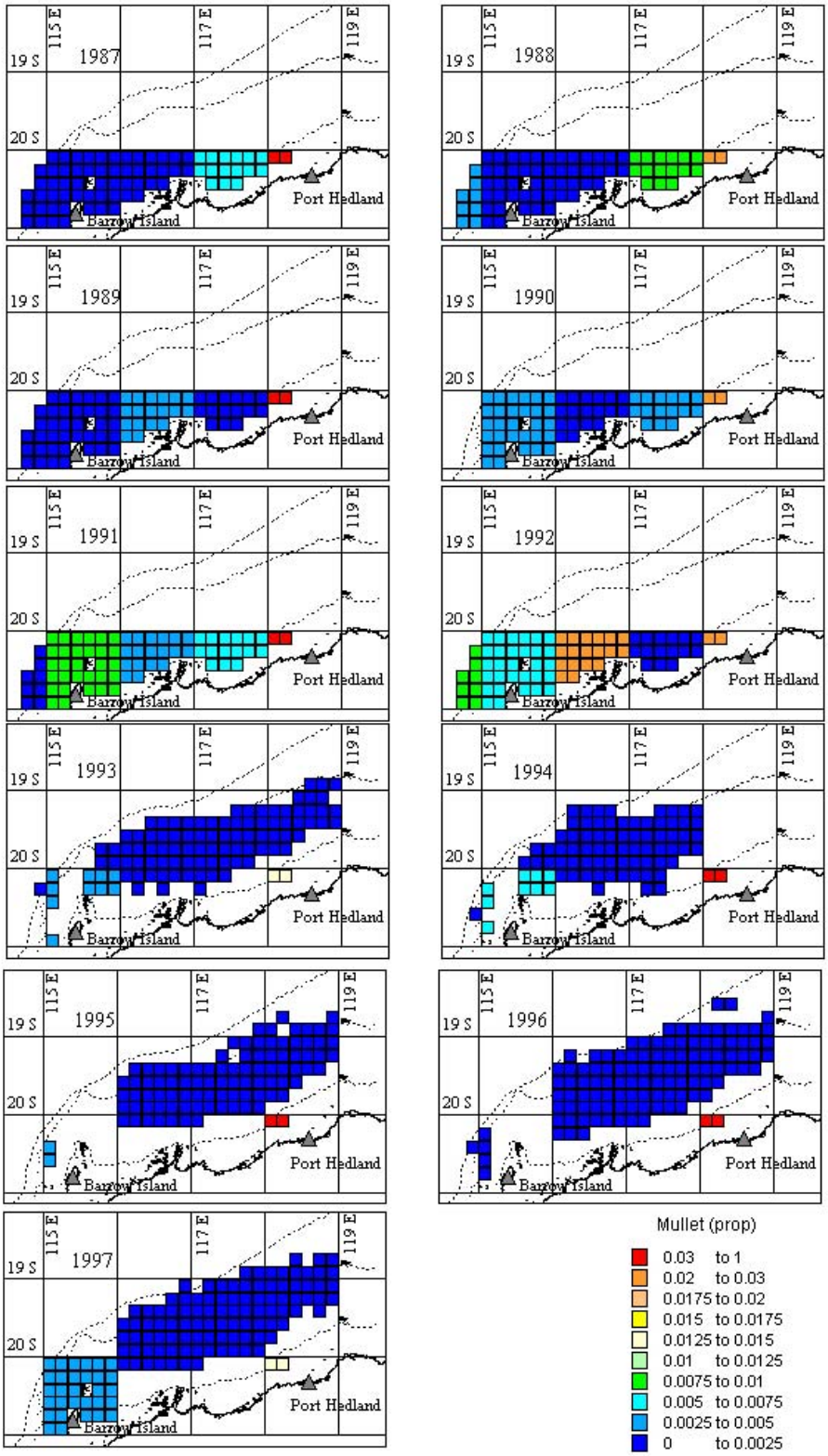

Figure A.20 (b): Proportional catch of mullets (CAES, 1987-1997).

A.21 Mackerels and tunas (Macktuna, Scombridae)

Distribution maps depicting ranges of the proportionate catch of mackerels and tunas (Macktuna, Scombridae) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) AFMA), the domestic fishery ((b) and (c) CAES, all methods), and the CSIRO surveys (d) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

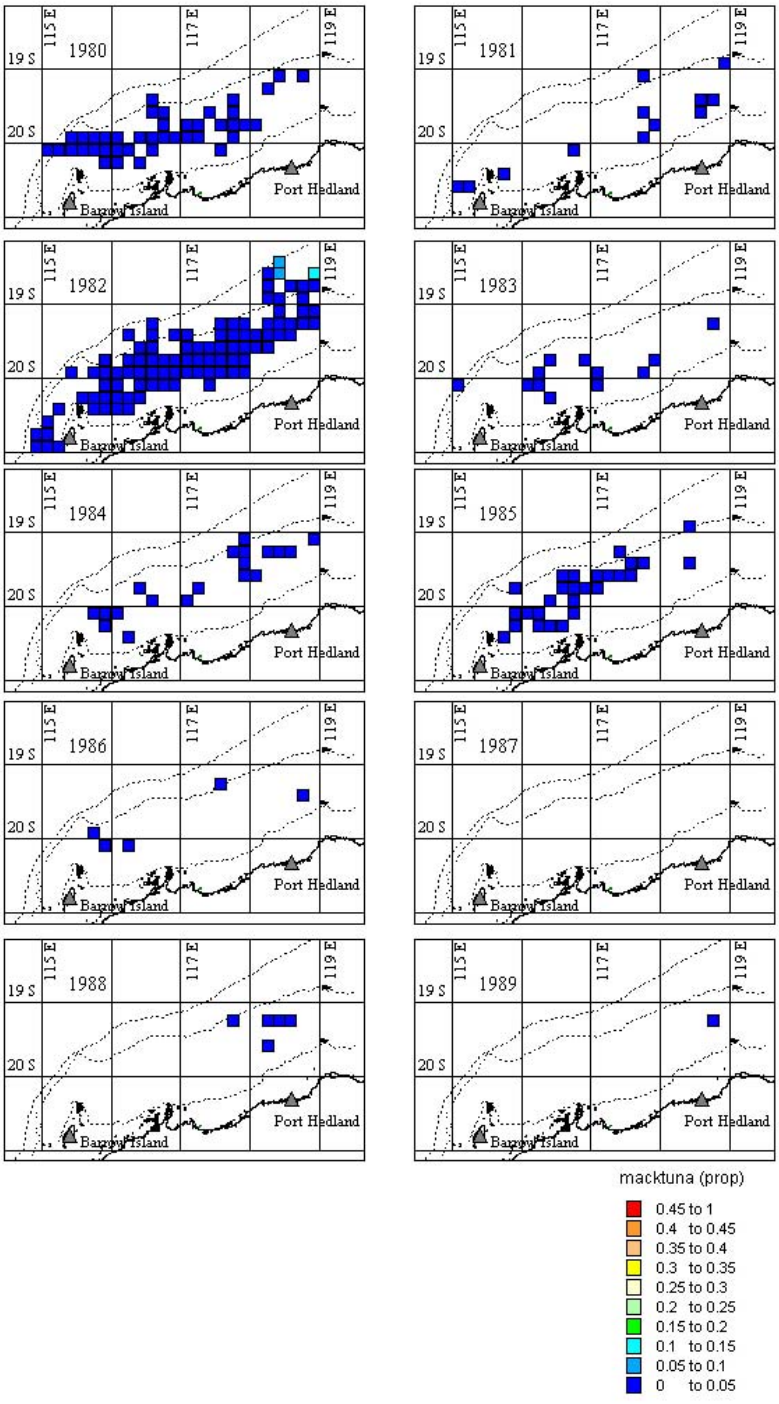

Figure A.21 (a): Proportional catch of mackerels and tunas (AFMA).

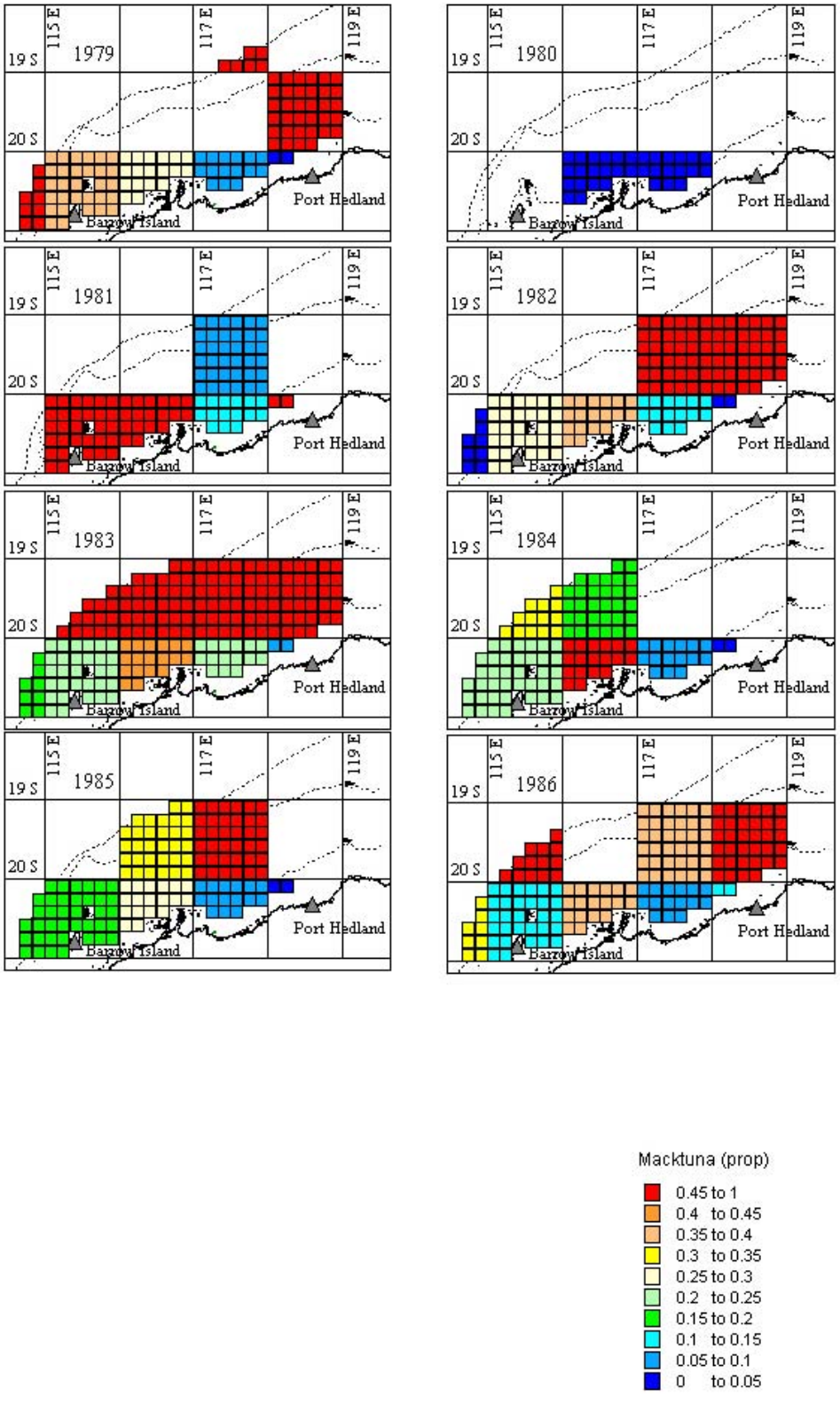

Figure A.21 (b): Proportional catch of mackerels and tunas (CAES, 1979-1986).

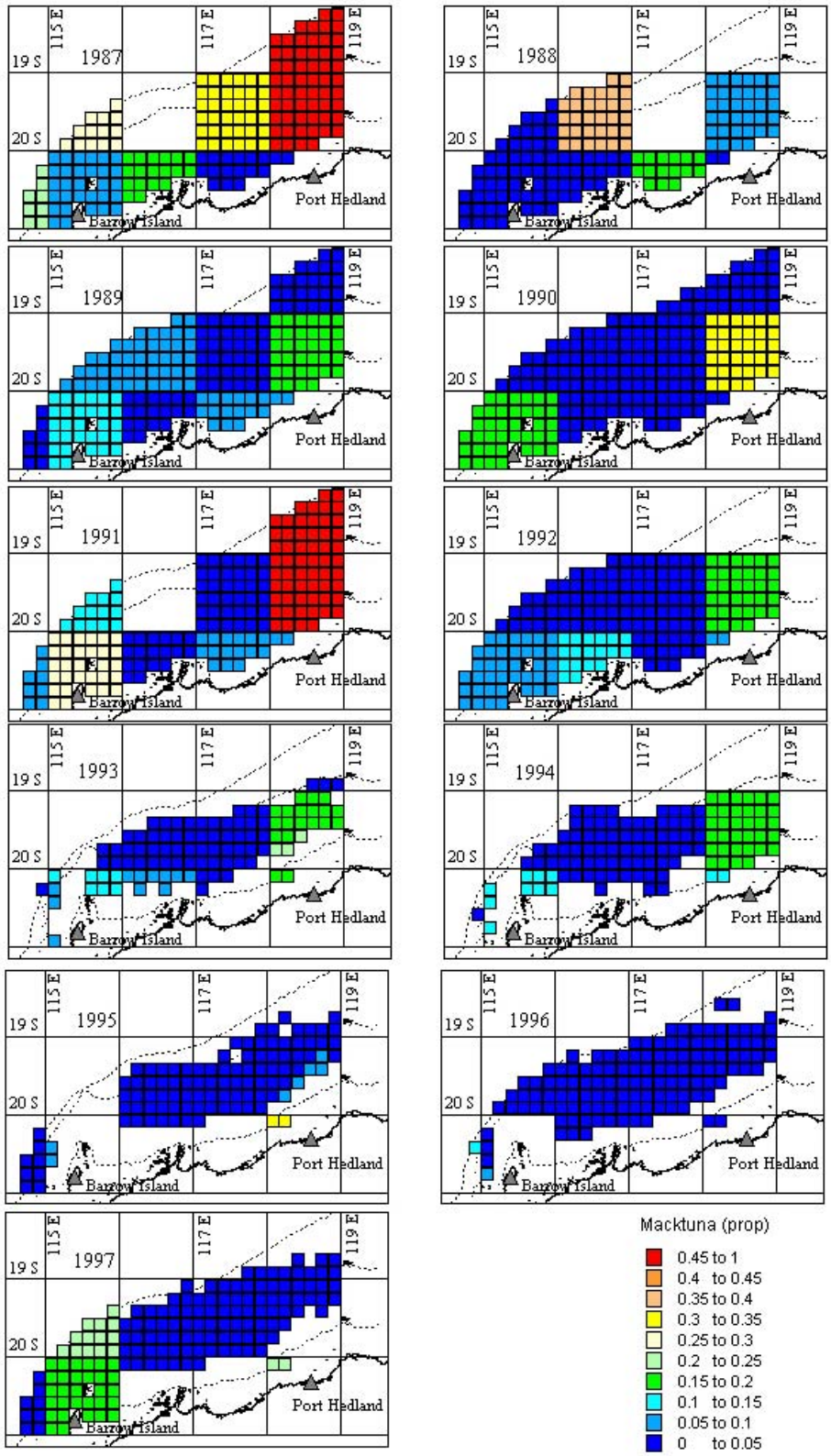

Figure A.21 (c): Proportional catch of mackerels and tunas (CAES, 1987-1997).

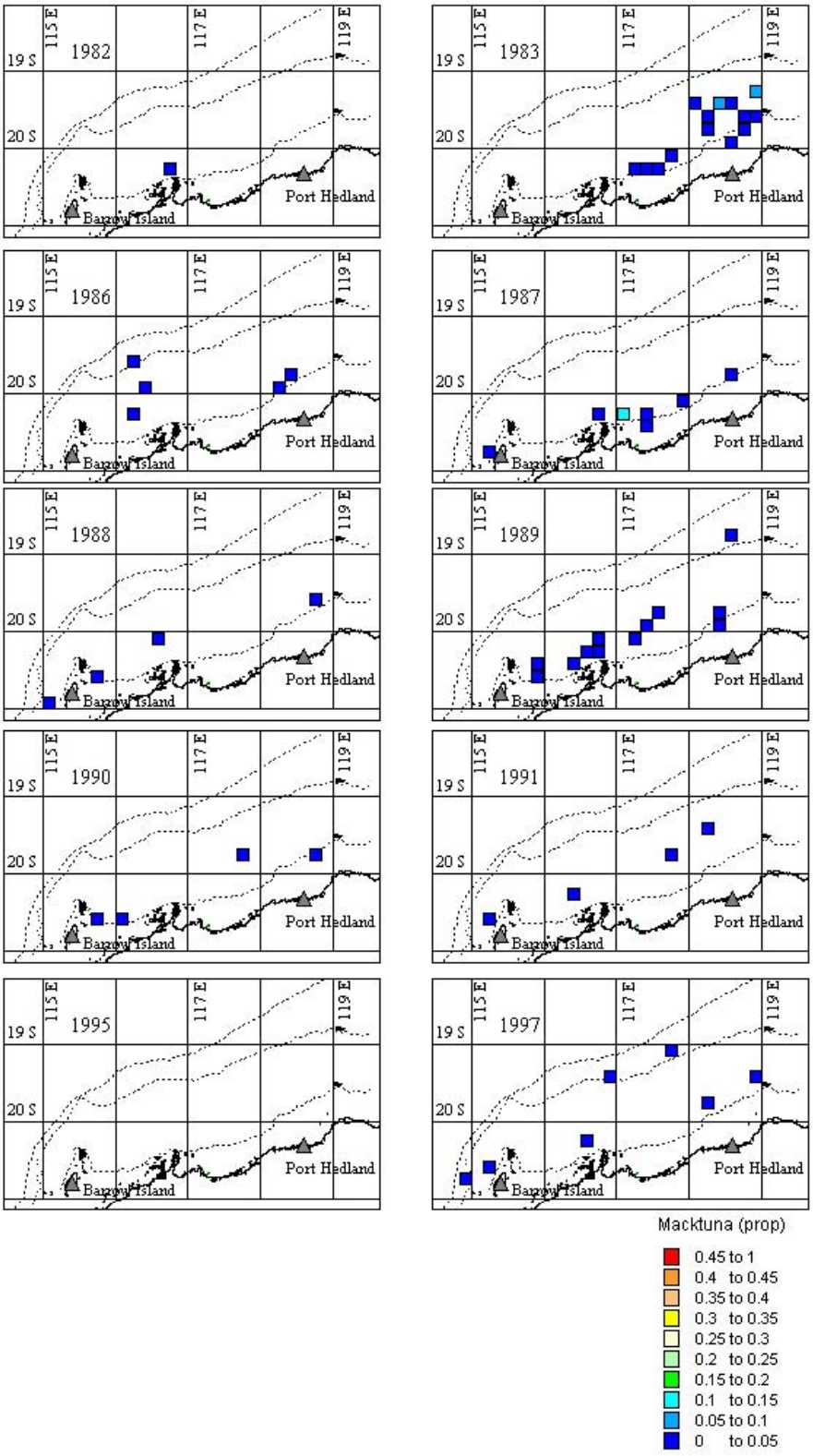

Figure A.21 (d): Proportional catch of mackerels and tunas (CSIRO surveys).

A.22 Other fish species

Distribution maps depicting ranges of the proportionate catch of all other fish species (Fother) by year on a 10 by 10 minute grid scale, for the foreign trawl fishery ((a) Taiwanese and (b) AFMA), the domestic fishery ((c) and (d) CAES, all methods), and the CSIRO surveys (e) in the North West Shelf of Australia. Ranges: lower limit exclusive, upper limit inclusive.

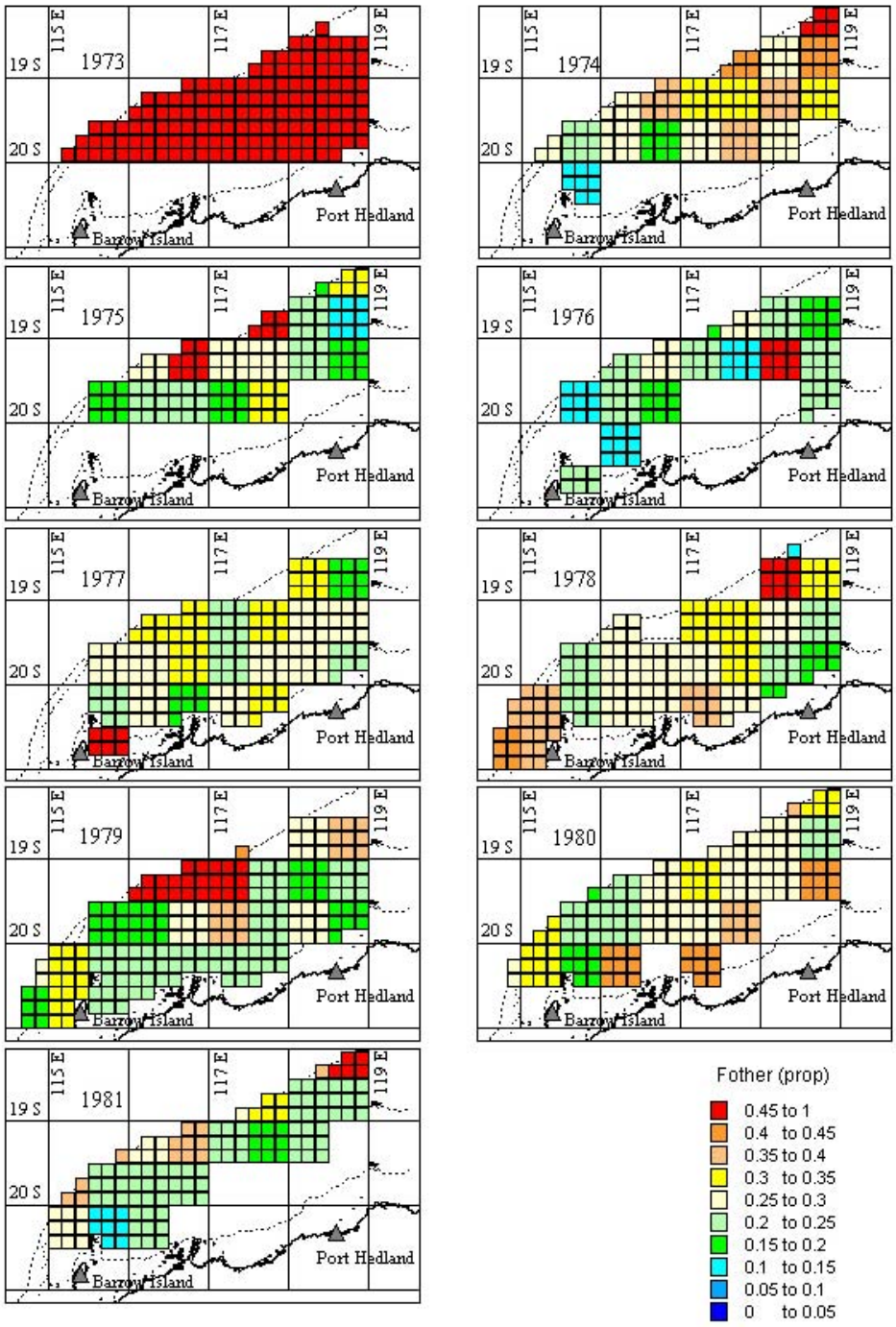

Figure A.22 (a): Proportional catch of other fish (Taiwanese logbooks).

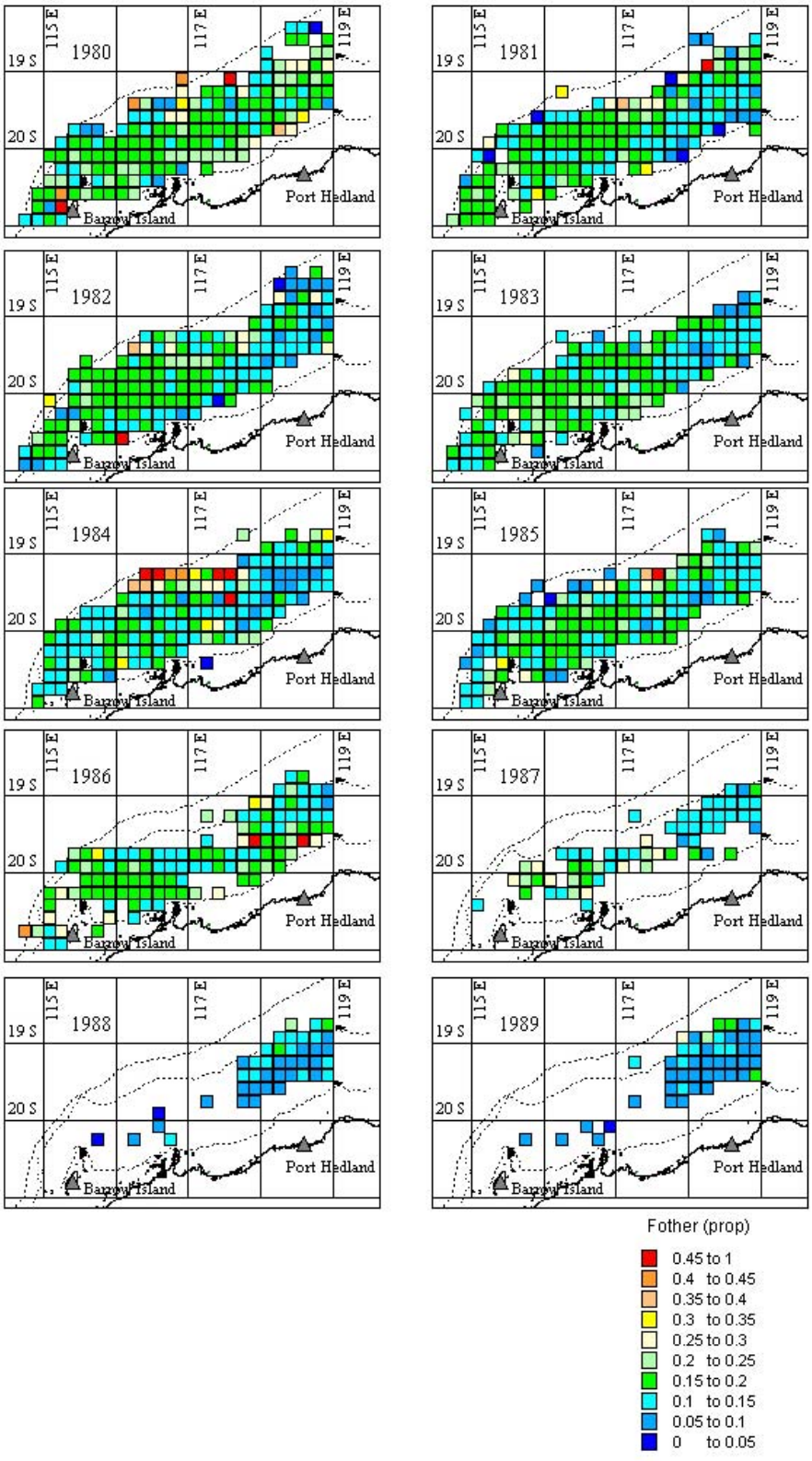

Figure A.22 (b): Proportional catch of other fish (AFMA).

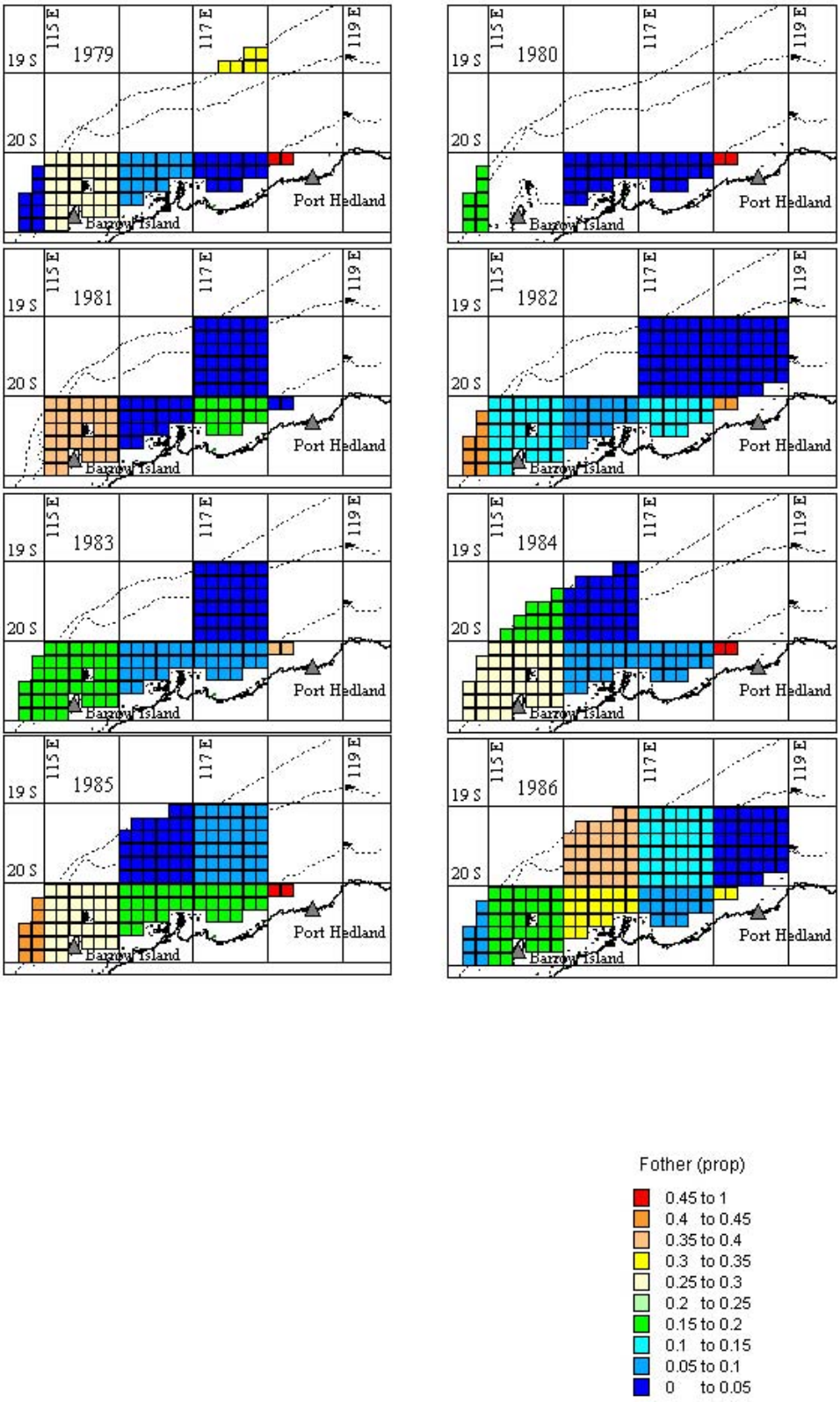

Figure A.22 (c): Proportional catch of other fish (CAES, 1979-1986).

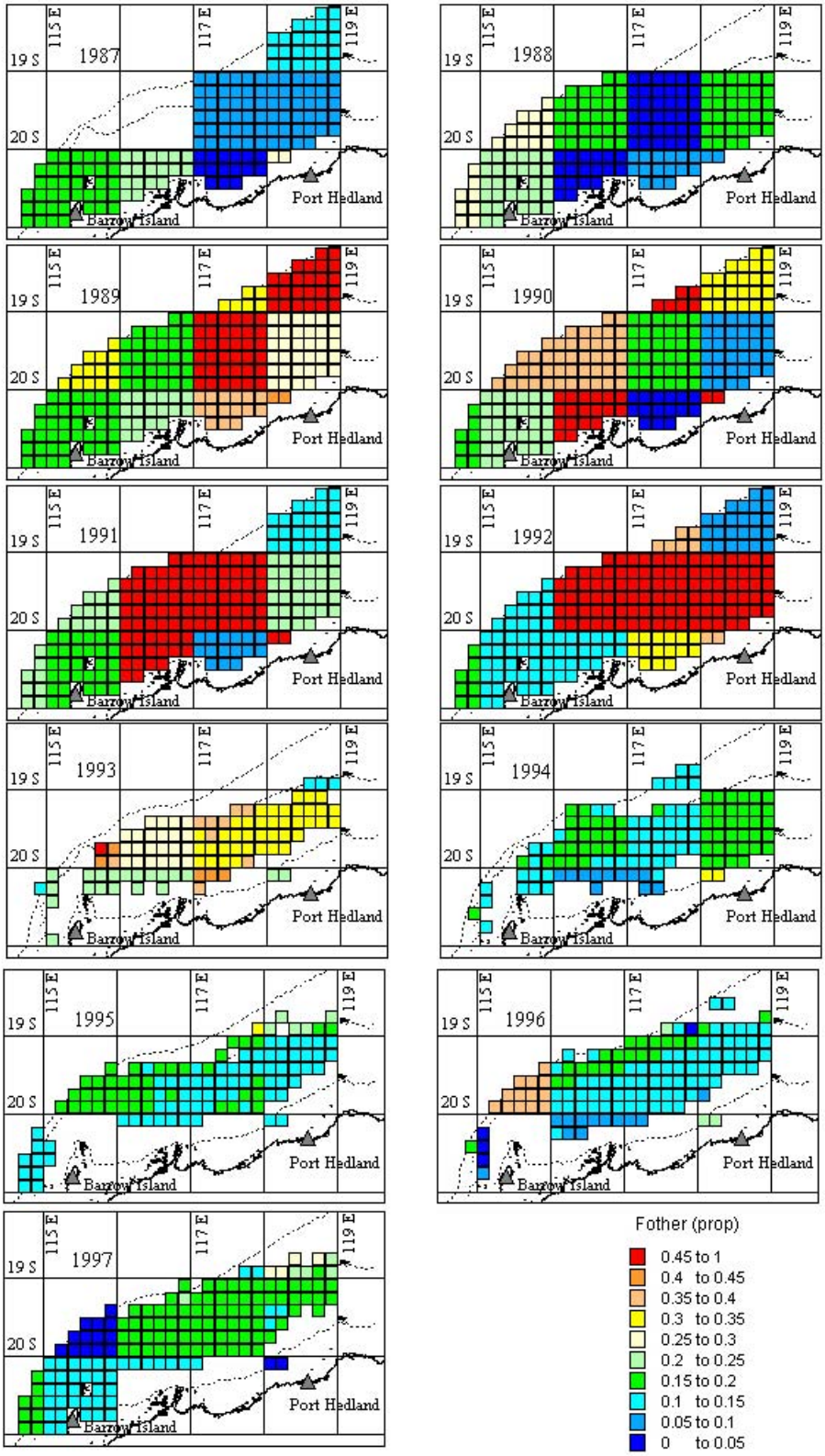

Figure A.22 (d): Proportional catch of other fish (CAES, 1987-1997).

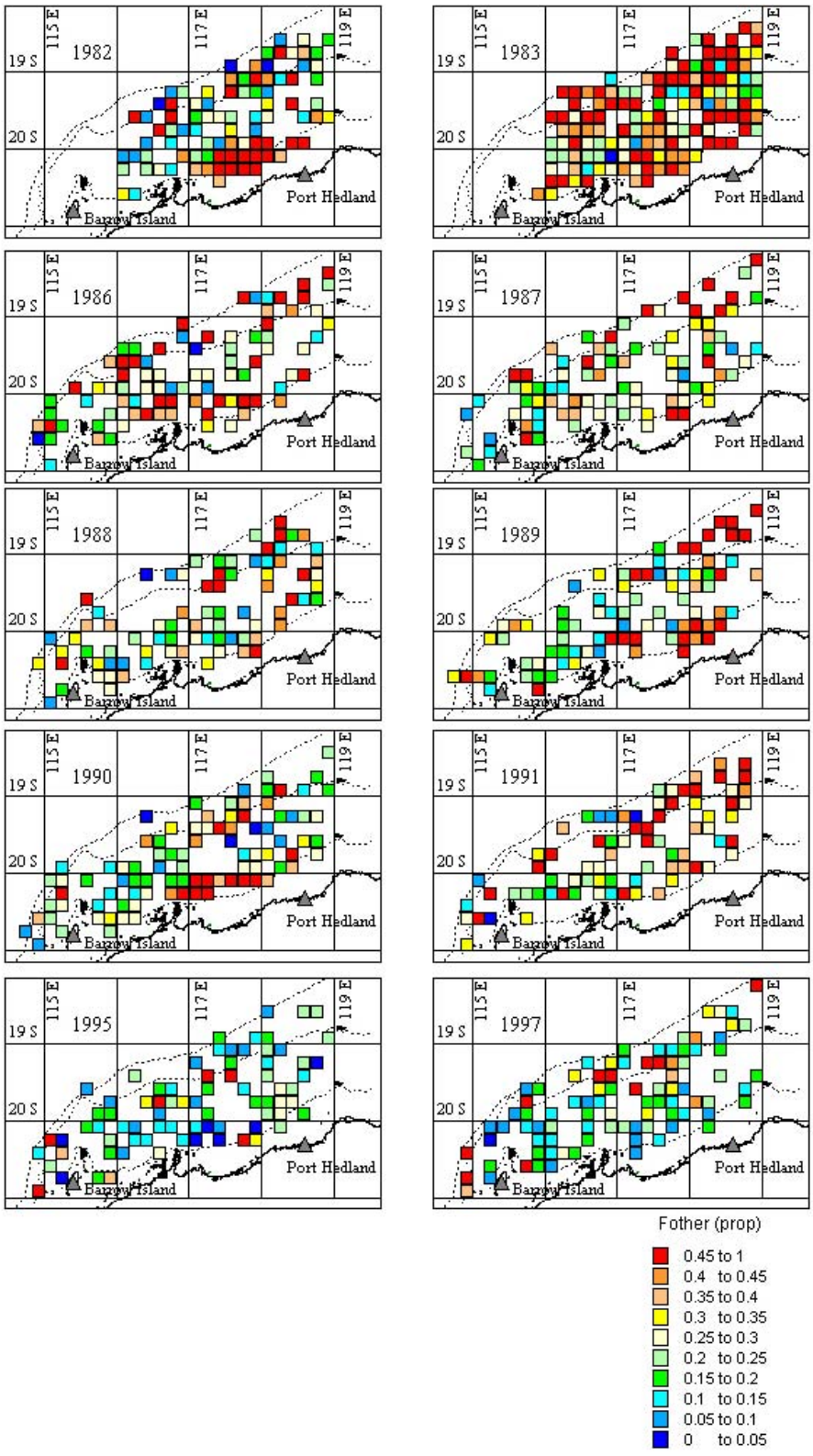

Figure A.22 (e): Proportional catch of other fish (CSIRO surveys).

ACKNOWLEDGMENTS

The following people and agencies have contributed significantly to the Study through the provision of technical expertise and advice, and historical data and information. The Study partners gratefully acknowledge their contribution.

Western Australian State agencies
Department of Environment and Conservation (Department of Conservation and Land Management and Department of Environment)
Department of Fisheries
Department of Industry and Resources (Department of Mineral and Petroleum Resources)
Department of Land Information
Department for Planning and Infrastructure (Department of Transport)
Pilbara Tourism Association
Shire of Roebourne
Town of Port Hedland
Tourism Western Australia
Western Australian Land Information System
Western Australian Museum

Commonwealth agencies
Australian Institute of Marine Science
Geoscience Australia (formerly Australian Geological Survey Organisation)

Consultants
Cognito Consulting
David Gordon International Risk Consultants
METOCEAN Engineers (formerly Weather News International, Perth)
Oceanica (formerly DA Lord and Associates)

Industries
Australian Petroleum Production Exploration Association (APPEA)
Apache Energy
BHP Petroleum
Chevron Australia
Dampier Salt
Hamersley Iron
Mermaid Marine
Woodside Energy

Individuals
Clay Bryce
Graham Cobby
Nick D'Adamo
Mike Forde
David Gordon
Andrew Heyward
Barry Hutchins
Bryan Jenkins
Di Jones

Ian LeProvost
Ray Masini
Mike Moran
Steve Newman
Eric Paling
Kelly Pendoley
Bob Prinz
Chris Simpson
Shirley Slack-Smith
Di Walker

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Helen Webb – Editorial consultant/Project Manager

Front cover photos courtesy of:
Centre – Coral reef ecosystem, WA Museum, Clay Bryce
Aquaculture pearls, Department of Fisheries WA
Recreational fishing, Department of Fisheries WA, Jirri Lockman
Offshore petroleum platform, Woodside Energy Ltd
Commercial Fishing, Department of Fisheries WA
Tourism, CSIRO
Coastal development aerial photos, Hamersley Iron Pty Ltd