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Seawater temperature, *Gambierdiscus* spp. variability and incidence of ciguatera poisoning in French Polynesia

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Abstract

In the context of global warming and climate change, ciguatera disease is put forward as an indicator of environmental disturbance. However, to validate this indicator, some unknown parameters such as the delay between environmental perturbation and outbreaks of ciguatera need to be investigated. The main goal of this study was to investigate the temporal link between the growth of *Gambierdiscus* spp., and one of its influencing factors and the declared cases of ciguatera disease in humans. Algal cell density and seawater temperature (SWT) were recorded monthly from February 1993 to December 2001 on the Atimaono barrier reef of Tahiti Island. Reports of ciguatera cases were obtained from three community health clinics near the study sites. The autoregressive integrated moving average model (ARIMA) shows: (1) SWT were positively associated with *Gambierdiscus* spp. growth at a lagtime of 13 and 17 months ($p < 0.001$); (2) *Gambierdiscus* spp. growth measured at a given time is related to a peak number of cases of ciguatera recorded 3 months after peak densities of this dinoflagellate ($p < 0.001$). These results allow the construction of a predictive model of the temporal link between ciguatera disease in humans and its etiologic agent: *Gambierdiscus* spp. This model constructed by using 1993–1999 data, then validated by 2000–2001 data, demonstrates an appreciable ability to predict changes in the incidence of ciguatera disease following algae blooms.

Keywords: ARIMA model; *Gambierdiscus* spp.; Ciguatera; Forecasting; French Polynesia; Prevention tools

1. Introduction

Ciguatera poisoning is the most common and widespread seafood poisoning afflicting approximately 50,000 victims every year in the world (Fleming et al., 2000). This ichtyosarcotoxism is endemic in tropical areas spreading from 35°N to 35°S

Abbreviations: ARIMA, autoregressive integrated moving average; SWT, seawater temperature; CTX, sciguatoxins; ACF, autocorrelation functions; PACF, partial autocorrelation functions; IACF, inverse autocorrelation functions; AICA, kaike information criterion; CCF, cross-correlation function; MA, moving average; AR, autoregressive

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latitudes (Bagnis, 1992; Chinain et al., 1999; Hales et al., 1999), French Polynesia being one part of the world highly affected with an annual incidence of 330 per 100,000 in 1999 (data from the Health Directorate, French Polynesia, 2001).

Ciguatera disease is characterized by a myriad of rapidly appearing gastrointestinal, neurological and cardiac symptoms, manifesting in just a few minutes to a few hours following the ingestion of contaminated seafood (Swift and Swift, 1993; Van Dolah, 2000). While this seafood illness presents a low fatality rate (<0.1%), its severity, long-term health effects and economic impacts make it a serious public health problem (Fleming et al., 2000).

This seafood poisoning is essentially induced by the ingestion of reef fish that have been contaminated by highly potent neurotoxins, named ciguatoxins (CTXs) (Swift and Swift, 1993; Van Dolah, 2000). CTXs are mainly produced by a dinoflagellate of the genus *Gambierdiscus,* amongst which the best known *Gambierdiscus toxicus* was first discovered in the Gambiers Islands (French Polynesia) (Yasumoto et al., 1977). These microalgae live on coral reef in epiphytic association with a range of other macroalgal species. Distribution and growth of these dinoflagellate communities seem to be influenced by abrupt changes of their natural environment such as hurricanes, storms, heavy rains or by gradually changing environmental factors such as seawater temperature, salinity, and nutrient concentration (Carlson, 1984; Gillespie et al., 1985; Bomber et al., 1988; Chinain et al., 1999; Hales et al., 1999).

Various studies examining the impact of climate change and similar phenomena such as El Nino southern oscillation on the incidence of human diseases, particularly vector born diseases, have been published (Epstein et al., 1993; Colwell, 1996; Hales et al., 1999, 2000). Ciguatera disease by its vectoral nature appears to be one disease on which climate changes may have a significant impact. Recently, New Zealand researchers found a strong positive correlation between the annual incidence of ciguatera and local warming of surface seawater during El Nino conditions (Hales et al., 1999). According to these authors, increases in incidences of ciguatera may happen if the climate continues to warm as predicted by many leading climatologists. Ciguatera seems to be a sensitive indicator of environmental disturbance in tropical marine ecosystems (Hales et al., 1999).

On the other hand, it is currently recognized that CTXs are the main causal agent of ciguatera disease with a well-known mode of transmission (Lehane and Lewis, 2000). *Gambierdiscus* spp. are grazed by herbivorous fish and CTXs consequently bioaccumulate in the food chain with the highest concentrations found in fish viscera and head. Thus, it is reasonable to expect that ciguatera incidence in humans may be associated with *Gambierdiscus* spp. blooms. However, the time period required for the transmission of CTXs from the dinoflagellate to humans is still unknown.

Thus, the aim of this study was to improve our knowledge of the transmission of ciguatera through the food chain while focusing on the temporal aspect. More precisely, this study aimed to provide an estimate of the temporal relation between dinoflagellate abundance and one of its main environmental growth factors, i.e. seawater temperature. Furthermore, this study intended to investigate the temporal link between the growth of *Gambierdiscus* spp. and the number of reported cases of ciguatera disease from February 1993 to December 1999, in French Polynesia a territory located in the South Pacific Ocean.

2. Materials and methods

2.1. Data collection

Records of seawater temperature (SWT) and *Gambierdiscus* spp. abundance were documented in five different sites of the Atimaono barrier reef in the Papara district (Tahiti, French Polynesia) (Fig. 1) from February 1993 to December 2001. SWT and algae samples were collected on a weekly basis and cell densities of *Gambierdiscus* spp. were assessed microscopically (Chinain et al., 1999). SWT was recorded using a field thermometer (Testo 925; BIOTECK, France). SWT and *Gambierdiscus* spp. densities data analyzed here represent the weekly arithmetic mean from the five collection sites previously presented. These weekly data were then aggregated into monthly mean data in order to display them on a time-scale identical to that against which cases of ciguatera were recorded.

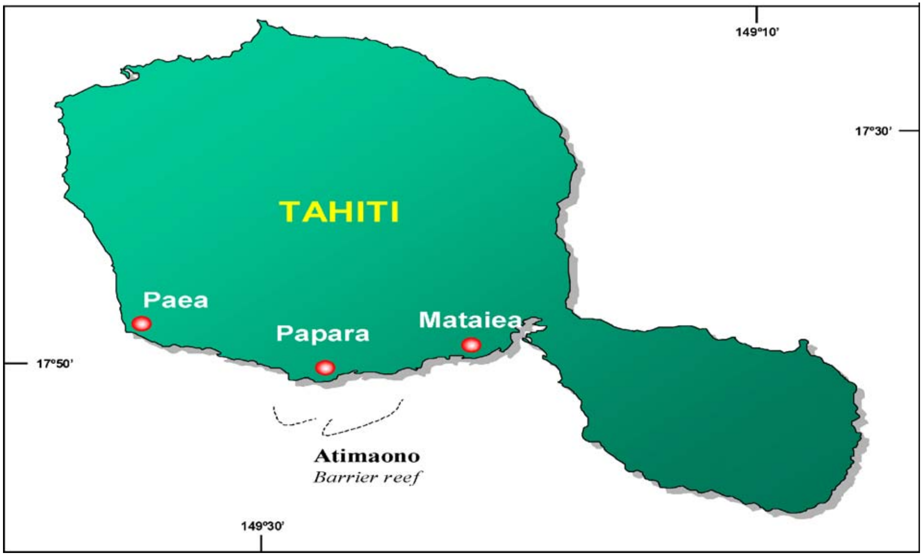

Fig. 1. Geographic location of Atimaono barrier reef in Papara's district and three clinics under study on Tahiti Island, French Polynesia. Map adapted from Chinain et al. (1999).

Cases of ciguatera were recorded by three different clinics near the area where SWT and *Gambierdiscus* spp. density were measured (Fig. 1). Data analyzed here correspond to the monthly ciguatera reports from the three health centers named, respectively, clinic of Paea, Papara, and Mataiea. The French Polynesian public health authority provided these monthly case reports. This institution supervises 82 health centers spread across the entire French Polynesian territory including public hospitals, dispensaries, and clinics that report cases of reportable diseases such as ciguatera poisoning.

2.2. Statistical analysis

In order to describe variables observed over a long period of time, specialized statistical techniques had to be used. Indeed, long series of consecutive points are sometimes joined by autocorrelations, and classic regression techniques presume the independence of residuals between time points (Box and Jenkins, 1976; Helfenstein, 1991; Nelson, 1998; Nobre et al., 2001). Thus, autocorrelation violates conditions of application of classic statistical tools and leads to incorrect tests of significance (Box and Jenkins, 1976; Nelson, 1998). Time–series analysis takes into account these autocorrelations and is one of the most appropriate approaches to address this issue (Box and Jenkins, 1976; Helfenstein, 1991; Lapointe, 1998). We performed confidence intervals of autocorrelation coefficients to test the presence of autocorrelation in the three different time–series analyzed here. According to conclusions obtained from these tests, autoregressive integrated moving average (ARIMA) models were used to describe the temporal pattern of the three different variables of interest.

For each variable, the identification of the best fit for the time–series model was based upon three consecutive stages, i.e. identification, estimation, and diagnostic steps (Lapointe, 1998; Nelson, 1998). The inspection of the crude time–series plot, the autocorrelation functions (ACF) plot, the partial autocorrelation functions plot (PACF), and inverse autocorrelation functions plot (IACF) allowed us to determine if a differentiation of crude series was required before creating the model and identifying parameters to be included in the model. Differentiating is necessary to obtain a stationary series that corresponds to series with a constant mean and variance through the time. The model's parameters were estimated by maximum likelihood method (Lapointe, 1998). According to the model selected and after checking the stationarity or the invertibility conditions, the Ljung–Box–Pierce statistics (known as the Q' statistics) were calculated in order to evaluate the goodness of fit of the model, i.e. residual series correspond to white noise (Box and Jenkins, 1976; Ljung and Box, 1978; Lapointe, 1998). This test was performed for the first 12 residuals of a series. We inferred that subsequent residuals would correspond to white noise if the first 12 were white. In the event that more than one model was retained, the Akaike information criterion (AIC) was used to compare models; the best model was the model with the lower AIC value.

To examine the impact of one series on another, i.e. the impact of SWT on *Gambierdiscus* spp. densities and the impact of *Gambierdiscus* spp. abundance on ciguatera case reports, we used transfer models applied in ARIMA context (Lapointe, 1998). This approach is based on the same statistical principle exposed before, but in this case the model is built in bivariate context. This allowed us to compute the cross-correlation function (CCF) between the residuals of two series introduced in the model. As presented before, we estimated parameters of the model and their p value. The goodness of fit of the transfer model was determined with Q' statistics that test autocorrelation of residuals and cross-correlation of residuals that are with noise. The AIC was also used to compare and to choose the best model.

We divided our data into two sets according to the time period. The first set was used to build models. This data set covered the period from February 1993 to December 1999. The second data set covering the period from January 2000 to December 2001 was used as the validation set to examine the forecast ability of the models previously created.

All statistical analysis was performed using SAS software release 8.02 (SAS Institute Inc., Cary, NC, USA) with a 5% threshold acceptance.

3. Results

Over the 7 years study period, the mean (±S.D.) value of monthly seawater temperature (SWT) was 27.7 (±1.0) °C. From January to July 1994, SWT monitored exhibited high temperatures, up to 29 °C and reaching 30.3 °C. Except for this period, SWT showed stable variation according to both seasons varying from 26 (minima) to 29 °C (maxima). A significant statistical difference was observed between mean SWT during hot and cool seasons (Table 1).

Table 1
Descriptive statistics of variables of interest from 1993 to 1999, and for cool and hot seasons, respectively

Parameters	Mean	I.C.[a]	p-Value[*]
Monthly seawater temperature (°C)			
All year	27.7	27.4–27.9	
Cool season[b]	27.1	26.8–27.4	<0.001
Hot season[c]	28.0	27.8–28.3	
Monthly *Gambierdiscus* spp. cell density (per g^{-1})			
All year	629.3	508.3–876.1	
Cool season	689.3	502.5–776.8	0.40
Hot season	585.5	426.1–745.0	
Monthly number of ciguatera cases recorded			
All year	2.3	1.1–3.4	
Cool season	2.1	0.3–3.9	0.81
Hot season	2.4	0.9–3.9	

[a] Confidence limit for mean at 95%.
[b] Cool season: from May to September.
[c] Hot season: from October to April.
[*] p-Value of difference between seasons.

However, no significant difference was revealed in mean dinoflagellate cell densities when both seasons were compared (Table 1). Similar negative results were obtained in mean monthly cases of ciguatera disease ($p = 0.81$).

The confidence interval of the coefficient of autocorrelation indicates the presence of significant autocorrelations for all variables, and prohibits the use of classic regression techniques. Indeed, SWT, and dinoflagellate cell densities showed a significant first order autocorrelation (SWT $r = 0.77$, I.C. [0.56–0.98]; dinoflagellate cell densities: $r = 0.38$, I.C. [0.17–0.60]) and monthly cases of ciguatera showed a 17th order autocorrelation ($r = 0.25$, I.C. [0.03–0.48]). All crude series had a stationary variance and mean except for SWT that displayed a seasonality, therefore a seasonal differencing at 12 months were applied to SWT series to reach stationarity.

The SWT series displays an autoregressive seasonal model (AR_{12} (1)). This model indicates that the SWT value depends on a fraction of previous month, plus fractions of value attained a year ago, plus a random error (p value of all parameters <0.001). The dinoflagellate cell density series follows an autoregressive model of order two that predicts the change in *Gambierdiscus* spp. community, in this region, as an average change of algae population, plus some fraction of the two previous months, plus a random error (p value of all parameters <0.001). Finally, monthly cases of ciguatera poisoning series follows a moving average model of order 17 (MA (17)) that indicates the variation in number of cases of ciguatera, a random error, plus some fraction of the random error in the 17th preceding months (p value <0.001).

3.1. Effect of SWT on Gambierdiscus spp. density

The transfer models obtained reveal a significant association between SWT and *Gambierdiscus* spp. cell densities (Table 2). SWT exerts a double impact on *Gambierdiscus* spp. cell densities at a 13-month lag (Model 1a: $p < 0.001$) and 17-month lag (Model 1b: $p < 0.001$). Among the three models presented in Table 2, the model retained in the validation process was the more complex model (Model 1b) that included double impacts. The Akaike information criterion of this model was the lowest (AIC = 1014) compared to others (Model 1a: AIC = 1083 and Model 1b: AIC = 1027). Q' statistics show that there was no significant autocorrelation (12th first order) in the residuals of the regression model (Table 2).

Fig. 2 represents the dinoflagellate cell density fluctuations estimated by this latest model versus the data measured during the period under study. This model appears relatively in accordance with measured data of the validation set when the forecasting procedure was applied on the model. The discordance observed between two curves is related to fluctuations in cell densities not explained by SWT, and highlights the potential influence of other factors in *Gambierdiscus* spp. growth.

3.2. Relation between Gambierdiscus spp. densities and case reports of ciguatera in humans

ARIMA analysis indicates that *Gambierdiscus* spp. cell densities seem to play a significant part in

Table 2
Transfer models relative to seawater temperature impact on dinoflagellate growth (Model 1), and dinoflagellate cell fluctuations impact on declared cases of ciguatera (Model 2)

Parameters	Estimates	Standard error	p-Value
Model 1a			
SWT at 13 lag	22.93	3.75	<0.001
AR (2)[a]	0.38	0.11	<0.001
Autocorrelation of residuals at lag 12	–	–	0.499
Cross-correlation of residuals at lag 12	–	–	0.148
Model 1b			
SWT at 17 lag	24.19	3.69	<0.001
AR (2)	0.34	0.11	<0.01
Autocorrelation of residuals at lag 12	–	–	0.592
Cross-correlation of residuals at lag 12	–	–	0.339
Model 1c			
Constant	−10575.8	3016.2	<0.001
SWT at 13 lag	141.41	72.91	0.055
SWT at 17 lag	−265.27	74.39	<0.001
AR (1)	0.26	0.13	0.039
Autocorrelation of residuals at lag 12	–	–	0.535
Cross-correlation of residuals at lag 12	–	–	0.458
Model 2			
Gambierdiscus spp. cell density at lag 3	0.004	0.0008	<0.001
Autocorrelation of residuals at lag 12	–	–	0.865
Cross-correlation of residuals at lag 12	–	–	0.674

Model 1a, b, c: different transfer models with *Gambierdiscus* spp. cell density as response variable and seawater temperature as explanatory variable. Model 2: transfer model with cases of ciguatera as response variable and *Gambierdiscus* spp. cell density as explanatory variable.
[a] Autoregressive component.

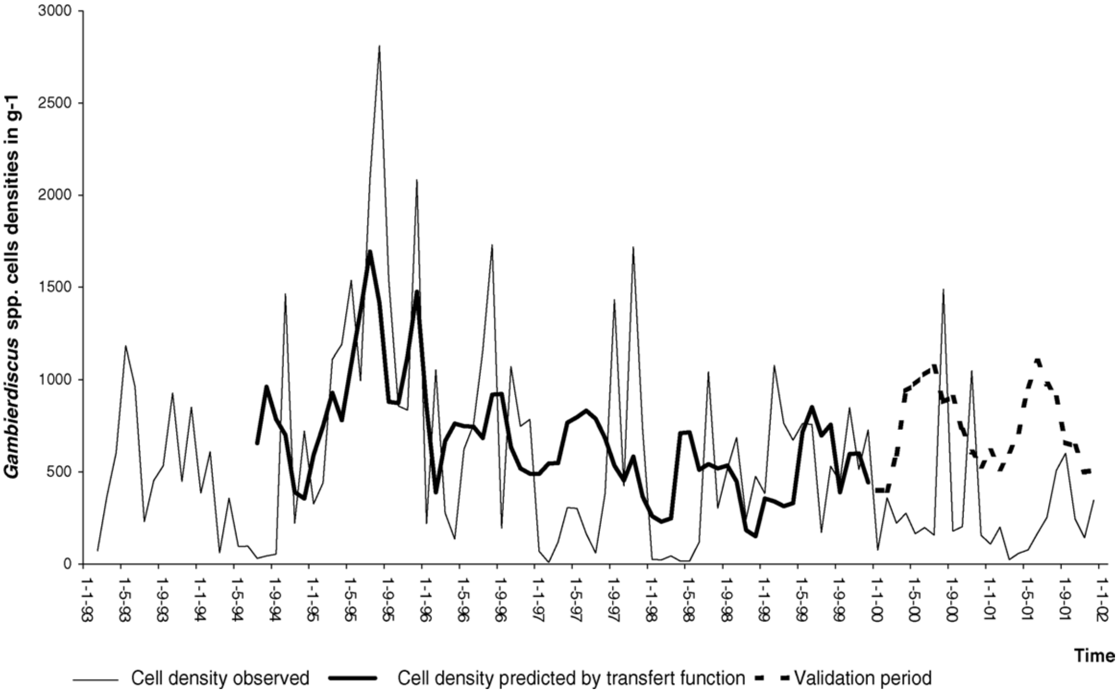

Fig. 2. Modeling of *Gambierdiscus* spp. cell densities from February 1993 to December 2001 in the Papara district as a function of seawater temperature. The thin solid line represents data on density measured during the study period; the thick solid line represents densities estimated by the transfer model, whereas the dashed line represents forecasts of *Gambierdiscus* spp. cell density from January 2000 to December 2001.

recorded cases of ciguatera poisoning. Specifically, the transfer model showed that the onset of the disease in human populations at a specific time is significantly related to the dinoflagellate cell densities recorded 3 months before (3-month lag: $p < 0.001$) (Table 2). Q' statistics show that there was no significant autocorrelation (12th first order) in the residuals of the regression model.

Fig. 3 presents the fluctuations of cases of ciguatera recorded from February 1993 to December 2001. The left side of the solid line in Fig. 3 shows the number of cases of ciguatera recorded over a 2-year validation period. As observed in this part of this figure, our model demonstrates a good ability to predict a varying number of cases of ciguatera as a function of *Gambierdiscus* spp. cell density fluctuations.

4. Discussion

The theory of the transmission of ciguatera disease from microalgae to humans through the food chain initially proposed in the early 60 s (Randall, 1958; Helfrich and Banner, 1963) is currently fully accepted. Furthermore, ciguatera incidence has been related to change in the marine environment (Carlson, 1984; Gillespie et al., 1985; Bomber et al., 1988; Chinain et al., 1999; Hales et al., 1999). However, this seafood poisoning is still an unpredictable disease. The delay between changes of environmental parameters, blooms of harmful algae producing ciguatoxins, and the appearance of ciguatera disease in humans remains unknown. This study is the first attempt to look into this question by analyzing simultaneously ecological and health data obtained from long-term surveillance.

The first results presented here confirm that dinoflagellate growth is strongly related to seawater temperature and is in accordance with previous experimental and observational findings suggesting that *Gambierdiscus* spp. abundance positively correlates with seawater temperature (SWT) (Carlson, 1984; Gillespie et al., 1985; Bomber et al., 1988; Bagnis et al., 1990; Lewis, 1992; Morton et al., 1992; Hokama et al., 1996).

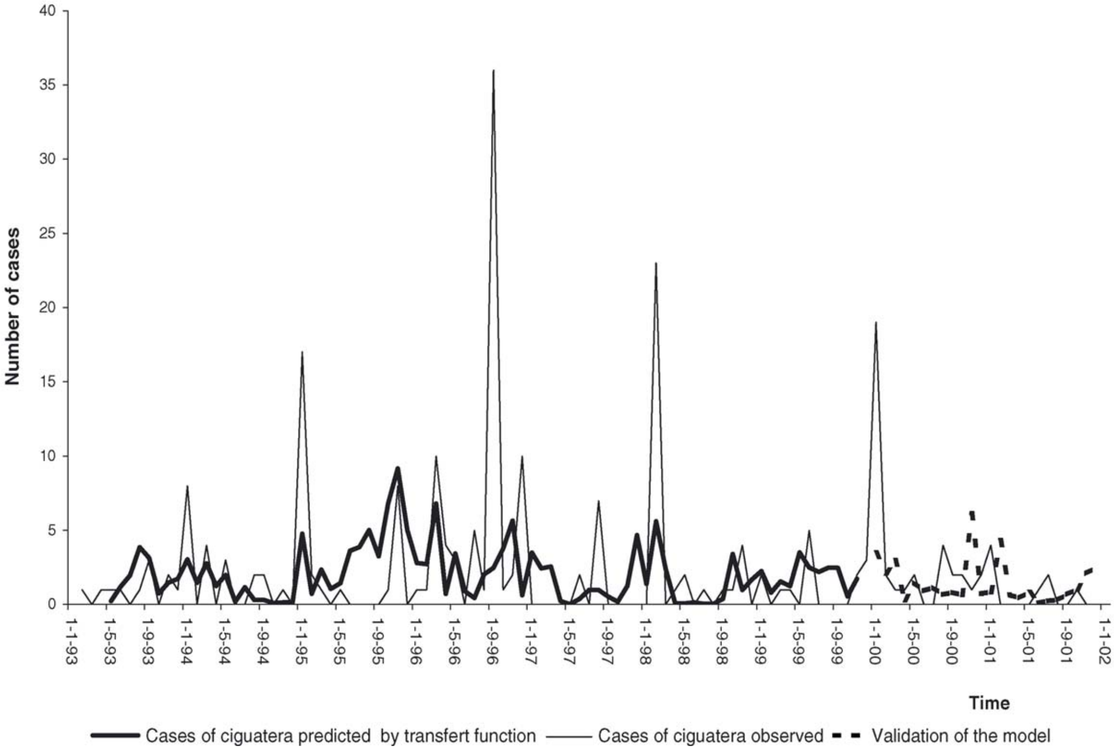

Fig. 3. Modeling of cases of ciguatera from February 1993 to December 2001 in the Paea-Papara-Mataiea district as a function of *Gambierdiscus* spp. cell density. The thin solid line represents cases of ciguatera recorded during the study period and the thick solid line represents cases of ciguatera estimated by the transfer model, whereas the dashed line represents forecasts of cases of ciguatera from January 2000 to December 2001.

In French Polynesia, earlier findings suggest that blooms of *Gambierdiscus* spp. occurred predominantly at the beginning and the end of the hot season (Bagnis, 1992; Chinain et al., 1999; Hales et al., 1999). In this study, our effort has been directed towards elucidating the lag of the impact of a change of SWT on *Gambierdiscus* spp. cell densities. Our results show a 13- and 17-month lag. A detailed description of events occurring during the study period revealed that the Atimaono reef barrier was exposed to a sustained elevated temperature concomitant with coral mass bleaching from January to July 1994. Then, increasing peak densities and frequency of *Gambierdiscus* spp. blooms were observed from the end of 1994, 1995 until 1996. These latest observations may explain lags found in our analysis. However, we performed time–series analysis excluding the years 1993 and 1994 in order to exclude abnormal events. We obtained similar lag results; the 13-month lag remained statistically significant and the 17-month lag became non-statistically significant (data not shown). This suggests that lags observed are not only related to an exceptional phenomenon. Moreover, events in 1994 adduce a biological plausibility of the 13- and 17-month lag found here. This time would be required to provide for *Gambierdiscus* spp. ideal conditions of growth such as dead coral as ‘‘new surfaces’’ for colonization (Bagnis, 1992; Chinain et al., 1999; Hales et al., 1999).

Nevertheless, we do not suggest that water temperature is the only factor affecting dinoflagellate growth, since *Gambierdiscus* spp. growth is related to numerous environmental factors such as salinity, nutrient concentrations, competition with other microalgae or else, the presence of epiphytic bacteria (Carlson, 1984; Morton et al., 1992; Morton and Faust, 1997; Sakami et al., 1999) as well as endogenous growth factors (Sakamoto et al., 1996). Differences observed between our model and measures of *Gambierdiscus* spp. growth highlight the importance of these other factors on algae growth. As an example, the model described here does not seem able to predict drastic decreases in cell concentrations near the zero value measured. The speed, with which dinoflagellate cells disappear, 1 month in some cases, rules out the involvement of the factors presented above but rather suggests occurrences of strong water motion that could have washed the cells away. This hypothesis is supported by labile features of attachment of this dinoflagellate on its macroalgal support (Nakahara et al., 1996), and is strengthened by climate perturbations reported during the period under study, such as the strong rainy period followed by the tropical storm named Ursula that came close to Tahiti in January 1998 (data provided by Météo France, French Polynesian department, 2001). The labile features of attachment of this dinoflagellate may also explain the variability observed between measures of cell densities in five collection sites. This could have probably weakened the temporal relation between SWT and *Gambierdiscus* spp. abundance. Despite the fact that our model does not explain all the cell variations of *Gambierdiscus* spp., it provides a main trend and allows us to propose SWT as a predictor of *Gambierdiscus* spp. cell abundance.

The seasonality of ciguatera poisoning has often been discussed in literature, but no consensus has been reached to date (Lawrence et al., 1980; Bourdeau and Bagnis, 1989). Ciguatera cases seem to occur predominantly from late spring to early summer in subtropical areas and tend to appear at any time in the tropics (Legrand and Bagnis, 1991). Our results show no seasonal pattern in the number of ciguatera cases declared. A monthly comparison presents January as the month with the highest number of cases of ciguatera disease (data not shown). It would be hazardous to present only 1 month as a ciguatera period, considering the numerous unknown factors likely to influence the number of intoxicated people. Indeed, this result could be strictly contextual and may be linked to the end of the year celebrations. However, we observed autocorrelations in the case report series that may imply other factors as predictors of ciguatera occurrences such as *Gambierdiscus* spp. dynamics.

The transfer model obtained highlights a clear temporal relation between ciguatera disease and *Gambierdiscus* spp. cell densities during the study period. Even though it is recognized that ciguatera outbreaks in a given area are more dependent on the clonal nature (i.e. species composition and toxin content) rather than the densities of *Gambierdiscus* cells, no identification of *Gambierdiscus* species was done in this study. Indeed, given that in this genus toxin production is more a strain-dependent rather than a species-dependent characteristic (Bomber et al., 1989; Tosteson et al., 1989; Holmes et al., 1991; Micouin et al., 1992), in the case of this study, species identification appears less critical than the actual toxicity of *Gambierdiscus* cells present in our sampling sites. Toxin content of *Gambierdiscus* populations was monitored on a weekly basis over a 2 years period (data not shown) and toxicity of sporadic blooms was also screened throughout the study period. Our data tend to indicate that toxin production is a constant temporal characteristic of these populations, and also show a relatively high toxicity of Tahitian blooms contributing to a high toxic reservoir in fish (Bagnis, 1992; Chinain et al., 1999; Hales et al., 1999).

All these considerations allow us to propose that the cyclical pattern of ciguatera poisoning suggested in the literature is related to fluctuations of *Gambierdiscus* spp. cell densities that produce the causative agent of ciguatera disease, i.e. ciguatoxins. Indeed, according to previous reports on sensitivity of the dinoflagellate towards its ambient temperature (Bomber et al., 1988; Bagnis et al., 1990; Morton et al., 1992; Hokama et al., 1996) and our results, it is possible to hypothesize that disparity of ciguatera occurrences in subtropical and tropical areas is attributable to temperature.

Our model is able to predict the emergence of ciguatera cases and demonstrates a good ability to detect a peak of the disease but it failed to discover the magnitude of the phenomenon. In other words, it cannot predict how many people will be intoxicated. This is essentially related to "dependent happenings" features of ciguatera poisoning, a concept quite similar to the one expressed by Sir Ross in 1916 in an infectious disease context (Halloran, 1998). Indeed, ciguatera outbreaks depend on context, on the number of people who share the same ciguatoxic fish as well as the type of fish consumed—herbivorous or carnivorous. Consequently, predicting the magnitude of ciguatera outbreaks would necessitate a much more complex model than the one proposed here and finally with benefits, in terms of prevention tools, no better than those obtained with our current model. However, this ability to detect the magnitude of peaks of ciguatera could be improved by replacing cell densities by toxicity of the blooms in the model. This was not done here because the screening of toxicity was monitored interruptedly.

The other methodological limitation of this study is related to the nature of cases recorded. Indeed, data prohibit distinguishment between sporadic cases and outbreaks. However, we performed time–series analysis with cases recorded in the entire Tahiti Island and we observed similar results as observed near the Atimaono zone (data not shown). This latest result allows us to think that our model is not strongly biased by a banquet bias.

In addition, our results may be biased by the well-known fact inherent to ciguatera disease: under-declaration. This limitation could have probably weakened the temporal relation between *Gambierdiscus* spp. abundance and cases of ciguatera observed in this study. However, we have no reason to think that this under-declaration changed over the period under study or in between the three dispensaries considered here. Moreover, we assumed that all ciguatera cases declared, and subsequently analyzed in this study were associated with fish harvested in Atimaono zones. With the data at our disposition, we had no means of distinguishing if people who reported ciguatera disease had really eaten fish harvested in this zone. However, considering the fishing tradition of people who live in this area, i.e. people consumed mainly fish caught locally, our assumption seems reasonable.

According to recent research, it appears that dynamic linear model techniques would be more appropriate given the geographical conditions and the distribution of the disease in the present study (Nobre et al., 2001). To date, unavailability of this modeling in current statistical software prevents, to date, its practical use. However, it will be interesting when this method is available to apply it in a future study in order to compare and validate our current results.

Despite these limitations, the present findings suggest an influence of climate, environmental modifications and dinoflagellate dynamics on disease pattern. The relation found here shows that in response to change in seawater temperature, a modification in *Gambierdiscus* spp. density appears 13–17 months later and that repercussions on human health might be observed 3 months later. In other words, a 20-month period, approximately, is necessary to observe a modification in human health after a modification of the ecological parameters of *Gambierdiscus* spp. growth. This was supported by results of the model on the influence of SWT on disease fluctuations that highlighted a 19-month lag (data not shown). The lags proposed here might be contextual and related to the study area. Thus, they require to be refined by future investigations. Nevertheless research outcomes from this study might be useful for assisting ciguatera risk management initiatives in endemic areas. The lag time found here suggest that practical application of our method in public health surveillance of ciguatera would be preferentially based on *Gambierdiscus* spp. monitoring program. As well, the results correspond to needs clearly expressed by numerous researchers in the last few years (Fleming et al., 2000; Moore and Shaw, 2000; Rose et al., 2001). Moreover, the dependence of ciguatera occurrence on temperature observed here and elsewhere (Hales et al., 1999) brings this seafood poisoning into the larger picture of climate change and human health and supports the expanding of early warning systems based on climate and environmental modifications.

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