This section presents the results of the assessment of the impacts of each of the five predefined GIWA concerns i.e. Freshwater shortage, Pollution, Habitat and community modification, Overexploitation of fish and other living resources, Global change, and their constituent issues and the priorities identified during this process. The evaluation of severity of each issue adheres to a set of predefined criteria as provided in the chapter describing the GIWA methodology. In this section, the scoring of GIWA concerns and issues is presented in Table 9. Detailed scoring information is provided in Annex II of this report.

Table 9 Scoring table for South/Southeast Atlantic Basins, East Atlantic Basins and São Francisco River Basin.

<table>
<thead>
<tr>
<th>South/Southeast Atlantic Basins</th>
<th>East Atlantic Basins</th>
<th>São Francisco River Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental impacts</td>
<td>Economic impacts</td>
<td>Health impacts</td>
</tr>
<tr>
<td>Freshwater shortage</td>
<td>1.8*</td>
<td>1.8</td>
</tr>
<tr>
<td>Modification of stream flow</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pollution of existing supplies</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Changes in the water table</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pollution</td>
<td>2.0*</td>
<td>2.7</td>
</tr>
<tr>
<td>Microbiological pollution</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Chemical</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Solid waste</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Thermal</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Radionuclide</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Spills</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Habitat and community modification</td>
<td>2.6*</td>
<td>2.3</td>
</tr>
<tr>
<td>Loss of ecosystems</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Modification of ecosystems</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Unsustainable exploitation of fish</td>
<td>2.7*</td>
<td>1.7</td>
</tr>
<tr>
<td>Overexploitation</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Excessive by-catch and discards</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Destructive fishing practices</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Decreased viability of stock</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Impact on biological and genetic diversity</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Global change</td>
<td>1.3*</td>
<td>1.8</td>
</tr>
<tr>
<td>Changes in hydrological cycle</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Sea level change</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Increased UV-B radiation</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Changes in ocean CO₂ source/sink function</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Assessment of GIWA concerns and issues according to scoring criteria (see Methodology chapter) The arrow indicates the likely direction of future changes.

0 No known impacts 1 Slight impacts 2 Moderate impacts 3 Severe impacts ⊗ Increased impact ⊗ No changes ⊗ Decreased impact

* This value represents an average weighted score of the environmental issues associated to the concern. ** This value represents the overall score including environmental, socio-economic and likely future impacts. *** Priority refers to the ranking of GIWA concerns.
Freshwater shortage

Brazil’s territory holds 8% of all the freshwater in the world. However, 80% of this amount is found in Amazon region and the other 20% is unevenly distributed in the rest of the territory where 95% of the Brazilian population is concentrated. Scarcity due to climate conditions is found in the semi-arid region named “The Drought Polygon” that encompasses several states in the Northeast Brazil region. Thus, despite of the total large amount of water in the country, this is a resource that requires efficient regional management and pollution control to avoid conflicts raised by multiple uses.

The concern Freshwater shortage was considered as first priority in São Francisco Basin, and third priority in both East Atlantic Basins and South/Southeast Atlantic Basins. These results illustrate the differences between the sub-regions and the importance of assessing the issues separately in each sub-region, before assessing the whole region. Although freshwater shortage was considered to cause moderate impacts in Brazil Current sub-regions, scarcity of water already occurs in specific areas where a combination of high population density and medium to low specific discharges is found (PNRH 2003). Wherever this situation is controlled by efficient engineering and management practices, such as flow regulation, groundwater exploitation or transfer of water from another basin, environmental and socio-economic impacts due to freshwater shortage were assessed as slight to severe. The scoring procedure for the concern freshwater shortage was based on the degree of severity as a result of anthropogenic pressures. Areas suffering from freshwater shortage due to existing climatic conditions, regardless of human activities, only received high score if the impacts due to natural causes were significantly worsened by anthropogenic pressures.

There are catchment areas in Brazil (particularly in GIWA region 39 Brazil Current) where, despite the high natural availability of water, unplanned and disorganised settlement has created problems of disputes over water, mainly due to scarcity of water of required quality. Portions of the South/Southeast and East Atlantic Basins fit into this category. At the other extreme, there are areas with low natural water availability, such as the semi-arid sub-middle and lower portion of the São Francisco Basin, where an association between low rainfall and high evaporation is found (PNRH 2003). In this area, uneven distribution of rainfall throughout the year and in multi-annual periods further worsens the scarcity of water. It is in the semi-arid areas, such as the lower São Francisco Basin, that drought hits hardest. In contrast, in the upper course of São Francisco River, as well as in most of East Atlantic and Southeast/South Atlantic Basins, freshwater shortage is raised by high and multiple demands and conflictive uses (particularly the excessive use in irrigation), aggravated by pollution, which limits the potential uses of water (PNRH 2003).

According to the indicator “mean discharge per capita”, (m$^3$/year/inhabitant) used to define water availability, the Brazil Current encompasses areas that fit basically in three different categories (PNRH 2003): Regular (1 000-2 000 m$^3$/year/inhabitant), Sufficient (2 000-10 000 m$^3$/year/inhabitant) and Rich (10 000-100 000 m$^3$/year/inhabitant). There are only two exceptions in the Brazil Current that fall below the category Regular availability; the basins in the littoral of Rio de Janeiro state (59 in Figure 2), which is classified in the category Poor (500-1 000 m$^3$/year/inhabitant), mainly due to high population density, and the upper portion of the East Atlantic Basins in Sergipe and Bahia states (50 in Figure 2), classified in the category of Very Poor (less than 500 m$^3$/year/inhabitant), mainly due to climate conditions.

Non-consumptive uses of water are those that do not consume water and, for that, do not need to be considered in the water budget. However, these uses may still cause restrictions for the water resources management. Non-consumptive uses are those usually performed directly in the river stream such as electricity generation, transport, aquaculture and leisure/recreational activities. Consumptive uses consume part of the water budget and are basically performed outside the river stream, such as human and animal consumption, irrigation and industrial uses. The consumptive uses, or simply, consumption, of water in each sub-region of the Brazil Current are briefly commented below.

Irrigation is developing along different models. In southern/ southeastern Brazil, private investments predominate (similar to irrigation projects in Uruguay), with emphasis on rice fields and grain crops (upper São Francisco River Basin and the southeast portion of South/Southeast Basins). In these areas the investments in irrigation depend on the return obtained from the sale of the crops. In semi-arid portions of the East Atlantic Basins, the public sector is the main investor for stimulating regional development in an area with severe social problems. In this latter region investments in the cultivation of traditional crops, such as corn and beans, have not given the expected return and the focus has moved to irrigated fruit production with greater added value and economic return. This shift has altered the characteristics of both seasonal and total annual demand for water (PNRH 2003).

In Uruguay, hydrological studies have shown that during spring-summer seasons, water deficit is observed in the majority of the soils, which represents a constraint for agriculture development during these
seasons. Irrigation became a common practice in Uruguay agriculture after the implementation of the Programme of Natural Resources and Irrigation Development (PRENADER) (Programa de Recursos Naturales y Desarrollo del Riego). About 7 700 km² of land were irrigated in 1993 (CIA World Factbook 2003). Irrigation is used on large scale for rice production, including the Mirim Lagoon basin, under the Law of Irrigation (Ley de riego), which should prevent the soil degradation. Irrigation is also used locally in fruit and vegetable production.

In the South/Southeast Atlantic Basins, irrigation alone is responsible for 77% of the total consumption of water, followed by the human supply, which is about 11% of the total demand (Table 10). Although the Rio de Janeiro Metropolitan region hosts 9 million inhabitants, the littoral of Rio de Janeiro has low water availability (76 m³/s) and depends on transfer of water for 90% of its demand from another basin, the Paraíba do Sul River. According to the state water sewage company, CEDAE, this water transfer is the only way to supply demand of the Rio de Janeiro littoral (59 in Figure 2), which is situated entirely in the littoral plain (PNRH 2003). Due to the large areas cultivated with rice, irrigation in the Guaíba Lake and Mirim Lagoon basins (both in Rio Grande do Sul state, southern South/Southeast Atlantic Basins) represents almost 60% of the total consumption of water in the South/Southeast Atlantic Basins. If the human consumption in Rio Grande do Sul state (with a high urban concentration in Guaíba River Basin) is added to this figure, more than 75% of the total consumption of the South/Southeast Atlantic Basin occur inside the state of Rio Grande do Sul. As shown in Table 11, the demand in the littoral of Rio Grande do Sul surpasses the water availability (231%) where water supply is achieved through regulation of reservoirs (PNRH 2003).

In the East Atlantic Basins, the urban consumption (26.3%) shows the highest demand compared to the human consumption in other sub-regions (Table 10). This result reflects the strong influence of the Rio de Janeiro Metropolitan area (RJ), Salvador (BA), Vitória (ES) and Aracaju (SE). The Paraíba do Sul River basin (58 in Figure 2), supplies not only the demands in the Basins, but also 9 million inhabitants and activities carried outside the Basins, in Rio de Janeiro littoral (59 in Figure 2). More than 60% of the total demand for water in the East Atlantic Basins is concentrated in the Paraíba do Sul River basin. The semi-arid portion of the East Atlantic Basins suffers restrictions of water supply for irrigation purposes.

In the São Francisco River Basin, irrigation is by far the main consumptive use of water, corresponding to about 68.1% of the total water consumption in the Basin. It is likely that animal consumption is underestimated due to the following aspects: (i) cattle for milk production mostly in the upper São Francisco usually requires more water due to intensive husbandry; and (ii) the consumption of water by other animals (e.g. pig and chicken) is not included in this calculation. The other consumptive demands come from industry, mostly in the upper São Francisco in Minas Gerais state (responsible for 60% of the industrial uses) and sub-middle São Francisco (e.g. Petrolina/Juazeiro municipalities that host a number of industries). The highest demand/availability ratio (13.5%) is found in the upper São Francisco due to the high urban demand. The lowest ratio (1.4%) is found in the lower São Francisco (PNRH 2003).

In some basins of the South/Southeast Atlantic and East Atlantic Basins, water demand exceeds the available water resources (Table 11). This situation requires special management policies such as flow regulation, preservation of springs, groundwater exploitation and transfer of water from other basins or, in the last resort, rationing (PNRH 2003). Nevertheless, considering South/Southeast Atlantic and East Atlantic Basins together, the demand is comfortably below the average available water.

In South/Southeast Atlantic and East Atlantic Basins water quality is more important than water quantity from the environmental viewpoint. In São Francisco Basin, quantity is the main concern and changes in the stream flow due to damming have severely affected the ecosystems and the aquatic diversity, as well as the sediment transport to the coast.

### Table 10  Water availability and demand per sector.

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Availability (m³/s)</th>
<th>Rural</th>
<th>Livestock</th>
<th>Industry</th>
<th>Irrigation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>South/Southeast Basins</td>
<td>813</td>
<td>41.5</td>
<td>9.1</td>
<td>6.0</td>
<td>34.2</td>
<td>294.9</td>
</tr>
<tr>
<td>% sub-regional demand</td>
<td>10.8</td>
<td>2.4</td>
<td>1.6</td>
<td>8.9</td>
<td>76.5</td>
<td>47.5</td>
</tr>
<tr>
<td>East Atlantic Basins</td>
<td>1 063</td>
<td>65.7</td>
<td>31.3</td>
<td>12.1</td>
<td>35.8</td>
<td>104.6</td>
</tr>
<tr>
<td>% sub-regional demand</td>
<td>26.3</td>
<td>12.5</td>
<td>4.9</td>
<td>14.4</td>
<td>41.9</td>
<td>23.5</td>
</tr>
<tr>
<td>São Francisco Basin</td>
<td>1 077</td>
<td>35.3</td>
<td>8.7</td>
<td>7.8</td>
<td>12.9</td>
<td>138.2</td>
</tr>
<tr>
<td>% sub-regional demand</td>
<td>17.4</td>
<td>4.3</td>
<td>3.8</td>
<td>6.4</td>
<td>68.1</td>
<td>18.8</td>
</tr>
</tbody>
</table>

(Source: PNRH 2003)

### Table 11  Water demand/availability ratio in basins of the Brazil Current region where water demand (D) is higher than available water (Q).

<table>
<thead>
<tr>
<th>Basin</th>
<th>Area (km²)</th>
<th>P (mm)</th>
<th>E (mm)</th>
<th>Q (m³/s)</th>
<th>q (l/s/km²)</th>
<th>D/Q (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itapicuru &amp; Vaza-barris basin</td>
<td>67 761</td>
<td>950</td>
<td>915</td>
<td>75</td>
<td>1.1</td>
<td>144.3</td>
</tr>
<tr>
<td>Paraguaçu River basin</td>
<td>71 134</td>
<td>1 073</td>
<td>974</td>
<td>224</td>
<td>3.1</td>
<td>182.1</td>
</tr>
<tr>
<td>Rio de Janeiro Littoral basin</td>
<td>19 698</td>
<td>1 344</td>
<td>699</td>
<td>403</td>
<td>20.3</td>
<td>109.1</td>
</tr>
<tr>
<td>São Paulo Littoral basin</td>
<td>4 893</td>
<td>1 823</td>
<td>1 217</td>
<td>94</td>
<td>19.2</td>
<td>102.1</td>
</tr>
<tr>
<td>Rio Grande do Sul Littoral basin</td>
<td>56 554</td>
<td>1 381</td>
<td>731</td>
<td>1 168</td>
<td>20.6</td>
<td>231.3</td>
</tr>
</tbody>
</table>

Note: P=Precipitation, E=Evapotranspiration, Q=Mean flow over a longer period, q=Specific flow. (Source: PNRH 2003)
Environmental impacts

Modification of stream flow

Modification of stream flow produces moderate environmental impact in the South/Southeast Atlantic and East Atlantic Basins, but produces severe environmental impacts in São Francisco River Basin. Stream flow monitoring has been carried out in many rivers in Brazil. In 2002, the monitoring network in Brazil had 8 144 stream flow monitoring stations monitored by different institutions, among them, 948 stations which also monitor water quality (PNRH 2003). However, in some cases the quality of the data needs to be improved. One methodological constraint highlighted in Clark & Dias (2003) is that stream flow versus water level function adjustments are required when erosion takes place, yet collecting the necessary data is constrained by the fact that many of the stations are remote and difficult to access. There are indications of modification of stream flow in many rivers in the Brazil Current. Few studies have addressed this issue in a scientific long-term perspective, which would be necessary to address more precisely the causes of flow modification. Some illustrations of stream flow modification leading to both freshwater scarcity and flooding are described below.

Modification of stream flow is observed in several rivers in South/Southeast Atlantic Basins, not always related to freshwater shortage. In some basins, the impacts can be considered as severe. One example occurs in Santa Catarina state. Intensive deforestation has caused erosion, reduction of water infiltration and siltation of riverbeds, which in turn is associated to increased flooding in the Valley of Itajaí River (basin 83 in Figure 2). Associated to climatic conditions, changes in land cover have caused water scarcity and flooding in this area. In the upper Itajaí River basin, deforestation of the hillsides and degradation of riparian vegetation lead to impacts on watercourses, which dry up due to silting (Frank 1995). Deforestation has reduced the soil capacity for rainwater storage and has affected the stream flow. Increased human activity in urban and rural regions has reduced the areas not subject to flooding (Frank 1995). During the drought periods, freshwater availability for human consumption and irrigation in the higher parts of the Itajaí Valley has decreased. However, the most severe socio-economic impacts are due to flooding in the lower parts. The floods have been a long-term problem for Itajaí Valley and since 1850, 67 floods have been recorded in the city of Blumenau. However, since the 1920s, when occupation of the upper part of Itajaí Valley expanded, the frequency of smaller floods has increased (Figure 22).

Freshwater shortage in the East Atlantic Basins is a result of the combination of regional and local weather conditions and anthropogenic causes. The region is characterised by a sharp gradient of climate. For natural reasons, freshwater shortage in the East Atlantic Basins decreases from north to south because of the climate gradient, which varies from semi-arid in the north to humid in the south. This is also seen in the seasonal variations of river flows, where the northern flows are intermittent and the southern are perennial. The area with the worst freshwater shortage is therefore the northern coastal area. In addition to climate, the construction of dams and use of the water for multiple purposes (e.g. drinking water and irrigation) on many rivers has changed the water balance in the region. Even excluding the atypical low levels of rainfall during 2000-2001, there is a clear decrease in water flow compared to historical values in tributaries of medium-sized basins in the East Atlantic Basins, including the transboundary basins of Contas, Jequitinhonha, Mucuri, Doce and Paraíba do Sul rivers. In order to investigate flow changes and statistical significance of these, in the Paraíba do Sul River, stream flow time series data taken from one monitoring station (Guaratingetá) were analysed from the beginning of the 20th century (Marengo et al. 1998), using the Mann-Kendall statistical method. A significant trend towards flow reduction (negative trend) was observed in this important water supply body. The same statistical modelling applied to the rainfall data taken from the upper and middle portions of the basin showed no significant changes (Marengo et al. 1998). The reduction observed in the stream flow was therefore imputed to anthropogenic activities in the basin.

The Doce River basin (56 in Figure 2) has an area of 83 500 km², 86% located in Minas Gerais state and 14% in Espírito Santo state. During the last decades, the River has suffered from progressive land degradation. Progressive erosion contributes to the pollution with suspended solids and siltation of riverbeds. Pasture with an excessive number of

Figure 22 Explored areas in the Itajaí River basin and the occurrence of flood events per year in Blumenau city in 20 year intervals (1850-1990).
(Source: IPA/FURB in Comitê do Itajaí 2002)
animals per hectare (overgrazing) and deforestation of steep slopes have been the main cause of erosion, followed by the type of grass in the pasture areas, and annual burning as a routine agriculture practice. These practices reduced the productivity in the region with a tendency to replacement of pasture by Eucalyptus trees, which resist to low fertility and high acidity of the soil. In the Doce River basin, the sub-basins specific flows vary from 5-10 to 30-35 l/s/km², and there is a significant stormwater run-off due to silting (suspended solids issue) and low infiltration rate, causing a shortage of water for vegetation, groundwater recharge and consequently more erosion and stream flow modification. The consequence is drought or flooding, depending on the climatic conditions.

Although the severity of environmental impacts due to freshwater shortage in the Brazil Current as a whole was moderate, specifically in São Francisco Basin the issue modification of stream flow has caused severe environmental impacts according to the criteria: significant increased silting or erosion due to changing in flow regime. As previously mentioned, this basin is partially located in the Brazilian semi-arid region (The Drought Polygon). Although rainfall rates in excess of 1 300 mm per year prevail in the upper São Francisco area, as one travels downstream, the climate changes and becomes gradually drier, changing from a humid tropical climate in the upper part, to sub-humid, semi-arid, and then returning to sub-humid near the coast (Figure 23). There is clear evidence of declining flow rates of São Francisco River streams, particularly those located in the semi-arid region. Similarly to the investigation carried out for Paraiba do Sul River (Marengo et al. 1998), time series analysis for São Francisco River stream flow (Juazeiro station) were carried out from the beginning of the 1900s (Marengo et al. 1998). Using the Mann-Kendall statistic method, significant trends towards flow reduction (negative trend) were observed. Rainfall time series analysis for the region did not show any negative trend. Therefore, the stream flow reduction was again imputed to anthropogenic activities in the basin. Irrigation is an activity of little significance restricted to the driest months in the upper São Francisco River but becomes essential and is intensively practiced in the middle and lower São Francisco.

Above all, the construction of a cascade of dams along São Francisco River has resulted in flow regulation and reduction of the peak flows as well as an increase in evaporation of the order of 10-12% from the constructed reservoirs (ANA 2002b). As a consequence, during the last years, a significant reduction in sediment transport has occurred, particularly after the construction of Xingó Dam. Severe impacts such as coastal erosion and reduction of primary productivity are noticed (Machmann de Oliveira 2003).

**Pollution of existing supplies**

The issue pollution of existing supplies as part of the concern Freshwater shortage is assessed in more details under the concern Pollution, where different issues related to pollution of freshwater and coastal/marine water are investigated. Here, pollution will be briefly addressed and the emphasis will be put instead on water scarcity aspects due to pollution. Since in a causal chain analysis perspective, if pollution is the cause of water scarcity, the policy options and initiatives to be proposed will focus on pollution. Pollution of existing supplies was assessed as causing moderate environmental impacts in South/Southeast Atlantic and East Atlantic Basins and slight environmental impacts in São Francisco River Basin. The majority of the Brazilian rivers which are monitored for water quality (surface, sediments and groundwater) have incomplete time series and monitoring methodological problems. Therefore, pollution severity in water supplies at regional level might be underestimated due to insufficient available information. In 2001, the Brazilian National Agency of Water (ANA) estimated, based on monitoring programmes and data, that about 70% of all rivers included in the South/Southeast Atlantic and East Atlantic Basins of the Brazil Current and the contiguous GIWA region 40a Brazilian Northeast, were polluted as a consequence of human activities. ANA concluded that these rivers are contaminated by pesticides, fertilisers, industrial effluents, domestic sewage due to inappropriate land use and occupation and the by-products of...
mining and deforestation. The southeastern Brazilian coast is the most industrialised and urbanised part of the South American coast and has the largest industrial parks and ports of the sub-continent (Lacerda et al. 2002). Insufficient or lack of treatment for both domestic as well as industrial sewage represents a serious threat to the freshwater supplies. In the whole Brazil Current, the most common widespread type of pollution is the organic load/nutrients discharged into rivers, mainly from untreated domestic sewage, which is in part naturally mitigated. Other important types of pollution of water supply bodies (e.g. chemical, suspended solids and spills) are more site-specific and depend on the sector activities in each basin. Chemical pollution comes mostly from industries and agriculture along river catchments and pollution by heavy metals (mostly in sediments) has been the most frequently studied. Due to recent episodes in both South/Southeast Atlantic and East Atlantic Basins, pollution by toxins released during algal blooms in reservoirs and lagoons is gaining importance in the environmental debate (for details, see section on Pollution and Annex III).

In some parts of the coast of São Paulo, for instance, sewage is pumped straight into rivers or the sea, although thanks to the efforts of the local and the state government during the last decade, the problem has been reduced (Municipality of Santos 1997). Rivers contaminated with heavy metals and other hazardous substances is found in the Ribeira Valley, in the São Paulo portion included in South/Southeast Atlantic Basins. Among the most severe cases of water pollution in the South/Southeast Atlantic Basins, the Valley of Itajai (83 in Figure 2) and the Guaiaba Lake (87 in Figure 2) should be mentioned. In the Guaiaba Lake, the main pollution sources are the domestic sewage, metal industry, food and textile industry and sand extraction. In the Itajai Valley the main sources are sugar cane and alcohol production.

Although the environmental impacts in the East Atlantic Basins resulting from contamination of existing water bodies were considered moderate, there are basins that suffer from severe impacts, such as some tributaries of the transboundary rivers in the Brazil Current: Paraíba do Sul, Doce, Jequitinhonha and Pardo. Pollution of these water supplies has transboundary implications and has caused periods of water scarcity/rationing. Economic activities in the upstream state such as mining, agriculture, urbanisation and industry are polluting the water that supplies the downstream state. These implications are now addressed by the states sharing the drainage basins through interstate basin Committees, recently created, according to the Brazilian Federal Water Law No. 9 433, 8th January, 1997. Two recent episodes involving Paraíba do Sul River illustrate the severity of this transboundary issue and the risk of water scarcity downstream: (i) an event of algal bloom in the Funil Reservoir in Rio de Janeiro due to pollution transported from the upstream São Paulo state (Diário do Vale 2001, O Globo 2001); and (ii) an accident with the Cataguazes paper-pulp plant, located in the upstream Minas Gerais state, causing contamination downstream in the north of Rio de Janeiro state, resulting in increased mortality among domestic animals and interruption of domestic supply (FEEMA 2003a, FEEMA 2003b) (for details, see Annex III). Due to their importance as water supply bodies and the transboundary management complexities, the basins of Paraíba do Sul River and Doce River are priority candidates for governmental actions.

The main sources of pollution in São Francisco Basin are domestic sewage, industrial wastewater, and diffuse pollution by pesticides and fertilisers from agricultural areas. Although freshwater shortage is the first priority concern in São Francisco Basin, pollution is not the main cause (see Modification of stream flow in São Francisco Basin). Excluding the upper São Francisco Basin (Belo Horizonte Metropolitan area), pollution was considered as having moderate impact on freshwater shortage. The Belo Horizonte Metropolitan area in the upper São Francisco is alone responsible for 54% of the domestic organic load discharged in the whole basin. Besides domestic and industrial sewage, mining and mineral processing industry is also an important source of pollution in the upper São Francisco Basin. The sugar cane alcohol industry still discharges large amounts of wastewater into the upper São Francisco, although some improvement has been noticed since the start of the practice of using waste from transformation of alcohol to irrigate agriculture.

In Uruguay East region, the impacts of increasing activities such as agriculture, livestock and tourism on the water quality have not been fully addressed. In this region, many cities with 10 000 to 20 000 inhabitants are found in the heart of agricultural areas. In some of these cities and their surroundings, levels of nitrates higher than the threshold limits have been found in wells used for human supply and other uses. This pollution seems to be limited to local aquifers and the pollutant transport parameters vary from area to area (JICA 1994). In many cases, groundwater pollution is related to bad construction of wells, inefficient wastewater management and lack of protection of the wells and the recharge areas (Anido 2003).

Changes in the water table
For South/Southeast Atlantic and East Atlantic Basins the environmental impacts due to changes in the water table were considered slight. However, São Francisco Basin suffers from moderate environmental impact. In Brazil, the volume of groundwater has been estimated at 112 000 km³ and there are approximately 300 000 wells being used and over 10 000 new wells are bored every year (PNRH 2003). In contrast to
the monitoring of surface water, groundwater monitoring in Brazil is much more fragmented, being the responsibility of the state, instead of the federal government (Clark & Dias 2003). The state Company of Mineral Resources Research (CPRM) has been organising a databank (SIAGAS) for groundwater quality that hopefully will help to improve the information available. The use of groundwater for supply purposes varies from basin to basin. In the sub-basin of Taquari-Antas in Rio Grande do Sul state (South/Southeast Atlantic Basins), for instance, 74 out of 111 municipalities are totally dependent on groundwater for human consumption. In Paraiba do Sul River basin (58 in Figure 2) groundwater is mostly used by the industries that need higher quality of water and such use is more relevant in the state of São Paulo (Taubaté). In the Brazil Current region, a high number of wells have been abandoned or deactivated due to salinisation of the water. Among groundwater contaminants in Brazil, the most important is nitrogen (ammonium ($\text{NH}_4^+$), nitrite (NO$_2^-$) and nitrate (NO$_3^-$)) as a consequence of the low percentage of sewage collection and treatment. Irrigated agriculture also contributes to elevated levels of nitrate in the groundwater. As a consequence of growing industrialisation and agriculture with irrigation and intensive use of fertilisers, other pollutants that have become important are phosphate, sulphur, selenium, mercury, cadmium, lead and zinc.

Groundwater pollution has been detected in São Francisco Basin, where the dependency on this supply of water is greater than in the rest of the Brazil Current region. Two geological formations coexist in São Francisco Basin. The potential of crystalline rocks and their overlying soils as water resources is limited due to lack of permeable aquifer volume, rendering such resource insufficient for human consumption. The largest reserves of groundwater are located in sedimentary rocks and their associated soils. Some areas intended for agriculture have been impaired by salinisation, resulting in a loss of cultivation capacity in those areas. In northern Bahia state, the use of groundwater for domestic, agricultural and industrial purposes is considerably higher than in southern Bahia, where it is used mostly for industrial purposes. During periods of drought in São Francisco Basin, the use of groundwater compensates for the water scarcity in non-perennial rivers. The drainage area bound to the north by the São Francisco Basin and to the south by the Todos os Santos Bay in Bahia state (50 in Figure 2) shows regional scale of salinisation, and perennial waterways are drying up. In the basins of Vaza-Barris, Sergipe and Piauí-Fundo-Real, for instance (50 in Figure 2) the salinisation of wells is documented in areas of extensive cattle farming and non-irrigated agriculture.

**Socio-economic impacts**

**Economic impacts**

The economic impacts due to anthropogenic activities arising from freshwater shortage in the Brazil Current were considered moderate in all sub-regions at present but with a clear tendency to be aggravated in the future. In South/Southeast Atlantic and East Atlantic Basins during the 1990s, due to the low economic growth rate, the federal and the state governments made limited investments to avoid water scarcity. Diversion of river course for water transfer are costly and environmentally questionable. The project proposed for São Francisco River to transfer water to the semi-arid portion of the basin has been exhaustively discussed during decades, with no clear conclusion about its convenience. Water policy is becoming more and more restrictive. According to the Federal Law of Water No. 9 433 8th January 1997, plans for any new sectorial activity dependent on water supply must be submitted to the basin committees formed by local/state government authorities, water users and representatives of stakeholders in order to obtain a permission to use a set quantity of water. Loss of opportunities for investments by economic sectors is likely to occur in those basins where such authorisation will be limited by the availability of water. In São Francisco Basin, where water scarcity is associated to quantity and climate conditions more than quality, economic impacts due to freshwater shortage are likely to turn from moderate to severe during the coming 20 years due to the worsening of the following: (i) limitation in agricultural productivity; in the municipalities of Petrolina, Juazeiro and Piauí, hundreds of fruit fields are dependent on irrigation, although energy generation has been a priority in this basin; (ii) limitation in future development of water-dependent activities; in upper São Francisco, the Três Marias hydropower plant restricts water consumption upstream of the dam, which impairs hydropower generation; and (iii) limitation due to low quality of the water; in the Rio das Velhas tributary, the uses of water for agricultural purposes, as well as for public supplies are restricted due to very low quality of the water. Other sectors affected by the low water quality are fishing, aquaculture and tourism.

**Health impacts**

In South/Southeast Atlantic and East Atlantic Basins as a consequence of the investments in water treatment and supply made by the state and municipal governments, health impacts due to freshwater shortage is considered to be slight at present. However, many coastal cities with a fast-growing tourism industry will require significant additional investments to fulfil the demands. Rationing due to water quality has been the strategy used when the treatment required to make potable water demands longer residence time in treatment stations, or more sophisticated procedures than usual. This has been the case in the water treatment facilities of Guandu that supplies 8 million inhabitants
of the Rio de Janeiro Metropolitan area. In March 2003, the previously mentioned accidental release of a large volume of toxic waste water from the Cataguazes paper-pulp plant caused severe pollution and health impacts were only avoided by interruption of water supply to 600,000 people living in the Lower Paraíba do Sul in Rio de Janeiro state. However, the pollution did kill all the fish and mortality among domestic animals were registered. In São Francisco River Basin, the health impacts due to water scarcity were deemed as moderate with tendency to severe, particularly in the semi-arid portion of the Basin, due to the great number of people affected, and the duration, since the impacts are suffered frequently.

Other social and community impacts
Social impacts occur due to floods in the South/Southeast Atlantic and East Atlantic Basins caused by the set of events: deforestation - erosion - reduction of infiltration - siltation of rivers - modification of stream flow - increased flooding. Damage to houses built in the hills during intensive rainfalls in the rainy season (summer) are registered in many cities. There is also an increasing consumption of mineral water among middle-class citizens as a consequence of the public perception that the water quality in the rivers is low, regardless the fact that the water in the distribution system is treated and therefore potable. The social impacts where considered moderate in the South/Southeast Atlantic and East Atlantic Basins. In the lower-middle and lower São Francisco Basin, severe social and other community impacts are described as a consequence of freshwater shortage; migration of populations (about 20%) occurs between not too distant locations (Machmann de Oliveira, pers. comm.). Other social impacts worth mentioning are changes in the family structure due to replacement of fishing by other economic activities caused by the depletion of fish stock, as a consequence of damming and changes in the stream flow, and reduction of fish as a protein source. Significant morphological changes observed in the lower São Francisco River, due to stream flow regulation, are causing cultural changes. As a consequence of a large number of sandbanks along the waterway, navigation, a traditional activity on São Francisco River, is now very difficult and only possible for small boats. In the Atlantic Basin of Uruguay (89 in Figure 2) assessed independently from the Brazil Current region, although the water scarcity is currently considered as producing slight environmental and socio-economic impacts, these impacts are expected to increase due to the seasonal population increases associated with the development of the tourism sector and the urbanisation of the Atlantic coast of Uruguay during the coming decades.

Conclusions and future outlook
According to the water availability indicator mean discharge per capita (m³/year/inhabitant), currently, the Brazil Current region encompasses basins that fit mostly in three categories: rich, sufficient and regular, which indicate that based on the quantity assessment, freshwater shortage is assessed as having moderate impact in the Brazil Current region. However, such an indicator does not take into consideration different degrees of economic development inside the Brazil Current region, population vulnerability, the anthropogenic pressures and the quality aspects of the water supply. The environmental impacts due to freshwater shortage are likely to increase moderately during the next two decades as a result of slow economic and population growth, aggravated by the littoralisation trend that will probably slow down during the coming decades. However, the most remarkable increase foreseen, in terms of severity of the impacts, will be the economic ones. In order to face the increasing demand for water and mitigate the pollution of existing supplies and reduce or, at least keep the impacts on human health and other social impacts under control, significant response from the society, in terms of investments and raised operational costs will be required.

Pollution

Aquatic pollution can be defined as the introduction of man-made substances into the aquatic environment which are harmful to life and to human or animal health (e.g. pesticides, hydrocarbons, PCBs) and the increase to harmful levels of naturally occurring elements (e.g. heavy metals, suspended solids, organic nutrients). According to the criteria of the GIWA assessment, the concern Pollution was assessed as moderate in South/Southeast Atlantic Basins and São Francisco River Basin, and severe in East Atlantic Basins. The concern was ranked as the priority in the South/Southeast Atlantic and East Atlantic Basins and the third priority in São Francisco River Basin (see Annex II). The same impact score but diverging priorities are due to the relative position the concern received inside each region. For the whole of the Brazil Current region, Pollution was assessed as having the highest priority. Evidence and indications that back this decision are presented below and in Annex III.

The pollution issues of great importance for the Brazil Current are microbiological pollution, eutrophication, chemical pollution and spills. In the Brazil Current region, these issues are usually associated to the process of littoralisation observed in Latin America (Hinrichsen 1998) and are likely to cause moderate to severe environmental impacts, particularly downstream of areas of high urban/industrial density. The severity of socio-economic impacts will depend on the
society’s response to the problem on a local and regional scale. Large
cities and metropolitan areas in the Brazil Current, from north to south
(metropolitan area/state) are: Salvador/BA, Vitória/ES, Rio de Janeiro/RJ
(Figure 24), Santos/SP, Joinville/SC, Florianópolis/SC, Tubarão/SC, Porto
Alegre/RS and Pelotas/RS. In these areas, the transport, dilution and
assimilation capacity of receiving waters may be exceeded.

For the case where pollution associated to the sub-regional water
availability is such that the supply is impacted, this impact was
considered in the previous section Freshwater shortage. However,
it was advisable to assess pollution of freshwater sources in the present
section, regardless of whether it causes freshwater shortage or not.

Environmental impacts

Microbiological

Environmental impacts due to microbiological pollution were assessed
as moderate in the South/Southeast Atlantic and East Atlantic Basins
and slight in São Francisco River Basin according to the following.

Those river basins in the Brazil Current densely occupied with
settlements have shown values of faecal coliforms above the threshold
limit established by the Brazilian National Council of Environment
(CONAMA) Resolution No. 020/1986 for waters in Class 2 (can be used
for water supply after conventional treatment and for direct contact
recreation activities such as swimming). Annex III includes information
and references about average faecal coliforms concentration values
found in Paraná do Sul River and Doce River (East Atlantic Basins) as
well as in São Francisco River. Only in the upper São Francisco does
microbiological pollution produce significant impact due to the sewage
discharge without treatment from the Metropolitan region of Belo
Horizonte, that hosts 2 million inhabitants (IGAM 2001).

According to the Brazilian Law (CONAMA Resolution No. 274/2000) a
segment of coastline (beach) is considered proper for bathing (meaning
direct contact and recreational uses) if 80% or more of water samples
during a 5 week-period do not exceed the threshold limit of 1 000 MPN
(Most Probable Number) faecal coliforms per 100 ml of water. Otherwise
it is considered inappropriate for bathing and the community is informed
via media. Monitoring programmes for thousand sampling points on the
Brazil Current coast using faecal coliforms as indicator are carried out
by local governments. Based on periodic results, the authorities have
recommended restrictions for recreational uses to several beaches
located downstream urban centres in basically all coastal municipalities.
Similarly to what occurs with rivers, beaches located downstream
densely populated urban centres or metropolitan areas are more likely
to be contaminated by faecal coliforms in concentrations above the
threshold limit, in the littoral of all the states which make up the coastline
of the Brazil Current. Rainfall regime has an important influence on the
quality of the coastal waters. Intense/long rainfalls increase the stream
flows and after these events the beaches receive the most contaminated
discharges. It should be highlighted that the majority of beaches in the
Brazil Current littoral are considered proper for bathing all year around
but they are located outside urban centres and fortunately represent the
major extent of the Brazil Current littoral. The efforts spent recently by
state and municipal governments with increasing investments in sewage
collection and treatment are likely to produce gradual improvements,
as the case of São Paulo state in the South/Southeast Atlantic Basins
(Municipality of Santos 1997, São Paulo 2002). In Annex III, average values
of faecal coliforms, mostly in bays and lagoons in both South/Southeast
and East Atlantic Basins are shown.

Eutrophication

The remaining organic load (organic load as BOD₅/day discharged in
recipient waters, including treated and untreated effluents) discharged
in the Brazil Current region is shown in Table 12 (PNRH 2003). The
higher value observed for East Atlantic Basins when compared to the others is due to the basins in the littoral of Rio de Janeiro state (59 in Figure 2), which alone contributes with 469 tonnes per day (Figure 25). Paraíba do Sul River basin (58 in Figure 2) contributes with 235 tonnes BOD, per day (PNRH 2003). In addition, domestic sewage, run-off from agricultural areas and industrial effluents can be added. Owing to the natural attenuation capacity of the waterways, the impacts caused by the organic load in water supply bodies are mostly observed at lagoons, bays and constructed reservoirs, the last of which usually have two functions: electricity generation and water supply.

Annex III includes examples of rivers in the Brazil Current region, which are important water supply bodies and due to the low quality found in some monitoring stations they are classified as Classes 3 or 4, according to Brazilian standards (CONAMA Resolution No. 020/86). The quality parameters considered, among others, are: BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), nutrients, faecal coliforms and heavy metals. Rivers that serve the purpose of human supply after conventional treatment and primary contact (e.g. swimming) have been initially placed as Class 2 or, in the worse case, as Class 3, but should never be of lower quality than that.

Although eutrophication is not widespread in the coast and rivers (the reason environment impacts are assessed as moderate), in those areas where it occurs, the environmental impacts as well as the socio-economic impacts are certainly severe. The assessment of eutrophication divides the Brazil Current in two categories:

- South/Southeast Atlantic and East Atlantic Basins that show moderate environmental impacts due to eutrophication observed in lagoons, bays, affecting coral reefs and constructed reservoirs (with episodes of fish kills) and;
- São Francisco Basin where the environmental impact observed is due to the reverse problem: low concentration of nutrients mostly in the middle-lower and lower São Francisco River, as a consequence of the trapping of sediments/nutrients in dams, which has caused a decrease in primary productivity (see Annex III) (Machmann de Oliveira 2003). The environmental impact was not

### Table 12: Remaining domestic organic load, based on estimated values.

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Domestic organic load (tonnes of BOD/day)</th>
<th>% in the country</th>
</tr>
</thead>
<tbody>
<tr>
<td>South/Southeast Atlantic Basins</td>
<td>1,042</td>
<td>16.4</td>
</tr>
<tr>
<td>East Atlantic Basins</td>
<td>1,258</td>
<td>19.8</td>
</tr>
<tr>
<td>São Francisco River Basin</td>
<td>498</td>
<td>7.8</td>
</tr>
</tbody>
</table>

(Source: PNRH 2003)

Figure 25  Rodrigo de Freitas Lagoon, Rio de Janeiro (East Atlantic Basins). Death of tonnes of fish during summer due to oxygen depletion, as a consequence of the increasing organic load and temperature rise.

(Photo: JOAO P. NGELBRECHT/UNEP/Still Pictures)
assessed as unknown or absent, but as slight impact due to the eutrophication process and blooms of toxic algae recorded in some reservoirs such as Paulo Afonso and Itaparica (Braga et al. 1999).

Several bays, estuaries, lakes and lagoons downstream from urban centres show different degrees of eutrophication, Guanabara Bay in Rio de Janeiro state (59 in Figure 2), being the most severe case. Anoxia or low oxygen levels (<3 mg/l) occur in lowland watersheds, estuaries and coastal lagoons and significantly affect coastal embayments (Lacerda et al. 2002). Fish kills due to low concentration of dissolved oxygen associated with the proliferation of algae or algal toxins are not uncommon in rivers such as Conceição Lagoon (Sierra de Ledo & Soriano-Serra 1999) in Santa Catarina state and Patos Lagoon estuary in Rio Grande do Sul state. According to the Standard Trophic State Indexes (Nixon et al. 1986, Rast et al. 1989), used to classify the trophic level of a water body and that take into consideration particulate organic carbon, nitrogen and phosphorus concentration, dissolved oxygen and chlorophyll a, the following systems have eutrophic to hypertrophic conditions (for details and references see Annex III):

- Guanabara Bay, Sepetiba Bay and Coastal Lagoons of Rio de Janeiro state;
- Ribeira do Iguape River, Santos Bay, Cananeia Lagoon in São Paulo state;
- Coastal Lagoons in Santa Catarina state;
- Patos Lagoon in Rio Grande do Sul state.

In the north of Bahia littoral (East Atlantic Basins), signs of eutrophication processes impacting the coral reefs distributed along a small strip of discontinuous carbonate build-ups have been described (Costa et al. 2000). Coral reefs extend for 20 km along the northern coast of the state. Over the last 15 years, this region has experienced an acceleration of generally unplanned urbanisation, with the irregular and indiscriminate use of septic tanks in urban centres contaminating the groundwater. High densities of macroalgae and heterotrophic organisms were found impacting Guarajuba coral reefs (downstream of a densely urbanised area) when compared to Papa Gente reefs (downstream an underdeveloped area). A model of nutrient enrichment via groundwater seepage, according to Costa et al. (2000) is a plausible mechanism to explain the eutrophication occurring in Guarajuba coral reefs. Costa et al. (2000) suggest that the infiltration of nutrients and pathogens is facilitated by both the soil permeability and an accentuated hydraulic head, which eventually leads to the percolation of nutrient-rich groundwater seaward to the reefs. Higher availability of nutrients in Guarajuba coral reefs is affecting the trophic structure in the study area, especially in Guarajuba, with increased macroalgal growth, reducing light penetration to the coral colonies, competing with the corals for space and inhibiting the settlement of new coral larvae.

Eutrophication in reservoirs constructed for energy generation and water supply, as well as in aquaculture tanks is a matter of great concern. Eutrophic conditions have been described in reservoirs located in all three sub-regions in the following states: Pernambuco, Sergipe, Bahia, Minas Gerais, Rio de Janeiro, São Paulo and Paraná, Santa Catarina, Rio Grande do Sul (for references, see Annex III). Algal blooms episodes in bays, lagoons and in constructed reservoirs in South/Southeast Atlantic and East Atlantic Basins include species like: Microcystis aeruginosa, Microcystis flos-aquae, Anabaena spp., Lyngbya confervoides, Sirochocystis aquatilis (f. salina), Phormidium spp., Cylindrospermopsis raciborskii and Coelosphaerium naegelianum. Fish kills are recorded in some aquatic systems (for references, see Annex III).

**Chemical pollution**

In South/Southeast Atlantic Basins, chemical pollution is causing moderate impacts (for references, see Annex III). The industrial park of Cubatão on the coast of São Paulo state are responsible for pollution along the coastline. Analyses of Santos estuary sediments demonstrated that the coast has received effluents with high concentrations, above threshold limits, of heavy metals, such as zinc, mercury, chromium, copper and lead, mainly released by the factories in Cubatão and now concentrated in the marine sediments. In Santa Catarina state, the use of pesticides in rice plantations and fruit farms in the Itajaí River basin, in addition to intense industrial activity in the city of Joinville is responsible for coastal chemical pollution. Concentrations of cadmium and nickel have been detected in biotic components of mangroves in Santa Catarina state.

In Rio Grande do Sul state, the use of pesticides and agricultural runoff, mostly from rice plantation in the catchment area of Patos-Mirim Lagoon system, are the main causes of pollution, followed by industrial wastewater discharges and titanium mining. Heavy metals have also been found in high concentrations in the water column of Patos Lagoon in Rio Grande do Sul. High concentrations of heavy metals in the estuarine sediments of Rio Grande do Sul have been associated to industrial activities such as petrochemical, metallurgical, pulp-paper and refineries. BHC (benzene hexachloride), chlordane, DDT and PCBs have been detected in mussels on the coast of Brazil Current (see Annex III). Organochlorine compounds in the mollusc’s tissues were detected in the coastal zone of Rio de Janeiro state (Cabo Frio, Guanabara Bay), Sao Paulo state (Santos Bay), Paraná state (Paranaguá Bay) and Rio Grande do Sul state (Patos Lagoon). Pyrite waste (iron sulphide) generated by mining activities in carboniferous reserves in south of...
Santa Catarina state has been contaminating the water bodies (PNRH 2003). In the Itajaí Valley, the combination of textile industry, irrigated rice and pig raising represents a source of chemical pollution.

In East Atlantic Basins, chemical pollution is responsible for moderate environmental impacts (for references, see Annex III). The coast of Rio de Janeiro state (mostly bays such as: Guaratiba, Sepetiba, Mangaratiba, Angra dos Reis and Guanabara Bay) has suffered environmental impacts over the past decades due to chemical pollution, mostly from industry; heavy metals are found in sediments above threshold limits, which together with urban effluents are responsible for a reduction in marine/estuarine life. One of the largest natural fish breeding grounds, Sepetiba Bay, has been under severe impacts due to silting, pollution and mangrove destruction. The construction of Sepetiba Port and the activity of dredging to deepen the shipping channel have caused impacts on the Bay due to resuspension of heavy metals accumulated in the sediments. Heavy metals such as cadmium, zinc, lead and chromium have been found on the Rio de Janeiro coast in the suspended material, sediments and in the biota (mussels, oyster, macroalgae) of bays in Rio de Janeiro state (Sepetiba Bay and Guanabara Bay). Evidences from the Paraíba do Sul River, Doce River and Jequitinhonha River reveals heavy metals concentrations in the sediments above threshold limits. Abrupt changes in the river flows can make these metals available to the food chain. Increasing suspended solids discharge due to deforestation for urbanisation, agriculture and timber exploitation has caused severe economic impacts in important reservoirs such as Funil on the Paraíba do Sul River. Deterioration of water quality in rivers and reservoirs due to pollution and groundwater salinisation by irrigated land contribute to the limited availability of freshwater in the Basins. In Sergipe state, hydrocarbons contamination is related to discharge of oil production. Occurrence of fish and mussel kills related to washing out of textile/organic effluents has been described. In Bahia state (Todos os Santos Bay) mercury is found 2 to 5 times higher than the baseline levels in hot spots (Lacerda et al. 2002). Mucuri River is the best example of a river affected by Eucalyptus spp. plantation and the associated paper industry.

Doce River Basin (Minas Gerais and Bahia states) is one hot spot for pollution and has as the main chemical polluting sources mining and industry, mostly steel industry. The results of monitoring data obtained during the period 1993-1996, compared to 1985-1990 (Gerenciamento Integrado da Bacia do Rio Doce 2003), revealed that in general terms an improvement of water quality occurred in 33% of all sampling points, a worsening was observed in 21% sampling points, while 46% remained at the same level of pollution. Based on water quality parameters, the quality of Doce River in many monitoring stations was classified as Class 3, the lowest quality permitted for supply purposes after receiving conventional water treatment. A total of 649 samples were analysed for 25 parameters. Currently, 59 monitoring stations are operating (Gerenciamento Integrado da Bacia do Rio Doce 2003).

The specific discharges of rivers in the eastern Brazil are naturally low and the construction of dams has increased the retention of suspended solids in the basins. Erosion along the river basin is an important factor in deteriorating the quality of the water in most rivers in the east, also provoking silt deposition along riverbeds and flooding. This increases during rainy seasons because of erosion of unprotected margins. Engineering works for transfer of water for supply purposes also means transfer of solid matter across catchment basins. In Sepetiba Bay (Rio de Janeiro littoral), for instance, diversion
of the adjacent Paraíba do Sul River basin (both in the East Atlantic Basins) to supply the Rio Janeiro Metropolitan area, starting in the 1950s has resulted in a ten-fold increase in the freshwater discharge to that bay and increased sedimentation from about 60 mg/cm²/year in the early 1970 to >320 mg/cm²/year in the 1990s (Forte 1996, Barcellos & Lacerda 1994, Barcellos et al. 1997). On the other hand, at the mouth of the Paraíba do Sul River, on the north coast of Rio de Janeiro state and about 300 km from Sepetiba Bay, extensive erosion of the coastline is destroying fringes of mangrove forests, dunes and small villages in the area, due to lack of sediment transport (Dias & Silva 1984). In this example, suspended solids transport/sedimentation dynamics that cause pollution problems in one basin is indirectly causing habitat and community modification in another basin.

Brazil is the one of the world’s largest iron ore producers and exporters. Iron has traditionally been the country’s largest export product, accounting for 5% of the total value of mineral exports. Production in 2000 was 200 million tonnes, of which 158 million tonnes was exported. Japan, Germany, China and South Korea were the main importers. One of the most productive areas is the Iron Quadrangle of the state of Minas Gerais (East Atlantic Basins). Important metallurgical industrial activities, such as the giant Companhia do Vale do Rio Doce are located in the Minas Gerais state, where reserves have been estimated at 1.3 billion tonnes of high iron grade hematite and 4.3 billion tonnes of rich itabrites. Mining is one of the activities responsible for soil erosion/pollution in the region.

Diversion and damming of São Francisco River are seriously affecting the erosion-accretion equilibrium of its estuary. These effects are most apparent where water resources are scarce, as the case of middle-lower and lower São Francisco River Basin. The total discharge of sediments in the São Francisco River estuary that in 1983 was 6 million tonnes per year was in 2000 reduced to 410 000 tonnes per year. This residual transported sediment is likely to be material generated in the lower São Francisco, since the sediments generated upstream are trapped in the cascade of reservoirs (Machmann de Oliveira 2003).

Solid waste
In the Brazil Current region, major efforts have been made by city authorities in an attempt to reduce litter as much as possible, and keep clean the urban centres and beaches with the greatest influx of tourists, since this is a considerable source of income. Educational campaigns have had positive results in changing citizens’ behaviour. Collection of municipal solid waste in the states entirely or partially included in the Brazil Current varies from 98.8% in São Paulo (in South/Southeast Atlantic Basins) down to 84.7% in Pernambuco (in East Atlantic Basins) (Table 13) (IBGE 2002). The poorest coverage is found in the shanty towns and the periphery of metropolitan regions and in the northeast portion of the Brazil Current region where the percentage collected is below the national average value.

When it comes to final disposal, the scenario is much worse; open dumps are still the most common final disposal option in many municipalities. The range varies from the best case: 53.7% of the municipal solid waste with appropriate final disposal in Santa Catarina (in South/Southeast Atlantic Basins) to the worst case: 22% in Sergipe state (in East Atlantic Basins).

Thermal
More research is needed to investigate the extension and the effects of thermal pollution in Brazil Current. Based on the current knowledge, there is no large-scale or significant output of effluents exceeding temperatures in receiving bodies in the Brazil Current region. The environmental impacts in South/Southeast and East Atlantic Basins were assessed as slight and unknown in São Francisco River Basin. The expansion of the number of thermal power plants in the region, as a result of the energy sector policy, will probably increase the impacts of thermal pollution.

Radionuclides
There is a potential risk for accidents in the region of Angra dos Reis in Rio de Janeiro, because of the nuclear power plants Angra I, II and III (South/Southeast Atlantic Basins). However, as regards these plants, the operation, maintenance and the radioactive waste deposits are considered adequately monitored and well controlled.

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### Table 13  Collection and final disposal of municipal solid waste in Brazil Current.

<table>
<thead>
<tr>
<th>State</th>
<th>Collection (%)</th>
<th>Adequate (%)</th>
<th>Inadequate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pernambuco</td>
<td>84.7</td>
<td>38.0</td>
<td>62.0</td>
</tr>
<tr>
<td>Alagoas</td>
<td>91.0</td>
<td>6.50</td>
<td>93.5</td>
</tr>
<tr>
<td>Sergipe</td>
<td>89.6</td>
<td>2.20</td>
<td>97.8</td>
</tr>
<tr>
<td>Bahia</td>
<td>85.0</td>
<td>39.6</td>
<td>60.4</td>
</tr>
<tr>
<td>Minas Gerais</td>
<td>91.9</td>
<td>33.0</td>
<td>67.0</td>
</tr>
<tr>
<td>Espírito Santo</td>
<td>91.8</td>
<td>49.4</td>
<td>50.5</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>94.3</td>
<td>45.9</td>
<td>54.1</td>
</tr>
<tr>
<td>São Paulo</td>
<td>98.8</td>
<td>42.4</td>
<td>57.6</td>
</tr>
<tr>
<td>Paraná</td>
<td>97.0</td>
<td>39.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Santa Catarina</td>
<td>96.8</td>
<td>53.7</td>
<td>46.3</td>
</tr>
<tr>
<td>Rio Grande do Sul</td>
<td>97.3</td>
<td>49.6</td>
<td>50.4</td>
</tr>
<tr>
<td>Brazilian average (for urban areas)</td>
<td>91.2</td>
<td>40.5</td>
<td>59.5</td>
</tr>
</tbody>
</table>

Note: Brazilian states entirely or partially included in Brazil Current. Figures in red indicate values below the national average for collection/adequate final disposal. (Source: IBGE 2002)
**Spills**

Several small-, medium- and large-scale spill events involving oil, grease and a number of chemical/hazardous substances have been registered in the marine, coastal and freshwater bodies of the Brazil Current region, particularly in South/Southeast and East Atlantic Basins. In few cases, recovery of habitats and species after the accidents has been described. In recent years, legal actions and high penalties have been applied.

In South/Southeast Atlantic Basins spills have been registered in São Paulo littoral (São Sebastião Channel), Santa Catarina littoral (e.g. Paranaguá Bay), Paraná state and Rio Grande do Sul littoral. Port activities, mainly in São Paulo and Paraná states, contribute to frequent small to medium-sized spills. According to the Environmental Accident Record (CADAC) of the Environmental Protection Agency of the state of São Paulo (CETESB), during the period from January 1980 to February 1990, there were 71 accidents involving oil and derivatives along the São Paulo coast, causing serious damage to estuary communities. The Centre South Ducts and Terminals (TEBAR-DTCS) on the São Paulo coast is the country’s main sea terminal, accounting for around 55% of all oil transported in Brazil. A large number of accidents, including leaks and accidental oil spills have been recorded during routine operations: 191 accidents between 1974 and 1994 (Poffo et al. 1996) and 18 between 1995 and 1998, contributed to chronic pollution in nearby areas. As a result of these spills, rocky coast and sand beach ecosystems have been systematically affected. The coastal environment which is most frequently affected are the coastal areas and beaches located in São Sebastião and Bela Island, mainly inside the channel, because of their proximity to the sources of pollution. However, coasts and beaches all along the São Paulo coast have been affected to a lesser extent by oil and derivatives (Poffo et al. 1996). Every year, around 3.5 million m$^3$ of sediments are removed from the estuary to provide passage for large ships. This activity, apart from the impact on several benthonic animals, promoted the re-suspension of toxic substances which are deposited in the sediment on the riverbed, increasing the spectrum of action and the impact of this activity, which can stretch into areas adjacent to the Santos Bay and have a transboundary effect.

Frequent spills of smaller proportion are common in Todos os Santos Bay/BA, Vitória/ES and Guanabara and and Sepetiba bays/RJ (East Atlantic Basins). However, episodes of more serious proportions have been described as, for instance, 1 500 litres of oil spilled from a Cypriot company that was docked at Tubarão Port, Vitória/state of Espírito Santo (Ministério Público Federal 1999). Two large-scale accidents occurred during the period 2000-2001 involving the Company Petrobrás: (i) in January 2001, 1.3 million litres of oil spilled into Guanabara Bay (part of 59, Figure 2), Rio de Janeiro state, after the pipe that connected Duque de Caxias refinery to the Ilha d’Água Terminal was broken (IBAMA 2002); and (ii) an accident with the P-36 platform in Campos, also in the state of Rio de Janeiro, that sunk after an explosion. During these accidents, millions of litres of oil leaked into the water bodies, resulting in serious impacts on the regional ecosystems. These accidents bring a question mark to the effectiveness of environmental quality certificates, such as ISO 9 000 and ISO 14 000, given out to the companies responsible. More examples of spills are presented in Annex III.

In São Francisco Basin the environmental impacts due to spills were assessed as slight.

**Socio-economic impacts**

**Economic impacts**

Basically, there are two categories of economic impacts resulting from pollution. First those associated to loss of opportunities or loss of the economic value of goods due to the low quality of the water resources/water environment, reduced options for water uses; and second increasing water treatment and surveillance costs and costs associated to recovery of degraded areas and penalties. In the Brazil Current region, in the first category, impacts of pollution on tourism and fishing, loss of property value, and exploitation of more expensive alternative sources (e.g. groundwater, instead of surface water) are found. The second category also found in Brazil Current includes costs of construction, operation, maintenance of water treatment plants, costs for recovering/remediation of polluted areas and penalties against companies responsible for accidents (e.g. major spills events). Taking into account all these aspects, the economic impacts due to pollution in the Brazil Current were considered severe. Investments for treatment of water bodies and remediation due to accidents and spills in the marine environment are already high, with a tendency to worsen in the near future as the economic development expands.

Eutrophication alone is already responsible for severe economic impacts in reservoirs in South/Southeast Atlantic Basins (COPPE/UF RJ 2002). Significant investments for pollution abatement and/or maintenance costs associated to pollution in the South/Southeast and East Atlantic Basins are found in Marques (1995), MPO et al. (1999), Lamardo et al. (2000), CETESB (2001), COPPE & UFRJ (2002), COPPE/UF RJ (2002) and Sistema de Gestão Integrado da Bacia do Rio Paraíba do Sul (2003). Gradual improvement of the awareness among citizens and more efficient legal instruments are likely to promote enforcement. More efficient enforcement will probably lift the insurance costs. Examples of recent penalties applied due to spills are found in Ministério Público Federal (1999), Luiz & Monteiro (2000), IBAMA (2002), O Globo (2002a) and O Globo (2002b) (see also Annex III). Some densely populated
areas of the Brazil Current littoral have already experienced economic losses, mostly in tourism, which is a natural vocation for the region and employs a large contingent of people. In the significant reduction of fish stocks due to changes in suspended solids/nutrients transport dynamics is responsible for moderate to severe economic impacts in the fisheries sector. Siltation in the upper and middle São Francisco is causing an economic impact on fluvial navigation, an important means of transportation within the basin.

Health impacts
Health impacts due to water pollution is mostly associated to the absence of sewerage system and therefore, to the low-income areas. Health impacts due to eutrophication in water supply reservoirs and aquaculture tanks have recently become an issue of concern in South/Southeast Atlantic Basins as well as in East Atlantic Basins. At least two episodes of severe health impacts, with hundreds of cases of intoxication followed by death due the presence of hepatotoxins released in the water supply after algae blooms have been recorded (Azevedo 1996, Costa & Azevedo 1994, Teixeira et al. 1993, Proença et al. 1996). More frequent is the association between water pollution and health impacts related to water-borne diseases such as microbiological and parasites diseases (Governo do Estado de São Paulo 2002). Increasing gastrointestinal symptoms related to the time of exposure to polluted beaches was described by CETESB in Governo do Estado de São Paulo (1999). In the Paraíba do Sul River Basin (East Atlantic Basins) the incidence of microbiological infection and parasitic diseases varies among municipalities from 0%-30% (Figure 26 and Figure 27) (IBGE 2001). For more details see Annex III.

Regarding risks to human health in São Francisco Basin, cases of schistosomiasis have been registered all over the Basin. In the upper São Francisco there are health problems resulting from microbiological contamination and the suspicion of problems resulting from chemical pollution, which are not confirmed, due to lack of proper investigation. While the percentage of the population affected is small, the degree of severity is high, due to the poverty level of those affected, among whom the frequency of occurrence of this problem is high.

Other social and community impacts
Among the social and other community impacts due to pollution, the loss of recreational and aesthetic values of many beaches can be mentioned. This occurs from northeast down to south of the Brazil Current region, in the coastal area and bays downstream densely urbanised centres. Another example is the impacts on Environmental Protection Areas (APAs) occurring after large-sized spills, such as those which occurred in Guanabara Bay (East Atlantic Basins), affecting the APA of Guapimirim. This area represents the largest mangrove area on the Rio de Janeiro coast. Fluvial transportation is limited in those
waterways that have suffered most by siltation, where there are also social impacts due to flooding. Below, five case studies of pollution associated to different sectors are briefly presented. Pollution has also been considered one of the causes of reduction of fish stocks, which causes social impacts in hundreds of communities of fishermen along the coast of the Brazil Current region.

**Case 1: Mining activities in Jequitinhonha River basin (East Atlantic Basins)**

Jequitinhonha River basin is a transboundary system that encompasses 53 municipalities, has a total area of 69,997 km², 65,517 km² (93.6%) of which in Minas Gerais state and 4,480 km² (6.4%) in Bahia state, and a population of 900,000. Gold, diamonds and other precious stones are the main natural resources explored. Although rich in mineral resources, the Jequitinhonha Valley (named by the UN the “Valley of Misery” in 1974) hosts one of the poorest populations in Brazil. Mining is the activity with the heaviest impact on the water resources in the region. Intensive dredging practices during many decades have changed the watercourse and caused pollution by mercury. Mining has also caused losses of riparian vegetation, ecosystems modification, erosion and silting. Some of the impacts due to mining during the last decades are considered irreversible. Besides mining, other activities that pollute the River are the use of pesticides and discharge of untreated sewage. Forest destruction has also contributed to erosion. Contamination by microorganisms and turbidity (suspended solids) are the most common parameters along the River which do not comply with standards. The socio-economic impacts include e.g. loss of transportation, which is no longer possible in the River. Sandbanks are seen in many portions of the River.

**Case 2: Industry and urbanisation in Guanabara Bay basin (East Atlantic Basins)**

The Rio de Janeiro littoral includes the City of Rio de Janeiro and the bays of Guanabara (Figure 28) and Sepetiba. Among the major stresses affecting these systems is discharge of domestic effluents and the petrochemical industry, emissions of trace elements, changes in sediment loading generated by river basin activities and other impacts by port activities.

Guanabara Bay (23°45’S, 44°45’W) represents an example of one of the most severely impacted systems of the Brazil Current region. The bay (384 km²) measures 28 km from west to east and 30 km from north to south, has a 131 km perimeter, and a mean water volume of 1.87 billion m³. The residence time is about 22 days and the average annual fresh water input from 35 small rivers is 125 m³/s and peaks in January/summer. Tides are mixed and mainly semi-diurnal with a range of 0.7 m. The salinity varies from 21 to 34.5 ‰ with weak vertical salinity stratification. The bay is located in a Tertiary depression, named the Guanabara rift. There are many out-crops of Precambrian origin abound the Guanabara Bay basin, such as is the case of the 400 m high Sugar Loaf. Elevated paleo-beaches and marine terraces from the Late Quaternary are common around the bay. The climate is “Aw” according to the Köppen classification with an average annual rainfall of 1,733 mm, and highest rainfall in summer.

The bay is one of the most polluted and eutrophic bays of Brazil. The overall mean of chlorophyll a in the bay is 57 mg/m³, the inner section 130 mg/m³ and primary production lies in the order of 400 gC/m²/year. The water quality is indicated by average faecal coliform counts of the
Iron ore mining, followed by gold and gems has been the geological context of the well-known Iron Quadrilateral in the state of Minas Gerais. Iron ore mining activities (now declining) have been highly damaging, as the ore refineries process 17% of the national oil and the bay suffers from chronic oil pollution and sporadic spills. About 18 tonnes of petroleum hydrocarbons enter the bay daily, 85% via urban run-off. Suspended solids with heavy metals accumulate at the bottom. At least 2 000 ships dock in the port of Rio de Janeiro, in Brazil second only to Santos port. Dredging takes place continuously to a depth of 17 m. Besides urban and industrial areas, the basin consists of agricultural fields and cattle grazing lands. The Atlantic Rainforest still extends to the shoreline in a few places and is only intact on the steep slopes of the Atlantic Range. The interior of the bay is fringed by 90 km² of mangroves, threatened by oil and firewood cutting. Landfills located in the Guanabara Bay basin around the bay receive 10 000 tonnes of solid wastes daily. A number of open dumps are also found in the basin. Spills have destroyed fishing grounds, fouled rivers and estuaries, polluted mangrove swamps, and killed seabirds, fish and crustaceans. Out of 6 000 industries, 52 are responsible for 80% of the industrial pollution discharged in the bay. Navigation in the inner part of the bay is no longer possible.

There is no marine life as such, in many parts of the bay. Fishing has decreased by 90% during the last 20 years and the mangrove areas have been reduced to 50% their original size and the 53 beaches are not recommended for swimming due to pollution. Notwithstanding the accentuated degradation, the bay is still important for fisheries, supporting 6 000 families. The annual catch measures 3 000 tonnes (2 700 of fish, 200 of mussels, 100 of shrimp). About 30 species of birds are resident and dolphins used to be abundant. The sediment accumulation rate is estimated to be 1 cm/year although in some regions it increases to 4 cm/year. Since 1994, with a loan obtained from Inter-American Development Bank (IDB) and the Overseas Economic Cooperation Fund (OECF) the state government is investing in water supply, sewage collection and treatment, drainage and solid waste projects.

Case 3: Mining in São Francisco Basin

Ore mining activities (now declining) have been highly damaging, as the effluents of such activity usually contain heavy metals and can contain cyanides. There has been intensive mining activity over centuries in the upper reaches of the basin of São Francisco’s tributary, Rio das Velhas, which has an area of 2 000 km². Coincidently, this basin is inscribed in the geological context of the well-known Iron Quadrilateral in the state of Minas Gerais. Iron ore mining, followed by gold and gems has been undoubtedly the most important mining activity of the region, both for its economic importance and that of associated infrastructure, and the magnitude of its pits and waste and tailings deposits. The following figures illustrate the importance of this activity: the annual tonnage of iron mined is 56 million tonnes per year; 55 million tonnes per year of waste material are removed and disposed of in heaps alongside the excavations; 17 million tonnes per year of tailings are deposited in tailing dams or ponds.

As a result of the removal of waste and the exploitation of ore, voids are formed due to mining excavations at a rate of more than 40 000 m³/year. The deepening of these pits nearly always requires lowering the water level of the aquifers. The iron formations in which the iron ore deposits are inserted, are the geological formations having the greatest potential for water in the area. These iron formations together with other geological formations with different groundwater potential, comprise a synclinal geological structure systems of great size, forming large groundwater basins, known geologically as the Moeda and Dom Bosco Aquifer systems, associated to the synclinals of the same name. These two large aquifer systems, apart from their large potential for water storage and availability, are responsible for the greater share of water supply to the surface springs in the Upper Rio das Velhas basin. In turn, this basin, through catchment of the Rio das Velhas and Morro Redondo Systems, with respective water flows of 5.20 m³/s and 0.60 m³/s, supplies nearly 50% of the requirements of the Belo Horizonte Metropolitan region. The most critical situation in the basin occurs in the Água Suja (Dirty Water) stream and on the stretch of River das Velhas downstream from the point at which these two watercourses meet. Its waters contain high values for organic load, turbidity related to domestic sewers and effluents from small industries, as well as from other sources such as rainwater drainage in both urban and rural areas and by mining liabilities.

Chemical pollution has been detected, e.g. high concentrations of arsenic which are found, show averages well above the threshold value define by the resolution CONAMA No. 020/86, and which may be the consequence of the former gold mining activities in the region and the geochemical characteristics of the local terrain, and the genesis of which is caused through the decomposition of rocks mineralised with gold bearing sulphides. The most serious problem appearing in the Itabirito River is its load of suspended solids, caused by iron ore mining operations. The River’s organic load is still kept within limits, allowing its natural oxidation, along the course of the River. The morphology of the riverbeds of the water courses in the region show an excellent capacity for physical aeration being fully oxygenated at the majority of observation points. There are signs though, that future increased
organic load may change this situation. Downstream, upon mixing with the main stream of the São Francisco, the pollution in the waters of the tributary of the Velhas River is diluted and quality improves, with reductions in the concentration of faecal coliforms and chemical pollutants. Poor management of municipal and industrial solid wastes occurs, but this problem causes no major identifiable impact other than aesthetic ones. There is no proper collection, transportation or final disposal of these wastes. In the São Francisco catchment area, a very small proportion of the population is supplied with treated water.

Case 4: Suspended solids in São Francisco Basin

Between the middle and lower São Francisco River Basin a cascade of reservoirs, such as Xingó have been constructed for power generation. These reservoirs trap most of the suspended solids (FUNDEPES 2001) and reduces the nutrients in the water. When the water loses gradient and flows slowly along the last 200 km until reaching the estuary, the River starts meandering, with consequent formation of sand banks and very low concentration of suspended solids. Inadequate agricultural practices represent another environmental problem in this basin. Irrigation projects have caused soil salinisation in some parts of the Basin.

Siltation is a serious problem over wide/ecologically significant areas and has resulted in markedly changed biodiversity and mortality of benthic species with concomitant changes in the nature of deposited sediments. In the upper and middle São Francisco River solid particles originating from mining, farming and livestock activities and from urban plotting areas form sandbanks along the river channel. Silt transportation occurs mainly as bottom load and very little in suspension. In the sub-basin of the Pará River, in the upper São Francisco, mining of clay, sands, granite, coal and, in the past, gold occur. Gypsum mining occurs in the Brigida River sub-basin. The Paraopeba River sub-basin witnesses an increase in sand exploitation and iron ore mining to meet the expansion of the civil construction and export. Other aggravating factors are connected with suspended solids from widely expanding agricultural and livestock activities. The problem of eutrophication in the São Francisco Basin occurs only in some reservoirs in the tributaries. In fact, there is a lack of nutrients in the main stream. A very low concentration of nutrients is noted in coastal areas as a result of a declining inflow of sediments and nutrients caused by the construction of dams. The smaller municipalities along the São Francisco Basin are not benefited by any sewage treatment, resulting in organic pollution of local water supplies.

Case 5: Pollution in the Uruguayan portion of Mirim Lagoon (South/Southeast Atlantic Basins)

The Uruguay East region is not a highly industrialised region and has a relatively low population density, particularly in the Mirim Lagoon basin (89 in Figure 2). According to the National Environmental Survey carried out by OPP et al. (1992), the main environmental problems in Uruguay at that time were related to: (i) internal causes (land use for agriculture, urban occupation of the coastal zones, deforestation, pollution of water supplies, highway and infrastructure development); (ii) transboundary causes, such as the pollution of the La Plata River (GIWA region 38, Patagonian Shelf) and pollution of the air due to the thermoelectric power plants in Brazil; and (iii) potential impacts due to international development projects (e.g. construction of regional waterways, bridges and highways). Since this national evaluation was made, livestock and rice production in the Mirim Lagoon basin and tourism in the Atlantic Basin of Uruguay have increased significantly. Pollution in the Atlantic Basin (89 in Figure 2) is assessed as producing slight environmental and socio-economic impacts, mostly related to the seasonality of the population during the summer. With the development of this economic sector, the impacts will probably become moderate, particularly the economic impacts due to the investments required to keep the environment clean and thus maintain the tourist flux.

Conclusions and future outlook

The overall impacts due to pollution was assessed as moderate in South/Southeast Atlantic Basins and São Francisco River Basin, and assessed as severe in East Atlantic Basins, based on a large amount of mostly proxy indicators. It is necessary to investigate more thoroughly the environmental effects these pollutants cause on the living resources. There is also a need for detailed epidemiological and economic studies to highlight the existing associations between pollution and economic-health impacts in the Brazil Current, where socio-economic activities associated to densely populated cities have imposed a heavy burden on water resources, expressed as pollution. Chronic as well as acute health impacts due to toxins released after algal blooms in reservoirs and aquaculture tanks must be carefully investigated and monitored. The information available indicates that for the next 20 years even a slow economic growth rate will generate economic impacts mostly associated to pollution abatement. Yet it is likely that costs for insurances and penalties for polluting will increase in the future, which hopefully will prevent the intensification of impacts on the environment and human health. A number of governmental initiatives, such as the Clean-up Programme of Hydrographic Basins (PRODES), created in March 2001 in Brazil under the responsibility of the National Agency of Water (ANA) is expected to contribute to the pollution abatement mostly the one associated to municipal sewage.
Habitat and community modification

The Brazil Current is composed of the drainage basin, the coastal and the shelf-oceanic compartments, all with a large number of habitats and ecosystems. The drainage basin contains the main biome Atlantic Rainforest; some portions of other biomes, such as Restingas (coastal sand spits), Caatinga (dry thornbush) and Cerrado (high plain bush); lakes and the man-made dams and reservoirs (see Regional definition). The coast includes various types of estuarine systems, like coastal lagoons, typical drowned river valley estuaries, bays, river-delta estuaries, wetlands (mainly mangroves), beach-ridges and dunes. The shelf-oceanic realm contains the nutrient poor (Brazil Current) and nutrient rich (upwelling) pelagic waters and the benthic organic- and carbonate-rich (calcareous algae and coral reefs) systems. The Atlantic Rainforest and the Brazil Current are common to the entire region. Several river basins are classified as extremely important regarding freshwater fish biodiversity (MMA 2000). The profile around estuaries, bays and coastal lakes is of fragile formations. Due to complex dynamics, formations and dimensions, when altered by natural or human pressures, these environments are irreversibly damaged. Land use has become a major driving force for both terrestrial and aquatic ecosystem modification and loss. Littoralisation has imposed a burden on habitats and communities. Information substantiating the assessment is briefly presented below.

Fishing in the Brazil Current region is dependent on species that spend a significant part of their life cycle in mangrove areas. Among these are crab species such as *Ucides cordatus*, *Callinectes danae* and *Cardisoma guanhumi*. The bivalves, *Mytella guyanensis*, *Macoma constricta*, *Anamalocardia brasiliana* and *Crassostrea rhizophorae*, which are an important source of income for populations living along the Brazilian coast, are also species dependent on mangrove forests. Species important to commercial fishing which are also dependent on mangroves for the completion of their life cycles are the fish species, *Mugil sp.*, *Centropomus sp.*, *Sardinella aurita*, *Brevortia tyrannus*, *Dicentrarchus labrax* (sea bass), “Manjuba” *Curimatella lepidura* (similar to Whitebait), *Bagre marinus* (catfish) and the shrimp, *Penaeus spp.* Mangrove destruction in the Brazil Current region has therefore a direct impact on fisheries.

Moderate to severe environmental impacts are exerted on estuaries, bays, coastal lagoons, rocky foreshores, marshes and humid coastal regions in the Brazil Current. There is more information available for the South/Southeast Atlantic Basins than for the other sub-regions.

Environmental impacts

Loss of ecosystems or ecotones

This issue refers to the destruction of aquatic habitats. For the purpose of the GIWA assessment, recent loss will be measured as a loss of predefined habitats over the last two to three decades. In the Brazil Current loss of ecosystem has moderate environmental impact and applies mostly to parts of the coastline and river catchment areas with high population densities.

Littoralisation-urbanisation, tourism, petroleum exploitation, several existing large-sized ports, agriculture and more recently, aquaculture are the main sectors causing that generate severely impacted compartments in the Brazil Current from north to south: Todos os Santos Bay (BA), Vitória Bay (ES), Guanabara Bay, Sepetiba Bay and Grande Island Bay (RJ) in East Atlantic Basins; and Paranaguá Bay (PA) and Patos-Mirim Lagoon complex in South/Southeast Atlantic Basins. The expansion of tourism and land occupation along the littoral with fast construction of hotels, resorts and summerhouses has impacted important coastal ecosystems such as restingas and mangroves. Changes in the sediment transport dynamics due to land-based activities in the coast are considered one of the most serious environmental issues (IBAMA 2002).

There are several endemic species in the convergence region of the western South Atlantic and migration of decapod crustaceans (crabs, shrimp) and fishes, which use the estuaries as breeding grounds in the marshy areas (Rio Grande do Sul state), mangroves (e.g. Santa Catarina and Rio de Janeiro states), sea grass areas and shallow small bays. Peixe Lagoon (Lagoon of Fish), in Rio Grande do Sul, acts as an important resting and feeding area for migratory birds. The floral composition of the mangroves is very important for the associated fauna and the relatively low biodiversity and greater fragility in the South/Southeast Atlantic Basins emphasise the importance of its conservation. In the extreme southern Atlantic, rice-farming irrigation and application of pesticides and fertilisers followed by run-off into natural systems have destroyed marshes and have had a severe impact on lakes. In the estuary of Patos-Mirim Lagoon, Tramandai and Laguna, overexploitation of fish has also impacted the habitats (BDT 2001). In Patos Lagoon estuary, 10% of marshland was lost during the last 40 years. The annual rate of loss of marsh area in this estuary is 0.25% (Seeliger & Costa 1997). The estuaries and bays located around the cities of Rio Grande, Tramandai and Torres (Rio Grande do Sul state), Itajaí, Laguna and part of São Francisco do Sul (Santa Catarina state) have suffered impacts due to river discharge of organic pollutants and increasing oxygen demand. Two important environmental protected areas in Rio Grande do Sul are highlighted: (i) the Ecological Station of Taim and (ii) the National Park of Lagoa do Peixe-PARNA included in the UNESCO Network of Biosphere Reserves.
The Rio-São Paulo highway connects the most industrialised and populated areas of South America. The Rio-Santos highway throughout the coastal zone exerts direct pressure over the coastal ecosystems. One of the greatest causes of biodiversity loss and reduction of fish stocks in Ilha Grande Bay, part of Rio de Janeiro littoral (East Atlantic Basins) has been the destruction of mangrove ecosystem that currently occupies an area of 2 000 ha, which represents 50% of the original formation. The intensive soil excavation and transport for construction of the Rio-São Paulo highway, the division of land into lots and urbanisation, associated to the regional rainfall regime, have caused intensive erosion and significant increase of suspended solids in coastal waters. The impacts include smothering of benthonic species, interference with the filtering species and fish respiration. Associated with this uncontrolled urbanisation, there are ports, oil terminals, aquaculture, introduction of alien species and run-off of fertilisers and pesticides (BDT 2001). The construction of decks, walls and land reclamation has destroyed the rocky foreshores and modified the beaches (IBAMA 1997). In Guanabara Bay, the mangrove ecosystem has been reduced, owing to: (i) the operation of the Gramacho metropolitan landfill that receives about 7 000 tonnes per day of solid waste; (ii) the illegal exploitation of mangrove wood for the brick industries in the environmental protection area of Guapimirim, which was created to preserve the mangrove; and (iii) occupation by low-income population.

Sepetiba Bay (Rio de Janeiro littoral) is a semi-enclosed water body located just before the Grande Island Bay in the direction Rio-Santos. It is connected to the sea in the east by a small shallow inlet with little water flow which crosses 40 km² of extensive mangrove forests (Lacerda et al. 2002). The sediment transport and sedimentation rates in the bay have changed dramatically, due to civil engineering work during the 1950s, with water transfer from another basin (River Paraíba do Sul) for the purpose of supplying the Rio de Janeiro Metropolitan area. The sedimentation rate increased from 30 mg/cm²/year to over 250 mg/cm²/year. The impacts on the bay’s ecosystems have not been properly addressed.

The Brazilian salt marshes flora can be characterised as being of low biodiversity, when compared with other types of vegetation in Brazil. Considering the whole set of habitats which form salt marshes, the biodiversity found is high. However, when each individual ecosystem is considered on its own, the biodiversity is relatively low (BDT 2001). The salt marsh fauna has been little studied, requiring systemic information on the composition of fauna communities along different points of the coast, which could be provided by a larger number of inventories with reliable listings, including data on the relationship between them and the vegetation. The main anthropogenic pressures on the salt marshes in the Brazil Current can be distributed by region as follows (BDT 2001):

- Littoral of Espírito Santo and Rio de Janeiro states (East Atlantic Basins) and São Paulo (South/Southeast Atlantic Basins): industrialisation, uncontrolled urbanisation and illegal land occupation, land speculative business associated to tourism, mineral extraction, transport;
- Littoral of Paraná, Santa Catarina and Rio Grande do Sul states (South/Southeast Atlantic Basins): agriculture, irrigation projects, cattle farming, illegal land occupation, coal processing and introduction of alien species, pollution, deforestation and tourism.

The mangrove ecosystem along Bahia state littoral (East Atlantic Basins) presents higher biodiversity than mangroves in the South/Southeast Atlantic Basins. In the estuaries, endemic species of fish, crab fish and molluscs, as well as migratory species of turtles and birds have been identified. In Santa Cruz, Espírito Santo state littoral, the extraction of calcareous algae and muddy sands is impacting the landscape, the geological stability, the biodiversity and the genetic flux of fauna and flora. Deforestation and changes in the sedimentation-erosion equilibrium within the estuaries cause significant impacts on ecosystems. A decrease of approximately 5% of the total sediment flux has been considered the critical threshold (Lacerda et al. 2002), beyond which the coastal system has shown evidence of significant deterioration and coastal erosion. This level of change results in loss of mangrove areas, such as occurs in the River Paraíba do Sul delta (Salomão et al. 2001).

In Brazil, the coral reefs are found along 3 000 km from Maranhão as far as southern Bahia (East Atlantic Basins), making up the only reef systems in the South Atlantic. The main coral species on these reefs occur only in Brazilian waters, where they form structures unparalleled in other regions.

There are major gaps in knowledge, mainly in terms of mapping of biological communities and data on oceanographic physical and chemical parameters and biological interactions (BDT 2001). The coast of Bahia state has 20 km of coral reefs and over the last 15 years, this region has experienced an acceleration of generally unplanned urbanisation, with the irregular and indiscriminate use of septic tanks in urban centres contaminating the groundwater. High densities of macroalgal and heterotrophic organisms were found impacting Guarajuba coral reefs. A model of nutrient enrichment via groundwater seepage is the mechanism proposed to explain the eutrophication occurring in coral reef systems on the northern coast of Bahia (Costa et al. 2000). Data suggest that the great availability of nutrients is affecting the trophic structure in Guarajuba, with increased turf and...
macroalgal growth, reducing light penetration to the coral colonies, competing with them for space and inhibiting the settlement of new coral larvae (see Annex III).

Modification of ecosystems or ecotones

The state of Rio Grande do Sul (South/Southeast Atlantic Basins) and the 500 000 ha of lowlands in the departamentos of Rocha and Maldonado in Uruguay that form the “Bañados del Este” (eastern wetlands) host together a number of lagoons and wetlands with the highest importance in terms of biodiversity (Figure 11). In 1976, “Bañados del Este” (32° to 35° S; 53° to 55° W) in the departamento of Rocha, was declared as a “biosphere reserve”. The eastern wetlands region comprises a remarkable complex of ecosystems of high biological diversity and very rich wild life (MAB 2003). Low hills on rocky substratum also occur on the ocean coast and several coastal lagoons are among the features of the region. Most of them are separated from the sea by a narrow sand bar, which regularly opens allowing the entrance of seawater. The biosphere reserve is the only area in Uruguay where Butia palms exist covering an area of almost 70 000 ha. At present, the palm is at risk of extinction, due to the ageing of the shoots and the lack of renovation of the buds that are eaten by the cattle. Cyperaceae, Juncaceae, Gramineae, and also Monte psamofilo and extensive stands of conifers are dominant in the herbaceous community. The indigenous fauna remains almost intact except that the marsh deer (Lastocerus dichotomus) is now locally extinct. The major ecosystem types are temperate grasslands and coastal wetlands. The major habitats and land cover types are: the coastal wetlands; Butia palm associations (B. yatay); herbaceous communities of Cyperaceae, Juncaceae, Gramineae (Scirpus californicus, Typha spp., Zizaniopsis bonaerensis etc.); and conifer woodland with Pinus atlantica. In 1997, 235 687 people lived in this biosphere reserve developing activities such rice plantation, cattle raising, hunting of fur and aquatic mammals (MAB 2003). Some 100 000 tourists visit the reserve annually. The ecosystem is threatened with serious changes as livestock raising gradually gives way to rice fields. Pesticides are now being used and there has been an attempt to dry the lake areas and alter the water levels in the flood zones. Sites of prehistoric archaeological interest also exists that need to be protected for their study and preservation defining their patrimonial value. The environmental and the socio-economic impacts were both assessed as severe at present, with a tendency of increase during the coming years, due to the tourism and the agriculture sectors. According to the MAB programme (MAB 2003), the biosphere reserve has developed several planning and territorial management activities, incorporating the environmental dimension in local economic and social systems, local participation and knowledge generation (MAB 2003).

Table 14 shows the main lagoons and wetlands in the region comprised by Rio Grande do Sul (South/Southeast Atlantic Basins), Uruguay East region and the main impact sources and threats against these habitat and ecosystems (Menegheti 1998). Noteworthy in Uruguay are: the Rocha Lagoon, “Laguna Negra y Bañados Santa Teresa” (Negra Lagoon and Santa Teresa marshes); Castillos Lagoon; Garzón and José Ignacio Lagoon systems; and several coastal lagoons such as Patos Lagoon system, Arroyo Valizas system, and others.

<table>
<thead>
<tr>
<th>Lagoon/wetland system</th>
<th>Urban land uses</th>
<th>Agriculture/land uses</th>
<th>Tourism</th>
<th>Transport</th>
<th>Petroleum</th>
<th>Mining</th>
<th>Dams</th>
<th>Pollution</th>
<th>Habitat fragmentation</th>
<th>Stream flow modification</th>
<th>Overexploitation</th>
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| Uruguay               |                 |                       |         |           |           |        |      |           |                     |                     |                  |
|-----------------------|-----------------|-----------------------|---------|-----------|-----------|--------|------|-----------|                     |                     |                  |
| Rocha Lagoon | x | x | | | | | | | | | |
| Garzon and Jose Ignacio Lagoon | x | x | | | | | | | | | |
| Negra Lagoon and Bañados de Santa Teresa | x | x | | | | | | | | | |
| Castillos Lagoon and Arroyo Valizas | x | x | | | | | | | | | |

(Source: based on information available in Menegheti 1998)
The lacustrine system of Peixe, for instance, includes five lagoons with a medium depth ranging from 0.3 to 3 m. The National Park of Peixe Lagoon is located in the state of Rio Grande do Sul, 220 km south of Porto Alegre and has an area of 34,400 ha. It is a large lowland area situated in the middle section of the coastal plains of the Rio Grande do Sul. It includes representative samples of the ecosystems of the Rio Grande do Sul coastal zone such as salt marshes, coastal dunes and lagoons, woods, grassy marshes, beach strips and marine area. Dunes which run parallel to the shoreline are a distinct feature and are formed by wind-borne deposits of sandy quartz material. The unique environment of Peixe Lagoon is one of the most spectacular sanctuaries of migratory birds in all of South America. Important species include *Limosoa haemastica* and *Calidris canutus*. This is the only place in Brazil where one can find flocks of *Phoenicopterus chilensis* all year round.

In the far north of the region, which is mainly a refuge, thousands of waterfowl such as *Cygnus melanocoryphus*, *Cocoroba coscoroba*, and several wild ducks including *Dendrocygna viduata*, *D. bicolor*, *Anas georgica*, *A. flavirostris* and *Netta peposaca*, occur. The Brazilian Institute for the Environment (IBAMA) owns 10% of the Park’s land with the remainder either being private property or federal property. Land use consists of extensive herd breeding, rice and onion farming, shrimp and mullet fishing in the lagoon, and net fishing in the sea, fishing with trawlers (at a range of 3 nautical miles), hunting, tourism and swimming. Reforestation with *Pinus* and the logging of native woods also occurs.

In Brazil, Patos Lagoon covering 10,360 km², suffers pollution resulting from the discharge of untreated chemical and organic effluents (see Diegues 1999 and the Causal chain analysis for Patos-Mirim Lagoon). Among the most serious threats to the Patos Lagoon ecosystem are the drainage for rice culture, the fishing of shrimp (*Penaeus sp.*) and mullet (*Mugil sp.*) during the spawning season, hunting, and land speculation in the beach area (Diegues 1999). In the Uruguayan portion of Mirim Lagoon basin, for instance, there are wetland areas replaced by rice plantation while some wetland areas are still preserved. Those still preserved are extremely important sites of resting for species such as *Phimosus infuscatus* and *Plegadis chilii* (*Threskiornitidae*). Field surveys have identified 500 members of *Phoenicopterus chilensis*, 262 *Cygnus melanocoryphus* and 293 *Cocoroba coscoroba*, 1,563 *Limnornis* from the discharge of untreated chemical and organic effluents, logging of native woods also occurs. Fishing in the sea, fishing with trawlers (at a range of 3 nautical miles), or federal property. Land use consists of extensive herd breeding, rice 10% of the Park’s land with the remainder either being private property or federal property. The Brazilian Institute for the Environment (IBAMA) owns 10% of the Park’s land with the remainder either being private property or federal property. Land use consists of extensive herd breeding, rice and onion farming, shrimp and mullet fishing in the lagoon, and net fishing in the sea, fishing with trawlers (at a range of 3 nautical miles), hunting, tourism and swimming. Reforestation with *Pinus* and the logging of native woods also occurs.

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Vermelha (Brycon vermelha) in the River Mucuri (East Atlantic Basins) is threatened by deforestation, pollution and plans to construct hydropower plants in Minas Gerais and Bahia states;

Surubim (genus Steindachneridion) in Jequitinhonha and Doce rivers (East Atlantic Basins) is threatened by pollution, deforestation and hydropower plants;

Andirá (Henochilus wheatlandii) only found in a tributary of the Doce River (East Atlantic Basins) is threatened by overfishing and the plans to construct hydropower plants;

Peracuca (Kalyptodoras bahiensis) in the Paraguaçu River that discharges into Todos os Santos Bay (Bahia state) has been wiped out by river silting;

Pira-tamanduá (Conorhynchos conirostris) has economic importance in the São Francisco River where it can reach more than 10 kg. The main threats are the hydropower plants and pollution;

Annual small-sized fishes (approximately 10 cm length) are highly endemic species living in marshes and swamps. In the Caatinga biome (see Regional definition) they are called cloud fishes by the locals because they appear and suddenly disappear, returning in the next rainy season. They have the highest importance as protein source for the local and poor communities. In Rio Grande do Sul (South/Southeast Atlantic Basins), the main threat is the rice plantation. Deforestation and urban development are the main threats in São Paulo and Rio de Janeiro littoral and Bahia littoral. 52 species of annual fishes are included in the list of 165 endangered species (Bomfim 2003).

Biodiversity of freshwater fishes in the River Paraíba do Sul (East Atlantic Basins), where endemism reaches the highest level due to the Atlantic Rainforest, is classified as extremely important (Figure 29) according to the classification of the Brazilian Ministry of Environment (MMA 2000). However, water quality deterioration of Paraíba do Sul tributaries has created barriers to genetic interchanges between different populations of ichthyofauna species. Genetic interchange is currently confined to tributaries where better water quality and environmental integrity are found.

Lack of information about ichthyofauna biodiversity before deforestation makes it impossible to evaluate the magnitude of the impacts of deforestation on local ichthyofauna during the last two to three decades. However, it can be inferred that changes act more on groups which depend on visual orientation for capturing their prey, affected by increased sediments/suspended solids in the waterways, as it seems to be the cause for a decline in the Brycon species. In some sections of the River Paraíba do Sul (between Resende and Volta Redonda and downstream Juiz de Fora), domestic and industrial pollution loads eliminated more sensitive fish species. Those sub-basins which still present good water quality are used as the last refuge for local species. In some sections of the Grande River, discharge of effluents is magnified by the relatively low stream flow and the impacts are deformities and lesions in Hypostomus affinis and Rhamdia parahybae. In the tributary, the Muriaé River, the increased microbiological pollution, and BOD and COD has caused the disappearance of fish species. In the Lower-Paraíba do Sul from São Fidélis to the river estuary, there are a large number of lentific water bodies (swamps, lakes and pools) fed by flooding from the Paraíba do Sul. This section has a small slope with an average value of 0.22 m/km. Due to recent disappearance of flooding as a consequence of stream flow control by damming, these systems have been badly affected. A marked aspect along the Paraíba do Sul is the large number of aquaculture farms. This is more prevalent in the middle and upper reaches of the River and the species cultivated include snapper, tilapia (Tilapia rendalli), Characidae, Cichlydae, carp, tambacú and African catfish. Aquaculture imposes risk of accidental introduction of alien species into the Basin.

Figure 29 Priority basins in terms of freshwater fish biodiversity/endemism in the Atlantic Rainforest in Brazil Current. Almost all areas extremely important regarding fish biodiversity are inside the Brazil Current region: among 35 freshwater bodies of importance for freshwater fish biodiversity marked on the map, 24 are inside the region. The area with the highest endemism of fishes is formed by a group of rivers in Rio de Janeiro state (e.g. Paraíba do Sul and São João Rivers). (Source: MMA 2006)
The results obtained from a detailed study about anthropogenic impacts and aquatic biodiversity in the Doce River (Minas Gerais and Bahia states in East Atlantic Basins) showed that the biodiversity of ichthyofauna found in the basin is low and the ichthyofauna is composed by species that show a wide geographical distribution and high tolerance to environmental changes and pollution (Barbosa et al. 2000). These results indicate that significant ichthyofauna biodiversity reduction has already occurred. Among the main economic activities are those associated to steel industry, mining, agriculture and monoculture with timber production (Eucalyptus). The causes behind biodiversity reduction is likely to be increasing turbidity, increased organic load and reduced oxygen content of the water, together with chemical pollution (de Paula et al. 1997).

The construction of dams and stream flow regulation in the São Francisco River Basin has caused the elimination of rapids, isolation of marginal lagoons and margin niches, sandy bottoms due to the reduction of terrigenous inflows and some fish species that need the currents to reach sexual maturity has therefore disappeared. The rice plantation and other water demanding crops in the Basin has been largely impacting the region and these very cultures have been subjected to the attacks of rodent epidemics. The elimination of riverine belts (riverine forests) has resulted in riverbank erosion. Such erosion has directly affected the presence of shoals and, therefore, the fishing activities, as the destruction of such ecosystems impacted the reproduction of several fish species. Fluvial navigation has been directly affected due to sitation and the formation of large sand banks. The introduction of alien fish and mollusc species has occurred over the years in the lower São Francisco region. It is planned an increase in the hydropower capacity of the cascade of reservoirs on the São Francisco, to meet the regional demand for energy. Considering the present level and flow of the River, which has no capacity to transport the sediments accumulated in many sandbanks, and for the sake of the environment, it has been proposed (Machmann de Oliveira 2003) that the new reservoirs should operate during some weeks every year at full discharge rate, in order to reproduce the natural flooding, which was suppressed by the cascade of reservoirs. During this “artificial high stream flow”, the sediments deposited in sandbanks will be transported to the oceanic region, minimising erosion and biomass depletion due to lack of nutrients. The environmental benefits are clear but the direct and indirect costs of such operational procedure need to be defined in more details. The lower São Francisco River and its estuary, located at the coastal boundary of and shared by Alagoas and Sergipe states, has suffered significant morphological changes due to stream flow regulation as a consequence of the cascade of constructed dams. Significant reduction of sediment/nutrient transport has caused sediment deficit in coastal areas, erosion and modification of ecological niches. Figures 30, 31 and 32 show the trophic status of the pelagic ecosystems through measurement of biomass of phytoplankton, microplankton and macroplankton in the São Francisco River, the River’s estuary and the contiguous sea (Machmann de Oliveira 2003).

In all seasons, the values of plankton biomass found in lower São Francisco River, estuary and contiguous sea were extremely low, close to the lowest limit expected for coastal zones, indicating that the River...
contributes very little for the planktonic production in the coastal zone (Machmann de Oliveira 2003). This is likely to be the main cause of the low level of fish production recorded at the River’s mouth (Figure 33) and some tributaries (Figure 34).

Socio-economic impacts

Economic impacts

The economic impacts due to habitat and community modification in the Brazil Current were considered moderate with tendency of worsening. Economic impacts include: loss of revenues from tourism; loss of property value; reduction of fisheries; increased costs for coastal areas maintenance due to higher vulnerability to erosion, lower stability of coastline, recovery costs after the occurrence of floods; costs with maintenance and recuperation of river banks; and control of alien species. Even with a short-medium term economic return obtained with the economic sectors, this compensation does not eliminate the aforementioned losses.

The size of economic and public sectors affected by the habitat and community modifications were considered large in South/Southeast and East Atlantic Basins, and small São Francisco River Basin. The frequency/duration of these impacts once they occur was considered continuous, since losses and significant modifications of habitats are hardly reversible.

Health impacts

Health impacts in the region due to habitat and community modification include major risks for humans from disease caused by habitat alteration, such as proliferation of disease agents. Low-income population is particularly exposed to these kinds of impacts.

Other social and community impacts

Social and community impacts in the region include: reduced capacity of local populations in meeting basic human needs, particularly in São Francisco River Basin where fish stocks have been drastically reduced; and changes in work opportunities, loss of aesthetic and recreational values, mostly in the coastal areas of region South/Southeast and East Atlantic Basins where loss of habitats have reduced the beach and the stability of the coastline. Loss and/or modification of ecosystems and ecotones have also created generational inequity, loss of scientific and cultural heritage since the disappearance of aquatic species is irreversible.

Socio-economic impacts associated to habitat and community modifications and sectorial activities are also addressed in other chapters of this report (e.g. the Causal chain analysis).

Conclusions and future outlook

After land settlement and water resources exploitation, modification of aquatic habitats is one of the first impacts observed. Particularly in high densely populated regions, such as the coastal zone of the Brazil Current region, not surprisingly, the impacts are severe. The expansion of tourism in both the Brazil Current coastal zone and the Atlantic Basin of Uruguay (Vertiente Atlantica 89 in Figure 2) represent a serious threat to those coastal ecosystems that are still preserved. This concern, together with pollution, was considered as a priority concern for the Brazil Current region. The common root causes and sector activities responsible for both pollution and habitat and community modification will be highlighted during the causal chain and policy options analyses performed for selected aquatic systems. Habitat and community modification as well as pollution is responsible for part of the observed depletion of fish stocks (which is also caused by unsustainable exploitation) and part of the changes in the hydrological cycles (which are also a result of the global changes). The precedence position of
these two concerns in a causal chain connecting all concerns was also taken into consideration when establishing the priority concerns. Knowledge about the ecosystems in the Brazil Current region is limited and better assessments of the impacts of anthropogenic activities are dependent on better inventories.

Unsustainable exploitation of fish and other living resources

Based on global productivity estimates from SeaWiFS, the Brazil Current portion corresponding to the LME 15, Large Marine Ecosystem South Brazil Shelf (Figure 1), is considered Class II: Moderately high productive ecosystem (150-300 gC/m²/year). This productivity is reduced as one moves northwards and the LME 16, East Brazil Shelf (Figure 1), is classified as Class III: Low productivity ecosystem (<150 gC/m²/year). LME 16 has a more diverse food web but has the lowest productivity of Brazilian marine ecosystems.

Estimates of the potential annual fisheries yields of Brazil up to depths of 200 m made by Yesaki (1974) are 1 400 to 1 700 tonnes and 1 100 to 1 600 tonnes by demersal and pelagic fisheries respectively. The potential of the South/Southeast Atlantic Basins is about five times higher (950 tonnes) than the potential of the East Atlantic Basins (200 tonnes). The GIWA region 40a Brazilian Northeast has a mere 100 tonnes (Hempel 1971). The estimates are about two-fold higher than Brazil's total annual fisheries catches (IBGE statistics for 1980-1994 in Paiva 1997), which fluctuated around 750 000 tonnes in the 1980s, declined towards about 600 000 tonnes in the early 1990s and recovered by about 10% thereafter (Matsura 1998, Paiva 1997, Matsura 1998, FAO 2000). The East Atlantic Basins and the GIWA region 40a Brazilian Northeast account for similar catches with 41 000 tonnes and 39 000 tonnes, respectively, and the South/Southeast Basins of 425 000 tonnes (South=75 000 tonnes, Southeast=350 000 tonnes).

In the southeast, sardines (Sardinella brasiliensis) and mackerel (Scomber japonicus) are most important by weight, reflecting the pelagic oriented production in the area. In the south, demersal fish biomass is higher than in the southeast. The important fishery species are the demersal hake (Merluccius hubbsi) and sciaenids (Umbrina canosa, Micropogonias furnieri), but also shrimps (Xiphopenaeus kroyeri, Panaeus paulensis, Panaeus brasiliensis), and pelagic anchovies (Engraulis anchoita) and sardines (Sardinella brasiliensis) (Paiva 1997).

In clear contrast to the South/Southeast, the oligotrophic character of the marine component of the East and Northeast is related to its diverse food web (structure (Matsura 1998, Ekau & Knoppers 1999). Common to both sectors, however, are the mesopelagic species of the Brazil Current, along and beyond the shelf edge. Their ichthyoplankton serve as food for higher trophic level carnivorous fish. A considerable fraction of the commercial fisheries of this oceanic realm is tuna, including Thunnus albacares, Thunnus atlanticus, Thunnus thynnus thynnus and Katsumonos pelamis. The catches of the northern sector of the East Atlantic Basins are similar to those of GIWA region 40a, being dominated by snappers, crabs (Ucides cordatus), shrimps (Penaeus schimitii), lobsters (Panulirus sp.) and some mullet (Mugil sp.). On the Abrolhos Bank (Bahia state littoral), demersal species dominate the system. The food web at the Abrolhos Bank, with a high diversity in herbivorous fish, possibly relying on the primary production of benthic algae, is in sharp contrast to the South/Southeast where diversity is low at the herbivorous level (Matsura 1998).

In the Atlantic Basin of Uruguay (89 in Figure 2, assessed separately from Brazil Current), fishing has different dynamics from those found in Brazil Current. The Patagonian Shelf LME 14 (highly productivity ecosystem) provides a favourable reproductive habitat for anchovies and sardines, when physical processes such as upwelling and mixing combine favourably in special configurations (Bakun 1993), so that fish larvae remain close to food sources. There are favourable reproductive habitats for small, pelagic-spawning clupeids (Bakun & Parrish 1991). Common hake is abundant on the northern shelf and off of Uruguay and southern Brazil. The Atlantic anchovy (Engraulis anchoita) is a key species in the trophic system (Bakun 1993). Only Argentina targets the Atlantic anchovy, and it is presently under-exploited. It inhabits an extended stretch of coastal habitat from Cabo Tres Puntas in south-central Argentina to Cabo Frio in Rio de Janeiro (upper limit of South/Southeast Atlantic Basins). It spawns in the southeastern Brazilian Bight from late winter to early summer, and is a temperate rather than a tropical species, occurring at depth or in upwelling plumes (Bakun 1993). Uruguay has an artisanal fishery of croakers and weakfishes. In Bañados del Este, the project PROBIDES financed by GEF stimulates the production of smoked fish in order to aggregate value to the product and reduce the pressure on the fish stocks exerted by the artisanal fishing colonies. Since this region receives tourists all year around, selling a more expensive product is not a problem.

Environmental impacts

Overexploitation

The severe impacts of overexploitation of fish applies to the marine component of the Brazil Current region as a whole, as follows:
The fluctuations of Brazil's total catches may be attributed to manifold natural and cultural impacts, as exemplified for the sardine and anchovy fisheries of the South/Southeast Atlantic Basins (Bakun & Parrish 1991, Paiva 1997, Matsuura 1998). The sardine fishery recorded a maximum catch of 228 000 tonnes in 1973, followed by a decline in the following years up until 1986 when catches were down to 90 000-140 000 tonnes per year and has since suffered a near collapse. Major declines were due to recruitment failures in 1975 and 1987, attributed to oceanographic anomalies, such as less intense intrusions of the northward flowing colder nutrient rich South Atlantic Central Waters (SACW) onto the inner shelf and coastal regions. The process is controlled by atmospheric/oceanic conditions of regional scale. On the other hand, some fish stocks in South/Southeast Atlantic Basins have become either fully exploited or overexploited, raising doubts if the level of exploitation can be sustained without impairing the productivity and integrity of the ecosystems. A 90% reduction of the catches of viviparous shark occurred at the Patos Lagoon estuary and Netuno spp. has also been overexploited (Montu & Gloeden 1982, Haimovici et al. 1997). Fish stocks in Sepetiba Bay have declined 20% during the last decade (lacerda et al. 2002). Dramatic declines due to overexploitation have been registered for the lobster fisheries in the northern sector of the East Atlantic Basins, including the estuary of São Francisco River and especially in another GiWA region 40a Brazilian Northeast. Examples of marine fish species whose exploitation exceeds the Maximum Sustainable Yield (MSY) in São Francisco River and estuary are: large prawns, catfish, sea shrimp. It is worth mentioning that a reduction in the production of some important species, particularly of shrimps (more details, see Habitat and community modification) in São Francisco River, has been the result of reduction of sediment/nutrients transport due to flow regulation by dam construction and the subsequent dramatic reduction in primary productivity, followed by a drop in the ichthyofauna production in the Basin and at the River mouth. Such impact on biodiversity dramatically reduced the stocks and limited even further the sustainability of fisheries in this basin.

The commercial fisheries statistics of Brazil continue to be a difficult issue. The socio-economic characteristics of the fishing industries are highly variable, due to the large geographical extension of the coast (8 400 km), local to regional differences of the productivity of coastal waters and cultural influences upon the industries. A particular problem for the gathering of reliable statistical data is the coexistence of artisanal and industrial fisheries. The former accounts for about 40% of Brazil's total fisheries catches (Paiva 1997), operating with a fishing fleet of 23 000 small to medium-sized boats, in contrast to the industrial coastal fleet with 1 630 boats and the industrial oceanic fleet with 52 boats (FAO 2000). Its landings are local-scale at numerous small fishing ports and villages. The industrial statistics are sounder, because catches are restricted to a few major state ports. The relative importance of artisanal fisheries diminishes from north to south, supporting the argument that statistics of the South/Southeast Atlantic Basins are more reliable (Paiva 1997).

Artisanal fisheries practiced at the littoral of Rio de Janeiro, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul (South/Southeast Atlantic Basins) have been about 22% of the total commercial catch (Paiva 1997). As artisanal fisheries capture a much larger amount of species with lower biomass than industrial fisheries, they have a different impact upon biodiversity. Better statistics are thus particularly necessary for the tropical oligotrophic waters with high biodiversity of the East Atlantic Basins and the GiWA region 40a Brazilian Northeast (Paiva 1997). In Sepetiba Bay, state of Rio de Janeiro littoral, traditional fishing communities have almost disappeared and workers have moved to other activities.

In Barbitonga Bay, state of Santa Catarina (South/Southeast Atlantic Basins) overexploitation of crab, shrimp and mollusc in the mangrove areas can be observed. There is overexploitation of these groups in the mangroves of the South/Southeast Atlantic Basins: the Itajai-Açú River estuary, the Camboriú River estuary and the Porto Belo Bay, state of Santa Catarina, which has severely affected the stocks. In the coast of the state of Rio Grande do Sul (South/Southeast Atlantic Basins) artificial lakes and reservoirs have been under much pressure from sport fishing, which is often carried out illegally, and no evaluation is made of its impact.

Artisanal landings for East Atlantic Basins and São Francisco River Basin (states of Espirito Santo, Bahia, Sergipe and Alagoas) have been estimated to account for up to 85% of the total commercial catches, which is even higher than for region 40a Brazilian Northeast with about 59%. Although most of the state of Alagoas belongs to Brazilian Northeast, its landings originate in large part from the area of the São Francisco river mouth and shelf.

The lagoon systems in the states of Rio Grande do Sul and in the Uruguayan East region hosts important lagoon systems in a total of 13, according to the Wetlands International. Eight lagoon systems are suffering overexploitation of fish: Peixe Lagoon system; Laguna Castillos and Arroyo Valizas do Taim; both Brazilian and Uruguayan portions of Mirim Lagoon; Patos Lagoon; Laguna de Rocha; Laguna Negra y Bañados de Santa Teresa; Laguna Garzón y Laguna José Ignacio; and Bañados San Miguel-Los Indios.
Excessive by-catch and discard

By-catch and discard is currently one of the main problems being faced in the coastal area outside the Paraná state coast section (South/ Southeast Atlantic Basins), mainly in the areas between the cities of Ilha Comprida and Pontal do Sul. Trawlers have constantly acted illegally near the beaches, at depths of less than 2 m, and within the area forbidden under federal law. Apart from the capture of juvenile and adult fish during reproduction periods, these boats discard enormous quantities of small and valueless dead fish close to the beach, causing an impact due to organic build-up. An equally undesirable practice is that the city councils clean the beaches, removing sand along with the fish remains, which worsens the problem in the water. Commercial fish populations have shrunk and some of them are in critical condition in the lagoons of northern Rio Grande do Sul coast. Discards occur, even if in small quantities, inasmuch as accidental fishing is in large part used for human consumption. If species of little direct economic importance comprising accidental fishing are considered, the impact score might go up. Accidental fishing of juvenile fish jeopardises the MSY.

The excessive by-catch and discard in the mouth of the São Francisco River is severe. However, considering the São Francisco Basin as a whole, the impact was considered moderate. Maritime discards are traditionally high. Trawling of any one area of seabed is occurring 1 to 10 times per year. The introduction of tilapia species, tucunare (Cichilydae) and tambaqui (Characidae) in some areas of the São Francisco Basin has threatened native species, due to food competition. Additionally, the tucunaré eats eggs and young forms of native species. In ocean fishing, 80% is by-catch (on the Sergipe and Alagoas coast this can reach 90%) with discards around 60%, the boats retaining only those species with the higher market value, due to their limited capacity.

Destructive fishing practices

There is the general practice of trawling, affecting all demersal species. Valuable species such as shrimp, line species such as Serranidae, pelagic species (sardine, tuna) and benthonic species (Portunidae, mussels, crab) are exploited above the MSY level. Many habitats are lost because of trawling. The use of bombs or poison is seen in most estuaries in the state of Sergipe (East Atlantic Basins). There are indications along the entire Bahia coast (East Atlantic Basins) of the use of explosives for fishing, destroying reefs and mangroves.

Decreased viability of fish stocks

There has been an increase in the number of disease occurrences and there is data on malformation, tumours, loss of scales and increases in mycoses. In some sub-basins, such as Muriá River in the city of Muriaé, in the past few years some local species have disappeared, which until then were uniformly distributed. Discharge of domestic sewage in parts of the River with low circulation has dramatically increased faecal coliforms, BOD and COD.

Impact on biological and genetic diversity

There are several examples of species undergoing alterations of the biological diversity among native species on the Brazilian coast. For example, on the northern Rio Grande do Sul coast (South/Southeast Atlantic Basins) the porrudo (Trachaelopterus lucena) was introduced into the region, probably through irrigation systems for rice plantations. Fish farm activities are expanding, especially using alien species, such as carp (Ciprinus spp.), with potential for invasion of natural systems and the introduction of diseases and pathogens among native species. Changes have been seen in the composition and genetics of native fish species following the introduction of species in the dams of the state of Minas Gerais as well as shrimp farms in the state of Bahia (East Atlantic Basins). In more than one sub-basin of Sergipe, hybrids were seen and the local disappearance of some species of ichthyofauna is suspected to be a result of the introduction of alien species. There is also a record of parasite species which came with the breeders to the farms. Among benthic organisms, the Melanoïdes tuberculata and some species of Macrobrachium spp. were accidentally introduced. The species Melanoïdes tuberculata has been responsible for the disappearance of native gastropods and for being home to some life cycles of trematodes which cause diseases in fish and man.

Socio-economic impacts

Economic impacts

Most species of fish, crustacean and molluscs in southern estuary regions are of great importance considering not only the formal but also the informal economy, sustaining a high number of traditional fishermen who have lived for generations off this activity. Fishing of shrimp, crab, mussels, oysters, catfish and other species are part of the tradition of fishing families in Rio Grande do Sul and Santa Catarina since the last century. In turn, line fishing for more valuable species such as verne, namorado, red porgy, and others (many for export) also shows signs of overfishing.

Industrial fishing in the state of Rio de Janeiro as well as the states of Bahia and Espírito Santo (East Atlantic Basins) has been hit hard over the years with falling sardine production, and the closure of many salting and canning companies. On the coast of the state of São Paulo (Santos and Guarujá), industrial fishing and fish food industry are important economic activities with processing factories for export. On the other hand, small and artisanal fishing is in freefall, due to overexploitation in coastal and near regions, and direct competition from large fleets.
On a sub-regional scale, the size of the economic sector affected by overexploitation of fish and other living resources is considered small in comparison with the whole economy of the South/Southeast Atlantic and East Atlantic Basins, where other sectors (e.g. industry, agriculture, energy, services, etc.) represent the largest component of the economy. In these sub-basins, the economic impact as regards the size of economic sectors affected by non-sustainable exploitation of fish resources was considered to be moderate. However, in São Francisco Basin, fisheries play a relatively more important role in the basin economy and the economic impact is moderate.

The degree of impact (cost, output changes, etc.), although limited to one economic sector (differently from freshwater shortage, which affects several sectors) is classified as moderate to severe. This means that the sector suffering the impact (fisheries, both industrial and artisanal) has suffered it severely. From the frequency point of view, the economic impacts varies from frequent to continuous, although some stocks might recover up to the previous level, depending on the management strategy.

As a consequence of the declining stocks and interruption of industrial activities (fish salting and canning) unemployment in the industrial sector associated to seafood processing increased. Some processing industries replaced the local raw material by imported material. *Sardinella brasiliensis*, for instance is still caught in Brazilian coastal waters, particularly from Cabo Frio and Angra dos Reis (Rio de Janeiro littoral), Santos (São Paulo littoral) and Itajaí (Santa Catarina littoral), all littorals of South/Southeast Atlantic Basins. However, *Sardina pilchardus* and *Sardinella aurita* are imported from Venezuela, among other sources (Silva & Batista 2003).

**Health impacts**

Health impacts associated to overexploitation of fish would occur if the protein originally obtained from fish could not be replaced by other sources of animal protein. This has not been the case of the majority of fishing communities in South/Southeast and East Atlantic Basins, where the labour force available due to reduction of fish stocks is usually occupied by the service sector in the coastal zone of the Brazil Current. However, given that this occupation does not absorb 100% of the labour force, the degree of impact might be considered at least slight. In São Francisco River Basin although poverty among the communities is worse than in the other sub-regions, health impacts were considered moderate.

**Other social and community impacts**

Several fishing colonies have been closed and the labour force has been diverted into services associated to tourism. Canoeing and fish (dourado) festival are tourism activities in the Paraíba do Sul River (in the East Atlantic Basins), mainly along the Minas Gerais section of the Paraibuna River for canoeing, and in Itaúca where the dourado festival attracts many fishermen from other areas. Professional fishermen in the Paraíba do Sul River basin, state of Rio de Janeiro portion, have been traditionally organised into four colonies. As reported by the Brazilian Institute for the Environment (IBAMA), these associations have gradually disintegrated and currently only two colonies remain. A similar trend has been observed all over the Brazil Current. It should be noted that fishing has the highest social significance, as a subsistence activity not accounted for in the formal economy. Traditional fishing is intrinsic to coastal communities, consolidating the importance of estuarine species as a social, cultural and economic element in the region.

In the São Francisco Basin, even though the size of economic sectors affected and the number of people’s health affected are deemed small in comparison to the economy and population of the Basin, the degree and severity of impacts have been deemed high and permanent, taking into account that if the Basin’s fish shoals are jeopardised, this would result in the end of subsistence activities.

**Conclusions and future outlook**

Severe environmental impact on fish species and other living resources in the Brazil Current is a consequence of overexploitation, use of destructive fishing practices, decreased viability due to pollution and destruction of coastal ecosystems such as mangroves, which are important for the reproductive cycle of several species. Regarding economic impacts, the fisheries sector has a peculiar condition in the Brazil Current, since it constitutes a relatively small portion of the GDP, to which other economic sectors such as industry, agriculture, urbanisation, tourism, energy, and services, provide a much bigger share. However, severe impacts are seen on the fisheries sector economy, affecting the population directly dependent on the sector (e.g. fishermen and their families, food industry).

In the Brazil Current, the development of aquaculture mostly in South/ Southeast Atlantic Basins and São Francisco River Basin has been a clear trend during the last two decades. The state of Santa Catarina (South/Southeast Atlantic Basins) has been the states with the greatest growth. The environmental impacts of this growing activity should not be neglected and must be properly addressed to avoid the severe environmental destruction due to aquaculture observed in other parts of the world, such as Asia.
Global change

Climate change can be seen as one of many pressures on the water resources. Freshwater shortage and pollution illustrate alterations in the hydrological systems of the Brazil Current region as a consequence of land use and land-management practices, which often lead to deterioration in the resource baseline. For rivers in semi-arid lands included in the Brazil Current region, significant negative trends of river flow have been detected, but these variations seem to be related to consumption by agriculture and damming, rather than climate-induced changes (INRENA 1994, Marengo 1995, Marengo et al. 1998). Global warming and sea level raise are likely to influence the hydrological cycle, agricultural yield and threaten human health and property security (IPCC 2001). The association between climate changes and the fluctuation of Brazilian sardine catches has been investigated (Rossi-Wongtschowski et al. 1996). However, complex climatic patterns, which result in part from interactions of atmospheric flow with topography, intermingled with land use and land-cover change, make it difficult to identify common patterns of vulnerability to climate change in a given region (IPCC 2001). Global warming and regional climate change resulting from land-cover change may be acting synergistically to exacerbate stress over the region’s tropical ecosystems (IPCC 2001). In several cities in South/Southeast Brazil, studies on long-term time series for temperature, from the beginning of the 20th century, indicate warming tendencies (Sansigolo et al. 1992). This could be attributable to urbanisation effects or to systematic warming observed in the South Atlantic Ocean since the beginning of the 1950s (Venegas et al. 1996, Venegas et al. 1998).

Based on available information, Brazil Current sub-regions are differently impacted by some issues of the concern Global change, as briefly illustrated below. For the South/Southeast Atlantic Basins, there is more information substantiating the impacts than for the other sub-regions.

Environmental impacts

Changes in the hydrological cycle and ocean circulation

For South/Southeast Atlantic Basins and particularly for the semi-arid portion of the two other sub-regions, environmental impacts due to global changes were assessed as moderate. Based on that, the severity of environmental impacts for the whole of the Brazil Current was assumed to be moderate. The criterion was: “Extreme events such as flood or drought are increasing”. Although there is no definitive evidence, for the South/Southeast Atlantic Basins, a second criterion supporting the moderate score that would also apply is: “Aquatic productivity has been altered as a result of global phenomena such as ENSO events.”

Regardless the incomplete picture (Calder 1999) about the role played by forests in the regional hydrological cycle, if the extent of deforestation were to expand to substantially larger areas, rainfall is expected to be reduced in the centre-south region of Brazil (GIWA region 38 Patagonian Shelf), and south region of Brazil, as a consequence of reduction in evaporotranspiration (Lean et al. 1996). According to the same principle, the large-scale deforestation of the Atlantic Rainforest in the Brazil Current during the 20th century (currently, only 7% of the original forest area remains, according to Fundação SOS Mata Atlântica & INPE 2002) has probably affected the hydrological cycle, resulting in increased surface temperatures, decreased evaporotranspiration and reduced precipitation. However, there is insufficient data to substantiate this hypothesis.

As regards El Niño, there are evidences of changes in hydrological cycles and ocean currents as a result of the El Niño Southern Oscillation (ENSO). In the sub-tropical area of Brazil, precipitation exhibits a long-term change, with a sharp increase in the period 1956-1990 after a dry period during 1921-1955 (Barros et al. 1995). South Brazil is the region most impacted by these changes. The effects of El Niño and La Niña in Brazilian territory are presented in Table 15.

Table 15  Variability and impacts of El Niño and La Niña on different Brazilian and GIWA regions.

<table>
<thead>
<tr>
<th>Climatic/Hydrological variable</th>
<th>Brazilian region</th>
<th>Source</th>
<th>Observation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe droughts</td>
<td>Northeast Brazil</td>
<td>Silva Dias &amp; Marengo 1999</td>
<td>1901-1997</td>
</tr>
<tr>
<td>High precipitation and flooding</td>
<td>Southern Brazil</td>
<td>Rebelo 1997</td>
<td>1982-1983</td>
</tr>
<tr>
<td>Increase in precipitation, higher run-off</td>
<td>Northern Amazon</td>
<td>Marengo et al. 1998, Méggers 1994</td>
<td>1970-1997, Paleoclimate</td>
</tr>
<tr>
<td>Severe droughts</td>
<td>Southern Brazil</td>
<td>Grimm et al. 1996 and 2000</td>
<td>1956-1992</td>
</tr>
</tbody>
</table>

Notes: 1. Extreme of the Southern Oscillation (SO) are responsible in part for a large portion of variability at inter-annual scales in Latin America. El Niño (ENSO) events represent the negative (low) phase of the SO. “La Niña” is the positive (high) phase of the SO. “Part of GIWA region 40a Brazilian Northeast and the semi-arid portion of the São Francisco River Basin.” “Part of GIWA region 39 South/Southeast Atlantic Basins and the upper Patagonian Shelf, GIWA region 38.”

El Niño/La Niña disrupts some of the “normal” climatic conditions described in the Regional definition. During El Niño, the polar frontal systems are blocked and diverted eastwards out to the Atlantic and trade winds are barred at the front. The blockage system extends from southern Peru to southern Brazil and its position oscillates in relation to the degree of enhancement of the sub-tropical jet stream and, of course, intensity of the El Niño phenomenon. This situation provokes an anomalously high rainfall in the blocking zone and drought northward, as well as modification of the wind patterns, and consequently of the
wind-driven littoral dynamics. ENSO leads to floods in the southern portion of the South/Southeast Atlantic Basins (Rio Grande do Sul, Santa Catarina and Paraná states), in the Atlantic Basin of Uruguay (89 in Figure 2) and in the GIWA region 38 Patagonian Shelf, provoking the reverse effect in the rest of the Brazilian coastal regions. The upper São Francisco Basin follows the pattern of the southern portion of South/Southeast Atlantic Basins: the more El Niño intensifies, the more rain will fall (positive effect). The semi-arid portion of São Francisco Basin and GIWA region 40a Northeast Brazil, exhibits anomalously dry conditions during these periods (Table 15) (IPCC 2001). On the contrary, under the influence of La Niña, rainfall is significantly reduced in the southern portion of South/Southeast Atlantic Basins; meanwhile in the northeast region rainfall increases. Northern Amazon (in GIWA region 40b Amazon) follows the pattern of the northeast coast.

During the period 1982-1983, El Niño caused severe drought in the north of Brazil and flooding in the south. The rainfall in Santa Catarina (events with more than 900 mm) for instance, caused severe socio-economic impacts (Rebello 1997) (see also Socio-economic impacts in this section). Despite heavy rains during El Nino, a reduction in the average stream flow of some major rivers in the Brazil Current has occurred during the last decades, as a result of damming and consumption.

Stream flow in Uruguayan rivers exhibited a negative trend from 1901 to 1970, which reversed after this period. Multidecadal variability is also observed in discharges in Uruguay (Genta et al. 1998). However, in other parts of South America outside Brazil Current, there has been an increase of stream flow since 1970s in northwest Amazon (Marengo et al. 1998) and since 1960s in the southeastern part of South America (Patagonia region in Argentina) (Genta et al. 1998).

According to IPCC (2001), on decadal to centennial time scales, changes in precipitation and run-off may have significant impacts on mangrove forest communities. There are indications that major declines of sardines stocks previously credited exclusively to overexploitation, in some years (e.g. 1975 and 1987) were mainly due to oceanographic anomalies, such as less intense intrusions of the northward flowing colder nutrient rich South Atlantic Central Waters (SACW) onto the inner shelf and coastal regions. The process is controlled by atmospheric/oceanic conditions of regional scale. However, the contribution of each concern (Global change and Unsustainable exploitation of fish) to the decline of sardine stocks in the Brazil Current is not fully understood.

Garcia and Vieira (2001) analysed the species composition and species diversity in the Patos Lagoon estuary before, during, and after the 1997-1998 El Niño. A total of 20 hauls were made monthly at four beach stations from August 1996 to August 2000, using beach seine hauls. Species were grouped as follows: (i) estuarine resident; (ii) estuarine dependent; (iii) marine vagrant; and (iv) freshwater vagrant. Species diversity was evaluated by H’ index, species richness by the rarefaction method and evenness by the Evar index. Confidence intervals were obtained by the bootstrap method. The El Niño phenomenon causes higher than average rainfall in southern Brazil and directly affects river discharge, which changes salinity in estuaries. Rainfall exceeded the average and salinity was lower than average during the studied El Niño event. Fish species diversity was higher in Patos Lagoon (South/ Southeast Atlantic Basins) estuary during the El Niño, and this was strongly influenced by an increase in the number of freshwater species, and to a lesser extent, due to an increase in species evenness.

**Sea level change**

The environmental impacts due to changes in sea level, were considered slight. According to IPCC (2001), a slightly rising rate of global warming and sea levels have been observed in the world. Modelling indicates that there will be an increase in the frequency and intensity of atmospheric fronts, leading to growing problems of coastal erosion because of so-called spring tides, a phenomenon which is most evident in the south portion of the South/Southeast Atlantic Basins and in the neighbouring GIWA region 38 Patagonian Shelf. In the South/Southeast Atlantic Basins many engineering constructions along the coast have been destroyed during the last decade. The sea level along the Brazilian coast has been subjected to changes between 18-40 cm per century (IPCC 2001) and there has been a sea level rise in the middle section of the Brazilian coast, which is found to be within the normal worldwide variation and changes in ocean streams. Studies of vulnerability to sea level rise (Perdomo et al. in IPCC 2001) have suggested that countries such as Uruguay could suffer adverse impacts, leading to losses of coastal land and biodiversity, saltwater intrusion, and infrastructure damage. Likely impacts would be multiple and complex, with major economic implications.

Rising sea level may eliminate mangrove habitat at an approximate rate of 1% per year (IPCC 2001). Decline in some of the region’s fisheries at a similar rate would be observed because most commercial shellfish use mangroves as nurseries or refuges. Coastal inundation stemming from sea level rise or flatland flooding resulting from climate change may seriously affect mangrove ecology and associated human economy (IPCC 2001). Sea level in a global change perspective is associated to temperature increase. Temperature anomalies related to the El Niño event and coral bleaching has long been observed along the Brazilian coast. In Abrolhos archipelago, an environmental protected area in the littoral of Bahia state in the East Atlantic Basins that has been studied.
regarding the environmental impacts (Ekau 1999), two episodes of coral bleaching have been recorded related to a rise of sea surface temperature (Leão 1999). The first episode was during a sea surface temperature anomaly in the summer of 1994 when 51-88% of colonies of the genus Mussismilia were affected (Castro & Pires in Leão 1999). The second one was related to the strong ENSO event that began by the end of 1997 in the Pacific Ocean, and also caused a rise of the sea surface temperature on the eastern coast of Brazil. The most affected species were Porites branneri and Mussismilia hispida, both with more than 80% of their colonies totally bleached, M. hartii with an average of 75% of its colonies affected, and Porites asteroidea with all colonies showing some sign of bleaching (Leão 1999). According to the authors, although the species Agaricia agaricites did not show a totally bleached colony, more than 90% of them had a pale colour.

**Increased UV-B radiation as a result of ozone depletion**

There is no known impact of increased UV-B radiation as a result of ozone depletion in the South/Southeast Atlantic Basins and São Francisco River Basin, and slight impact in the East Atlantic Basins. However, the destruction of the ozone layer would probably increase the effects of UV-B radiation.

**Changes in the ocean CO₂ source and sink function**

The are no known impacts of changes in CO₂ source/sink function in the aquatic systems of Brazil Current. On a global level, there are indications of modifications in the CO₂ exchange between the atmosphere, the land and the sea. These indications support the theory that global changes could interfere in the ocean’s function as a CO₂ source/sink. However, on the Brazil Current’s level, there are no sufficient studies or information on this matter. No known impact is, therefore, the most appropriate assessment for environmental impacts due to this issue.

**Socio-economic impacts**

**Economic impacts**

One methodological approach recently applied to assess economic impacts due to global changes is to estimate the aggregate monetised impact, based on current economic conditions and populations, for a 1.5 to 2.5°C temperature increase (Tol et al. in Beg et al. 2002). According to this criteria, developing countries have greater economic vulnerability to climate change. At lower levels of climate change, damages might be mixed across regions; for example, poorer countries are likely to be net losers, and richer countries might gain from moderate warming.

Economic activities such as tourism and fishing, settlements and structures are particularly vulnerable to physical changes associated with sea level rise. Tourism is one of the most prominent economic activity in the Brazil Current region. Protection, replenishment, and stabilisation of existing beaches might represent a relevant mitigation to the economic impacts. However, it is difficult to separate the impact of climate-induced sea level rise from erosion associated with changes in the sediment transport dynamics due to damming and the continuous effect of the sea on the coast.

In South/Southeast Atlantic Basins, the economic impact due to flooding caused by El Niño/La Niña is severe and affects many economic sectors, however, these impacts are not continuous. The sectors more affected by flooding are: services, urban/housing, transport, industry, agriculture and fishing. Civil engineering works for flood prevention and recovery of affected areas represent considerable costs to the local, state and eventually, federal governments, and also contribute to the economic impacts. Silviculture is a major land use in Brazil and is expected to expand substantially over coming decades (Fearnside 1998). Climatic change can be expected to reduce silvicultural yields to the extent that the climate becomes drier in major plantation states such as Minas Gerais and Espírito Santo (East Atlantic Basins) among other parts of Brazil, as a result of global warming and/or reduced water vapour transport from the Amazon River (Eagleson 1986). Dry-season changes can be expected to have the greatest impact on silvicultural yields. Modelling results (Gates et al. 1992) indicate that annual rainfall changes would cause yields to decrease by 8% in southern Brazil (South/Southeast Atlantic Basins) and increase by 4% in the northeast (East Atlantic Basins and São Francisco River Basin). During the June-July-August (JJA) rainfall period, yields would decrease 14% in southern Brazil, and 21% in the northeast (Fearnside 1999).

Potential effects of climate change in Brazil suggest changes of 4 to 4.5°C in surface temperature as a result of increased CO₂ concentrations (de Siqueira et al. 1994, de Siqueira et al. 1999). Agriculture is impacted by temperature increase in different ways: (i) it reduces crop yields by shortening the crop cycle; and (ii) it reduces fishing and forestry productivity (IPCC 2001). Based on General Circulation Models (GCMs) and long-term crop model forecasts, decreased yields for some crops in South/Southeast Atlantic Basins (e.g. wheat, maize) are expected due to increase in the temperature (IPCC 2001). In Uruguay, a yield reduction of 5 to 10% is foreseen (Baethgen & Magrin 1995). However, this impact might be felt mostly in the Uruguayan portion of region 38 Patagonian Shelf, where the main wheat plantations are found. It has been pointed out that lack of consistency in the various GCM precipitation scenarios makes it difficult to make a precise assessment of crop production under climate change, even when the relationships between precipitation and crop yields are well known. Some of the relatively weak cold surges may exhibit unusual intensity, causing frosts and low temperatures in...
coffee-growing areas of southeastern Brazil (South/Southeast Atlantic Basins), resulting in heavy damage and losses in coffee production (Marengo et al. 1997).

Health impacts
The magnitude of the impacts of climate change on health primarily depends on the size, density, location, and wealth of the population. It is likely that extreme weather events increase death and morbidity rates (injuries, infectious diseases, social problems, and damage to sanitary infrastructure) particularly in developing countries (IPCC 2001). There is evidence that the geographical distribution of vector-borne diseases (e.g. malaria, dengue) in Brazil change when temperature and precipitation increase. On longer time scales, El Niño and La Niña cause changes in disease vector populations and the incidence of water-borne diseases in Brazil. The exact distribution of these diseases, however, is not clear (IPCC 2001). Additionally, floods represent risks mainly to the population that live in risky areas, not only from the safety but also from the health viewpoint, because of water-borne diseases. Areas of high risk include all poor settlements and shanty towns on hill slopes and river banks in metropolitan areas of the Brazil Current in both South/Southeast and East Atlantic Basins.

Other social and community impacts
Flood and drought periods are related to migrations or relocations, giving rise to social and community impacts, which affect a significant part of the population. The severity of the impact is high during events but the duration is short and not frequent, since episodes of population displacement from areas affected are usually followed by the return of the displaced population to their original area. According to IPCC (2001), under climate change conditions, subsistence farming might be severely impacted in areas such as the Northeast region of Brazil, which includes the upper part of East Atlantic Basins and the lower São Francisco River Basin. In many coastal societies, cultural values are associated to the use of a wide range of natural products from the coastal wetlands and surrounding waters (Field 1997). Sea level change and erosion promote changes in the coastal environment.

During the last two decades, the most severe El Niño events in the Brazil Current region occurred in 1982-1983, 1986-1987 and 1997-1998 (Rebello 1997). The floods was considered a result of synergy between El Niño and stream flow changes due to land erosion and siltation (See Pollution, Suspended solids). In the south portion of South/Southeast Atlantic Basins severe socio-economic impacts have taken place (Rebello 1997). During the event 1982-1983, three states were most impacted: Rio Grande do Sul, Santa Catarina and Paraná. Of the total area of the state of Santa Catarina (95 000 km²), 79% (75 000 km²) were affected by flooding, including 135 cities, and 300 000 inhabitants that needed to leave their homes. Taking only the city of Blumenau, the magnitude of the flooding event is illustrated by the following indicators (Defesa Civil de Blumenau, in Rebello 1997):

- 31 days of duration (from 6 of July to 5 August 1983);
- On the 9th July 1983, the Itajaí River reached its highest water level: 15.34 m above normal;
- The previous experience of flooding at this level of severity was recorded in the year 1911;
- 50 000 inhabitants moved out from their homes and 38 000 households were affected.

The harvesting losses in 1983 due to the flooding included (Rebello 1997):

- State of Rio Grande do Sul: 693 777 tonnes;
- State of Santa Catarina: 1 626 298 tonnes;
- State of Paraná: 1 568 700 tonnes.

Conclusions and future outlook
Among the global climate changes foreseen for the next 100 years, in a “business as usual” scenario, the most significant ones for Brazil and in particular for GIWA region 39 Brazil Current are associated to changes in the hydrological cycle and ocean circulation such as temperature and sea level rise, changes in the rainfall regime and alterations in the distribution of extreme climate events, such as drought and flooding (Nobre 2001). However, insufficient information or lack of significant impacts due to some issues means that the overall impact for Global change is slight. The information available globally seems to indicate that a general worsening on environmental as well as socio-economic impacts is foreseen due to global changes. However, to express this expectation, the GIWA baseline is too short (year 2020) and it would be pointless to predict changes in such a short time, the reason the severity of impacts remains the same in the future conditions of GIWA (see Annex II). The following comments refer to the expected impacts in a long-term perspective, as has been discussed globally.

Although climate change may bring benefits for certain regions of Latin America (e.g. rainfall intensification in semi-arid areas during La Niña), increasing environmental deterioration, combined with changes in water availability and agricultural lands, may reduce these benefits to a negligible level (IPCC 2001). The adaptive capacity of socio-economic systems in Latin America is very low, particularly with respect to extreme climate events, and vulnerability is high. Some economic and health problems could be exacerbated in critical areas, fostering migrations from rural and small urban settlements into major cities and giving rise to additional stress at the national level and, at times, adversely affecting international relations between neighbouring countries (IPCC 2001).
Therefore, under climate change conditions the risks to human health may increase.

According to Beg et al. (2002), although climate change does not feature prominently within the environmental or economic policy agenda of developing countries, evidence shows that some of the most adverse effects of climate change will be in developing countries, where populations are most vulnerable and least likely to easily adapt to climate change. According to Beg et al. (2002), climate change could exacerbate current inequalities due to uneven distribution of damage costs, in addition to the cost of mitigation and adaptation efforts. Some synergies already exist between climate change policies and the new sustainable development agenda in some developing countries, including Brazil and Uruguay, such as energy efficiency, renewable energy, transport and sustainable land use policies (La Rovere 2002). In Brazil, renewable energy production and efficiency improvements in energy use in the 1980s have made a significant contribution to reducing greenhouse gas (GHG) emissions. The programme of energy efficiency improvements in the use of electricity (PROCEL) alone, has led to significant GHG emission mitigation (La Rovere 2002). La Rovere (2002) also predicts that changes in rainfall patterns and in ENSO induced by climate change may further affect the already limited availability of water resources and aggravate the risk of famines due to the disruption of agricultural and cattle raising activities.

Understandably, vulnerability to the adverse impacts of climate change is one of the most crucial concerns of developing countries engaged in climate policy discussions, which including the countries that form GIWA region 39 Brazil Current (Brazil and Uruguay). It is also a critical element in planning any long-term climate and development strategy. According to IPCC (2001), climate change does not in itself stimulate development of new adaptive strategies, but it encourages a more adaptive, incremental, risk-based approach to water management.

**Priority concerns**

**Establishing the priority concern for further analysis**

Drainage basins and coastal zones in developing countries, densely occupied, heavily exploited in terms of their natural resources and with diverse and increasing economic activities, are likely to suffer from moderate to severe impacts due to at least four of the five GIWA concerns (Freshwater shortage, Pollution, Habitat and community modification, and Unsustainable exploitation of fish and other living resources). This is the result of high anthropogenic pressures due to population and economic growth, associated to institutional weakness and governance failure, which are common root causes of environmental degradation in developing countries. The fifth GIWA concern, Global change is dependent on anthropogenic activities occurring in a global context, plus complex interactions with global climate; therefore local/regional impacts caused by global changes does not necessarily reflect the local/regional anthropogenic pressures.

The results of the GIWA assessment confirmed that the majority of the Brazil Current drainage basins fit into the above-description and therefore, not surprisingly, the overall impacts caused by four of five environmental concerns in the Brazil Current were considered moderate with trend of becoming severe, if no clear and strong response is given by society. Such parity of severity of four concerns represents a difficulty when establishing their priority rank for further analysis (Causal chain analysis and Policy options analysis), as required by the GIWA assessment protocol. The need to select a priority concern arises from the limited availability of financial and human resources to support the initiatives needed to mitigate the impacts. If differences in fractions of units between scores calculated from the weighting and averaging procedures were considered significant, the ranking could be established (e.g. score 2.4 for Pollution, considered higher than score 2.2 for Habitat and community modification). However, the scores become the same if the decimal fractions are rounded off (e.g. score 2 for Pollution; score 2 for Habitat and community modification).

**Criterion of precedence**

After the degree of severity of the impacts is scored, in the case of equality between concerns, there is a further criterion based on the concerns’ precedences (Figure 35), which is useful to give them priority rank.

Concerns and their constituent issues may be linked in a causal chain. One concern, for instance, can be one of the causes that lead to another concern. The Assessment section illustrates several situations in the Brazil Current when such causal links occurs. Concerns may also be linked to each other through their combined impacts and/or common causes. The scoring procedure combined with the analysis of the precedence function in sub-regions (Figure 35) revealed that the concerns Pollution or Freshwater shortage are placed as the first priority depending on the system studied (Table 16) and Habitat and community modification is the second priority in all systems. According to the GIWA methodology, where the precedence function increases the importance of a concern for policy purposes, this should be taken into account in ranking of priorities. The most relevant causal-effect relationships among different concerns in the Brazil Current, based on
available information of impacts summarised in Figure 35, indicate that, among them, pollution is the concern that contributes to raise all the other main concerns.

Selecting the aquatic systems for causal chain and policy options analyses

Due to the existing diversity in the Brazil Current regarding different aspects (biodiversity, water availability, economy, social and cultural aspects, etc.), it is very unlikely that one policy option proposed for the whole region Brazil Current would have a good performance in terms of effectiveness, efficiency, equity, political feasibility and implementation capacity. Therefore, in order to elaborate policy options with good performance in terms of these criteria, it is necessary to focus on specific aquatic systems inside the region. Having this in mind, some aquatic systems or “hot spots” included in the Brazil Current region were selected. To select aquatic systems for the Causal chain analysis four criteria were considered:

1. The aquatic systems is international (shared by more than one country) and therefore, present transboundary issues;
2. The aquatic system is a one-nation transboundary system (shared by more than one state), and present a high degree of complexity in terms of planning and management of integrated strategic plans, in the executive spheres of more than one state;
3. The aquatic system suffers environmental and/or socio-economic impacts at a degree of severity representative of/or higher than the degree of severity assessed for the whole region Brazil Current;
4. The aquatic system is strategic in terms of multiple uses (human consumption, irrigation, industrial supply, etc.) or in terms of the importance of the habitats, ecosystems and biodiversity hosted and threatened by anthropogenic activities (coral reef, endemic species of fish, etc).

Only one aquatic system in the Brazil Current region meets criterion 1: Mirim Lagoon in South/Southeast Atlantic Basins, which is a bi-national aquatic system shared by Brazil and Uruguay. A number of aquatic systems in the Brazil Current meet criteria 2, 3 and 4. Among them, the Doce River basin in East Atlantic Basins was selected. It is a national transboundary basin shared by two states: Minas Gerais and Bahia and represents a common environmental problem in Brazil Current basins: Pollution associated to land use, erosion, changes in the transport/sedimentation dynamics of suspended solids, siltation of rivers and flooding. Based on the assessment results, São Francisco River Basin can be seen as one of the strongest candidate for further causal chain and policy options analysis. However, an on going GEF/UNEP project is already carrying out the policy options analysis and significant investments from both national and international sources are already planned for the mentioned Basin.

Table 16  Priority concerns selected for each basin in GIWA region 39, Brazil Current.

<table>
<thead>
<tr>
<th>Rank</th>
<th>39a South/Southeast Atlantic Basins</th>
<th>39b East Atlantic Basins</th>
<th>39c São Francisco River Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pollution</td>
<td>Freshwater shortage</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Habitat and community modification</td>
<td>Habitat and community modification</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Unsustainable exploitation of fish and other living resources</td>
<td>Pollution</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Freshwater shortage</td>
<td>Unsustainable exploitation of fish and other living resources</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Global change</td>
<td>Global change</td>
<td></td>
</tr>
</tbody>
</table>

Figure 35  The main causal-effect relationships among the five GIWA concerns in the Brazil Current region.

Numbers in the cycles represent the sub-regions where the link is substantiated. Dashed arrows are those causal links with controversial or still inconclusive indications supporting them.