

# The implications of ecosystem dynamics for fisheries management: A case study of selected fisheries in the Gulf of Paria, Trinidad

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## Abstract

It is accepted that if fisheries resources are to remain renewable and able to sustain livelihoods, appropriate management practices must be implemented. Even while fisheries management grapples to resolve single-species issues, the biological and economic interactions among species mandate that to be effective, management techniques must be based on more interactive and aggregate-level analyses. In order to implement these techniques, the actual links, and the potential impact of these links, among the fisheries must be established. Vector autoregression (VAR) analysis has the potential to play an increasingly important role in ecosystem modelling for fisheries management. This study uses VAR analysis to demonstrate the quantitative impact of certain ecosystem changes on the productivity of the carite, honey shrimp and croaker fisheries of the Gulf of Paria, Trinidad, in the particular context of the ecosystem dynamics of trophic linkages, bycatch and multispecies fisheries. Four VAR models are constructed to investigate the extent to which these factors affect the production of the selected fisheries, and to evaluate the management implications of these linkages. The empirical analysis is further evidence that, if sustainable management of fishery resources is to be achieved, management practices based on more multi-species, ecosystem approaches must replace the traditional, single-species management techniques.

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## 1. Introduction

For many small islands the marine environment can be the most important economic resource (Bass, 1993). It is commonly accepted that the marine resources available to island states can, if properly utilised, significantly contribute to the sustainable development of the region (Dolman, 1990). The small-scale artisanal fishery sector in particular plays a critical socio-economic role (Dolman, 1990; Food and Agricultural Organization, 1999). To island states in particular, therefore, proper management of the marine fishery resources is essential.

Fisheries management objectives are multiple in nature and may be characterised by internal conflict (Mardle et al., 2002). There are many alternative management techniques designed to achieve the stated objectives (McAllister et al., 1999). Current trends of declining fishery resources and habitat degradation indicate, however, that current management techniques, either in conceptualisation or implementation, are failing to sustainably manage the resources. During the past 50 years, the dominant fisheries management paradigm has been to focus on a target species at a time (FAO, 2003). Failure has been linked to the fact that these management practices tend to reduce fisheries into their component parts, with stocks assessed on a species by species basis (Roberts, 1997; Tegner et al., 1999; FAO, 2003). It is now accepted that the complexity of fisheries requires sophisticated management processes (Cochrane, 1999; Gislason et al., 2000). Even as fisheries management struggles to resolve single-species

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issues, it is increasingly being called upon to take a multispecies and ecosystem perspective (Caddy and Cochrane, 2001; FAO, 2003).

The biological interactions among species require management techniques based on more aggregate-level analyses. Traditional fishery management models have, however, regarded exploited populations in isolation from their surrounding environment and have largely ignored species interactions (Goni, 1998). Because the ecosystem dynamics of species interactions are not accounted for, these models are not equipped to effectively manage the resources (Roberts, 1997; Bax, 1998; Arnason, 2000; Caddy and Cochrane, 2001; Manickchand-Heileman et al., 2004; Heymans et al., 2004).

Fisheries management objectives often assume that fishing mortality is the only factor that contributes to variation in species survival rates (Bax, 1998; Goni, 1998). Complex and numerous species interactions through the dynamics of predation and competition can cascade through entire ecosystems via direct and indirect ecosystem effects (Bax, 1998; Shannon et al., 2003). Losses to predation can sometimes exceed losses to fisheries (Bax, 1998). Yet the world's fisheries continue to remove large amounts of catch with little or no consideration of what may be the consequences of excessive removal of a predator or prey on the trophic structure (Parsons, 1992; Bax, 1998).

The incidental harvesting of unwanted, untargeted species or age classes is an issue that poses sustained challenges to fishery management and remains firmly on the fisheries and conservation agendas (Boyce, 1996; Bache, 2003). While bycatch may be of other fish species, it can sometimes include taxa very different from targeted harvests such as birds and mammals (Norman, 2000). Bycatch can also often change the trophic structure of entire ecosystems with the encouragement of scavengers (Gislason et al., 2000; FAO, 2003). Shrimp trawl fisheries in particular warrant particular attention, where the shrimp-catch is, in most cases, outweighed by the weight of the fish-dominated bycatch (Stratoudakis et al., 2001; Stobutzki et al., 2003).

The nature of the marine environment and the inherent non-selectivity of fishing gear imply that it is hardly practical or profitable to target a single species at any one time. Multispecies fisheries and their ecosystem effects are one of the most prevalent problems in fisheries, with the incorporation of multispecies dynamics into resource management being increasingly investigated and implemented (Squires et al., 1995; Walters et al., 1997; Cochrane, 1999; Arnason, 2000; Le Pape and Vigneau, 2001). A path of conservative management can often be the prescription for fisheries that consciously and simultaneously harvest, by the same gear, different species that are characterized by different points on the over-exploitation scale (Dedah et al., 1999).

In order to implement ecosystem management approaches that can effectively deal with the challenges posed

by more holistic analysis, the interlinkages between the various ecosystem components and the potential impacts of these linkages must be established. This paper seeks to empirically demonstrate the ecosystem interactions of trophic linkages, bycatch and multispecies fisheries among the carite, croaker and honey-shrimp fisheries of the Gulf of Paria, Trinidad, and to evaluate the implications of these interactions for their future effective management.

## 2. The Gulf of Paria, Trinidad

The island of Trinidad is the most southerly of the Caribbean island chain. It lies just off the coast of Venezuela and is part of a twin island state known as Trinidad and Tobago. The west coast of Trinidad borders the waters of the Gulf of Paria, a shared body of water on the northeastern continental shelf of South America, between eastern Venezuela and the west coast of Trinidad, covering an area of 7600 km<sup>2</sup> (Manickchand-Heileman et al., 2004). The Gulf of Paria coastline is the most utilised coastal zone of the island of Trinidad and one of the most industrialised areas in the region. More than 90% of the country's 1.2 million population resides and works along the west coast and in the watershed areas draining into the Gulf of Paria (FAO, 1998) Fig. 1.

The Gulf of Paria is an enclosed basin with a flat bottom and gentle slopes, and with an average depth of ~20 m. Because of the island's proximity to the South American continent, the Gulf has often been defined as part of the greater Orinoco region of Venezuela (Boodoosingh, 1992). The Orinoco is among the world's largest rivers and drains an area of approximately  $9 \times 10^5$  km<sup>2</sup> in Colombia and Venezuela. Prevailing winds and currents result in the movement of outflow of the Orinoco directly into the Gulf of Paria. These nutrient rich and sediment laden waters contribute considerably to the high productivity to be found within the Gulf. The Gulf of Paria is presently the most active fishing area around the island of Trinidad (Boodoosingh, 1992).

Biologically, the marine fisheries of Trinidad and Tobago can be broadly categorised into pelagic and demersal. The most important pelagic fishes are the carite, kingfish, cavalli and sharks, while the more important demersal stocks are the penaeid shrimp, croaker, sharks, snapper and salmon (Boodoosingh, 1992). The industry has traditionally been an inshore and artisanal one, and remains largely unmanaged (Manickchand-Heileman et al., 2004).

"Carite" is the local name for the Spanish mackerel *Scomberomorus brasiliensis*. In terms of weight it is the most commercially important species in Trinidad (Fisheries Division, 1993a). The carite can live up to 9 years (Fishbase, 2004) and are coastal inhabitants. The carite has been found to spawn throughout the year with periods of peak spawning activity from October to April in the Gulf of Paria, from May to September on the Guyana shelf and from July to September off northeastern Brazil.

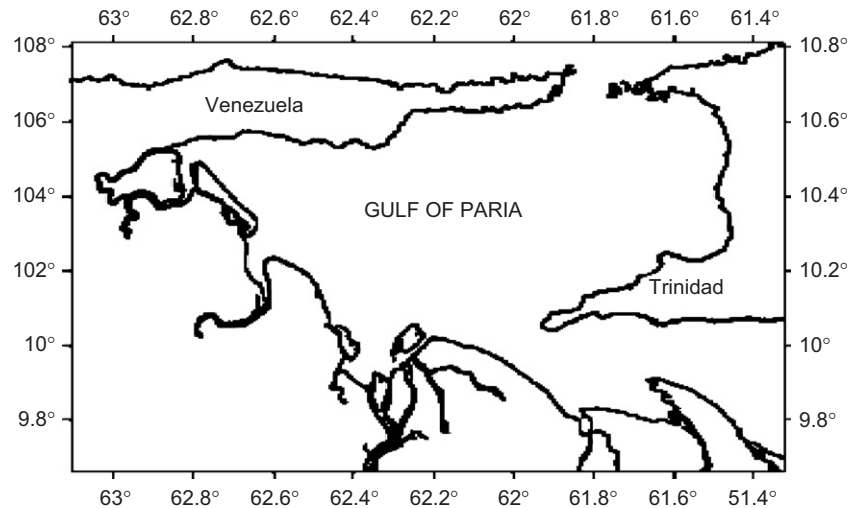


Fig. 1. Map of the Gulf of Paria (Manickchand-Heileman et al., 2004).

The carite generally feeds on fishes, and to some extent on penaeid shrimps and squid. In Trinidad the carite is caught in the Gulf of Paria by a variety of gear types of which gillnets and lines are the most common (Fisheries Division, 1993a). A preliminary assessment of the carite fishery of Trinidad conducted in 1991 indicated that the fishery was heavily exploited (Fisheries Division, 1993b).

“Croaker” or “Cro Cro” is the local name for a popular groundfish *Micropogonias furnieri*. The whitemouth croaker has an average maximum age of 7 years with a maximum size of 60 cm (Fishbase, 2004). Greatest spawning activity occurs from February to August. The croaker is found in muddy and sandy bottoms in coastal waters and in estuaries where the nursery and feeding grounds are located. Its feeding habits vary with its developmental stage and season; juveniles feed on benthic migratory crustaceans while adults are benthos feeders and occasionally capture fish (Fishbase, 2004). It is an inshore fishery, with most fishing is done in depths between 9–14 m. Croaker are fished by the gillnet fishery in the Gulf of Paria, whose main target species is the carite.

“Honey Shrimp” is the local name for one type of penaeid shrimp. *Xiphopenaeus kroyeri*. The honey shrimp lives in coastal water, remaining inshore in fairly shallow waters. They are bottom-dwellers (benthic), preferring sandy/muddy substrates rich in organic matter such as river mouths and mangrove areas. They are usually filter feeders, feeding mainly on decomposing plant and animal matter. Penaeids are fast-growing animals with an extremely short lifespan of ~2 years. The major spawning period is from April to November. Honey shrimp are harvested by the artisanal trawlers in the Gulf of Paria.

The challenges posed for single-species management approaches in terms of the ecosystem dynamics of trophic linkages, bycatch and multispecies fisheries can be illustrated via these three fisheries of the Gulf of Paria. A trophic link exists between the carite and honey shrimp, with shrimp constituting one of the species upon which the

carite preys. Shrimp trawling is notorious for the bycatch it produces, and the croaker is a well known and prominent bycatch of the shrimp trawl fishery (FAO Fisheries Report, 2001). The carite and croaker fisheries are both harvested by the same gear of gillnets.

### 3. Methodology: vector autoregressive (VAR) modelling

The goal of VAR analysis is to determine interrelationships among variables (Enders, 2004). VAR models are useful for policymaking, forecasting and causality analysis (Watson et al., 2002). They allow for interdependence among a set of endogenous variables, and as such have the potential to play an increasingly important role in ecosystem modelling for fisheries management. VAR models have been previously applied to fisheries interactions, analysis and forecasting (Stergiou, 1991; Stergiou et al., 1997; Dalton, 2001). However, VAR analysis is not yet a widespread tool for fisheries researchers.

VAR modelling involves the regression of a set of endogenous variables against their own values in each of the  $n$  preceding periods, against the values in each of the  $n$  preceding periods of all other variables included in the model, and against a constant term and exogenous variables.

The parameterisation of a VAR revolves around three elements:

- the inclusion of  $n$  endogenous variables (and hence  $n$  equations);
- the inclusion of  $p$  lags;
- the inclusion of purely ‘exogenous’ elements (such as constant terms, deterministic trends and dummy variables).

Once the endogenous variables are selected, the construction of the VAR is made on the basis of tests for lag lengths and tests for exogenous elements. Appropriate lag length

selection is critical—lag lengths that are too long will result in the waste of valuable degrees of freedom, while lag lengths that are too short will result in a misspecified model (Enders, 2004). Two criteria are used to determine the appropriate lag length: the likelihood ratio test and the AIC/SBC criteria (where the model with the lower AIC/SBC value is chosen).<sup>1</sup> A general-to-specific methodology is adopted, where longer lag lengths are moved to shorter ones on the basis of these tests.

Likelihood ratio tests are also used in the determination of the exogenous variables to be included in the VAR models. Seasonal dummies in particular are initially hypothesised in all models, due to the seasonal nature inherent in fisheries analysis. Their validity is examined in the context of likelihood ratio statistics constructed around comparisons of both restricted and unrestricted models.

Due to the presence of contemporaneous variables in each equation which causes simultaneous bias in the parameter estimates, a priori restrictions must be imposed on the systems before evaluation of the VAR models can take place. This is done via the well-known *Choleski Decomposition*. This can be an arbitrary restriction that nonetheless transforms the system into a recursive one. Such restrictions impose a causal chain among the variables. For this analysis the Choleski decomposition will follow the hypothesised causal link among the endogenous fisheries variables.<sup>2</sup>

The coefficient values estimated in a VAR model are similar to reduced form coefficients and are therefore without great interest in their own right and impossible to interpret from an economic point of view. Evaluation is traditionally done through an analysis of *impulse response functions* and *forecast error variance decompositions* which together make up what is termed *innovations accounting* (Watson et al., 2002; Enders, 2004). An impulse response function traces the response of an endogenous variable to a change in one of the innovations. The variance decomposition of a VAR gives information about the relative importance of each of the random innovations in the explanation of each variable in the system.

### 3.1. Var models: results and discussion

Four VAR systems are estimated in this paper, representing the three ecosystem dynamics issues of trophic linkages, bycatch and multispecies considerations as well as one aggregated system including all three fisheries variables. Monthly landings data for the carite, croaker and honey-shrimp fisheries for the period January

1995–December 2002 were obtained from the Marine Fisheries Analytical Unit of the Fisheries Division, Ministry of Land, Agriculture and Marine Resources, Trinidad and Tobago. For the carite and croaker, this data was provided for the entire island, whereas landings and effort for the honey shrimp were obtained for the Gulf of Paria. However, because the Gulf of Paria is the most fished coastal region of the island, it is assumed that the majority of landings came from the Gulf and so it is used as a proxy. Missing data points were filled via a process of moving averages.

The data analysis was performed using WinRATS and EViews. All three variables were first verified for stationarity using Augmented Dickey–Fuller unit root tests. Lag lengths were determined (see Appendix 1) and dummy variables tested (see Appendix 2). Choleski decompositions were imposed that follow the causal chain among the variables. Evaluations were conducted through an analysis of the impulse response functions<sup>3</sup> and variance decompositions. Appendix 3 gives the VAR systems that were estimated in each of the four cases.

### 3.2. Trophic VAR model results: the carite and honey-shrimp fisheries

The carite and honey-shrimp species interactions illustrate trophic linkages due to the nature of their predator/prey relationship. As the carite feeds on the honey shrimp, one would expect that if carite landings increase, the honey shrimp population and therefore its harvest, will also increase as its major predator is undergoing greater removal via harvesting. Given the variation in life cycles of these two species, it would be expected that this effect would be felt with a periodic lag.

Testing procedures revealed that the most appropriate lag length for this system is 2 (see Appendix 1). The dummy variables were also determined to be significant and are included in the VAR specification (see Appendix 2). The Choleski decomposition that was imposed set the current honey shrimp landings to zero, that is, the most appropriate causal chain is assumed to be:

Carite landings → Honey shrimp landings

Fig. 2 illustrates the effects on carite and honey shrimp landings of a shock to the carite landings innovation. The graphs indicate the response of first carite landings and then honey-shrimp landings to a one standard deviation shock. The first graph indicates that, as expected, carite landings immediately increase. This increase continues but at a decreasing rate, with the fishery eventually returning to equilibrium in period 24. The second graph indicates that, as carite landings are increased, honey shrimp landings first fall, and then sharply increase. These increases continue, though at a decreasing rate after period 6. There is a return to equilibrium in period 24. The initial decrease in

<sup>1</sup>There may be cases where the two criteria selected to choose lag lengths yield conflicting results. In cases such as this the LR statistic will be used because it is a stronger criteria. There may also be instances where the AIC and SBC give conflicting results. In this case, the SBC will be chosen because it is more conservative with respect to degrees of freedom reducing the chance that the VAR may be overparametrized.

<sup>2</sup>For a detailed mathematical explanation of the Choleski Decomposition, the interested reader is referred to Enders (2004).

<sup>3</sup>The impulse response functions can be interpreted as growth rates relative to time period.



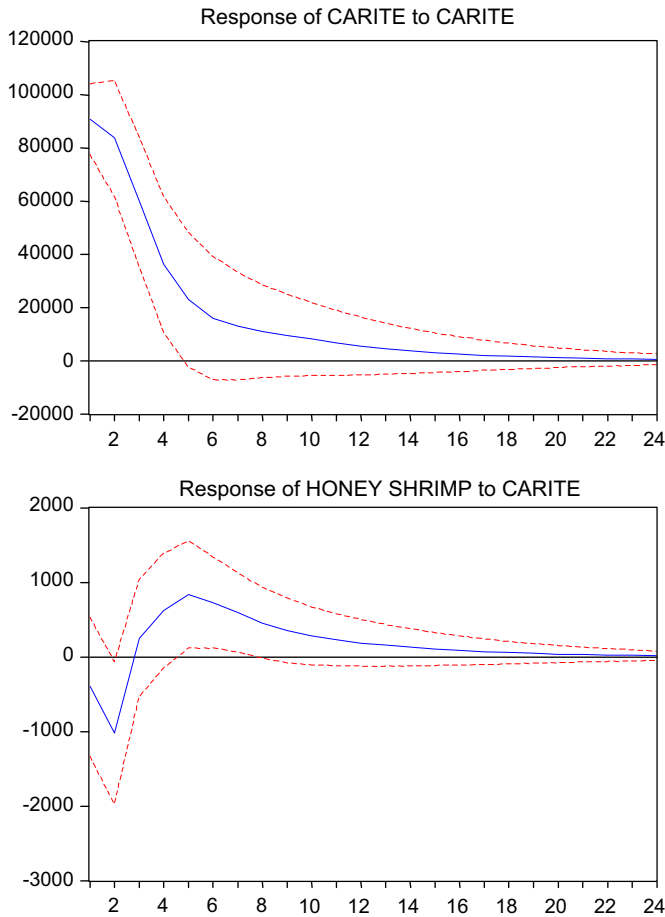


Fig. 2. Impulse Responses of a Shock to the Carite Landings Innovation.

honey-shrimp landings is feasibly indicative of the dynamic interplay of the two species, where it can be hypothesised that a rise in carite landings decreases the predator threat to the honey-shrimp fishery, which is then (after a lag) able to sustain greater population levels and by extension harvest levels.

Table 1 gives the variance decompositions of both the carite and honey-shrimp fisheries over 24 time periods. Note that in the first time period, the carite accounts for 100% of its change. This is due to the imposition of the Choleski decomposition that sets current honey shrimp landings in the carite landings equation to 0 (see Appendix A). Honey shrimp landings begin to affect carite landings in time period 2, but to a very small degree. The effects of honey shrimp landings on carite landings begin to increase across the time periods, where a seeming equilibrium of 4.7% is reached at period 13 and maintained until period 24. Turning now to the variance decomposition of the honey shrimp fishery, we can see that, while carite landings affect honey shrimp landings by only 0.7% in period 1, there is a considerable increase to 5% in period 2. There is then a steady increase to period 12, where an approximate level of 13% seems to be maintained to the end of period 24.

These results are in keeping with the relative impacts of each species on the other in terms of trophic interactions,

Table 1

Variance decompositions of carite and honey shrimp landings

Period	SE	Carite	Honey shrimp
Carite landings			
1	90850.48	100	0
2	123520.9	99.9243	0.075703
3	137727.9	99.25109	0.748912
4	143163.7	98.26093	1.739072
5	145831.1	97.17166	2.82834
6	147297	96.43493	3.565073
7	148244.5	95.97089	4.029108
8	148885.6	95.70036	4.299643
9	149334.8	95.53537	4.464632
10	149645.6	95.43103	4.568975
11	149857.9	95.36186	4.638144
12	150001	95.31515	4.684849
13	150096.9	95.28338	4.716615
14	150161.1	95.26186	4.738144
••	••	••	••
24	150290.2	95.21834	4.781658
Honey shrimp landings			
1	4536.385	0.764442	99.23556
2	4835.971	5.118921	94.88108
3	5027.623	4.991892	95.00811
4	5090.61	6.357292	93.64271
5	5180.362	8.773611	91.22639
6	5241.551	10.51848	89.48152
7	5284.771	11.62864	88.37136
8	5310.989	12.2523	87.7477
9	5327.897	12.62111	87.37889
10	5338.741	12.84926	87.15074
11	5345.976	12.99954	87.00046
12	5350.831	13.10109	86.89891
13	5354.121	13.17044	86.82956
14	5356.344	13.21759	86.78241
••	••	••	••
24	5360.848	13.31309	86.68691

and also lend evidence to the a priori Choleski decomposition which, in this case, assumes the direction of causality to be from carite to honey shrimp. Shrimp is a part of the carite diet, and so it can be expected that as shrimp landings increase, carite landings may fall due to the lower availability of the food source. However, shrimp is not the only element of the carite diet and, given the reputation of this species as a voracious feeder, it is reasonable to hypothesise that as the availability of shrimp decreases, the carite will be able to compensate with other food sources. Hence the relative effect of shrimp landings on carite landings only reaches 4.7%. This is not the case with an analysis of shrimp landings. While carite landings initially have a small effect, there are then jumps from period to period, until a high of 13% is reached. This indicates that, while shrimp removal may not play a large part in the survival of the carite, carite removal definitely plays an increasing role in the honey shrimp species viability. As more carite is landed, this analysis seems to indicate that this lowers the trophic pressure on the shrimp species, thereby allowing the species, in time, to regenerate to higher population levels which will then be reflected in higher levels of catches.

### 3.3. Bycatch VAR model results: the croaker and honey-shrimp fisheries

The croaker and honey-shrimp species interactions can indicate bycatch effects, given that croaker is a significant bycatch of the shrimp trawl fishery. This type of relationship would suggest that if there is an increase in the honey shrimp landings then croaker landings would fall, as a result of the increased mortality imposed upon croaker as a bycatch and so a reduction in the amount of croaker harvestable by man.

Testing procedures revealed that the most appropriate lag length for this VAR structure is 15. The dummy variables were determined to be significant and so are included in the VAR specification. The chosen Choleski decomposition sets current croaker landings in the first equation to zero. This was chosen due to the nature of the relationship between both fisheries. The croaker is a bycatch of the honey shrimp, and so it is assumed that while it is affected by the honey-shrimp, it does not itself significantly affect the honey-shrimp. This decomposition therefore aims to propose that the causal chain is:

Honey shrimp landings → Croaker landings

Fig. 3 illustrates the responses of the honey shrimp and croaker fisheries to a shock in the honey shrimp landings

innovation. The first graph indicates that a shock to the honey shrimp landings innovation causes honey shrimp landings to initially increase. This increase continues but at a decreasing rate, beginning to approach equilibrium from period 16. The shock to the honey shrimp landings innovation causes the croaker landings to initially decrease. It then increases but at fluctuating rates for the rest of the sample period. There may be an indication of equilibrium at period 22.

Table 2  
Variance decompositions of honey shrimp landings and croaker landings

Period	SE	Honey shrimp	Croaker
Honey shrimp landings			
1	3857.25	100	0
2	4022.014	99.9973	0.002701
3	4356.989	98.67531	1.324695
4	4659.195	95.11304	4.886957
5	4752.23	92.05268	7.947317
6	4823.861	91.35935	8.64065
7	4922.94	90.37767	9.622331
8	4997.949	88.14341	11.85659
9	5009.52	87.85222	12.14778
10	5062.992	86.01837	13.98163
11	5071.512	85.99288	14.00712
12	5077.674	85.78601	14.21399
13	5085.328	85.81616	14.18384
14	5170.92	84.52386	15.47614
15	5217.3	84.51913	15.48087
16	5230.073	84.17725	15.82275
17	5231.817	84.14651	15.85349
18	5248.953	83.69145	16.30855
19	5252.83	83.60627	16.39373
20	5259.859	83.61271	16.38729
21	5275.09	83.27193	16.72807
22	5306.98	82.63942	17.36058
23	5316.829	82.33775	17.66225
24	5323.739	82.15852	17.84148
Croaker landings			
1	10388.92	0.930542	99.06946
2	12272.06	1.218962	98.78104
3	12505.05	1.568456	98.43154
4	12942.3	2.437454	97.56255
5	13203.93	4.557819	95.44218
6	13985.62	14.80297	85.19703
7	14917.17	20.95982	79.04018
8	15132.81	20.82063	79.17937
9	15168	20.7702	79.2298
10	15331.42	22.36028	77.63972
11	15342.01	22.4511	77.5489
12	15735.79	25.82515	74.17485
13	15945.83	25.32985	74.67015
14	16144.96	25.25179	74.74821
15	16545.43	27.78477	72.21523
16	16800.04	29.74072	70.25928
17	16950.73	30.74029	69.25971
18	17583.54	34.29223	65.70777
19	18369.98	39.36451	60.63549
20	19047.54	42.70147	57.29853
21	19330.69	43.75712	56.24288
22	19348.95	43.80932	56.19068
23	19428.18	44.11896	55.88104
24	19500.52	44.47175	55.52825

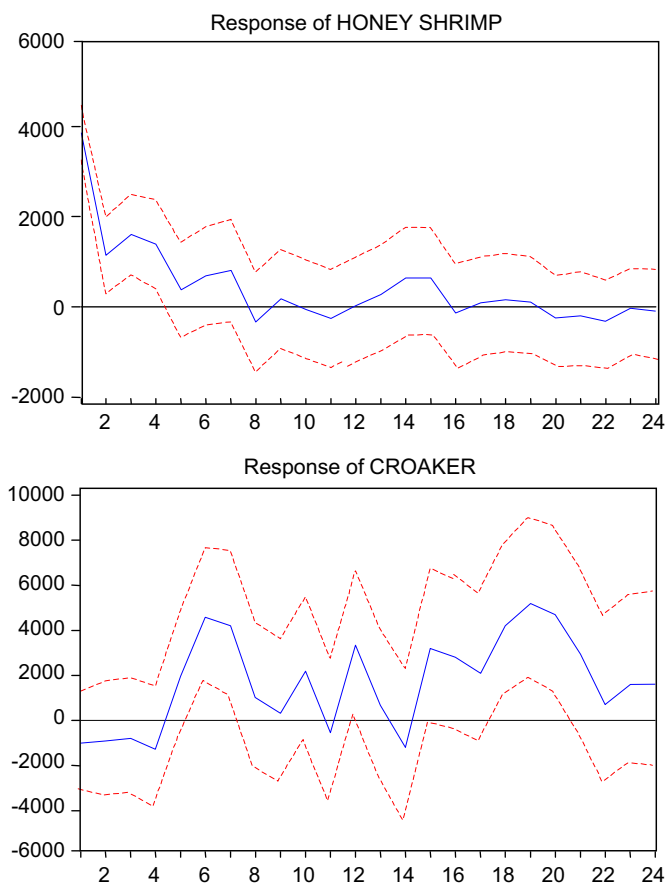


Fig. 3. Impulse Responses of a Shock to the Honey Shrimp Landings Innovation.

Table 2 gives the variance decompositions for both species. Croaker seems to have an increasing impact on honey shrimp from one period to the next, eventually settling at  $\sim 17\%$ . However, an analysis of the variance decomposition for the croaker landings variable is much more startling. Beginning with a relatively small contribution of 0.9%, honey shrimp landings have impacts of increasing magnitudes on the croaker landings variable. Time periods are characterised by jumps in these increases, by a magnitude of as much as 10% from period 5 to period 6. By period 24, the honey shrimp landings are accounting for up to 44% of the croaker landings. These numbers not only lend credence to the a priori Choleski decomposition and the assumed direction of causality, but also indicate just how intimately these two fisheries are linked through the severe bycatch implications which characterise the shrimp trawl fishery.

### 3.4. Multispecies VAR model results: the carite and croaker fisheries

Because both the carite and croaker fisheries are harvested by the gillnet fishery, a joint analysis can bring to the fore the issue of multispecies fisheries. While croaker is of importance as a food fish, the carite is the species that is of greater commercial value. It is therefore assumed (and borne out by the data) that in any gillnet catch, the proportion of carite will far surpass that of the croaker landings. If we expect that there is some fixed capacity of the gillnet as a method of harvesting, this implies that a negative relationship should be expected between the carite and the croaker. An increase in carite landings should be accompanied by a fall in croaker landings, as the method of harvesting is taken to capacity.

Appropriate testing revealed that the lag length for this system is 2. The dummy variables were also found to be significant and so are included in the VAR specification. The chosen Choleski decomposition sets current croaker landings to zero. This decomposition aims to propose that, due to the commercial importance of carite, the causal chain is:

Carite landings  $\rightarrow$  Croaker landings

Fig. 4 illustrates the impulse responses of the carite and croaker landings variables to a shock in the carite landings innovation. As expected, this shock causes carite landings to increase, but at a decreasing rate until equilibrium is clearly reached at period 16. Croaker landings, however, fall steadily until equilibrium at period 16. The two opposing effects on these two variables, and the arrival at equilibrium at the same point in time, justify the initial hypothesis that, due to a limited gear capacity, increases in the landings of one will invariably imply decreases in the landings of the other.

The variance decompositions of the two landings variables as shown in Table 3 indicate that, while the effects on each other are indeed small, the carite landings play a relatively larger role (3%) in the croaker landings

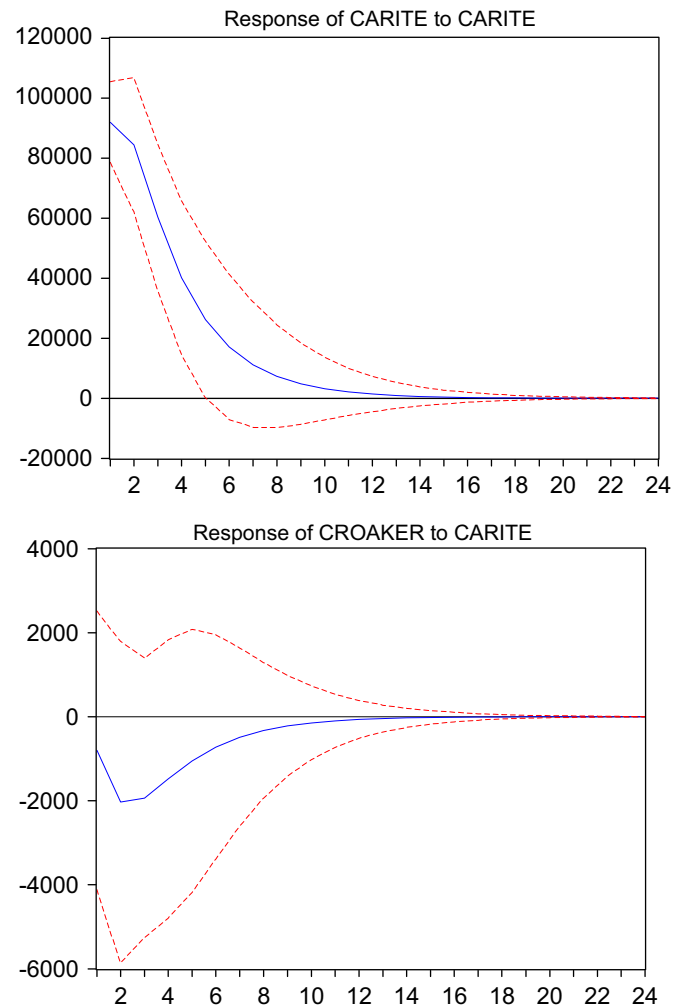


Fig. 4. Impulse Responses of a Shock to the Carite Landings Innovation.

than the croaker landings do in the carite landings (1%). This verifies the initial a priori direction of causality as imposed by the Choleski decomposition.

### 3.5. Aggregate VAR model results: the interactions among the carite, croaker and honey-shrimp fisheries

The above analyses were used to construct  $2 \times 2$  models of these three fisheries of the Gulf of Paria. However in reality, all species co-exist in time and space and trade-offs will invariably exist between the variables that interplay to keep ecosystems in a state of moving equilibrium. The three issues of trophic interactions, bycatch and multispecies fisheries were therefore combined into a single, aggregate VAR model. The appropriate series of tests revealed that the most appropriate lag length for this system is 2. The dummy variables were found to be significant and were therefore included in the specification. The chosen Choleski decomposition sets current honey shrimp and croaker landings to zero. This ordering was seen to be the most appropriate one based both on the relative commercial importance of these species as well as

Table 3  
Variance decompositions of carite landings and croaker landings

Period	SE	Carite	Croaker
Carite landings			
1	92017.66	100	0
2	124970.5	99.89531	0.104691
3	138774.3	99.88701	0.112987
4	144620.1	99.68355	0.316445
5	147180.7	99.42268	0.577317
6	148328.8	99.21741	0.782585
7	148848.2	99.08814	0.911857
8	149083.1	99.0162	0.983797
9	149188.8	98.97908	1.020917
10	149236.2	98.96085	1.039154
11	149257.4	98.95218	1.047823
12	149266.8	98.94815	1.051852
13	149271	98.94631	1.053694
••	••	••	••
24	149274.2	98.9448	1.055198
Croaker landings			
1	16083.15	0.246615	99.75338
2	18828.78	1.346797	98.6532
3	19597.31	2.219139	97.78086
4	19846.1	2.720565	97.27944
5	19935.26	2.973751	97.02625
6	19969.35	3.094396	96.9056
7	19982.95	3.150228	96.84977
8	19988.53	3.175634	96.82437
9	19990.86	3.187072	96.81293
10	19991.84	3.192183	96.80782
11	19992.27	3.194456	96.80554
12	19992.45	3.195463	96.80454
13	19992.53	3.195907	96.80409
••	••	••	••
24	19992.59	3.196257	96.80374

the results of the models analysed above. This decomposition therefore proposes that the causal chain is:

Carite landings → Honey-Shrimp landings → Croaker landings

Fig. 5. above illustrates the impulse responses of the three landings variables as a result of shocks to the carite, honey-shrimp and croaker innovations, respectively. The three graphs along the main diagonal of this illustration demonstrate the response of each variable to a shock in its own innovation. These results are clearly predictable—each one experiences increases but at decreasing rates until equilibrium is once more restored.

The graphs on the off diagonal positions of Fig. 5. demonstrate the interactions that were previously analysed in a  $2 \times 2$  manner with the earlier VAR models. In response to a shock to the carite landings innovation, honey shrimp initially falls but then increases, and continues to increase at a decreasing rate until equilibrium is restored. This can be accounted for by a lagged response to the lowering of the predator levels, as the eventual regeneration of the honey shrimp population to higher levels of equilibrium are, in time, reflected in increasing harvests. This innovations shock also causes croaker landings to face decreasing levels, due to the limited capacity of the common gear.

The second column of Fig. 5. indicates the responses to a shock in the honey-shrimp landings innovation. First we consider the response of the carite landings variable. After an initial fall, there is a strong increase that continues at a decreasing rate until equilibrium is attained. The initial fall

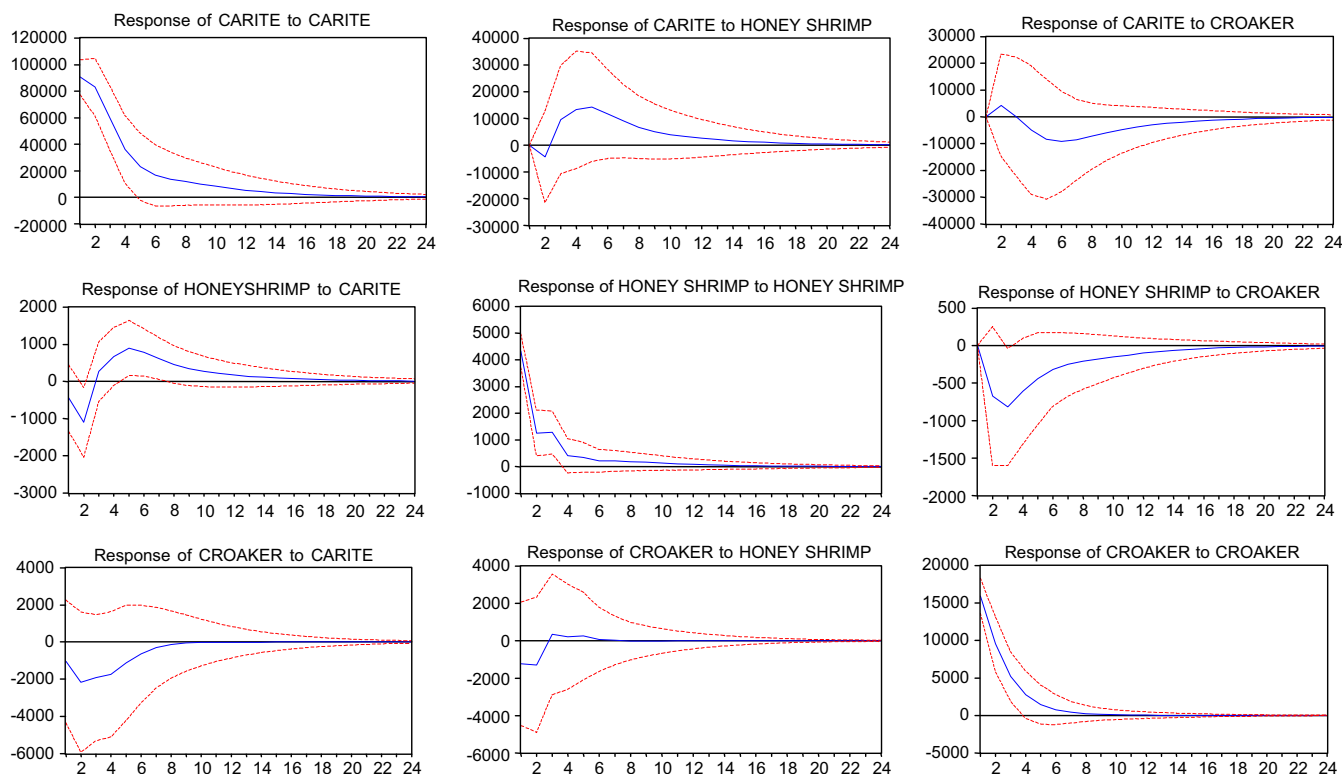


Fig. 5. Impulse Responses of a Shock to the Carite, Honey Shrimp and Croaker Innovations.



can be accounted for by the fact that, as a factor in the carite diet, an increase in honey-shrimp harvests may cause an initial decline in carite population and so carite harvests due to the role that honey shrimp plays in the carite diet. However, as the carite adjusts to other existing food sources, increases are soon experienced which are reflected in increasing harvests. As such, the increase in honey-shrimp harvest plays only a small role in affecting the carite landings for a short time only.

The response of croaker landings to this innovations shock is surprisingly different from that illustrated in Fig. 3. In Fig. 5, we can see a small decrease in croaker landings that immediately returns to equilibrium by period 4. This is at odds with earlier results, and with knowledge of bycatch effects as a whole. It is expected that increases in honey-shrimp landings would have a strong effect on croaker landings, and yet this is not illustrated here.

The third column of Fig. 5 illustrates the response of the variables to a shock in the croaker landings innovation. Croaker landings have not been assumed as a causal variable, either in earlier models or in this current, aggregate model. We see, however, that after an initial increase, carite landings seem to respond negatively to croaker landings. This is explained by the scenario of the common gear with limited capacity—as croaker landings increase, the carite landings must fall due to the competition for space in the gillnet fishery. Honey-shrimp landings also seem to face a strong decrease from the increase in the croaker landings innovation, until period 3 is passed, after which these decreases start approaching equilibrium once more. This is again a surprising result, since earlier models reflected that the direction of causality lies strongly from honey shrimp to croaker due to the bycatch issues associated with shrimp trawling.

Table 4 gives the variance decompositions for all three landings variables. In each fishery, as is expected, the major player is the landings variable itself—94% of the changes to carite, 78% of the honey-shrimp landings and 95% of the croaker landings being explained by the variables themselves. Interestingly, this can lend some justification to management approaches that focus on single species. Of the honey shrimp and croaker variables, honey-shrimp plays a relatively larger role in impacting the carite fishery (3.6%) than does the croaker variable (1.8%). The carite landings impact the honey-shrimp landings by a much greater amount (14.7%) than does the croaker landings variable (6.95%). Finally, croaker landings are affected by the carite landings variable by 3.5%, as opposed to the honey-shrimp landings of 0.84%.

#### 4. Conclusions

By nature of their characteristics, small island economies can pay a heavy price for environmental degradation. The available fisheries resources in particular can provide substantial, indirect, non-economic benefits. Fish provides the basic source of animal protein for many SIDS, and figures

Table 4

Variance decompositions of the carite, honey shrimp and croaker landings

Period	SE	Carite	Honey shrimp	Croaker
Variance decomposition of carite landings				
1	90478.75	100	0	0
2	122913.9	99.74962	0.125105	0.125272
3	136792.1	99.30735	0.591414	0.101234
4	142156.5	98.36829	1.416218	0.215497
5	144955.9	97.13838	2.326529	0.53509
6	146661.1	96.1738	2.91035	0.915848
7	147827.8	95.52279	3.240604	1.236611
8	148630.6	95.12857	3.409823	1.461605
9	149180.1	94.89187	3.501169	1.606963
10	149545.6	94.74728	3.554069	1.698649
11	149783.2	94.65575	3.587356	1.75689
12	149935.5	94.59652	3.609074	1.794407
13	150032.7	94.55785	3.623355	1.818795
14	150094.7	94.53269	3.632644	1.83467
15	150134.3	94.51642	3.638614	1.844965
16	150159.7	94.50597	3.642419	1.851607
17	150176	94.49929	3.644837	1.855873
18	150186.4	94.49502	3.646376	1.858606
••	••	••	••	••
24	150203.7	94.48796	3.64891	1.863126
Variance decomposition of honey-shrimp landings				
1	4360.685	1.061471	98.93853	0
2	4719.377	6.362161	91.60814	2.029698
3	4964.785	6.033372	89.40879	4.557839
4	5063.869	7.553058	86.60703	5.839917
5	5174.109	10.26776	83.41072	6.321523
6	5246.153	12.17559	81.30903	6.515383
7	5293.054	13.32087	80.05082	6.628305
8	5320.301	13.91879	79.36278	6.718422
9	5337.128	14.24586	78.96352	6.790618
10	5347.631	14.43589	78.71938	6.844726
11	5354.415	14.55574	78.56201	6.882251
12	5358.812	14.63413	78.45893	6.906939
••	••	••	••	••
••	••	••	••	••
••	••	••	••	••
••	••	••	••	••
••	••	••	••	••
••	••	••	••	••
••	••	••	••	••
24	5366.76	14.77947	78.27036	6.950163
Variance decomposition of croaker landings				
1	16029.01	0.430038	0.587978	98.98198
2	18821.07	1.624739	0.89325	97.48201
3	19626.68	2.453571	0.851785	96.69464
4	19899.66	3.15462	0.840174	96.00521
5	19985.21	3.444493	0.849289	95.70622
6	20010.88	3.541889	0.848496	95.60962
7	20017.86	3.563092	0.847979	95.58893
8	20019.91	3.566887	0.84792	95.58519
••	••	••	••	••
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24	20020.92	3.567692	0.847981	95.58433

heavily in the food security equation in these countries (FAO, 1998). The fisheries sector is important not only as the provider of this food resource but also because it is an avenue for self-employment—this in a developing world context where employment opportunities are increasingly limited and labour decreasingly mobile across and between sectors due to sector industrialisation, and lack of skill and education as a barrier to entry. The harvesting and marketing of the resource can also present opportunities to the inhabitants to participate in an economic activity to which in some cases they would not otherwise have access.

There exists a high interdependence among fisheries due to the nature of the ecosystems in which species reside. While it is accepted that fisheries management is a crucial element in maintaining the long-term sustainability of marine resources and the communities that depend upon them, management techniques that aim at one particular species can have unforeseen effects throughout the ecosystem unless a more dynamic and holistic approach is adopted. The interactions discussed in this paper are illustrative of this.

In this paper, analyses were conducted on the carite, croaker and honey shrimp fisheries of the Gulf of Paria, Trinidad.  $2 \times 2$  models were constructed to investigate the ecosystem linkages of trophic interactions, bycatch, and harvesting by a common gear. Results indicated that, while the primary influence on the harvest level of these fisheries still remains the fisheries themselves, there is an increasing need to take into account the interactive effects of changes in landings with other ecosystem variables. Both the impulse response functions and the variance decomposition tables indicate that, if effective management is to be achieved, species cannot be considered in isolation of their ecosystem linkages. VAR models such as these have tremendous potential in the investigation of the potential ecosystem impacts of management techniques, in an immediate as well as a dynamic, inter-temporal sense.

Policies (or lack of) that compromise the integrity of this resource can have devastating effects, both in an immediate sense as well as in the longer term. The interlinked island ecosystems will respond to changes in one of the constituent parts. Furthermore, as the economy begins to respond to the environmental changes, shifts in the economic structure itself will impact the way in which the environmental resources are exploited. In the end, if marine resources are left unmanaged or at best managed in a less than holistic sense, it is the rural coastal communities of our small island economies and their future generations who will suffer the most.

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## Appendix A. Lag length tests

The initial lag length can depend on a variety of factors including the seasonality of the data, the length of the data set and in this case the life cycle features of the fisheries. The initial lag lengths are set as the largest permissible by the data set.

The null and alternative hypotheses for these lag length tests are:

**H<sub>0</sub>:** The restricted model (the model with the smaller lags) is true.

**H<sub>1</sub>:** The unrestricted model (the model with the larger lags) is true.

### A.1. Trophic VAR model: the carite and honey-shrimp fisheries

24 versus 18 lags:

	AIC	SBC
System with 24 lags	2884.75	3107.86
System with 18 lags	2908.56	3077.03
LR stat = 21.94	$p$ -value = 0.582	

18 versus 12 lags:

	AIC	SBC
System with 18 lags	3187.83	3362.23
System with 12 lags	3160.80	3278.64
LR stat = 10.75	$p$ -value = 0.99	

12 versus 8 lags:

	AIC	SBC
System with 12 lags	3399.28	3520.83
System with 8 lags	3384.99	3467.65
LR stat = 14.76	$p$ -value = 0.54	

8 versus 6 lags:

	AIC	SBC
System with 8 lags	3583.07	3622.30
System with 6 lags	3529.03	3593.44
LR stat = 5.54	$p$ -value = 0.70	

6 versus 4 lags:

	AIC	SBC
System with 6 lags	3621.46	3677.45
System with 4 lags	3603.38	3648.38
LR stat = 5.85	$p$ -value = 0.66	

4 versus 2 lags:

	AIC	SBC
System with 4 lags	3679.31	3724.71
System with 2 lags	3671.26	3696.48
LR stat = 7.09 $p$ -value = 0.53		

12 versus 9 lags:

	AIC	SBC
System with 12 lags	3598.00	3721.98
System with 9 lags	3593.32	3678.39
LR stat = 22.43 $p$ -value = 0.13		

2 versus 1 lag:

	AIC	SBC
System with 2 lags	3748.61	3774.04
System with 1 lag	3864.31	3874.48
LR stat = 119.55 $p$ -value = 0.00		

8 versus 6 lags:

	AIC	SBC
System with 8 lags	3761.24	3847.94
System with 6 lags	3755.59	3822.47
LR stat = 8.11 $p$ -value = 0.42		

#### A.2. Bycatch VAR model: the croaker and honey-shrimp fisheries

24 versus 18 lags:

	AIC	SBC
System with 24 lags	2669.87	2892.98
System with 18 lags	2654.81	2823.28
LR stat = 10.06 $p$ -value = 0.994		

6 versus 4 lags:

	AIC	SBC
System with 6 lags	3839.20	3906.69
System with 4 lags	3835.34	3882.84
LR stat = 10.12 $p$ -value = 0.25		

18 versus 15 lags:

	AIC	SBC
System with 18 lags	2872.40	3046.80
System with 15 lags	2960.05	3108.51
LR stat = 5.11 $p$ -value = 0.95		

4 versus 2 lags:

	AIC	SBC
System with 4 lags	3917.34	3965.25
System with 2 lags	3907.72	3935.46
LR stat = 5.62 $p$ -value = 0.69		

15 versus 12 lags:

	AIC	SBC
System with 15 lags	2960.05	3108.51
System with 12 lags	3087.05	3208.59
LR stat = 22.94 $p$ -value = 0.028		

2 versus 1 lag:

	AIC	SBC
System with 2 lags	3991.43	4019.41
System with 1 lag	4111.89	4124.60
LR stat = 122.59 $p$ -value = 0.00		

#### A.3. Multispecies VAR model: the carite and croaker fisheries

24 versus 18 lags:

	AIC	SBC
System with 24 lags	3074.83	3300.22
System with 18 lags	3061.37	3232.12
LR stat = 10.07 $p$ -value = 0.994		

12 versus 8 lags:

	AIC	SBC
System with 12 lags	5042.36	5314.61
System with 8 lags	4285.33	4456.08
LR stat = 12.7 $p$ -value = 0.99		

18 versus 12 lags:

	AIC	SBC
System with 18 lags	3323.60	3500.36
System with 12 lags	3328.09	3448.28
LR stat = 26.24 $p$ -value = 0.34		

8 versus 6 lags:

	AIC	SBC
System with 8 lags	5273.94	5459.74
System with 6 lags	5266.00	5407.21
LR stat = 19.44 $p$ -value = 0.36		

6 versus 4 lags:

	AIC	SBC
System with 6 lags	5377.83	5520.32

#### A.4. Aggregate VAR model: the carite, croaker and honey shrimp fisheries

System with 4 lags 5366.31 5463.80  
LR stat = 18.76  $p$ -value = 0.41

4 versus 2 lags:

	AIC	SBC
System with 4 lags	5479.82	5578.17
System with 2 lags	5472.06	5522.50
LR stat = 25.31 $p$ -value = 0.11		

2 versus 1 lag:

	AIC	SBC
System with 2 lags	5579.41	5630.27
System with 1 lag	5582.24	5607.67
LR stat = 20.64 $p$ -value = 0.01		

## Appendix B. Dummy variable tests

Once lag lengths have been determined, the VAR systems are tested for the inclusion of seasonal dummy variables. The systems are estimated (with the correctly specified number of lags) with the dummy variables and then without. The residuals are used to calculate the likelihood ratio statistic.

The null and alternative hypotheses can be represented as follows:

**H<sub>0</sub>:** the dummy variable is insignificant

**H<sub>1</sub>:** the dummy variable is significant

Model type	Likelihood ratio statistic	$p$ -value
Trophic	119.55	0.00
Bycatch	21.29	0.00
Multispecies	122.59	0.00
Aggregate	20.64	0.00

## Appendix C. The VAR specifications

### C.1. The general VAR model specification

The general form of a VAR model including two endogenous variables,  $X$  and  $Y$ ,  $n$  lags and an exogenous variable  $Z$  can be represented as follows:

$$X_t = c_1 + a_{11}X_{t-1} + a_{21}X_{t-2} + \dots + a_{n1}X_{t-n} + b_{11}Y_{t-1} + b_{21}Y_{t-2} + \dots + b_{n1}Y_{t-n} + d_1Z_t + e_{1t},$$

$$Y_t = c_2 + a_{12}X_{t-1} + a_{22}X_{t-2} + \dots + a_{n2}X_{t-n} + b_{12}Y_{t-1} + b_{22}Y_{t-2} + \dots + b_{n2}Y_{t-n} + d_2Z_t + e_{2t},$$

where  $X_{t-n}$  and  $Y_{t-n}$  are the variables of interest  $n$  periods before time  $t$ ;  $c$  is a constant;  $a$ ,  $b$  and  $d$  are coefficients of the model; and  $e_1$  and  $e_2$  are the error terms.

This general model is adapted below to each ecosystem dynamics case. The abbreviations are as follows:

$c$  = carite landings;  $h$  = honey shrimp landings;  $cr$  = croaker landings;  $sd$  = seasonal dummy variables;  $\varepsilon$  = error terms.

### C.2. The Trophic VAR model specification: the carite and honey-shrimp fisheries

This 2-variable system is estimated with a lag length of 2, and a seasonal dummy included:

$$c_t = b_{10} + b_{11}h_t + b_{12}sd_{1t} + \gamma_{11}h_{t-1} + \gamma_{12}h_{t-2} + \gamma'_{11}c_{t-1} + \gamma'_{12}c_{t-2} + \varepsilon_{ct},$$

$$h_t = b_{20} + b_{21}c_t + b_{22}sd_{1t} + \gamma_{21}c_{t-1} + \gamma_{22}c_{t-2} + \gamma'_{21}h_{t-1} + \gamma'_{22}h_{t-2} + \varepsilon_{ht},$$

The Choleski decomposition is imposed to set the current honey-shrimp landings  $h_t$  in the first equation to 0.

### C.3. The Bycatch VAR model specification: the honey-shrimp and croaker fisheries

This 2-variable system is estimated with a lag length of 15, and a seasonal dummy included:

$$h_t = b_{10} + b_{11}cr_t + b_{12}sd_{2t} + \gamma_{11}cr_{t-1} + \dots + \gamma_{1(15)}cr_{t-15} + \gamma'_{11}h_{t-1} + \dots + \gamma'_{1(15)}h_{t-15} + \varepsilon_{ht},$$

$$cr_t = b_{20} + b_{21}h_t + b_{22}sd_{2t} + \gamma_{21}cr_{t-1} + \dots + \gamma_{2(15)}cr_{t-15} + \gamma'_{21}h_{t-1} + \dots + \gamma'_{2(15)}h_{t-15} + \varepsilon_{crt}.$$

The Choleski decomposition is imposed to set the current croaker landings  $cr_t$  in the first equation to 0.

### C.4. The Multispecies VAR model specification: the carite and croaker fisheries

This 2-variable system is estimated with a lag length of 2, and a seasonal dummy included:

$$c_t = b_{10} + b_{11}cr_t + b_{12}sd_{1t} + b_{13}sd_{2t} + \gamma_{11}cr_{t-1} + \gamma_{12}cr_{t-2} + \gamma'_{11}c_{t-1} + \gamma'_{12}c_{t-2} + \varepsilon_{ct},$$

$$cr_t = b_{20} + b_{21}c_t + b_{22}sd_{1t} + b_{23}sd_{2t} + \gamma_{21}c_{t-1} + \gamma_{22}c_{t-2} + \gamma'_{21}cr_{t-1} + \gamma'_{22}cr_{t-2} + \varepsilon_{crt}.$$

The Choleski decomposition is imposed to set the current croaker landings  $cr_t$  in the first equation to 0.



### C.5. The Aggregate VAR specification: the carite, honey-shrimp and croaker fisheries

This 3-variable system is estimated with a lag length of 2, and a seasonal dummy included:

$$c_t = b_{10} + b_{11}h_t + b_{12}cr_t + b_{13}sd_{1t} + b_{14}sd_{2t} + \gamma_{11}h_{t-1} \\ + \gamma_{12}h_{t-2} + \gamma'_{11}cr_{t-1} + \gamma'_{12}cr_{t-2} + \gamma''_{11}cr_{t-1} \\ + \gamma''_{12}cr_{t-2} + \varepsilon_{ct},$$

$$h_t = b_{20} + b_{21}c_t + b_{22}cr_t + b_{23}sd_{1t} + b_{24}sd_{2t} + \gamma_{21}c_{t-1} \\ + \gamma_{22}c_{t-2} + \gamma'_{21}cr_{t-1} + \gamma'_{22}cr_{t-2} + \gamma''_{21}h_{t-1} \\ + \gamma''_{22}h_{t-2} + \varepsilon_{ht},$$

$$cr_t = b_{30} + b_{31}h_t + b_{32}c_t + b_{33}sd_{1t} + b_{34}sd_{2t} + \gamma_{31}h_{t-1} \\ + \gamma_{32}h_{t-2} + \gamma'_{31}cr_{t-1} + \gamma'_{32}cr_{t-2} + \gamma''_{31}cr_{t-1} \\ + \gamma''_{32}cr_{t-2} + \varepsilon_{crt}.$$

The Choleski decomposition is imposed to set the current honey shrimp landings  $h_t$  and current croaker landings  $cr_t$  in the first equation to 0.

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