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Impacts of climate variability on the tuna economy of Seychelles

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I

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

42
43 KEY WORDS: Climate variability, ENSO, tuna fisheries, Seychelles economy
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45
46

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). Coincidentally, 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).

97

98 Centrally located relative to the most productive tuna fishing grounds of the Indian Ocean, PV
99 consolidated its position as the major regional hub early in the development of the purse-seine
100 tuna fishery. The fishery is dominated by European-owned fishing vessels and under current
101 fishing agreements, the European Union (EU) and ship-owners paid 4.7 million euros (€) and
102 6.5 million € in 2005 and 2006, respectively, for access rights to the exclusive economic zone
103 (EEZ) of Seychelles (source: DG MARE). Since 1992, annual catches by the purse-seine tuna
104 fishery have varied between 250,000 and 400,000 t, with a trend of increasing annual growth
105 up to 2007 (Fig. 2). The percentage of tuna caught by the fishery and landed or transhipped in
106 PV has grown to over 90% in recent years. The development of the fishery peaked in 2006,
107 when around 1.1 million tonnes (t) of tuna (54% skipjack tuna, *Katsuwonus pelamis*; 36%
108 yellowfin tuna, *Thunnus albacares*; and 10% bigeye tuna, *Thunnus obesus*) were caught in the
109 Indian Ocean (source: IOTC), constituting one quarter of the global catch.

110

111 The importance of tuna to the Seychelles economy has been enhanced through expansion in
112 tuna canning capacity. Presently, the cannery (Indian Ocean Tuna Ltd) is one of the biggest in
113 the world with an average daily processing capacity of 350 t. Co-owned by foreign investors
114 (60%) and the Government of Seychelles (40%), it is a major employer of the domestic
115 economy with 1,975 workers in March 2007, of which 1,149 were local workers (58%) and
116 826 expatriates (42%). The company represents 19% of the formal employment in the private
117 sector, and accounts for more than 90% of national exports (source: CBS). Most canned tuna
118 exports are destined for Europe and Seychelles accounted for a 13% share of the European
119 market in 2007. However, the position of Seychelles has been eroded by the rise of competing
120 countries like Ecuador and Thailand, which rose above Seychelles in terms of European
121 canned tuna market share after 2006. This erosion is partly due to the pervasive changes of

122 trade rules under the World Trade Organisation (WTO) and is also dependent on the
123 availability of raw materials for processing.

124

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

131

132

2. METHODS

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

147

148 We employed the following climate indices in the analyses: (1) the Dipole Mode Index
149 (DMI), the east-west temperature gradient across the tropical Indian Ocean; (2) the Indian
150 Oscillation Index (IOI), the difference in sea level pressure standardized anomalies between
151 Seychelles and Darwin; (3) the Southern Oscillation Index (SOI), the difference in sea level
152 pressure standardized anomalies between Tahiti and Darwin, and (4) the Western Tropical
153 Indian Ocean sea surface temperature index (WTIO), the surface temperatures in the region
154 50°E - 70°E, 10°S - 10°N.

155

156 **2.1. Estimating spillover effects using a multiplier approach**

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

168

169

170

171

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

197 to take into account the seasonal behaviour of the variables. An unrestricted constant had to be
 198 used in the model when the I(1) variables presented linear trends and an intercept different
 199 from zero in the cointegration vectors. The Akaike Information Criterion (AIC) (Lütkepohl
 200 2005) determined the number of lags included, 4 being the maximum. Additionally, the model
 201 was checked for the absence of any statistical problems before determining the number of
 202 cointegration relationships, including autocorrelation LM tests up to order 4 (Johansen 1995)
 203 and the Jarque-Bera Normality test, with the results showing that the model was correctly
 204 specified.

205

206 *MS-VECM*

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

217

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

$$221 \quad \Delta x_t = \mu(z_t) + \sum_{j=1}^k A_j(z_t) \Delta x_{t-j} + \Pi(z_t) \Delta x_{t-1} + u_t \quad (3)$$

222 Where:

223 $x_t : (s_t, f_t^2, \dots, f_t^k)$; s_t = landings (in log terms); f_t^i = effort or input i ($i=2, \dots, h$) at time t ; $\mu(z_t)$

224 is a k dimensional vector of regime-dependent intercept terms; $u_t \sim NID(0, \Sigma(z_t))$;

225 $\Pi(z_t) = \alpha\beta'$; the state $z_t \in \{1, \dots, M\}$, M being the number of regimes.

226

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

233

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

241

242

3. RESULTS

243

3.1. Spillover effects estimated by a multiplier approach

244

245

246

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) SR₂₀₀₁ (i.e. 35 M€;
 average 1992-2006), the coefficient of induction was 1.57 (Fig. 4). In other words, every 100

247 SR spent by the PSTF in PV leads to a final net amount of 160 SR for the Seychelles
248 economy. The average 1992-2008 direct expenditure of the fleet was valued at 203 MSR₂₀₀₁
249 (29 M€) while the spillover (indirect and induced expenditures) effects were estimated at 181
250 MSR₂₀₀₁ (26 M€). Thus, a net induced contribution represents close to a 100% increase for the
251 rest of the economy. Including IOT expenditures and their spillover effects, the coefficient
252 rises to 2.50.

253
254 The evolution of direct, indirect and induced effects over the study period reveals an erosion
255 of the coefficient of induction, concurrent with the elevation of total expenditure due to the
256 steady fuel price increase since 2000 (Fig. 4). Interestingly, all types of effects show an
257 inflexion point in 1998, year of the main impacts of the 1997-98 warm event in the WIO (with
258 a mechanical increase of the induction coefficient due to lower expenses that particular year).
259 In 1998, the direct, indirect and induced effects declined by 58%, 34% and 60% (52%
260 decrease overall), respectively, compared with a yearly growth trend of 17%, 4% and 11%
261 (12% increase overall) for the same effects, respectively.

262 263 **3.2. Climate effects on purse seine vessel expenditures**

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

270

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

283

284 **3.3. Climate effects identified using cointegration and Markov analyses**

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

286 Prior to examining cointegration relationships, autocorrelation LM tests (4 lags; statistic: 3.10;
287 $p=0.54$) and the Jarque-Bera normality test (statistic: 7.35; $p=0.12$) determined that the model
288 was specified correctly.

289

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

294

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

$$297 \quad CHC_t - 1219592 - 116.12 \text{LANDING}_t = \varepsilon_t \quad (1)$$

298 CHC increase by 116 SR when total landings and transshipments in PV increase by 1 tonne (t).
 299 This proportionality of 116 SR/t of fish landed/transhipped corresponds well with the average
 300 unit price over the period. On average, with a standard level of 61,632 t landed/transhipped
 301 per quarter (mean 1992:1-2008:2), the estimated CHC expenditure would be of 8,376,092
 302 SR₂₀₀₁. Other things being equal, a 40% cut of landings caused by a warming event as extreme
 303 as that of 1997-1998 would result in a total CHC expenditure of 5,513,492 SR₂₀₀₁ per quarter,
 304 equating to a 34% loss for the local economy.

305

306 *Markovian analysis of the relationship between bunker costs and landings/transshipment*

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

310

311 The cointegration equation can be written as:

$$312 \quad \ln(\text{landing}) = 0.442 \log(\text{gasoil}) + 3.327 \quad (2)$$

313 \quad \quad \quad (0.071) \quad \quad \quad (1.215)

314 (): Standard deviation

315

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

320

321 Over 42 observations, the probability of entering the first (high) regime (p^*) is close to 0
322 (lower than 0.05) for 16 observations and is close to 1 (greater than 0.95) for 21 observations.

323 The lowest values of p^* generally occur when the variation in landings/transshipment is
324 strongly negative (11 observations over 15); this occurs mainly during the second quarter
325 when the vessels often land in other regional ports (11 obs. out of 16 are second quarters).

326 Consequently, regime 2 can be interpreted as a low regime for landings at PV. While not
327 defined by 3 quarters entering the low regime, 2007 was the only year since 1998 for which
328 there were two consecutive quarters in regime 2.

329

330 The best model was obtained with the IOI, the other models exhibiting a lower level of
331 significance (Table 3). With the WTIO, the model did not validate the significance of climate,
332 even at a 90% level, and the results are not shown. For all the climate index models, the
333 seasonal dummy variables exhibit the expected sign, i.e. negative for the second quarter and
334 positive for the first and third quarters. In terms of the IOI index, any strong deviation from
335 the mean decreases significantly the probability of entering the high regime of landings at PV.

336 Looking at the IOI values, the strongest deviations of the index were negative for the last
337 quarter of 1997 and first quarter of 1998, during the strong ENSO episode. To a lesser extent,
338 the SOI and DMI climate indices also have a negative and significant impact on the regime.

339 Any important variation of the climate index could have a depressing influence on
340 landings/transshipments in Seychelles (i.e. entering regime 2).

341

342

4. DISCUSSION

343 The findings of this study are suggestive of a link between climate variability and the tuna
344 economy of Seychelles. While it is recognized that causality has not been demonstrated, the

345 coincidence of a severe warming event in late 1997 and 1998 (Murtugudde et al. 2000) with
346 significant disruptions to the PSTF and loss of revenue for the national economy is
347 compelling evidence for a climate effect. Within the period corresponding to our expenditure
348 dataset (1992-2008) there have been several warming events in the WIO, some moderate
349 (2003 and 2004-2005) and some relatively strong (1994 and 2006-2007), none of which have
350 resulted in an PSTF expenditure response comparable to that experienced in 1997-1998. This
351 pattern may be expected as moderate temperature anomalies in the Indian Ocean do not strongly
352 affect the surface habitat of yellowfin tuna (Ménard et al. 2007). As strength of a climate
353 anomaly appears critical in terms of the economic impact, future research should investigate
354 thresholds to facilitate adaptive management responses.

355
356 Although the underlying changes to the fishery differ, the economic impacts of the 1998
357 warming event can be considered as an extended low season. In the Indian Ocean, the PSTF
358 demonstrates a high level of spatial mobility as they follow seasonally varying patterns in
359 abundance and accessibility to surface gear (Miller 2007). Seychelles normally experiences
360 seasonal lows in landings and transshipment during the second quarter of the year, when the
361 fleets target tuna in the northern Mozambique Channel and operate out of other regional ports.
362 In other quarters, landings at PV are higher and generally stable between years. However, in
363 1998, the 2nd quarter low season was bracketed by low levels of vessel expenditures in the 1st
364 and 4th quarters, leading to depressed annual revenue.

365
366 Economic impacts resulting from climate oscillations are acute compared to the chronic
367 changes that may characterise climate regime shifts, which are also more difficult to measure
368 or predict (Arnason 2007). After accounting for inflation and seasonal variation, all PSTF
369 vessel expenditures were sensitive to the 1998 oscillation, the extent of which was dependent

370 on the relative strength of inter-annual trends in landings, transshipment and service unit costs.
371 For the cargo handling costs, it was estimated that the 1998 episode had a negative impact of
372 34% on the PSTF expenditure in PV, in line with the cut in landings and transshipment for that
373 year and after taking into consideration the trend and seasonal components. Interestingly, this
374 impact is comparable to ENSO impacts on the Chilean and Peruvian fishmeal fisheries, where
375 the social welfare loss due to ENSO was estimated to be 42% below a normal year of
376 reference (Sun et al. 2001).

377

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

395

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

415

416 Similar to many SIDS situated in productive tuna fishing zones, Seychelles has come to rely
417 heavily on a 'tuna economy' as the world demand for tuna has grown steadily over recent
418 decades (Campling et al. 2007; Campling & Havice 2007). The importance of the Seychelles
419 tuna economy was, for the first time, estimated using a multiplier approach. However, beyond

420 the impact on the domestic wealth, of greater importance is the presence of the cannery for
421 national employment, since it represents 19% of private sector employment and 6% of total
422 employment. Landings to IOT create higher levels of employment than transshipment of frozen
423 tuna from purse-seiners to reefers. Given that the availability of tuna in the area of the
424 Seychelles EEZ is at the core of competitiveness for the canning industry, the socio-economic
425 implications of climate oscillations are severe. As evidence, the warming episode of 1998
426 resulted in major disruptions in IOT production and employment levels lasting for several
427 months.

428
429 Changes in the distribution and magnitude of fisheries resources will have important socio-
430 economic consequences at national and regional levels (Arnason 2007, Miller 2007, Sun et al.
431 2006). Climate change scenarios predict modification of skipjack tuna habitat and distribution
432 in the equatorial Pacific with implications for the important tuna economies of Pacific island
433 countries (Loukos et al. 2003). Considering commercially exploited species as a whole, catch
434 potential is predicted to decline across the tropical oceans under climate change scenarios
435 (Cheung et al. 2009), heightening the vulnerability that already characterises many tropical
436 countries (Allison et al. 2009). While climate change and variability are two of many factors
437 affecting fish stocks, not least of which is fishing pressure, their incorporation in population
438 and bio-economic fisheries models will be increasingly important for assessment, prediction
439 and management (e.g. Sun et al. 2006).

440
441 Given that trade in tuna and tuna products is international, the socio-economic effects of
442 climate variability in Seychelles are not limited to events in the WIO. Global price trends for
443 tuna are sensitive to the effects of ENSO acting on tuna fisheries in other regions. For
444 example, Taiwanese tuna purse seine fisheries in the south-western Pacific Ocean experienced

445 the effects of overproduction and a 50% drop in price at the major auction market in Thailand
446 during the 1998-2000 La Niña (Sun 2007).

447

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

464

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469 National Climate Change Committee for their support and encouragement during the study. L.

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471 the valuable contribution of data and information by numerous stakeholders and institutions in
472 Seychelles, and to Seychelles Fishing Authority for maintaining such excellent data collection
473 systems and databases since the development of the tuna industry.

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595 Under-estimating small-scale fisheries in the Pacific. Mar Resour Econ 21:355-374

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598

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

601

| Price relationships | Null hypotheses for the cointegration tests ^a | | | |
|---------------------|--|--------------------|----------|-------|
| | Rank = 0 | | Rank = 1 | |
| | 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

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604 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 |

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616 Table 3. Least squares regression model results for the Indian Oscillation Index (IOI),
 617 Southern Oscillation Index (SOI) and Dipole Mode Index (DMI). Dependent variable:
 618 PSTAR (P*); Adjusted sample: 1998Q1 – 2007Q3; 39 observations. Variable coefficients
 619 given for intercept (C), dummy variable (D1, D2, D3) and the climate index, with t-statistics
 620 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 | | | |

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631 **Figure legends**

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

634

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

638

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

641

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

644

645 Fig. 5. Factorial map of the (deflated) purse-seine vessel expenditure variables. The inter-
646 annual (time) trend is descending along factor 2 (vertical axis), the seasonal trend along factor
647 1 (horizontal axis). The first 2 Eigen-values accumulate 71% of the total variance.

648

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

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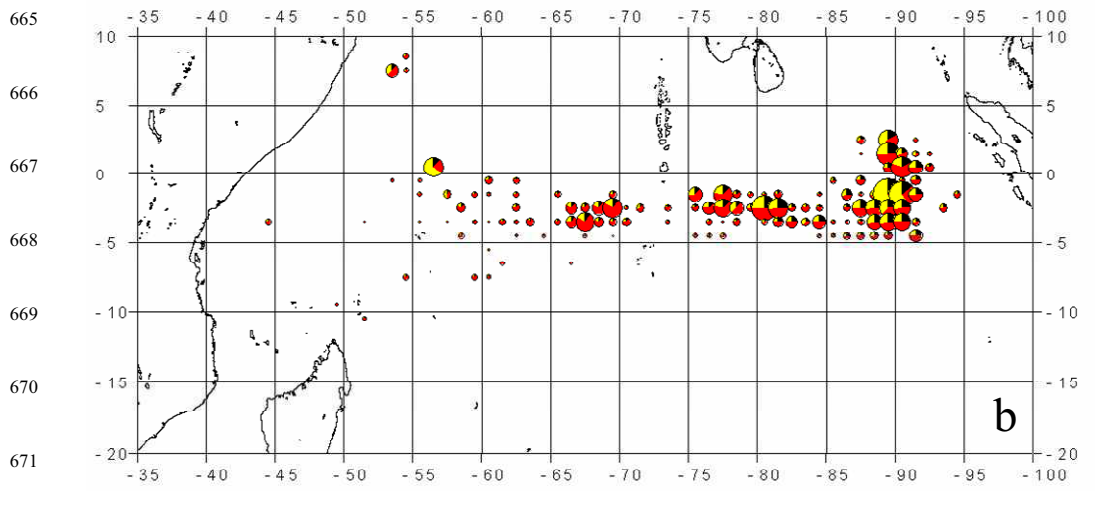
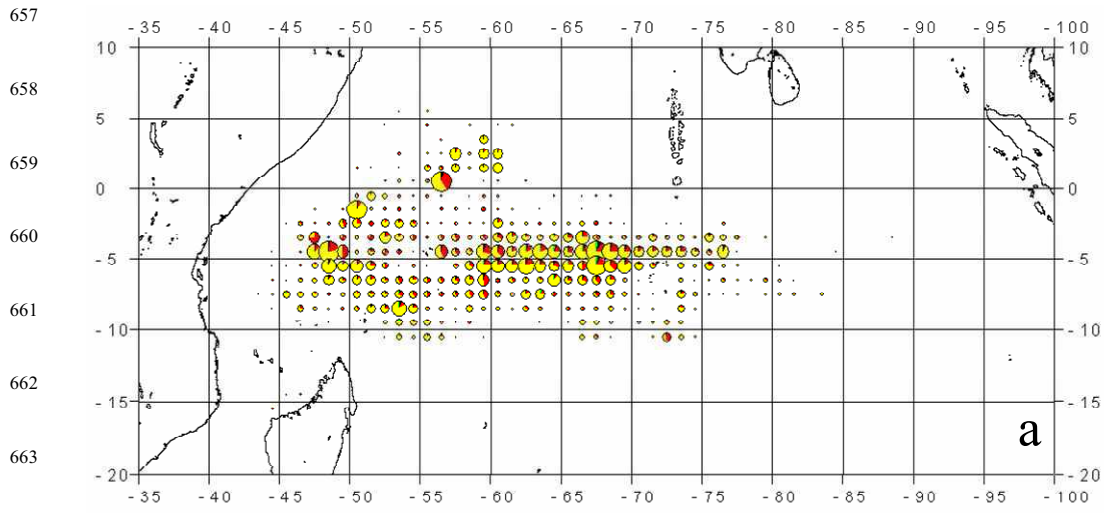
651 Fig. 7. Results of the MS-VECM model expressed as probability of entering a regime of high
652 level of landings (Regime 1).

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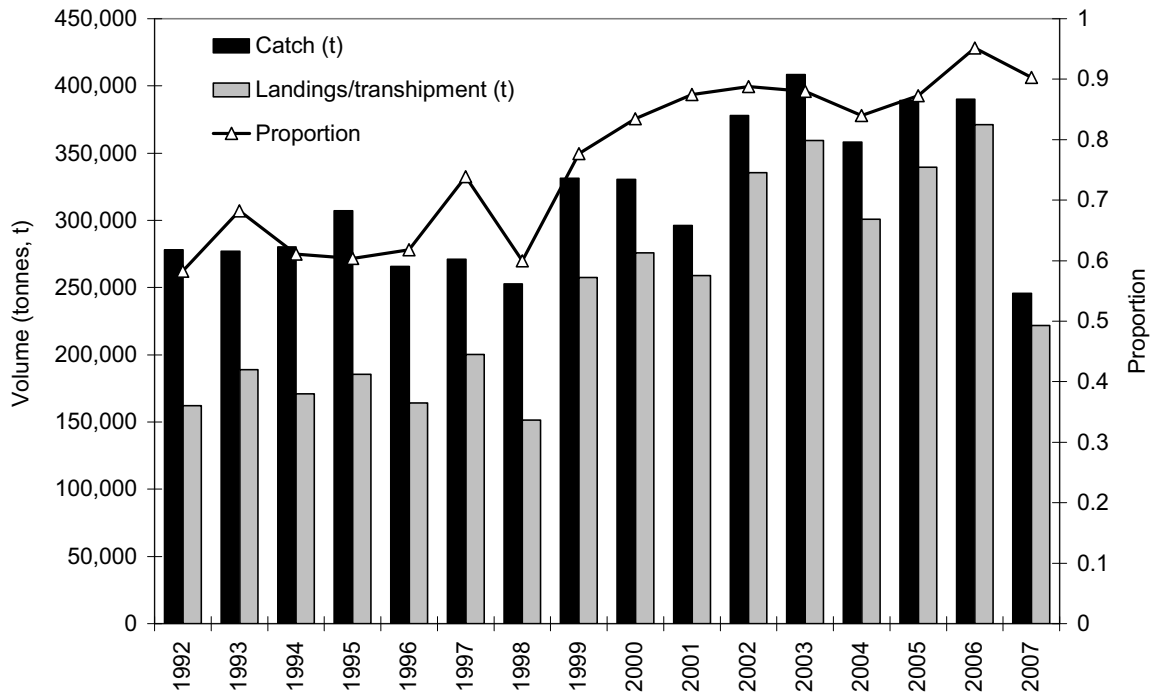
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656 **Figure 1 (a,b).**



681 **Figure 2**



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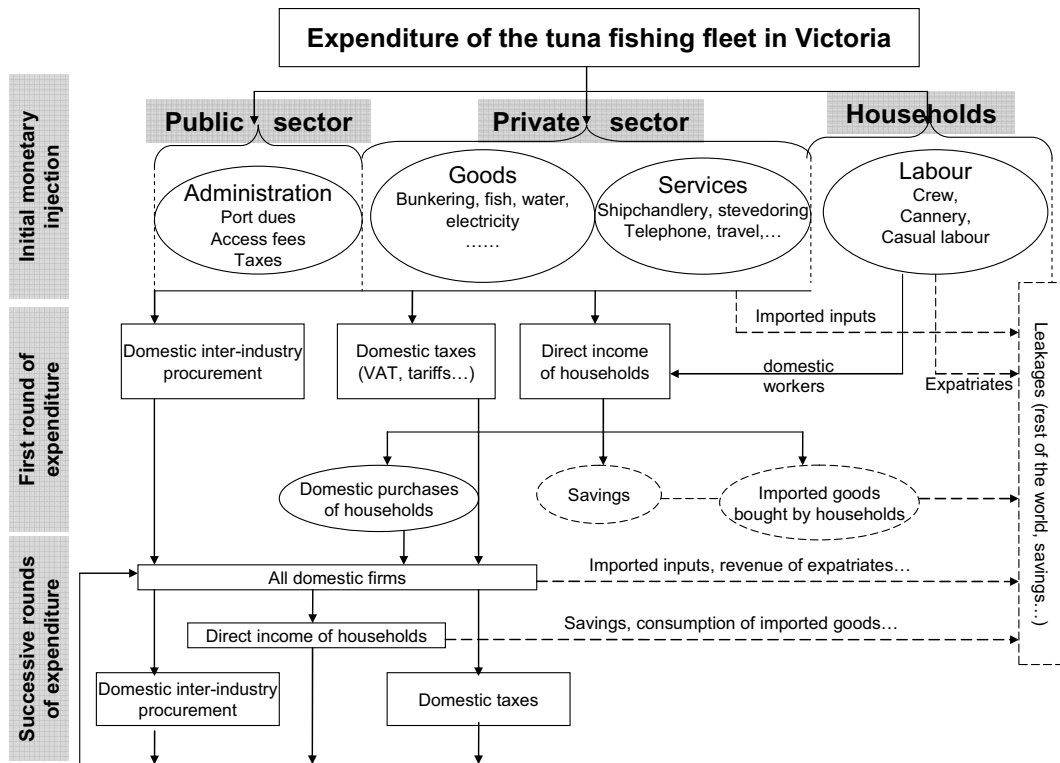
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Figure 3



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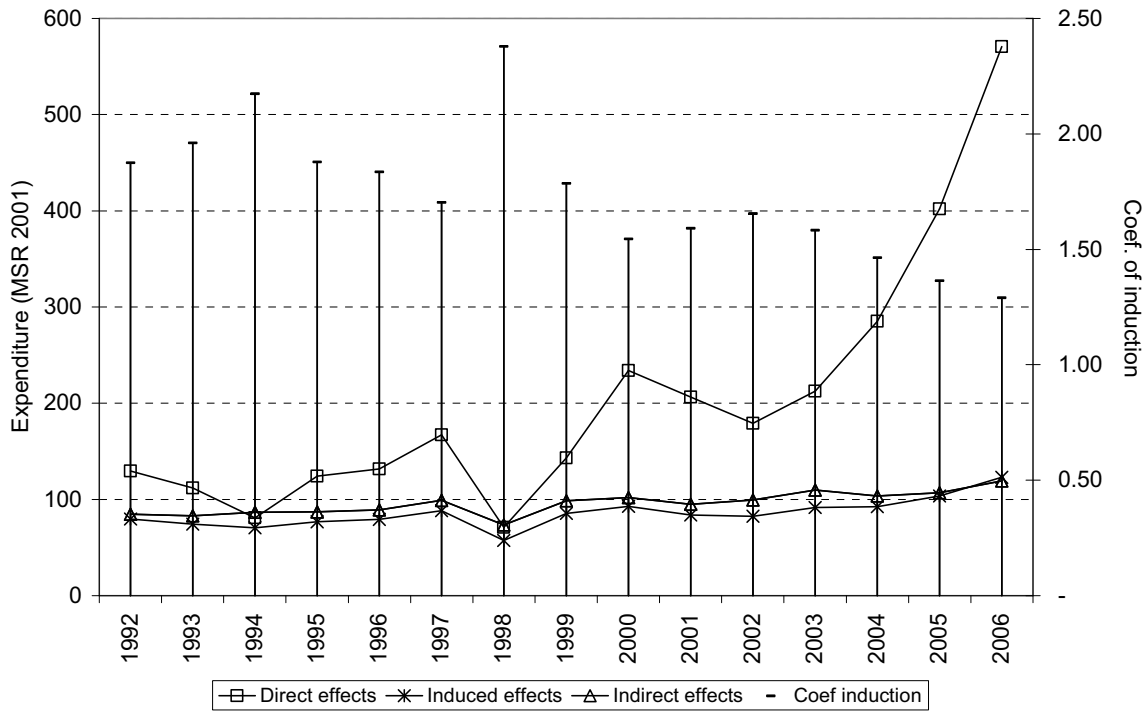
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713 **Figure 4**



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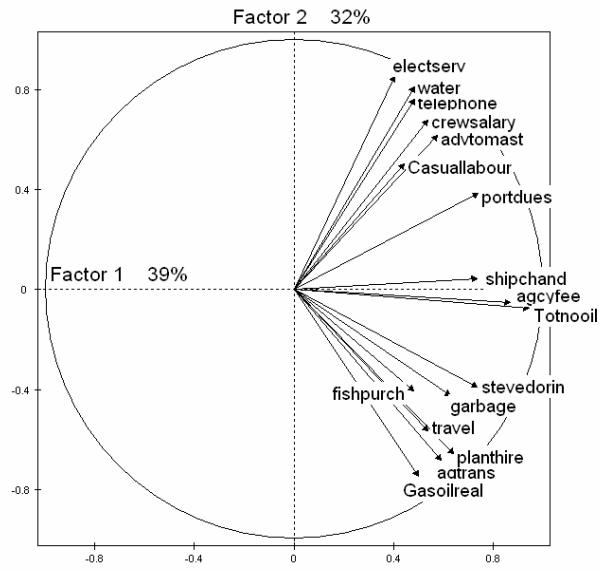
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729 **Figure 5**



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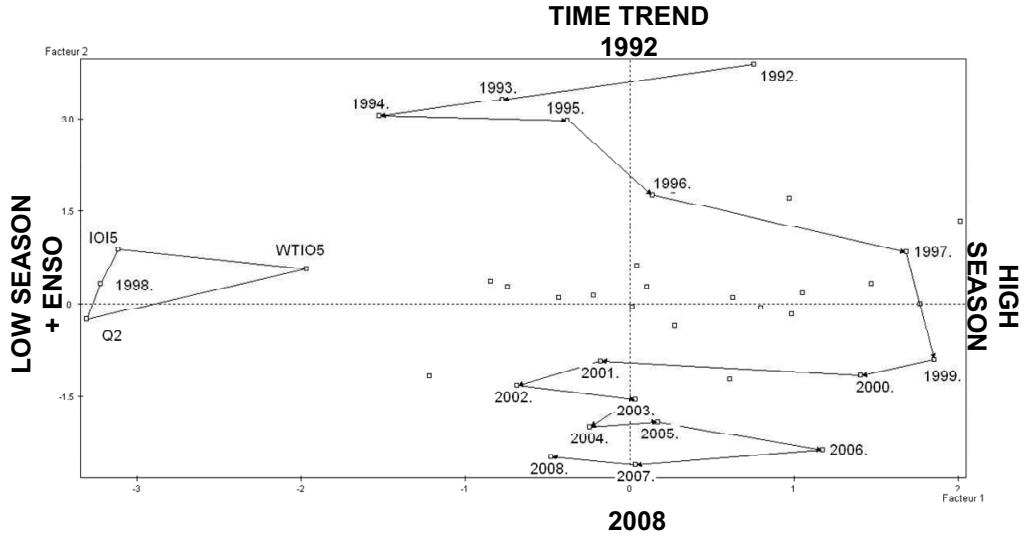
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748 **Figure 6**

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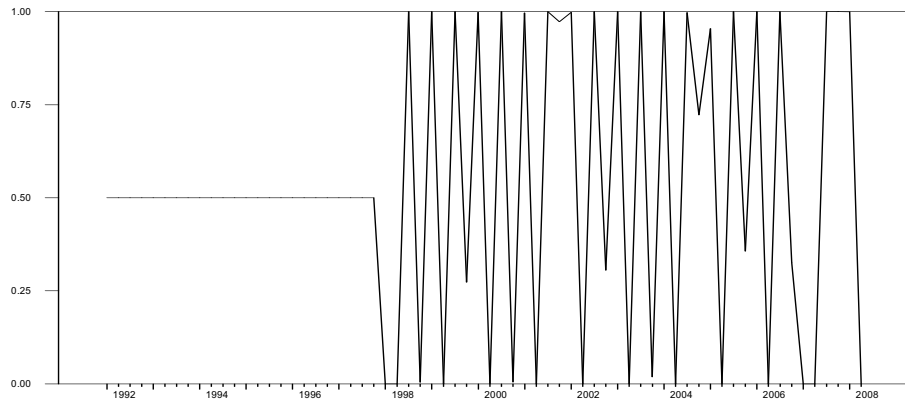
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765 **Figure 7**



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

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| 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 | <p>Contains aggregated data for when variables are not specified or are grouped.</p> <p>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,</p> |

storage rent etc are classified as others.