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Possible recruitment of jack mackerel (*Trachurus muphyi*) from oceanic waters off Chile to the stock in Peruvian and Ecuadorian waters in 2010

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Abstract

Observations on the distribution of juvenile jack mackerel (*Trachurus murphyi*) of year-class 2008 suggest a movement of these fish from oceanic waters off Chile towards the waters of Peru and Ecuador in the second half of 2010. The year-class was observed in high numbers by the international fleet in the oceanic waters off Chile in June 2010, but they were found in much lower numbers in the following year. However, fish of the same length appeared in large numbers in the waters of northern Peru and Ecuador in late 2010, and it is likely these fish belonged to the same group that was observed half a year earlier in the waters off Chile. The second half of 2010 was characterised by a strong La Niña in the eastern Pacific. The increased residual current and cooling of surface waters may have influenced the distribution of juvenile jack mackerel, either by increasing their passive northward transport by an intensified Humboldt Current, or by stimulating the fish to actively migrate further north in search of warmer waters. It is assumed that juvenile jack mackerel recruit to the adult stock in the area where they find themselves at the time of first maturation. In this way, descendants from the stock off central Chile could incidentally recruit to the adult stock in Peruvian/Ecuadorian waters, thereby providing an occasional boost to this stock.

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1 Introduction

One of the key questions in the assessment and management of jack mackerel (*Trachurus murphyi*) in the south-eastern Pacific is whether all fish in this region belong to the same stock, or whether the fish in different parts of the area constitute autonomous stocks that should be managed separately. Until 2011 the Science Working Group of SPRFMO (South Pacific Regional Fisheries Management Organisation) used to conduct only assessments in which all jack mackerel from the south-eastern Pacific were combined. Consequently the group provided management advice that applied to the entire population in the south-eastern Pacific. The application of this advice sometimes gave rise to problems, as the population in the region did not appear to behave as a homogenous unit. In 2011 countries participating in SPRFMO conservation talks agreed to reduce catches by 40% from 2010 to 2011 in order to restore the stock (SPRFMO 2011). For Chile and the international fleet operating outside the Chilean EEZ, this reduction posed no problems as their catches decreased anyway due to a scarcity of fish in the southern waters. For Peru, however, the agreed reduction was impossible to apply in practice when the abundance of jack waters in its zone suddenly increased in 2011 (IMARPE 2012a).

The contrasting developments in 2011 between the stock in Peru and in the waters further south strengthened Peruvian scientists in their conviction that the fish in the Peruvian zone constituted a self-contained stock that should be managed separately from the one off Chile (IMARPE 2012b). From a biological point of view there are several arguments in support of this hypothesis. Serra (1991) concluded on the basis of catch distributions and information on spawning areas that two self-sustaining populations existed in the south-eastern Pacific; one off Peru and the other off Chile. Catches in Peru and Ecuador fluctuate independently from those off Chile, which means that the Peruvian and Ecuadorian fleets exploit a stock that is different from the one exploited by the Chilean fleet. The growth rate of the jack mackerel in Peru is different from the one in Chile (Dioses 2013), which implies that at least the adult fish in the Peruvian zone stay there throughout their life time.

However, genetic studies have not yet shown a clear difference between the fish in both areas (Cárdenas et al. 2009), which indicates that some exchange probably occurs. But even in the absence of genetic differences, the jack mackerel in the south-eastern Pacific could constitute a "metapopulation", i.e. a group of subpopulations or stocks that maintain their integrity over a period of years (Gerlotto et al. 2010, 2012).

The lack of genetic differences between the fish in Peru and Chile implies that at some stage an exchange of individuals between the two stocks must occur. This exchange will most likely take place during the juvenile stage. The main concentrations of juvenile mackerel in the south-eastern Pacific are encountered off northern Chile, just south of the border with Peru. From here the Chilean juveniles normally recruit to the adult stock off central Chile, but it is possible that they also occasionally move north and recruit to the adult stock in Peru.

This paper considers the possibility of such a migration of juvenile jack mackerel from Chilean waters to Peru, using observations on year-class 2008. This year-class showed some remarkable features in its distribution and abundance at the age of two years. Whereas it was first observed in large numbers in the waters off Chile in June 2010, its abundance in this area was much lower in the

following year. At the same time, however, a strong recruitment of this year-class occurred in Peru and Ecuador by the end of 2010, resulting in a large increase in catches in these areas. These observations suggest that part of the year-class that was first observed in Chilean waters could have migrated to the waters of Peru and Ecuador in the second half of 2010.

This hypothesis will be tested in two steps. First it will be investigated whether the length composition of the fish taken in Peru and Ecuador in late 2010 – early 2011 corresponds to the cohort that was earlier observed off Chile. Secondly it will be investigated whether the hydrographic conditions in the south-eastern Pacific during the second half of 2010 were particularly favourable for a northward transport of juvenile fish from the Chilean zone towards Peru.

2 Data

Landing data for the various fleets in the south-eastern Pacific were obtained from the report of the 2013 SPRFMO Science Committee (SPRFMO 2013). Catch positions for European trawlers of the PFA fleet (Pelagic Freezertrawler Association) in 2010 were kindly provided by the captains of the vessels. The length frequency distributions of catches by PFA trawlers were collected by scientific observers on board these vessels. Length distributions of catches in Peru were kindly provided by N. Niquen from IMARPE, and for catches in Ecuador by M. Peralta from the Instituto Nacional de Pesca.

Monthly data on surface temperature anomalies in the south-eastern Pacific were obtained from Columbia University (http://iridl.ldeo.columbia.edu/maproom/ENSO/SST_Plots/Monthly_Anomaly.html?T=aug%202010)

Unpublished results of habitat modelling for jack mackerel in the south-eastern Pacific were kindly provided by J. Habasque from IRD, France.

3 Results

3.1 Catches of jack mackerel in 2011 by different fleets

In order to illustrate the effect of the different recruitment in 2011 in the various parts of the south-eastern Pacific, a short review is presented of the catches by the different fleets in that year.

The fishery for jack mackerel in the south-eastern Pacific is conducted by fleets from the coastal states (Chile, Peru and Ecuador), and by foreign fleets that operate in the international waters outside the Chilean EEZ. The fleets from Chile and Peru operate also outside their national EEZs. One of the foreign fleets operating outside the Chilean EEZ is the fleet from the European Union (EU). The main component of this fleet are pelagic trawlers that belong to the Pelagic Freezertrawler Association (PFA); an organisation of ship owners that is based in The Netherlands.

In 2011 there was a clear difference between the results of fleets working in the southern area (Chile and EU) and fleets in the northern area (Peru and Chile). The fleets working in the southern area saw their catches decline; even more than was required by the interim measures agreed by the SPRFMO Preparatory Conference in Cali in January 2011. According to this agreement, each country was to reduce its catch of jack mackerel in 2011 by at least 40% compared to 2010 (SPRFMO 2011). For the

southern fleets, this agreement presented no problems as their catches decreased anyway due to a scarcity of fish. The Chilean catch in 2011 decreased by 47% from 2010 (Undersecretariat for fisheries 2012) and the catch of the EU fleet operating outside the Chilean EEZ even by 97%.

For the northern countries, however, it turned out to be impossible to adhere to the agreed catch reduction because of a sudden increase of fish abundance in their waters. Under these conditions, it was impossible to hold back the national fleets. The catch in Peru increased from 17,559 to 257,241 tons (+1365%), and in Ecuador from 4,613 to 69,153 tons (+1399%).

Figure 1 puts the events in 2011 into perspective by comparing the catches of the different fleets for the whole period 2000 – 2013.

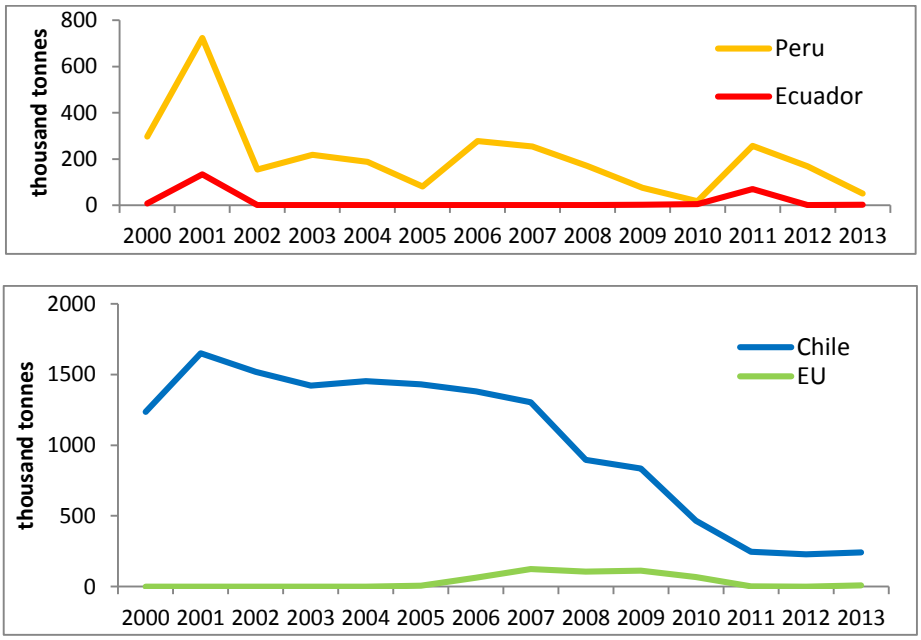

Figure 1. Catches of jack mackerel by country (in thousand tonnes). Note the contrast in the development of catches in 2011 between the northern fleets (Peru and Ecuador) and the southern fleets (Chile and EU). Data from SPRFMO 2013.

3.2 Distribution of juvenile jack mackerel in oceanic waters of the central Pacific in 2010

Two PFA vessels in 2010 encountered extensive concentrations of juvenile jack mackerel in the open central Pacific between 96° - 107°W and 37° - 41°S. These juveniles were found in May-June to the north and west of the areas where the adult jack mackerel occurred (Figure 2). Because of its small size, the fish was of little commercial interest, and after the vessels had taken some catches, they turned south-east again to target the larger jack mackerel.

The presence of large concentrations of juvenile jack mackerel in the area off central Chile was also reported by trawlers from Vanuatu (G. Geen, pers. comm.) and by Peruvian vessels that worked in this area (IMARPE 2012c). Moreover, Chilean research vessels and the Russian R/V Atlantida also encountered the juveniles in this area (A. Gretchina, pers. comm.).

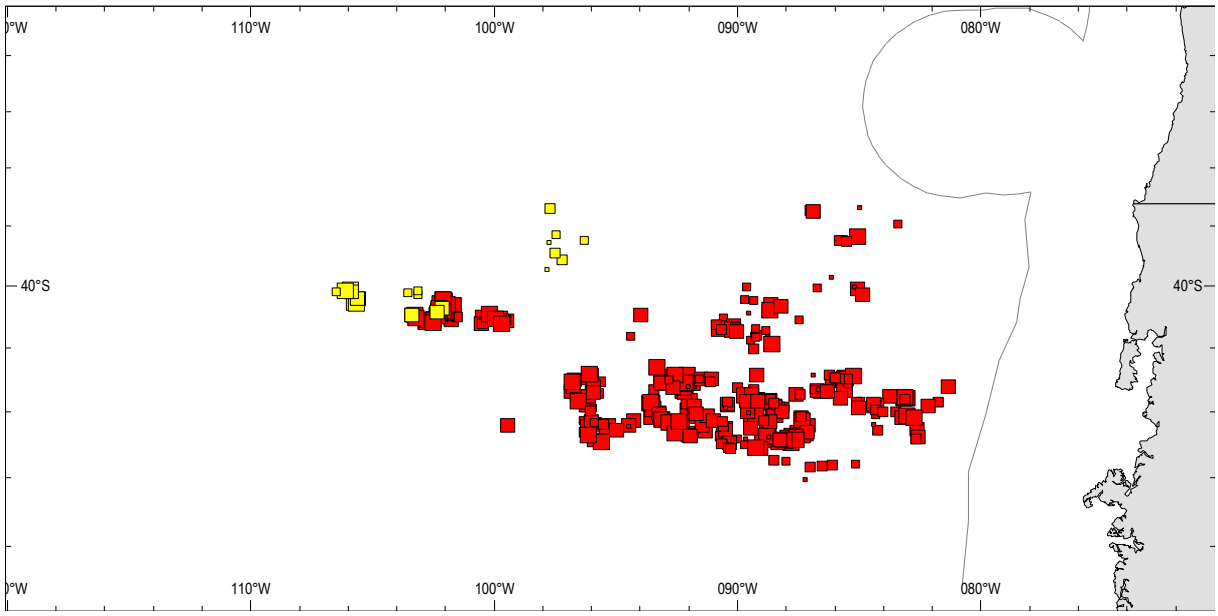

Figure 2. Distribution of catches of juvenile jack mackerel < 25 cm (yellow squares) by the PFA fleet during the 2010 fishing season compared to catches of larger jack mackerel (red squares). Size of squares is proportional to weight of the catches.

3.3 Length compositions PFA catches

Figure 3 presents length distributions obtained from the PFA observer programme in the Pacific since the start of the fishery in 2007. It is seen that the catches during 2007 - 2009 consisted exclusively of large fish with a unimodal length composition. The modal length shifted from 31 cm (fork length) in 2007 to 33 cm in 2008 and to 36 cm in 2009. There were no indications of any recruitment in these three years. The situation changed in 2010 when a large cohort of juvenile fish with a modal length of 20 cm was encountered. These fish were presumably 2 years old and born in the autumn of 2008. Although the vessels were not very interested in these fish because of their small size, the cohort made up 63% of the catch in numbers in that year. In 2011 the year-class was encountered again, and its modal length had increased to 27-29 cm (FL). The year-class had now reached a commercial size, but its absolute abundance was so low that the vessels could not make a profitable fishing on it. In 2012 there was no PFA fishery in the Pacific, so the growth of year-class 2008 could not be monitored that year. In 2013 one PFA trawler returned to the area. Catches were still very poor, and they consisted of a number of length groups, the dominant one having a modal length of 34 cm. It is assumed that this group corresponded to year-class 2008 that was first observed in 2010.

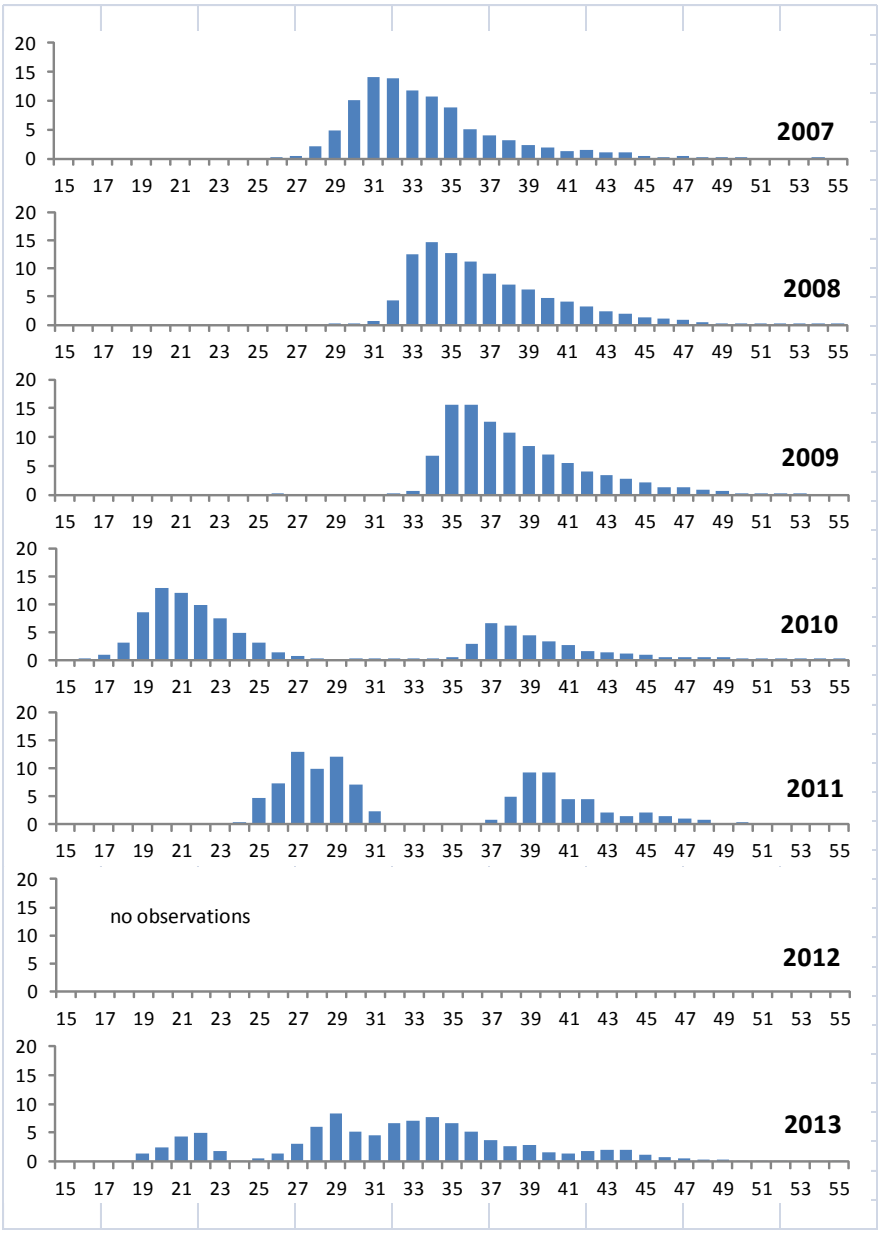

Figure 3. Length distribution of PFA catches from 2007 – 2013. All length are measured as fork length to the cm below.

3.4 Length compositions Peru and Ecuador

Length compositions of jack mackerel catches in 2010-2012 off Peru show the appearance of a very pronounced cohort by the end of 2010 (Figure 4). There had been some signs of juvenile fish already in August, but it was not until December that the year-class became very abundant and the fishery started to exploit the fish. This cohort continued to dominate the catches in Peru in 2011 and 2012. At the time of its first appearance in November, the cohort had a modal length of 25 cm total length.

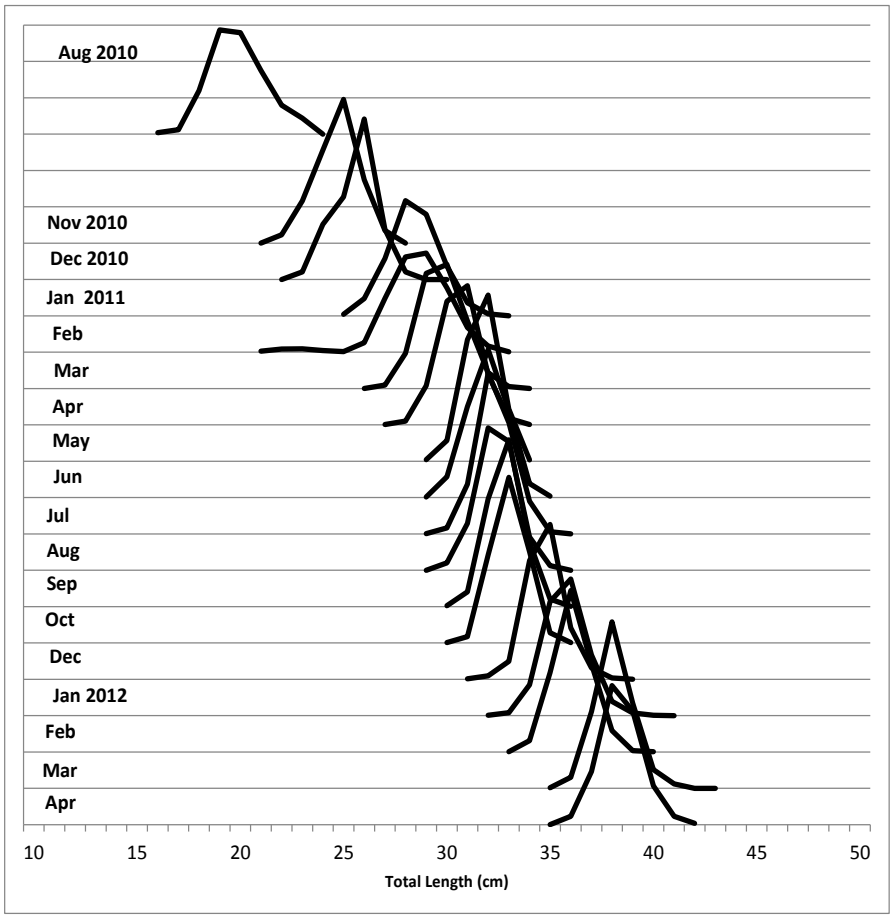

Figure 4. Length distribution of commercial catches in Peru in November 2010 – April 2012. Also shown is the length of juvenile jack mackerel sampled by a research vessel in August 2010. Data from IMARPE.

The cohort that was found in northern Peru in November/December moved north into Ecuadorian waters in the first months of 2011 (Figure 5). Length distributions measured from Ecuadorian catches in February 2011 show a very narrow, unimodal length distribution, comparable to that of the fish in Peru. The modal length of 29 cm (TL) is exactly the same as that of the fish sampled in Peru in February 201.

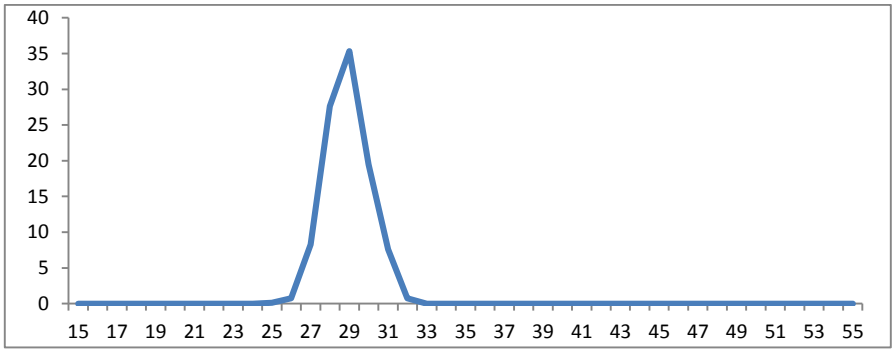

Figure 5. Length distribution of jack mackerel catches in Ecuador in February 2011 (length measured as total length). Data from Instituto Nacional de Pesca.

3.5 Comparison between length distributions in Chile and in Peru/Ecuador

In order to compare length measurements for the waters off Chile in May-June 2010 with those off Peru and Ecuador in late 2010 / early 2011, the measurements have to be expressed in the same units. European scientists working in the Pacific have adopted the Chilean method of measuring fork length. Peruvian and Ecuadorian scientists, on the other hand, use total length for jack mackerel. A simple formula to convert fork length into total length, calculated on the bases of PFA samples, is

Total length = 1.114 *(Fork length) + 0.07

Applying this formula to the length distribution of PFA catches in May-June 2010, the modal length of 20 cm FL corresponds to 22 cm TL. This value has been plotted on a time axis, together with the Peruvian length data in Figure 6.

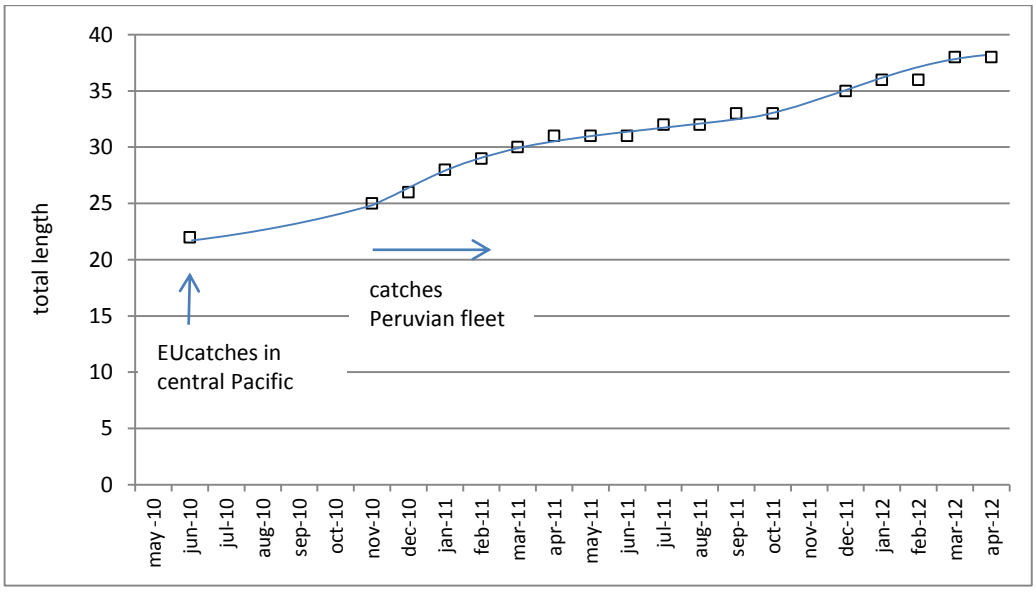

Figure 6. Time axis with modal length of juvenile jack mackerel in central Pacific (June 2010) and modal length in Peruvian catches (November 2010 – April 2012). The smooth line is a hand-drawn curve that best fits the series of data points.

It is seen that the modal length of the fish in the central Pacific in June 2010 matches well with the length of the fish that appeared in Peru in November, particularly if the variation in growth between the winter and summer is taken into account.

3.6 Hydrographic conditions in 2010

Hydrographic conditions in the eastern Pacific in 2010 showed two opposite phases. During the first half of the year, positive SST anomalies prevailed, indicating the occurrence of an El Niño (Figure 7). This situation changed drastically in June when negative anomalies started to appear. The negative anomalies intensified during the period July – December (Figure 8), and it was only in February 2011 that the SST values returned to normal. The second half of 2010 was thus characterised by a strong La Niña.

In Peru, the occurrence of an El Niño during the first half of the year resulted in an absence of jack mackerel during this period, which normally is the main fishing season (Ñiquen and Bouchon, 2011). The arrival of the

cold water in the second half of the year caused a displacement of the fish to the north, due to the increased speed and northward direction of the current. This northward shift of the stock brought the jack mackerel also into Ecuadorian waters.

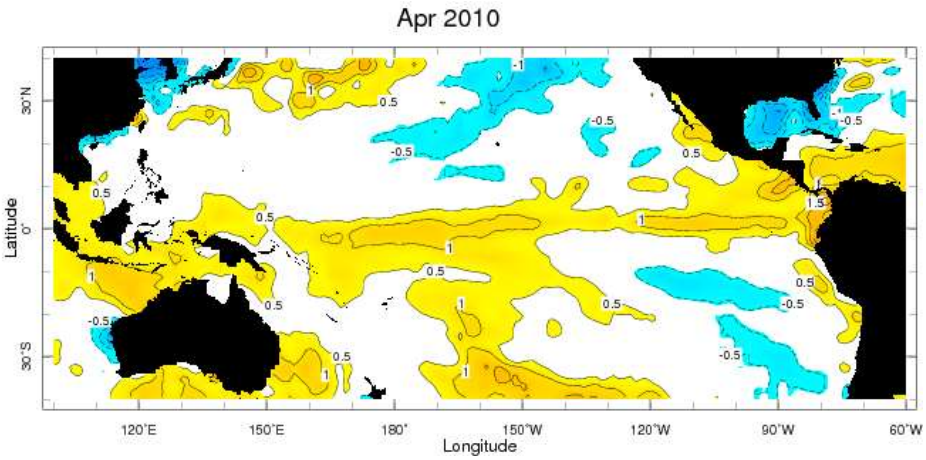

Figure 7. Positive SST anomalies in eastern Pacific in April 2010 illustrate the existence of an El Niño in the first half of 2010.

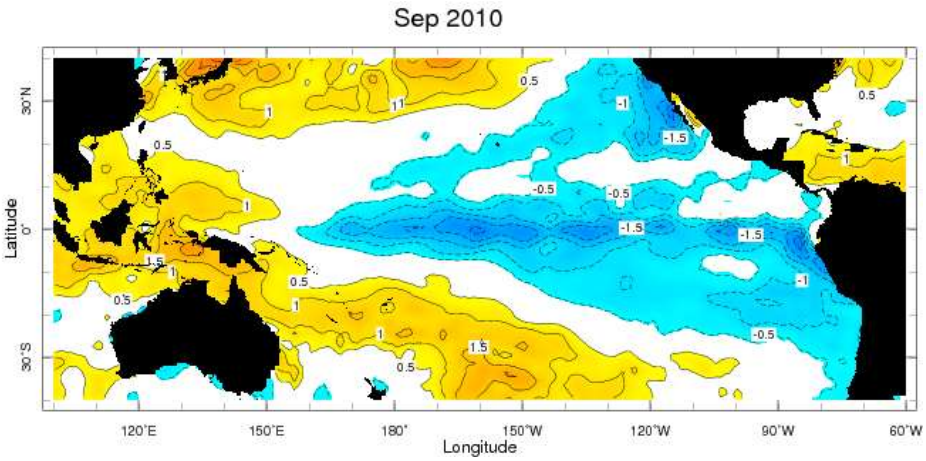

Figure 8. Strong negative SST anomalies in the eastern Pacific in September 2010 illustrate the existence of a La Niña in the second half of the year.

4 Discussion

4.1 Data in support of the migration hypothesis

There is a clear similarity between the length distribution of the juvenile jack found by PFA vessels off Chile in May-June 2010, and the fish that showed up in large numbers half a year later in northern Peru and Ecuador. Accounting for some reduction in growth rate during the winter, the fish that showed up in Peru in December 2010 obviously belonged to the same cohort that was observed off Chile in May-June 2010 (Figure 6).

One might argue that the fish in Peru did not necessarily originate from the waters off Chile, but that they could also have been born in Peruvian waters. In this case the strong recruitment in the Peruvian zone would have coincided with the one off Chile simply because the hydrographic conditions at the time of birth of the year-class (2008) had been optimal over the entire eastern Pacific. However, there is no evidence that a strong year-class was born in Peruvian waters in 2008. There are no observations of substantive amounts of juvenile jack mackerel in commercial catches or in acoustic surveys in the Peruvian zone in the first half of 2010. There were some catches of juvenile jack mackerel of 19-20 cm TL by a vessel in August 2010 (Ñiquen and Bouchon, 2011), but these observations are no evidence for the presence of a large recruiting year-class in the area.

If the fish that appeared in Peru by the end of 2010 had been born in Peruvian waters in 2008, it would be remarkable that they had exactly the same length at the age of two years as the ones that were born in 2008 off Chile. The growth rate of jack mackerel in Peruvian waters is higher than in Chile (Dioses 2013), so fish born in Peru in 2008 should be larger at the age of two years than fish born off Chile. The fact that the fish in Peru had the same size as those that were earlier observed off Chile suggests that they were not only born at the same time, but also grew up in the same area.

A further argument for the movement of year-class 2008 from the waters off Chile towards Peru and Ecuador is the marked drop in abundance in the area off Chile from 2010 to 2011. The year-class was abundant in Chilean waters in 2010, and it had in fact been observed already in the previous year by the Russian R/V Atlantida in the offshore waters around 105° W (Parada et al. 2014). The high abundance of the year-class in the waters off Chile in 2009 and 2010 had raised hopes among Chilean scientists hat this year-class would boost the Chilean fisheries in 2011 (A. Grechina, pers. comm.). However, although some fish of year-class 2008 were still around in Chilean waters in 2011, the sharp drop in CPUE of the EU fleet in 2011 indicated that the year-class had been strongly reduced in numbers between 2010 and 2011. Also the Chilean fishermen did not find important concentrations of the year-class inside the Chilean EEZ in 2011. The fact that year-class 2008 largely disappeared from the waters off Chile between 2010 and 2011, at the same time when large quantities of this year-class appeared in Peru and Ecuador, is another argument in support of the transport hypothesis.

The presumed transport of juveniles from the waters off Chile towards Peru and Ecuador occurred at a time when the hydrographic conditions in the eastern Pacific were favourable for a northward displacement of the juvenile fish. The strong La Niña that occurred in the south-eastern Pacific in the second half of 2010 resulted in an increased velocity of the northward Humboldt/Peru Current (Ñiquen and Bouchon, 2011). Such a current would have accelerated the transport of juveniles from the nursery area off northern Chile north into Peruvian and even Ecuadorian waters. Observations on the fishery in Peru in 2010 show that the fish arrived in November/December apparently as the result of a strong northward transport. From northern Peru the fish even continued into Ecuadorian waters in the first months of 2011. It was only after the La Niña ended in January 2011 that the fish slowly started to return south.

4.2 Could juvenile jack mackerel travel from Chile to Peru in six months?

A problem with the transport theory presented above is the sheer distance that the fish would have covered from June to December 2010. Figure 9 shows the area where the EU fleet encountered the juvenile fish in May-June 2010, and the area where fish of the same cohort showed up in large

numbers in December of the same year. The most likely route that the fish would have taken, making maximum use of ocean currents, would be north-eastward towards the South American continent, and then northward with the Humboldt/Peru Current (Vasquez et al. 2013). This would mean they had covered a distance of more than 4000 km in 6 months of time, which corresponds to an average speed of 22 km/day or 0.26 cm/sec.

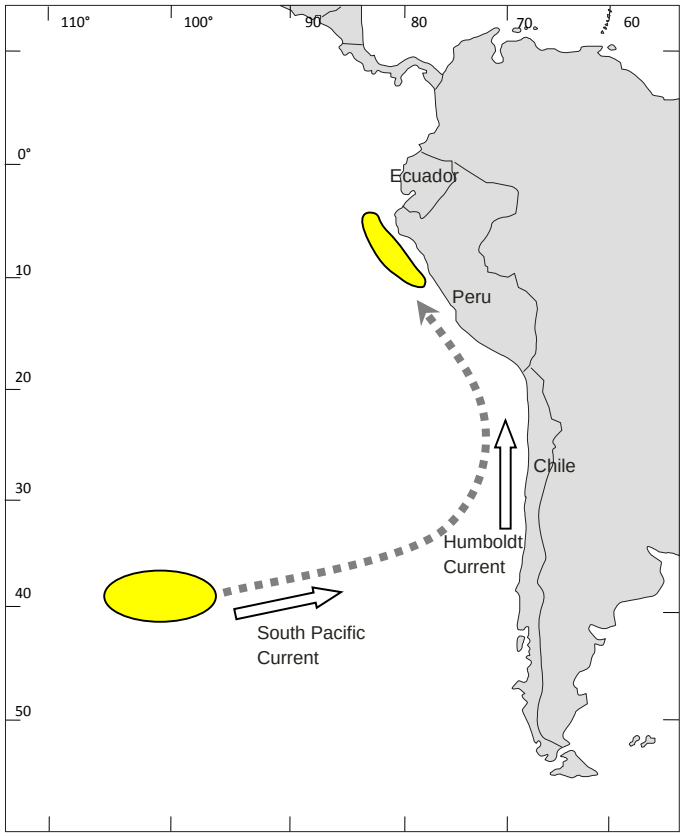

Figure 9. Presumed pathway of juvenile jack mackerel from June to December 2010.

Although this seems quite a long way, the fish would not have had to travel all this distance by active swimming but they could have lifted on the current. During the first part of their voyage, they could have travelled on the South Pacific Current which moves at an average of 0.20 m/sec (17 km/day) at latitudes around 38°S (Cubillos et al. 2008, Vasquez et al. 2013). Reaching the waters east of 80° W, they could have travelled north on the Humboldt Current; the speed of which increases from 0.15 m/sec at the latitude of 37°S to 0.25 m/sec between 32 – 28°S (Vasquez et al. 2013). The values for residual current speeds given above refer to normal periods. One may assume that during the La Niña in the second half of 2010, residual currents will have been substantially higher than during average periods. In Peruvian waters, the Peru Current during the La Niña in the second half of 2010 reached speeds of 0.23 m/sec (Ñiquen and Bouchon, 2011).

Maybe for some juveniles of year-class 2008, the distance to cover was smaller than indicated in Figure 9 because in June 2010 they may have been already further to the north-east than the concentrations encountered by the EU fleet. Juvenile jack mackerel are normally distributed in warm waters to the north of the area where the adults occur (Elizarov et al. 1993). A fishing fleet targeting

the adult component would therefore only touch the fringe of the juvenile distribution. Figure 2 confirms that the EU fleet took its catches of juvenile jack mackerel in positions to the north of the main fishing grounds. As the juveniles were not yet of an interesting commercial size, the fleet moved away from the juvenile concentrations and did not search further to the north-east. The EU fleet in 2010, therefore, may not have covered the entire distribution area of year-class 2008, and some juveniles may have been distributed already further to the north-east, which would have reduced the distance to the Peruvian waters.

4.3 The relationship between the jack mackerel populations off Chile and off Peru

The likelihood that an important fraction of year-class 2008 moved as 2 year-olds from the nursery areas in Chile towards Peru and Ecuador may shed some new light on the population structure of jack mackerel in the south-eastern Pacific. As mentioned in the Introduction, the discussion on this subject in recent years has focussed on the question whether all jack mackerel in the eastern Pacific should be considered as one unit stock, or whether the fish off Peru should be considered as a separate stock. In the Introduction, several arguments were listed that have been advanced in the past in support of the separate stock hypothesis. To these one might add the results of recent modelling studies on suitable habitats for jack mackerel in the south-eastern Pacific. These results show that two major habitats exist in the region: one off Chile and the other off Peru (Figure 10). These two habitats are connected only by a narrow corridor that constitutes a kind of "door" which may be open or closed, depending on hydrographic conditions (J. Habasque, pers comm). Since the year 2000, this door seems to have been closed most of the time due to the stagnation of the waters in this area and the shallow depth of the oxygen layer. It was only during La Niña episodes such as in 2008 that the door was temporarily opened.

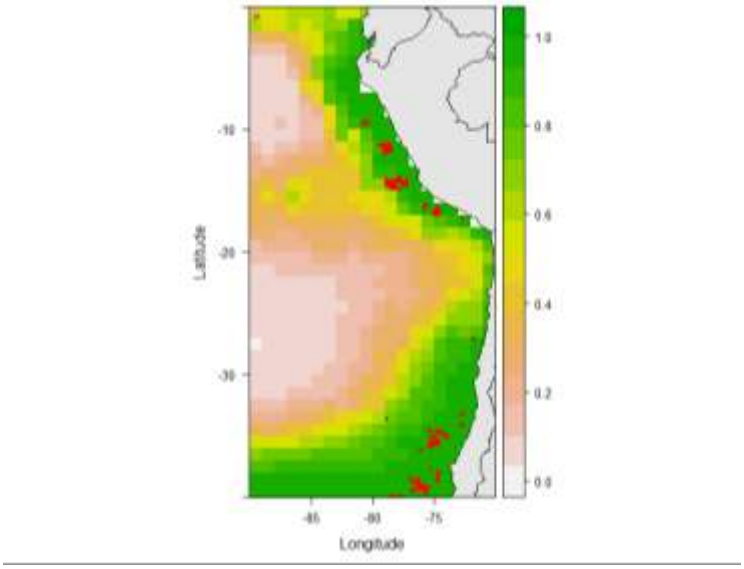

Figure 10. Suitable habitats for jack mackerel in the south-eastern Pacific. Figure provided by J. Habasque.

When the door between the habitats in Peru and Chile opens, it is unlikely that there will a large exchange of adult fish between the two zones. Adult fish in Peru and Chile have different biological

characteristics, which suggests that they stay in their respective areas for all their life. However, there is the possibility that juvenile fish may be transported on these occasions from Chile to Peru.

The classical scheme of juvenile jack mackerel migrations in the south-eastern Pacific assumed that there was no exchange of juveniles between the Chilean and Peruvian waters. The model proposed by Arcos et al. (2001) assumed that all juveniles from the nursery area in northern Chile would migrate south to join the adult population off central Chile (Figure 11).

Figure 11. Classical scheme of juvenile jack mackerel migrations off Chile. From Arcos et al. 2001

However, more recent studies (Gretchina et al. 2007) have modified this picture, and suggest that there is also an exchange of juveniles between northern Chile and Peru (Figure 12).

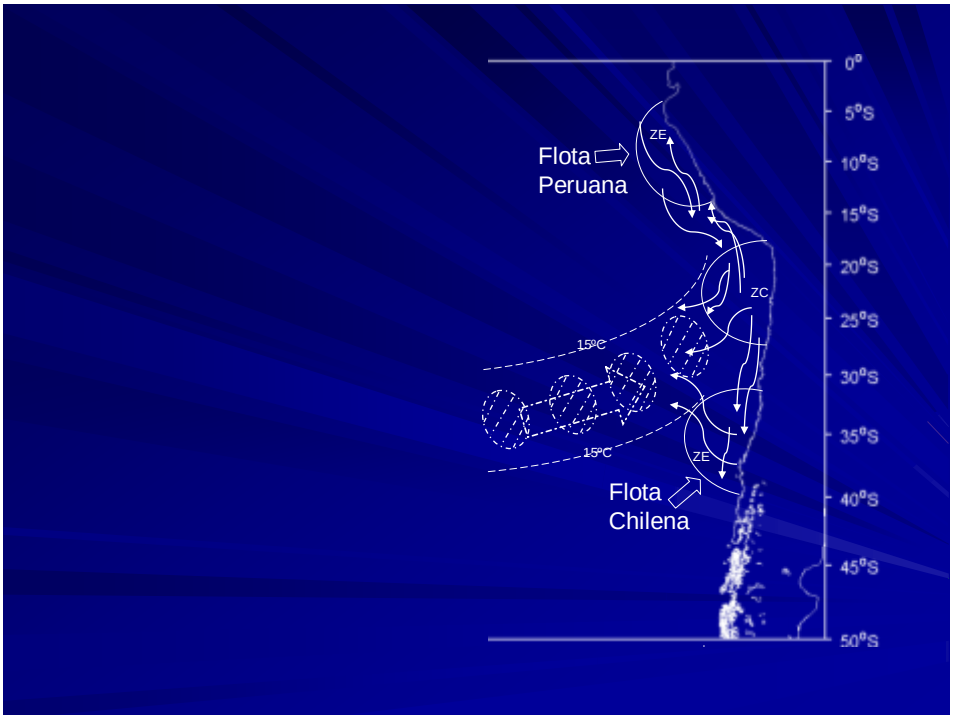

Figure 12. Recent model for migrations of juvenile jack mackerel in the south-eastern Pacific. From Gretchina et al. 2007

Considering the results of the habitat modelling studies mentioned above, this exchange will only occur during periods when the hydrographic barrier between the two habitats is temporarily lifted, and the "door" will be opened. This will happen during a La Niña period when the northward current increases, the water temperature drops and the oxygen layer deepens. This will allow the transport (passive or active) of juvenile fish from northern Chile towards Peruvian waters. Note that this is probably only a one-way traffic. It is unlikely that juveniles from Peru will take the opportunity to swim southward to Chile against the strong Peru Current at the moment when the door opens.

There are as yet no direct observations of a large scale northward displacement of juvenile fish during a La Niña period. However, the opposite phenomenon, i.e. a southward displacement during a warm period, has been observed and documented. Arcos et al. (2001) describe how the distribution of juvenile jack mackerel in Chile shifted south during the El Niño period of 1997-98 (Figure 13). This southward shift of juveniles may have been caused either by passive drift resulting from a change in residual currents, or by active migration of fish that tried to avoid the warm and nutrient-poor water masses in their normal nursery area.

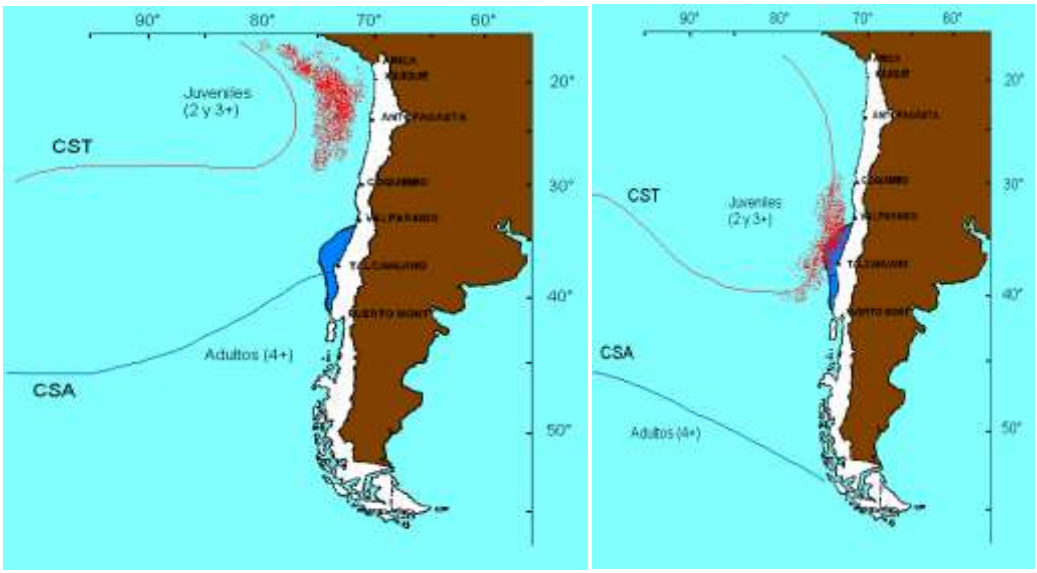

Figure 13. Distribution of juveniles (red cloud) off Chile in a normal year (left) and in an El Niño year (right). From Gretchina et al. 2007.

If a warming of the surface waters during an El Niño results in a southward displacement of the juveniles, one may assume that the opposite happens during a cold period. In this case the distribution of the juveniles would shift northward into the Peruvian zone.

In the Peruvian zone itself, it is know that the distribution of jack mackerel shifts to the north during La Niña periods. According to Peruvian scientists, the observed changes in latitude of the jack mackerel catch distributions in 2011 seemed to be clearly associated with increases in the speed and south-north direction of the Peruvian coastal current that was produced during and immediately after the La Niña (IMARPE 2012a). If the jack mackerel distribution in Peru shifts northward during a La Niña, it is likely that the northward shift will not be limited to the fish that area already in Peru, but that it will also apply to the juveniles in the border zone between Peru and Chile.

A large influx of juvenile jack mackerel from Chile into Peru will happen only on special occasions. Not only does it require the occurrence of a La Niña, but it also requires the presence of a strong recruiting year-class on the nursery grounds in northern Chile. The chance of these two conditions coinciding is small, and hence a large-scale inflow of juvenile jack mackerel from Chile into Peruvian waters will remain a rare event. The only other occasion (apart from 2010) in recent history when this seems to have happened, is the period 1999 – 2001 when peak catches in Peru and Ecuador were preceded by a La Niña in Chile and in Peru (Nunez 2008). Peruvian scientists have also drawn attention to the fact that high catches in Peru and Ecuador during earlier years were preceded by La Nina events, and they also explained this by increases in the speed and south-north direction of the Peruvian coastal current (IMARPE 2012a).

In normal years, recruitment to the Peruvian stock will probably originate from spawning in the waters off Peru itself, and it is only in exceptional years that the Peruvian stock receives a boost from the influx of juveniles from the south. Most likely these immigrants will settle in Peruvian waters for the rest of their lives. It has been observed in several pelagic fish species that the adults develop an

attachment to the area where they happen to find themselves during first maturation (McQuinn 1997, Corten 2002). This area they consider as their "home" for the rest of their life, and they join the local population. In the terminology of McQuinn (1997) they are "adopted" by the local population and become "adopted migrants".

Observations on jack mackerel indicate that this mechanism probably also exists in this species. The juvenile jack mackerel in Chile that moved south during the 1997-98 El Niño developed an attachment to the area off central Chile and did not return as adults to the north of Chile in 1999 (Arcos et al. 2001). In a similar way, jack mackerel born off Chile may become attached to the Peruvian zone if they are transported by chance into this zone as juveniles. These fish are expected to settle in this zone and turn into "Peruvian" jack mackerel, with similar biological characteristics (growth rate, parasites and maturity cycle) as the rest of the Peruvian population. The occasional incorporation of adopted migrants from Chile into the Peruvian stock would explain the lack of genetic differences between the populations in Chile and in Peru.

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