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Impacts of climate variability on the tuna economy of Seychelles

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Running head: Economic impact of climate variability

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ABSTRACT: Many small island states have developed economies that are strongly dependent on tuna fisheries. Consequently, they are vulnerable to the socio-economic effects of climate change and variability, processes that are known to impact upon tuna fisheries distribution and productivity. The aim of this study was to assess the impacts of climate oscillations on the tuna-dependent economy of Seychelles. Using a multiplier approach, the direct, indirect and induced economic effects of the tuna industry declined by 58%, 34% and 60%, respectively, in 1998, the year of a strong warming event in the western Indian Ocean. Patterns in tuna purse seine vessel expenditures in port were substantially modified by strong climate oscillations. A cointegration time-series model predicted that a 40% decline in tuna landings and transhipment in Port Victoria, a value commensurate with that observed in 1998, would result in a 34% loss for the local economy. Of several indices tested, the Indian Oscillation Index was the best at predicting the probability of entering a regime of low landings and transhipment. In 2007, a moderate climate anomaly was compounded by prior overfishing to produce a stronger that expected impact on the fishery and economy of Seychelles. The effects of fishing and climate variability on tuna stocks are complex and pose significant challenges for fisheries management and the economic development of countries in the Indian Ocean.

KEY WORDS: Climate variability, ENSO, tuna fisheries, Seychelles economy

1. INTRODUCTION

Many countries, particularly small island developing states (SIDS), rely heavily on fisheries for economic development (Weber 1993; Bellwood et al. 2003; Zeller et al. 2006). For island states that are dependent on highly migratory and shared fish stocks, climate change poses significant challenges for effective governance and the maintenance of economic opportunities and benefits (Miller 2007). Developing countries are vulnerable to climate change due to their high reliance on fisheries and poor adaptive capacity (Allison et al. 2009). Building potential for adaptive capacity at sector and national levels will be enhanced through knowledge of the mechanisms linking physical and socio-ecological systems and the economic impacts of variability and change.

Climate variability operates on seasonal, inter-annual, or decadal time scales and affects numerous biological and ecological processes (Stenseth et al. 2002). El Niño Southern Oscillation (ENSO) events impact ecosystem processes across the globe and are the major phenomena driving inter-annual ocean climate variability (Glantz 1996). The ENSO signal propagates in the Indian Ocean (Nicholson 1997) and is manifested as sea surface temperature and heat storage anomalies (Tourre & White 1995). Inter-annual climate variability in the Indian Ocean also results from coupled ocean-atmosphere-land interactions that operate independently of the ENSO forcing originating in the Pacific (Webster et al. 1999; Marsac 2006). The Indian Ocean zonal dipole mode (IOD; Saji et al. 1999; Webster et al. 1999) is a “basin-scale pattern of surface and subsurface temperature that seriously affects the inter-annual climate anomalies of many nations around the Indian Ocean rim” (Meyers et al. 2007). The positive or negative IOD events may occur in the same years as ENSO, such as in 1998, or in the absence of that oscillation. ENSO and IOD processes have a profound effect on tuna fisheries in the region (Marsac 1991; Marsac & Le Blanc 1998; Ménard et al. 2007, Marsac

2008). The 1997-98 warm event, which coincided with one of the strongest ENSO events in the last century acting in phase with a positive IOD event, caused dramatic temperature and wind stress anomalies in the equatorial Indian Ocean (Murtugudde et al. 2000). Coincidently, the distribution of the purse-seine tuna fishery was drastically modified, especially at the beginning of 1998 during the peak phase of the El Niño (Marsac & Le Blanc 1999). The usual fishing grounds of the western Indian Ocean (WIO) basin were deserted and the fleets underwent a massive shift to the eastern basin, as far as 100°E, a longitude never before reached by vessels based in the WIO (Marsac & Le Blanc 1999) (Fig. 1). Consequently, many vessels operated from Asian ports (notably Phuket, Thailand) and landings and vessel activity in Port Victoria (PV), Seychelles, decreased substantially, resulting in economic impacts for the fishing industry (Payet 2005). The eastward shift of the purse-seine tuna fleet (PSTF) during the 1997-98 warm event was mediated through changes in the behaviour of target tuna species and its effects on the fishery catch-per-unit-effort (CPUE). Of major concern to the tuna economy of Seychelles is the prediction that ENSO anomalies may increase in frequency and severity in relation to climate change (Timmermann et al. 1999).

The synchronies between climate oscillations and CPUE argue for a non-lagged effect of warm events on the catchability of tuna rather than for complex changes in the production regime, whereby anomalous thermocline depths associated with warm events in the WIO deepen the habitat for tuna and reduce their catchability to the purse-seine gear (Ménard et al. 2007). The modification of habitat for the surface swimming tuna species (particularly yellowfin tuna, *Thunnus albacares*) produced a change in behaviour, the fish undergoing a vertical migration to the deeper thermocline to forage. By contrast, in the eastern basin of the Indian Ocean, biological enrichment occurred through upwelling, keeping tuna in the surface layer and increasing their catchability (Marsac and Le Blanc 1999; Ménard et al. 2007).

Centrally located relative to the most productive tuna fishing grounds of the Indian Ocean, PV consolidated its position as the major regional hub early in the development of the purse-seine tuna fishery. The fishery is dominated by European-owned fishing vessels and under current fishing agreements, the European Union (EU) and ship-owners paid 4.7 million euros (€) and 6.5 million € in 2005 and 2006, respectively, for access rights to the exclusive economic zone (EEZ) of Seychelles (source: DG MARE). Since 1992, annual catches by the purse-seine tuna fishery have varied between 250,000 and 400,000 t, with a trend of increasing annual growth up to 2007 (Fig. 2). The percentage of tuna caught by the fishery and landed or transhipped in PV has grown to over 90% in recent years. The development of the fishery peaked in 2006, when around 1.1 million tonnes (t) of tuna (54% skipjack tuna, *Katsuwonus pelamis*; 36% yellowfin tuna, *Thunnus albacares*; and 10% bigeye tuna, *Thunnus obesus*) were caught in the Indian Ocean (source: IOTC), constituting one quarter of the global catch.

The importance of tuna to the Seychelles economy has been enhanced through expansion in tuna canning capacity. Presently, the cannery (Indian Ocean Tuna Ltd) is one of the biggest in the world with an average daily processing capacity of 350 t. Co-owned by foreign investors (60%) and the Government of Seychelles (40%), it is a major employer of the domestic economy with 1,975 workers in March 2007, of which 1,149 were local workers (58%) and 826 expatriates (42%). The company represents 19% of the formal employment in the private sector, and accounts for more than 90% of national exports (source: CBS). Most canned tuna exports are destined for Europe and Seychelles accounted for a 13% share of the European market in 2007. However, the position of Seychelles has been eroded by the rise of competing countries like Ecuador and Thailand, which rose above Seychelles in terms of European canned tuna market share after 2006. This erosion is partly due to the pervasive changes of trade rules under the World Trade Organisation (WTO) and is also dependent on the availability of raw materials for processing.

The aim of this study is to assess the impacts of climate variability on the tuna-dependent economy of Seychelles. This assessment is achieved by crossing scientific knowledge on the linkages between climate and fisheries with economic models and several statistical methods (cluster analysis, cointegration, Markov-switching VECM) to analyse the relationships between climate indices and available economic data relating to the PSTF and fisheries-related industries.

2. METHODS

Economic data relating to the expenditure of the PSTF during calls to PV are collected by the Seychelles Fishing Authority (SFA) from the two vessel agents acting for the European-owned fleets. These data consist mainly of port call expenses, including taxes, dues, agency and administrative fees, and expenses relating to labour, ship chandlery, utilities, transport, health, accommodation, repair and maintenance. In addition, data on the total expenses paid by the vessels for fuel are also collected (Annex 1). Data were screened, verified and compiled by vessel type, quarter, year and expenditure categories. Purse-seine tuna fishery catch data were taken from the fisheries databases maintained by SFA and imported to the economic database. Due to errors with some vessel trip data for records prior to 1992, only data from 1992 to June 2008 were used in the study. In addition, we compiled economic data from other sources, namely; expenditures of the tuna canning factory (Indian Ocean Tuna, IOT), bunker rates of the Seychelles Petroleum Company (SEYPEC), trade data and consumer price index from the National Statistics Bureau (NSB), and currency exchange rates from the Central Bank of Seychelles (CBS).

We employed the following climate indices in the analyses: (1) the Dipole Mode Index (DMI), the east-west temperature gradient across the tropical Indian Ocean; (2) the Indian Oscillation Index (IOI), the difference in sea level pressure standardized anomalies between Seychelles and Darwin; (3) the Southern Oscillation Index (SOI), the difference in sea level pressure standardized anomalies between Tahiti and Darwin, and (4) the Western Tropical Indian Ocean sea surface temperature index (WTIO), the surface temperatures in the region 50°E - 70°E, 10°S - 10°N.

2.1. Estimating spillover effects using a multiplier approach

The spillover effects of the expenditures by the PSTF in Seychelles were estimated using an input-output model and a multiplier approach (Leontief 1970). A model of the spillover effects was constructed (Fig. 3). The expenditure of fishing vessels landing or transhipping in PV is partly flooding into the national economy through the revenue transferred as wages or dividends (shareholders) to Seychellois households that is not saved or spent in imported goods. In addition to the direct (fleet) and indirect (cannery, government) expenses, a looping effect induced by the household expenditure can be estimated (left-hand bottom side of Fig. 3). The standard multiplier impact is obtained by dividing the sum of direct, indirect and induced expenditure by total expenditure of the PSTF. Concerning the direct and indirect effects of landings/transhipments, all expenditure series were deflated by the consumer price index (CPI base 100 = 2001) and averaged on a yearly basis over the period 1992-2008.

2.2. Identifying climate effects on vessel expenditures

To determine the relative importance of seasonal versus inter-annual effects, vessel expenditure data were analysed using principal component analyses (PCA) based on quarterly observations between 1992 and 2007. Seventeen variables of port call expenses by the PSTF were selected as active continuous variables in the reduction process of the correlation matrix. Several other continuous variables (catches, effort, catch-per-unit-effort) were selected as illustrative variables in the process, i.e. simply projected on the factorial axes without any influence on the matrix reduction calculus. Six discrete variables (year, quarter, and the four climate indices: IOI, SOI, DMI and WTIO) were also used as illustrative variables and projected on the principal components. A hierarchical ascending classification was then applied on the basis of the Ward criterion (minimum inertia within the clusters and maximum inertia between the clusters), a break in the loss of total inertia (where total inertia is the sum of Eigen values for all principal components) between two steps of the clustering process indicating the number of clusters to be chosen. Finally, each cluster was described by the most discriminating variables selected by a statistic, with its associated probability calculated from a normal law test of means between the cluster and the sample.

2.3. Assessment of climate effects using cointegration and Markov analyses

Cointegration approach

The relationship between cargo handling costs (CHC) and landings was tested through cointegration analysis (Johansen 1988), considering an unrestricted intercept and centred seasonal dummy variables as deterministic components of the model. After determining that the variables were not stationary (ADF and KPSS tests),

the long-run relationships were studied through a multivariate Johansen approach and Granger's causality tests were carried out. Centred seasonal dummy variables were included to take into account the seasonal behaviour of the variables. An unrestricted constant had to be used in the model when the I(1) variables presented linear trends and an intercept different from zero in the cointegration vectors. The Akaike Information Criterion (AIC) (Lütkepohl 2005) determined the number of lags included, 4 being the maximum. Additionally, the model was checked for the absence of any statistical problems before determining the number of cointegration relationships, including autocorrelation LM tests up to order 4 (Johansen 1995) and the Jarque-Bera Normality test, with the results showing that the model was correctly specified.

MS-VECM

Following a standard typology of shipping costs (Stopford 1997), we split the PSTF vessel expenditures into cargo handling costs (CHC; costs varying with the levels of landings) and the vessel or voyage costs (VC; i.e. avoidable fixed costs), of which the bunker costs represented 86% on average. Two models were tested through different time-series techniques; firstly, a cointegration approach of the relationship between landings and CHC was tested; followed by a Markovian approach. Due to the fact that the long-run expenditure of vessels at PV depended partly on the level of landings and transhipment of tuna, the equilibrium between landings/transhipment and fishing effort was analysed, with gasoil expenditure (bunker costs) used as a proxy of fishing effort. The influence of climate variability on the dynamics of this relationship was then assessed.

The statistical analysis was carried out in a VAR context, allowing for regime change in terms of a Markov process. We adopt a multivariate Markov-Switching model (MS-VECM) that allows for regime switching mean equation parameters and variance-covariance matrix:

$$\Delta x_t = \mu(z_t) + \sum_{j=1}^{k} A_j(z_t)\Delta x_{t-j} + \Pi(z_t)\Delta x_{t-1} + u_t \qquad (3)$$

Where:

$x_t : (s_t, f_t^2, ..., f_t^k)$; s_t = landings (in log terms); f_t^i = effort or input i (i=2,…,h) at time t; $\mu(z_t)$ is a k dimensional vector of regime-dependent intercept terms; $u_t \sim NID(0, \Sigma(z_t))$; $\Pi(z_t) = \alpha\beta'$; the state $z_t \in \{1,...,M\}$, M being the number of regimes.

To estimate this system, we proceeded as follows. First, the long-run relationship was determined using the ML procedure suggested by Johansen (1988). No regime switching was taken into account when obtaining estimates of the cointegrating vector. Then, we estimated the dynamic system above using the EM algorithm that allows for two regimes of high and low volatility. We then proceeded with the Markov chain estimation, allowing for two regimes. Determination of the lag length was based on the Bayesian Information Criterion (BIC).

Finally, we assessed the impact of climate variability on the two regimes identified through MS-VECM by conducting regression analyses to determine how variation in four climate indices (described above) influences the probability of entering regime 1 (pstar). We introduced three seasonal dummy variables in the regression model for the first three annual quarters (D1, D2 and D3); a dummy variable was not introduced for the last quarter to avoid multi-collinearity with the intercept. Then, we tested the influence of each climate index with squared values of the indices used as explanatory variables in the regression analyses.

3. RESULTS

3.1. Spillover effects estimated by a multiplier approach

Using the mean 2006 exchange rate (1€ = 6.93 Seychelles Rupees, SR) and with an annual total (constant) expenditure of the tuna fleets valuing 240 million (M) SR_{2001} (i.e. 35 M€; average 1992-2006), the coefficient of induction was 1.57 (Fig. 4). In other words, every 100

SR spent by the PSTF in PV leads to a final net amount of 160 SR for the Seychelles economy. The average 1992-2008 direct expenditure of the fleet was valued at 203 MSR_{2001} (29 M€) while the spillover (indirect and induced expenditures) effects were estimated at 181 MSR_{2001} (26 M€). Thus, a net induced contribution represents close to a 100% increase for the rest of the economy. Including IOT expenditures and their spillover effects, the coefficient rises to 2.50.

The evolution of direct, indirect and induced effects over the study period reveals an erosion of the coefficient of induction, concurrent with the elevation of total expenditure due to the steady fuel price increase since 2000 (Fig. 4). Interestingly, all types of effects show an inflexion point in 1998, year of the main impacts of the 1997-98 warm event in the WIO (with a mechanical increase of the induction coefficient due to lower expenses that particular year). In 1998, the direct, indirect and induced effects declined by 58%, 34% and 60% (52% decrease overall), respectively, compared with a yearly growth trend of 17%, 4% and 11% (12% increase overall) for the same effects, respectively.

3.2. Climate effects on purse seine vessel expenditures

The (deflated) expenditure data varied in their seasonal and time patterns with some showing a strong seasonal variation and little change over time (factor 1), while others variables exhibit a combination of change between years and seasons, lying between the axes (Fig 5). Seasonal variation in expenditure is a response to seasonal variation in landings, which are pronounced during the second quarter when the PSTF mainly fishes in the Mozambique Channel and utilises other regional ports.

In projecting expenditure data as a factorial plan, 1998 is isolated from other years and clusters with the second quarter patterns of low expenditure and extreme values of two climatic indices, the Indian Oscillation Index (IOI) and the Western Tropical Indian Ocean sea surface temperature index (WTIO) (Fig. 6). This suggests that anomalous ocean-climate conditions produces a similar response in expenditure to that typically observed during the second quarter of the year. Cluster analysis of seasonally adjusted quarterly expenditure data yielded an optimal of 5 clusters and isolated 1994 and 1998 from the recurrent seasonal pattern, clustering most quarters from those years (55% of observations in the cluster compared to an average of 13%) and rejecting the null hypothesis of a random distribution. The level of tuna landings in this cluster was 53% lower than average and can be considered as the seasonally adjusted impact of the 1997-1998 warm event on the Seychelles tuna economy.

3.3. Climate effects identified using cointegration and Markov analyses

Cointegration analysis of the relationship between landings and cargo handling costs (CHC)

Prior to examining cointegration relationships, autocorrelation LM tests (4 lags; statistic: 3.10; p=0.54) and the Jarque-Bera normality test (statistic: 7.35; p=0.12) determined that the model was specified correctly.

The number of cointegration vectors was determined using cointegration rank tests. Both the trace test and the maximum Eigenvalue test showed the existence of a cointegration relationship (Table 1). All the characteristic roots were inside the unit circle; as one of the characteristic roots was almost 1 (k-r=1), one cointegration vector was selected.

Having shown cointegration between both variables, the cointegration relationship was estimated, as follows:

$$CHC_t - 1219592 - 116.12\,\text{LANDING}_t = \varepsilon_t \qquad (1)$$

CHC increase by 116 SR when total landings and transhipments in PV increase by 1 tonne (t). This proportionality of 116 SR/t of fish landed/transhipped corresponds well with the average unit price over the period. On average, with a standard level of 61,632 t landed/transhipped per quarter (mean 1992:1-2008:2), the estimated CHC expenditure would be of 8,376,092 SR_{2001}. Other things being equal, a 40% cut of landings caused by a warming event as extreme as that of 1997-1998 would result in a total CHC expenditure of 5,513,492 SR_{2001} per quarter, equating to a 34% loss for the local economy.

Markovian analysis of the relationship between bunker costs and landings/transhipment

The long-term equilibrium between bunker costs and landings/transhipment was first tested in logarithmic terms. Again, the cointegration analysis (Table 2) shows that we cannot reject the hypothesis of a long-term equilibrium between the two variables.

The cointegration equation can be written as:

$$\ln(\text{landing}) = \underset{(0.071)}{0.442} \log(\text{gasoil}) + \underset{(1.215)}{3.327} \qquad (2)$$

( ): Standard deviation

The regimes are then identified in terms of levels of landings/transhipment. Regime 1 represents the higher level of landings/transhipment which mainly occurs during the third and the fourth quarters. Regime 2 corresponds to the lower landings/transhipment of the second quarter and also, frequently, of the first quarter (Fig. 7).

Over 42 observations, the probability of entering the first (high) regime (p*) is close to 0 (lower than 0.05) for 16 observations and is close to 1 (greater than 0.95) for 21 observations. The lowest values of p* generally occur when the variarion in landings/transhipment is strongly negative (11 observations over 15); this occurs mainly during the second quarter when the vessels often land in other regional ports (11 obs. out of 16 are second quarters). Consequently, regime 2 can be interpreted as a low regime for landings at PV. While not defined by 3 quarters entering the low regime, 2007 was the only year since 1998 for which there were two consecutive quarters in regime 2.

The best model was obtained with the IOI, the other models exhibiting a lower level of significance (Table 3). With the WTIO, the model did not validate the significance of climate, even at a 90% level, and the results are not shown. For all the climate index models, the seasonal dummy variables exhibit the expected sign, i.e. negative for the second quarter and positive for the first and third quarters. In terms of the IOI index, any strong deviation from the mean decreases significantly the probability of entering the high regime of landings at PV. Looking at the IOI values, the strongest deviations of the index were negative for the last quarter of 1997 and first quarter of 1998, during the strong ENSO episode. To a lesser extent, the SOI and DMI climate indices also have a negative and significant impact on the regime. Any important variation of the climate index could have a depressing influence on landings/transhipments in Seychelles (i.e. entering regime 2).

4. DISCUSSION

The findings of this study are suggestive of a link between climate variability and the tuna economy of Seychelles. While it is recognized that causality has not been demonstrated, the coincidence of a severe warming event in late 1997 and 1998 (Murtugudde et al. 2000) with significant disruptions to the PSTF and loss of revenue for the national economy is compelling evidence for a climate effect. Within the period corresponding to our expenditure dataset (1992-2008) there have been several warming events in the WIO, some moderate (2003 and 2004-2005) and some relatively strong (1994 and 2006-2007), none of which have resulted in an PSTF expenditure response comparable to that experienced in 1997-1998. This pattern may be expected as moderate temperature anomalies in the Indian Ocean do not strongly affect the surface habitat of yellowfin tuna (Ménard et al. 2007). As strength of a climate anomaly appears critical in terms of the economic impact, future research should investigate thresholds to facilitate adaptive management responses.

Although the underlying changes to the fishery differ, the economic impacts of the 1998 warming event can be considered as an extended low season. In the Indian Ocean, the PSTF demonstrates a high level of spatial mobility as they follow seasonally varying patterns in abundance and accessibility to surface gear (Miller 2007). Seychelles normally experiences seasonal lows in landings and transhipment during the second quarter of the year, when the fleets target tuna in the northern Mozambique Channel and operate out of other regional ports. In other quarters, landings at PV are higher and generally stable between years. However, in 1998, the 2nd quarter low season was bracketed by low levels of vessel expenditures in the 1st and 4th quarters, leading to depressed annual revenue.

Economic impacts resulting from climate oscillations are acute compared to the chronic changes that may characterise climate regime shifts, which are also more difficult to measure or predict (Arnason 2007). After accounting for inflation and seasonal variation, all PSTF vessel expenditures were sensitive to the 1998 oscillation, the extent of which was dependent on the relative strength of inter-annual trends in landings, transhipment and service unit costs. For the cargo handling costs, it was estimated that the 1998 episode had a negative impact of 34% on the PSTF expenditure in PV, in line with the cut in landings and transhipment for that year and after taking into consideration the trend and seasonal components. Interestingly, this impact is comparable to ENSO impacts on the Chilean and Peruvian fishmeal fisheries, where the social welfare loss due to ENSO was estimated to be 42% below a normal year of reference (Sun et al. 2001).

The large declines of purse-seine CPUE and catch in late 2006 and early 2007 were disproportionate in relation to the moderate strength of the El Niño and IOD oscillations of that period. One hypothesis that has been proposed to explain this observation identifies a synergistic effect between stock levels and environmental anomalies. Stock assessments recently conducted under the auspices of the Indian Ocean Tuna Commission (IOTC Working Party on Tropical Tunas, October 2008, and the IOTC Scientific Committee, December 2008) concluded that the yellowfin tuna stock was overfished during the 2003 to 2006 period. During this period, the main fishing grounds were characterized by an anomalous decrease of the mixed layer depth (MLD), bringing tuna to the surface and resulting in increased catchability, fishing mortality and, consequently, a decline in stock biomass (Marsac 2008). By late 2006/early 2007, the reduced biomass may have acted in concert with a moderate climate oscillation, which increased the MLD, to depress CPUE and catch (IOTC-2007-SC-R; Marsac 2008). While the reductions in vessel expenditures in 2007 were not of the magnitude observed a decade or so earlier, this latest event highlights the complex and important relationship between climate and tuna fisheries. In particular, it demonstrates how coupled ocean-atmosphere oscillations influence the levels of fishing mortality through the modification of tuna habitat, which has important consequences for fisheries management.

Climate indices representing dominant climate patterns in the oceans can be good predictors of ecological processes (Bakun 1996; Stenseth et al, 2002; Hallett et al. 2007). In this study, we demonstrate that they can also be used to examine economic effects. In particular, the IOI has been shown to be robust in tracking warm and cold events in the Indian Ocean and their ecological impacts (Marsac & Le Blanc 1998; Ménard et al. 2007, Marsac 2008) and now, in this study, economic effects. The climate oscillations described by the IOI and SOI, and to a lesser extent the DMI, influenced the dynamics between landings/transhipment and gasoil consumption (as a proxy for fishing effort), whereby the indices predicted, in the short-term, the switching between the high and low regimes of these variables that were identified by a MS-VECM model. Any deviation of the square IOI value from average values decreases by nearly 10% the probability of being in a normal (high) landing regime, other things being equal. Given that climate oscillations operate on a range of spatial and temporal scales, and that their interrelationships are not fully understood, it is important to examine observations using a range of indices. As an example of this, a moderate impact on expenditures was observed in 1994 in the absence of an ENSO event. However, this year was possibly characterised by strong IOD event that resulted in warming anomalies in the western basin. While the classification of 1994 as an IOD event is still being debated, it potentially represents an example of an Indian Ocean climate oscillation acting independently of ENSO (Meyers et al. 2007).

Similar to many SIDS situated in productive tuna fishing zones, Seychelles has come to rely heavily on a ‘tuna economy’ as the world demand for tuna has grown steadily over recent decades (Campling et al. 2007; Campling & Havice 2007). The importance of the Seychelles tuna economy was, for the first time, estimated using a multiplier approach. However, beyond the impact on the domestic wealth, of greater importance is the presence of the cannery for national employment, since it represents 19% of private sector employment and 6% of total employment. Landings to IOT create higher levels of employment than transhipment of frozen tuna from purse-seiners to reefers. Given that the availability of tuna in the area of the Seychelles EEZ is at the core of competitiveness for the canning industry, the socio-economic implications of climate oscillations are severe. As evidence, the warming episode of 1998 resulted in major disruptions in IOT production and employment levels lasting for several months.

Changes in the distribution and magnitude of fisheries resources will have important socio-economic consequences at national and regional levels (Arnason 2007, Miller 2007, Sun et al. 2006). Climate change scenarios predict modification of skipjack tuna habitat and distribution in the equatorial Pacific with implications for the important tuna economies of Pacific island countries (Loukos et al. 2003). Considering commercially exploited species as a whole, catch potential is predicted to decline across the tropical oceans under climate change scenarios (Cheung et al. 2009), heightening the vulnerability that already characterises many tropical countries (Allison et al. 2009). While climate change and variability are two of many factors affecting fish stocks, not least of which is fishing pressure, their incorporation in population and bio-economic fisheries models will be increasingly important for assessment, prediction and management (e.g. Sun et al. 2006).

Given that trade in tuna and tuna products is international, the socio-economic effects of climate variability in Seychelles are not limited to events in the WIO. Global price trends for tuna are sensitive to the effects of ENSO acting on tuna fisheries in other regions. For example, Taiwanese tuna purse seine fisheries in the south-western Pacific Ocean experienced the effects of overproduction and a 50% drop in price at the major auction market in Thailand during the 1998-2000 La Niña (Sun 2007).

Building adaptive capacity is critical to alleviating the socio-economic impacts resulting from climate variability and change (Allison et al. 2009). While this study was largely based on economic analyses, the potential social impacts are pervasive given that a large proportion of purse seine vessel and IOT expenditures are directed at local employment and companies: recent analyses of direct, indirect and induced employment indicate that 8,400 persons are dependent on the tuna industry and related activities (Liam Campling, personal communication), constituting approximately 10% of Seychelles' population. Moreover, reductions in government revenues resulting from climate variability and change would undermine social policy interventions (e.g. health, education and housing). The coral reef fisheries, important for food security as well as employment, are also threatened by climate change (Graham et al. 2007), and tourism, the second pillar of the economy, is threatened by coastal erosion and degraded reef sites (Payet 2005). While Seychelles has a relatively high adaptive capacity to cope with climate change, compared to other countries in the region (McClanahan et al. 2008), the reliance on the marine environment to support the two main pillars of the economy warrants a greater emphasis on strengthening adaptive capacity and incorporating climate change in national policy and management interventions.

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Table 1. Results of Johansen cointegration and proportionality tests. Critical values are provided by Osterwald-Lenum (1992).

	Null hypotheses for the cointegration tests [a]			
	Rank = 0		Rank = 1	
Price relationships	Max [b]	Trace [c]	Max	Trace
CHC/LANDING	18.762*	21.145*	2.353	2.353

a Null hypothesis: the number of cointegrating vectors equal to zero or one

b Maximum Eigenvalue test

c Trace test

Critical values are provided by Osterwald-Lenum 1992

*Significant at 1% significance level

Table 2. Results of a Trace test for the cointegration analysis (period 1992 Q1 to 2007 Q3).

Hypothesized no. of cointegration equations	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.
None	0.267	21.177	20.262	0.037
At most 1	0.042	2.564	9.165	0.665

Table 3. Least squares regression model results for the Indian Oscillation Index (IOI), Southern Oscillation Index (SOI) and Dipole Mode Index (DMI). Dependent variable: PSTAR (P*); Adjusted sample: 1998Q1 – 2007Q3; 39 observations. Variable coefficients given for intercept (C), dummy variable (D1, D2, D3) and the climate index, with t-statistics in square brackets.

	IOI	SOI	DMI
C	0.395* [5.073]	0.362* [4.448]	0.811* [10.856]
D1	0.562* [5.198]	0.513* [4.555]	-
D2	-0.372* [-3.538]	-0.266** [-2.342]	-0.727* [-5.866]
D3	0.642* [6.121]	0.660* [5.934]	-
Climate index	-0.091* [-3.660]	-0.090* [-2.834]	-0.053** [-2.193]
R-squared	0.793	0.767	0.519
AIC	-0.000812	0.119	0.741
Log-likelihood	5.016	2.675	-11.447
Durbin-Watson statistic	1.997	2.261	2.662
F-statistic	32.564	27.920	19.382
Prob. (F-statistic)	<0.001	<0.001	<0.001

AIC = Akaike Information Criterion

* Significant at the 1% level

**Significant at the 5% level

Figure legends

Fig. 1. First quarter catch-per-unit-effort (CPUE) for (a) the period 1992-2007, average values, and (b) 1998 only.

Fig. 2. Trends in annual Indian Ocean purse-seine vessel catches (tonnes, t), annual volumes (t) in landings/transhipment of frozen tuna to Port Victoria, and landings/transhipment as a proportion of catch.

Fig. 3. A model of spillover incurred by purse seine tuna fleet (PSTF) expenditure in Port Victoria.

Fig. 4. Direct, indirect and induced effects of the tuna purse seine fleet on the national economy (not incl. IOT).

Fig. 5. Factorial map of the (deflated) purse-seine vessel expenditure variables. The inter-annual (time) trend is descending along factor 2 (vertical axis), the seasonal trend along factor 1 (horizontal axis). The first 2 Eigen-values accumulate 71% of the total variance.

Fig. 6. Projection of nominal characteristics as a factorial plan.

Fig. 7. Results of the MS-VECM model expressed as probability of entering a regime of high level of landings (Regime 1).

Figure 1 (a,b).

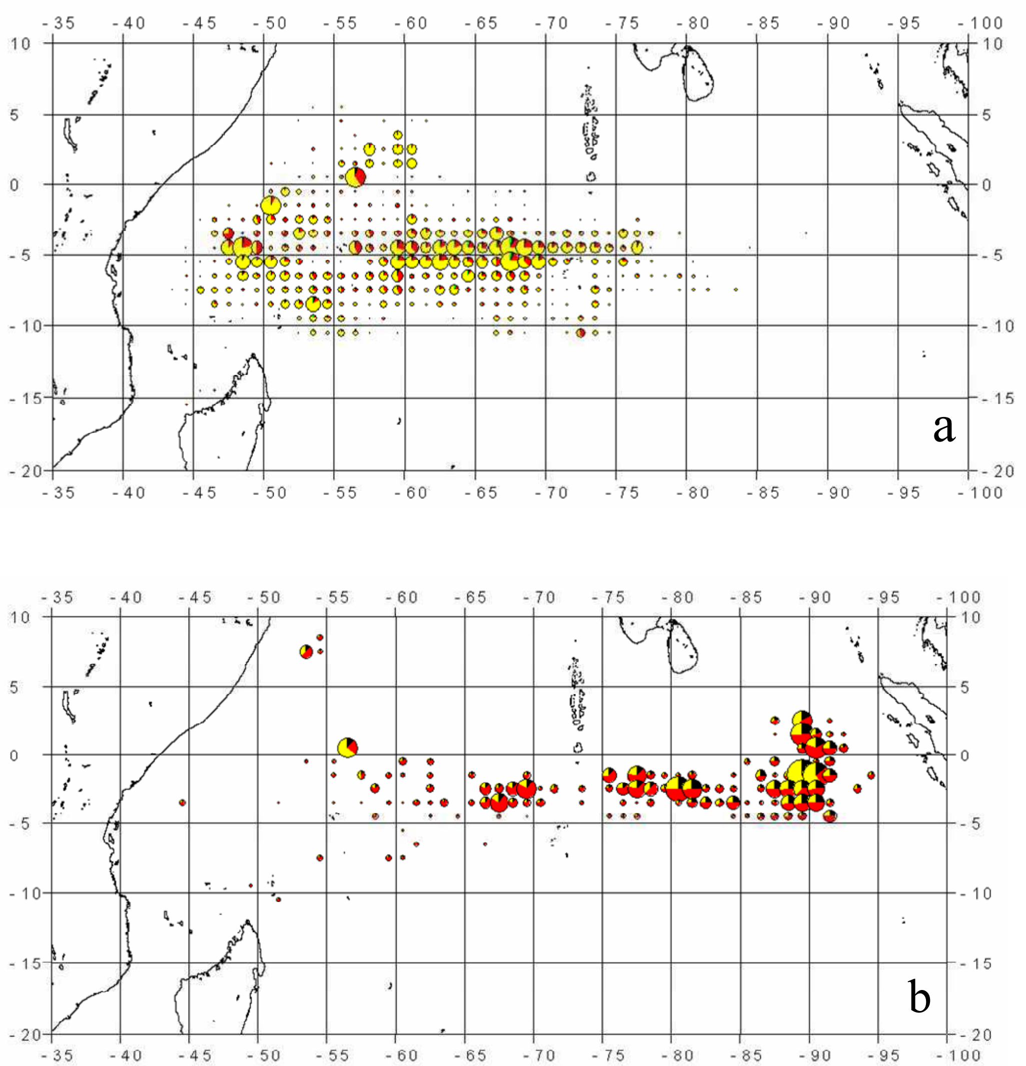

-35 -40 -45 -50 -55 -60 -65 -70 -75 -80 -85 -90 -95 -100
10 5 0 -5 -10 -15 -20
a
-35 -40 -45 -50 -55 -60 -65 -70 -75 -80 -85 -90 -95 -100
10 5 0 -5 -10 -15 -20
b

Figure 2

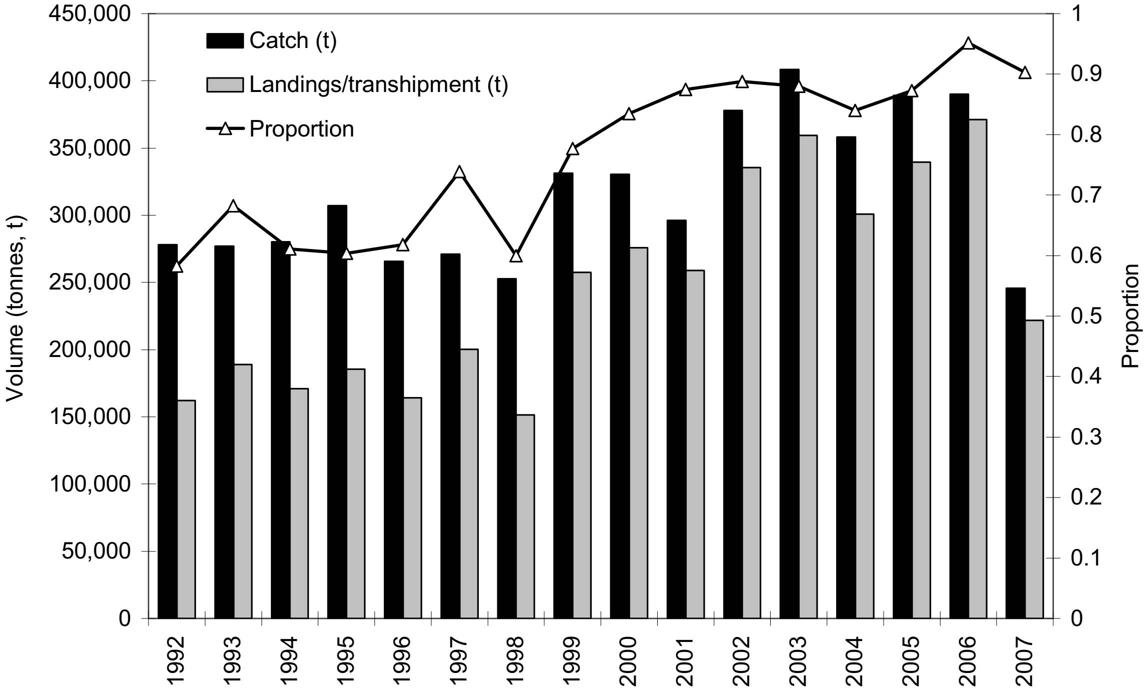

Catch (t)
Landings/transhipment (t)
Proportion
Volume (tonnes, t)
Proportion
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

Figure 3

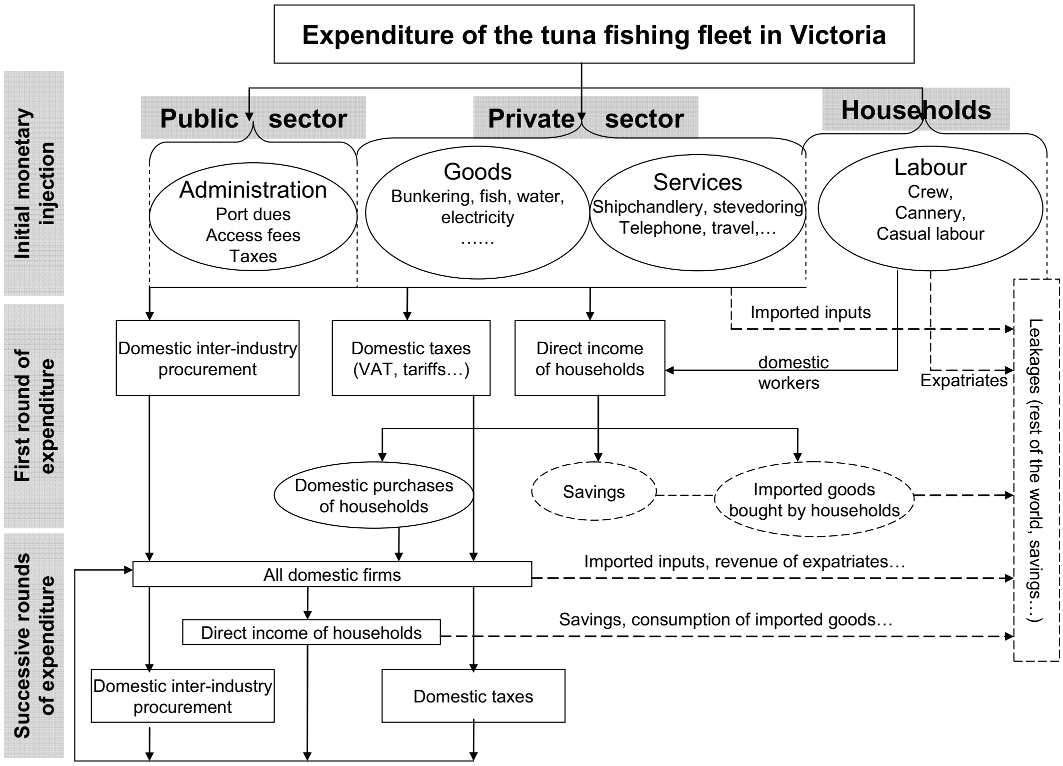
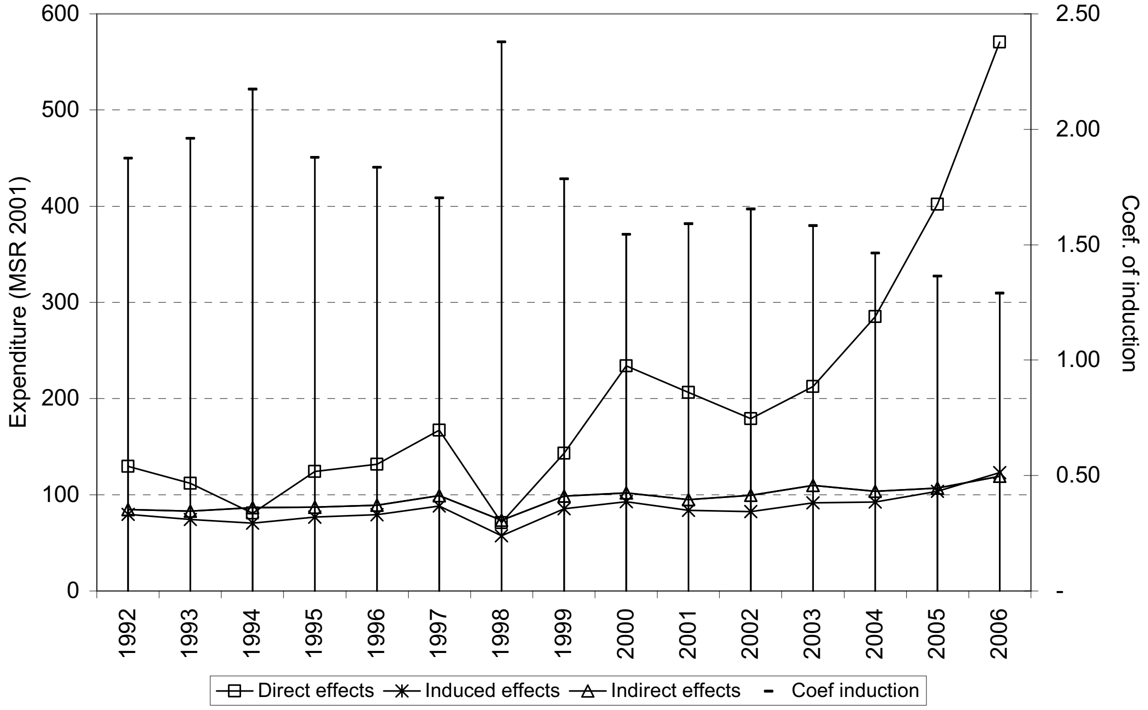

Expenditure of the tuna fishing fleet in Victoria
Initial monetary injection
Public sector
Private sector
Households
Administration
Port dues
Access fees
Taxes
Goods
Bunkering, fish, water, electricity
……
Services
Shipchandlery, stevedoring
Telephone, travel,…
Labour
Crew,
Cannery,
Casual labour
First round of expenditure
Domestic inter-industry procurement
Domestic taxes (VAT, tariffs…)
Direct income of households
Imported inputs
domestic workers
Expatriates
Leakages (rest of the world, savings…)
Domestic purchases of households
Savings
Imported goods bought by households
Successive rounds of expenditure
All domestic firms
Imported inputs, revenue of expatriates…
Direct income of households
Savings, consumption of imported goods…
Domestic inter-industry procurement
Domestic taxes

Figure 4



Expenditure (MSR 2001)
Coef. of induction
0
100
200
300
400
500
600
-
0.50
1.00
1.50
2.00
2.50
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Direct effects
Induced effects
Indirect effects
Coef induction

Figure 5

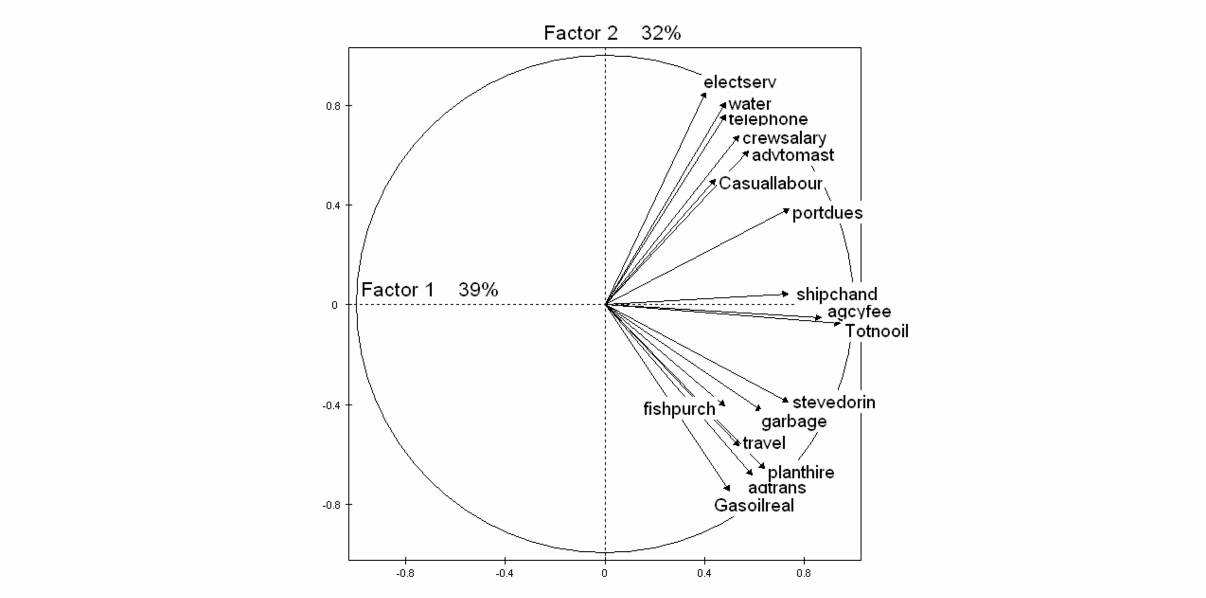
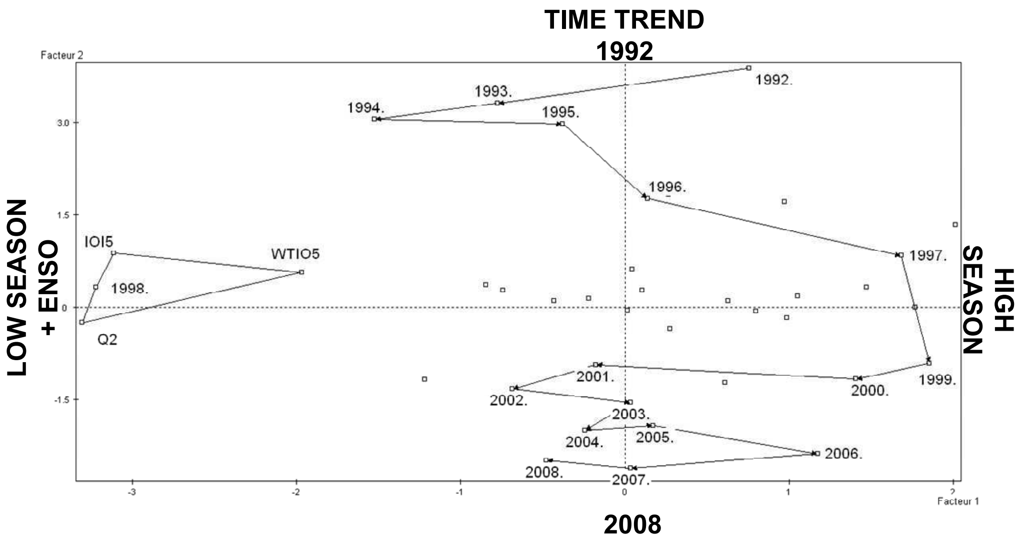
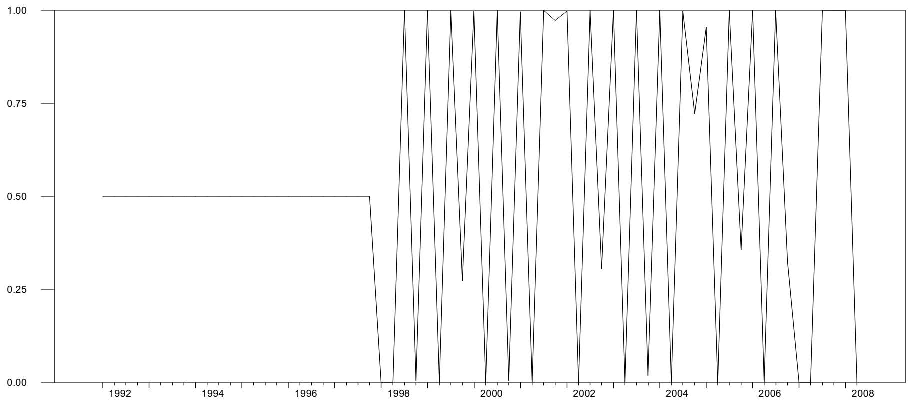

Factor 2 32%
Factor 1 39%
electserv
water
telephone
crewsalary
advtomast
Casuallabour
portdues
shipchand
agcyfee
Totnooil
stevedorin
fishpurch
garbage
travel
planthire
agtrans
Gasoilreal
0.8
0.4
0
-0.4
-0.8

Figure 6



TIME TREND
1992
Facteur 2
3.0
1.5
0
-1.5
1992.
1993.
1994.
1995.
1996.
1997.
1998.
1999.
2000.
2001.
2002.
2003.
2004.
2005.
2006.
2007.
2008.
IOI5
WTIO5
Q2
LOW SEASON
+ ENSO
HIGH
SEASON
-3
-2
-1
0
1
2
Facteur 1
2008

Figure 7


1.00
0.75
0.50
0.25
0.00
1992
1994
1996
1998
2000
2002
2004
2006
2008

Annex 1: List and description of the fields (variables) in the project database

Field	Description
Portdues	Port charges and costs related to entering and leaving ports such as pilot fees.
Agencyfee	Administrative fees paid to agencies
Shipchand	Shipchandling costs
Telephone	Expenses paid to phone companies for telephone, telex and fax services
Travel	Cost of car hires and travel agents
Stevedorin	Labour cost for stevedores
Agenttrans	Expenses paid to shipping agencies for transport such as for crew change
Advtomast	Advance to master
Water	Payments made for water consumption
Planthire	Cost of plant hire, sundry bill
Crewsalary	Payment of salaries for Seychellois crew
Marinebrok	Marine broker fees
Fishpurch	Purchases of fish
Garbage	Cost for removal of garbage and waste oil
Casulabour	Payment for casual labour
Bondcertif	Bond forms (tax)
Hospmedic	Medical expenses such as hospital bill, pharmacies, dental services
Custombill	Government taxes such as clearing, import cargo charge, cartage & delivery

Staffovert	Payment of overtime for agency staff
Electserv	Costs of electronic services and refrigeration
Miscelfuel	Cost of miscellaneous fuel other than gasoil and fuel oil
Slipengine	Cost of repairs and maintenance for marine and engineering works
Others	All other miscellaneous charges: see note below*
Offhourent	Costs accommodation for crew
TotalNoOil	Total expenditures excluding gasoil and fuel oil
Gasoil_Rs	Cost of gasoil
Fuel_Rs	Cost of fuel oil
GrandTotal	Total expenses (including gasoil and fuel oil)
TotalExpend('000)	Total expenses (including gasoil and fuel oil) in r1000
Effort	Purse seine fishing effort (fishing days)
TotalCatch	Purse seine total catch (mt)
Landing	Purse seine total landed/ transhipped catch (mt)
%Land/Catch	% Of catch landed/transshipped in Port Victoria
CPUE	Catch per unit effort (mt/fishing day)
* Others	Contains aggregated data for when variables are not specified or are grouped. Also, other expenses such as hardware/maintenance related supplies, rental of shed & yard, bamboo for FADs, insurance, shipping voucher, licensing fees, renewal of bonded warehouse administration, import rent, fire safety equipment purchase or repair, payment made to Seychelles Breweries ltd for drinks, payment made to bookshops,

	storage rent etc are classified as others.