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Articles

Journal of Maritime Research, Vol. I. No. 2, pp. 5-20, 2004

ISSN: 1697-4840

MATHEMATICAL MODELS OF SHIPS FOR MANOEUVRING SIMULATION AND CONTROL

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ABSTRACT

This paper reviews models with four degrees of freedom, including the roll motion, in order to describe the movement of a ship. The effects of yaw, sway and roll are also taken into account. These models are used in applications such as the simulation and steering control of a ship, or the study of sea vessels which act cooperatively.

Key Words: Mathematical model. Ship movement. Manoeuvring. Simulation.

INTRODUCTION

Computer simulation, which started in the fifties, is now the most widely used method for evaluating the manoeuvrability of conventional surface ships, submarines and other craft (Barr, 1993). Simulation is also a widely accepted tool used in ship design and research, selection and design of ship equipment, design and research of waterways and harbours and training of ship officers.

The simulation methods use hydrodynamic coefficients based on data obtained using captive model tests performed in a towing tank and/or a rotating arm. In marine science, time domain simulations have been used mainly to predict the controllability and manoeuvrability of all types of sea craft and systems.

For any control design, knowledge of the dynamic characteristics of the device or physical system to be controlled is essential. In the manoeuvring and control of ships, experience suggests that it is difficult to predict the characteristics of a ship from model tests, due to the lack of any exact knowledge of the steering and roll interactions (Blanke and Jensen, 1997). Hence, a great deal of research has been carried out in order to analyse this interaction (coupling). Knowledge of the dynamics related to yaw, sway and roll is useful both for improving manoeuvring models and, for example, developing roll damping control applications in which the dynamic couplings between the yaw, sway and roll are of great importance.

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Validation of an autopilot system is performed first by simulation, then by model and full-scale trials.

While models of three degrees of freedom for describing ship motion are well-known (Abkowitz, 1964 and Chislett and Støm-Tejsen, 1965), there have been very few studies describing the coupling between yaw, sway and roll. Results published by Son and Nomoto (1981) present the model of a container ship obtained by combining planar motion mechanism (PMM) data for lateral movements using different values of static heel for the model under test, with independent roll motion tests. Kalstrom and Otterson (1983) obtained a model by combining a lateral PMM model with theoretical estimates of roll coefficients, using free sailing model tests to calibrate the roll parameters. Blanke and Jensen (1997) obtain a full non-linear model of a container ship using the unique four degrees of freedom roll planar motion mechanism (RPMM) facility at the Danish Maritime Institute, and the model has also been validated via extensive full scale trials.

This paper describes models of four degrees of freedom used for simulation and control applications, presenting the hydrodynamic models of two container ships (Son and Nomoto, 1981) and (Blanke and Jensen, 1997).

SHIP MATHEMATICAL MODEL

Degrees of Freedom and Notations

The movement of a ship, considered as a rigid solid, has six degrees of freedom (DOF) which means that six independent coordinates are required to determine its position and orientation. Table 1 shows the description of each DOF and the corresponding nomenclature used to describe the ship's forces and motions. This is the standard notation recommended in SNAME, (1950) for use in ship manoeuvring and control applications.

Table 1: Notation and DOF description

DOF	Translation	Forces	Linear velocity	Position
1	surge	X	u	x
2	sway	Y	v	y
3	heave	Z	w	z
	Rotations	**Moments**	**Angular velocity**	**Angles**
4	roll	K	p	ϕ
5	pitch	M	q	θ
6	yaw	N	r	ψ

The first three coordinates and their derivatives are used to describe the position and translation movements on the axes x_B, y_B and z_B , while the other three coordinates and their derivatives are used to describe the orientation and rotation movements. For sea vessels, the six different motion components are defined as surge, sway and heave for translation motions in the three directions and roll, pitch and yaw for rotation motions around the three axes.

Using the above notation, the motion of a ship with six DOFs can be described by means of the following vectors:

• The speed vector which is normally defined in relation to the ship's coordinates system:

$$\mathbf{v} = \left[\mathbf{v}_1^T, \mathbf{v}_2^T\right]^T, \quad \mathbf{v}_1 = \left[u, v, w\right]^T, \quad \mathbf{v}_2 = \left[p, q, r\right]^T \tag{1}$$

• The external forces and motion vector which is also defined in relation to the ship's coordinates system:

$$\boldsymbol{\tau} = \left[\boldsymbol{\tau}_1^T, \boldsymbol{\tau}_2^T\right]^T, \quad \boldsymbol{\tau}_1 = \left[X, Y, Z\right]^T, \quad \boldsymbol{\tau}_2 = \left[K, M, N\right]^T \tag{2}$$

• The position and orientation vector defined with respect to the inertial reference system:

$$\boldsymbol{\eta} = \left[\boldsymbol{\eta}_1^T, \boldsymbol{\eta}_2^T\right]^T, \quad \boldsymbol{\eta}_1 = \left[x, y, z\right]^T, \quad \boldsymbol{\eta}_2 = \left[\phi, \theta, \psi\right]^T \tag{3}$$

Coordinate frames

In order to analyse the ship's motion at sea in six DOF, two coordinate frames are used, as shown in Figure 1.

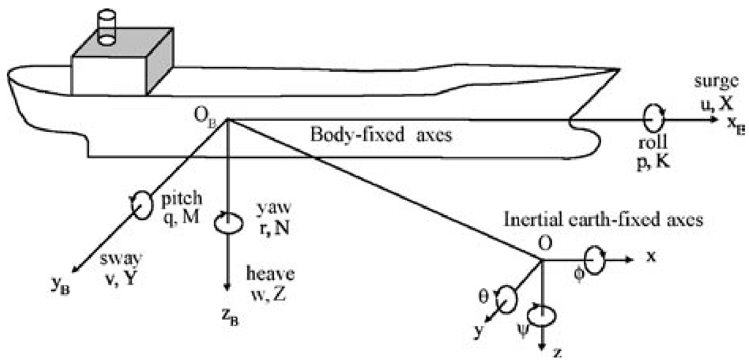


Figure 1 Coordinate Systems with definition of angles, velocities, forces and moments

The moving coordinate frame x_B, y_B, z_B is fixed to the ship and is called the body-fixed reference frame. The origin O_B of the ship's coordinate system can be selected to coincide with the Centre of Gravity (CG) if the CG is situated on the main plane of symmetry. Generally, however, this is not a good choice, since the CG is not located at any fixed point as the load conditions of the ship change constantly. The most widely used option, allowing a reduction in the complexity of the equation (Fossen, 1994), consists in selecting an orthogonal coordinate system parallel to the main axes of inertia in order to eliminate the products of inertia in the motion equations. These requirements are satisfied in practically all sea vessels, the origin being located at the intersection of the two planes of symmetry.

The motion of the body-fixed frame is described in relation to an inertial reference axis xyz, and it is normally assumed that the acceleration of one point of the surface of the Earth will have little effect on the slow motion of sea vessels. As a result, it can be considered that a reference system located on Earth O_{xyz} is an inertial system. Thus, the position and orientation of the ship is described in relation to the inertial reference system and its linear and angular velocities in the ship's mobile coordinate systems.

Ship Motion Equations

Representing the motion equations in the body-fixed reference frame, with the origin of the coordinates located at the intersection of the planes of symmetry, the motion equations of a ship, starting from Newton's equations, can be expressed (Norrbin, 1970), (Blanke, 1981) or (Fossen, 1994) as follows:

$$\begin{aligned} m\left(\dot{u} - rv + qw - (q^2 + r^2)x_G + (pq - \dot{r})y_G + (rp + \dot{q})z_G\right) &= X \\ m\left(\dot{v} - pw + ru - (r^2 + p^2)y_G + (qr - \dot{p})z_G + (pq + \dot{r})x_G\right) &= Y \\ m\left(\dot{w} - qu + pv - (p^2 + q^2)z_G + (rp - \dot{q})x_G + (qr + \dot{p})y_G\right) &= Z \end{aligned} \quad (4)$$

$$\begin{aligned} I_x\dot{p} + (I_z - I_y)rq + m\left(y_G(\dot{w} + pv - qu) - z_G(\dot{v} + ru - pw)\right) &= K \\ I_y\dot{q} + (I_x - I_z)rp + m\left(z_G(\dot{u} + qw - rv) - x_G(\dot{w} + pv - qu)\right) &= M \\ I_z\dot{r} + (I_y - I_x)pq + m\left(x_G(\dot{v} + ru - pw) - y_G(\dot{u} + qw - rv)\right) &= N \end{aligned} \quad (5)$$

where (x_G, y_G, z_G) is the position of the ship's CG; m is the mass of the ship; $u, v, w, \dot{u}, \dot{v}, \dot{w}$ represent the linear velocities and accelerations in the x_B, y_B and z_B directions; $r, q, p, \dot{r}, \dot{q}, \dot{p}$ represent the angular velocities and accelerations related to the axes x_B, y_B and z_B. I_x, I_y and I_z are the moments of inertia of the ship with respect to the same axes of the body-fixed frame. The forces and moments X, Y, Z, K, M and N represent the results of all external actions on the ship's body.

These equations can be expressed more concisely in vectorial form by the equation:

$$\boldsymbol{M}_{RB}\,\dot{\boldsymbol{v}} + \boldsymbol{C}_{RB}(\boldsymbol{v})\,\boldsymbol{v} = \boldsymbol{\tau}_{RB} \quad (6)$$

where $\boldsymbol{M}_{RB}$ is the inertial matrix, and $\boldsymbol{C}_{RB}(\boldsymbol{v})$ is the matrix of Coriolis and centripetal terms, both caused by the dynamics of the rigid solid. τ_{RB} is a generalised vector of the external motions and forces. These forces and motions can be broken down into several components according to their origin (Lewis, 1989), (Faltisen, 1990):

$$\boldsymbol{\tau}_{RB} = \boldsymbol{\tau}_H + \boldsymbol{\tau}_{CS} + \boldsymbol{\tau}_P + \boldsymbol{\tau}_E \quad (7)$$

τ_H: hydrodynamic forces and motions produced by the movements of the hull in the water, normally separated according to their origin into several groups using the equation $\tau_H = \tau_A - \tau_D - \tau_R$ (added mass, hydrodynamic damping and restoring forces).

τ_{CS} : forces and motions caused by the control surfaces (rudders, blades etc.).

τ_P: forces and moments generated by the propulsion systems (forces produced by the propellers and thrusters).

τ_{CE}: forces and motions which act on the hull due to environmental disturbances (waves, winds and currents).

Moreover, if the kinematics of the ship is to be included, the following equations are normally used as the vectorial expression of the 6-DOF motion equations:

$$\boldsymbol{M}\dot{\boldsymbol{v}} + \boldsymbol{C}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{D}(\boldsymbol{v})\boldsymbol{v} + \boldsymbol{g}(\boldsymbol{\eta}) = \boldsymbol{\tau} \quad \textbf{(8)}$$

$$\dot{\boldsymbol{\eta}} = \boldsymbol{J}(\boldsymbol{\eta})\boldsymbol{v} \quad \textbf{(9)}$$

where $\boldsymbol{M}=\boldsymbol{M}_{RG}+\boldsymbol{M}_A$ is the inertial matrix (including added mass matrix $\boldsymbol{M}_A$), $\boldsymbol{C}(\boldsymbol{v}) = \boldsymbol{C}_{RB}(\boldsymbol{v}) + \boldsymbol{C}_A(\boldsymbol{v})$ is the matrix of Coriolis and centripetal terms (including added mass matrix $\boldsymbol{C}_A(\boldsymbol{v})$), $\boldsymbol{D}(\boldsymbol{v})$, is the damping matrix, $\boldsymbol{g}_{(\eta)}$ is the vector of gravitational forces and moments and $\boldsymbol{\tau} = \boldsymbol{\tau}_{CS} + \boldsymbol{\tau}_P + \boldsymbol{\tau}_E$ is the vector of the propulsion forces and moments, control surfaces and environmental disturbances.

The concept of added mass is usually misunderstood to be a finite amount of water connected to the vehicle such that the vehicle and the fluid represent a new system with mass larger than the original system. Added (virtual) mass should be understood as pressure-induced forces and moments due to a forced harmonic motion of the body, which is proportional to the acceleration of the body (Fossen, 1994).

The term $\boldsymbol{J}_{(\eta)}$ of equation 9 is the transformation matrix used to represent the position and orientation vector η in the Earth-fixed frame. Equation 9 can be expressed by:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} \begin{matrix} c(\psi)c(\theta) & -s(\psi)c(\phi)+c(\psi)s(\theta)s(\phi) & s(\psi)s(\phi)+c(\psi)c(\phi)s(\theta) \\ s(\psi)c(\theta) & c(\psi)c(\phi)+s(\phi)s(\theta)s(\psi) & -c(\psi)s(\phi)+s(\theta)s(\psi)c(\phi) \\ -s(\theta) & c(\theta)s(\phi) & c(\theta)c(\phi) \end{matrix} & \mathbf{0}_{3\times3} \\ \mathbf{0}_{3\times3} & \begin{matrix} 1 & s(\phi)t(\theta) & c(\phi)t(\theta) \\ 0 & c(\phi) & -s(\phi) \\ 0 & s(\phi)/c(\theta) & c(\phi)/c(\theta) \end{matrix} \end{bmatrix} \begin{bmatrix} u \\ v \\ w \\ p \\ q \\ r \end{bmatrix} \quad \textbf{(10)}$$

where $s(\cdot) = \sin(\cdot)$, $c(\cdot) = \cos(\cdot)$, $t(\cdot) = \tan(\cdot)$.

HYDRODYNAMIC FORCES AND MOTIONS

An important step in the development of maneuvering models is to expand the forces and moments in Taylor's series. In this way, the hydrodynamic forces and motions are normally represented as a non-linear function of the accelerations $\dot{\nu}$, velocities ν, and Euler angles included in η:

$$\boldsymbol{\tau}_H = \mathbf{f}(\dot{\boldsymbol{\nu}}, \boldsymbol{\nu}, \boldsymbol{\eta}) \quad \textbf{(11)}$$

where the function **f** is calculated through the development in Taylor series of the functions *X*, *Y*, *Z*, *K*, *M* and *N* as, for example, for force *X*:

$$\frac{dX}{dt} = \frac{\partial X}{\partial u} u + \frac{\partial X}{\partial v} v + \ldots + \frac{\partial X}{\partial \dot{u}} \dot{u} + \frac{\partial X}{\partial \dot{v}} \dot{v} + \ldots \frac{1}{2} \frac{\partial^2 X}{\partial u^2} u^2 + \ldots \frac{1}{6} \frac{\partial^3 X}{\partial u^3} u^3 + \ldots \quad \textbf{(12)}$$

and the partial derivatives of the development, termed *hydrodynamic derivatives* or *hydrodynamic coefficients*, are represented by terms such as:

$$X_{\dot{u}} = \frac{\partial X}{\partial \dot{u}}, \quad X_{uu} = \frac{1}{2} \frac{\partial^2 X}{\partial u^2}, \quad Y_{vv} = \frac{1}{2} \frac{\partial^2 Y}{\partial \delta^2}, \quad N_{v|r|} = \frac{\partial^2 N}{\partial v \partial |r|} \text{ y } K_{ppp} = \frac{1}{6} \frac{\partial^3 K}{\partial p^3}, \quad \textbf{(13)}$$

evaluated at equilibrium conditions. The initial condition of motion equilibrium is chosen as straight ahead motion at constant speed (Abkowitz, 1964).

An approximation to the above expressions of equation (11), in stationary state, using the Taylor development around the state of equilibrium $u = u_0$ and $\nu = \dot{\nu} = 0_{6x1}$, obtaining a polynomial of the fourth order or lower (Kallstrom, 1982) if there is lateral symmetry of the ship (Lewis, 1989). In (Abkowitz, 1964) and (Lewis, 1989) it is proposed that up to the third order of development should be taken. No terms higher than the third order are included since experience has shown that their inclusion does not significantly increase accuracy. Moreover, several terms can be discarded due to the lateral symmetry of ships and by taking into account only terms with acceleration of the first order

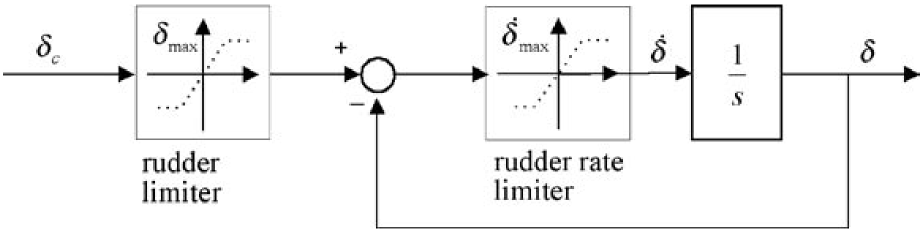
The hydrodynamic derivatives can be determined approximately from the hydrodynamics theory (strip theory) (Lewis, 1989), by experiments using scale models (Lewis, 1989), (Son and Nomoto, 1981), (Blanke and Jensen, 1997) or by system identification methods carrying out experiments on the ships (Astrom and Kallstrom, 1976), (Kallstrom and Astrom, 1981). However, it is difficult to determine all of the hydrodynamic coefficients of a ship. To obtain a good model of the vessel, these coefficients need to be determined reasonably accurately.

RUDDER SATURATION AND DYNAMICS

To include the action of the rudder in the model, the simplified model proposed by Van Amerongen (1982) has been used to represent the steering machine, as shown in Figure 4, where δ_c is the commanded rudder angle and δ is the actual rudder angle.

The rudder angle and rudder rate limiters will typically be in the ranges of $-35^{o} \leq \delta_{max} \leq 35^{o}$ and $2.5^{o}/\sec \leq \dot{\delta}_{max} \leq 7^{o}/\sec$.

Figure 2 Simplified diagram of the rudder control loop



Source: (Van Amerongen, 1982)

DYNAMIC EQUATIONS WITH FOUR DEGREES OF FREEDOM

In some vessels such as container ships, warships or high-speed ferries, as well as the motions of sway, yaw and surge, the roll motion must also be included in the mathematical model. If the coordinate system O_B is located in the ship to coincide with the main inertial axes, equation (4) shortens to:

$$\boldsymbol{M}_{RB(4x4)}\,\dot{\boldsymbol{v}} + \boldsymbol{C}_{RB(4x4)}(\boldsymbol{v})\,\boldsymbol{v} = \boldsymbol{\tau}_{RB(4x1)} \tag{14}$$

where the velocity vector is given by:

$$\boldsymbol{v} = \left[u,\ v,\ p,\ r\right]^{T} \tag{15}$$

The mass and inertia matrix has the form:

$$\boldsymbol{M}_{RB(4x4)} = \begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & -mz_G & mx_G \\ 0 & -mz_G & I_x & 0 \\ 0 & mx_G & 0 & I_z \end{bmatrix} \tag{16}$$

The centripetal and Coriolis force is:

$$\boldsymbol{C}_{RB(4x4)}(\boldsymbol{v}) = \begin{bmatrix} 0 & 0 & mz_G r & -m(x_G r + v) \\ 0 & 0 & 0 & mu \\ -mz_G r & o & 0 & 0 \\ m(x_G r + v) & -mu & 0 & 0 \end{bmatrix} \tag{17}$$

The vector of the total external forces at eh axes x_B and y_B (*X*, *Y*) and the total external motions at the axes z_B and y_B (*N* y *K*) are:

$$\boldsymbol{\tau}_{RB(4x1)} = \left[X,\ Y,\ K,\ N\right]^{T} \tag{18}$$

which can be more concisely represented as:

$$\begin{aligned} &\text{Surge:} \quad m(\dot{u} - vr - x_G r^2 + z_G pr) = X \\ &\text{Sway:} \quad m(\dot{v} - ur - z_G \dot{p} + x_G \dot{r}) = Y \\ &\text{Roll:} \quad I_x \dot{p} - m z_G (ur + \dot{v}) = K \\ &\text{Yaw:} \quad I_z \dot{r} + m x_G (ur + \dot{v}) = N \end{aligned} \quad \textbf{(19)}$$

MODELS WITH 4 DEGREES OF FREEDOM

This section reviews some models, presented by various authors, which can be used to simulate the dynamic behaviour of a ship. These models include hydrodynamic forces and motions

Son and Nomoto Model

Son and Nomoto presented a non-linear mathematical model of a high-speed container ship (Son and Nomoto, 1981) in order to study the coupled motions of yaw, sway and roll. In this model, the basic motion equations were formulated with four degrees of freedom of equation (19) as follows:

$$\begin{aligned} (m + m_x)\dot{u} - (m + m_y)vr &= X \\ (m + m_y)\dot{v} - (m + m_x)ur + m_y \alpha_y \dot{r} - m_y l_y \dot{p} &= Y \\ (I_z + J_z)\dot{r} + m_y \alpha_y \dot{v} &= N - Y x_G \\ (I_x + J_x)\dot{p} - m_y I_y \dot{v} - m_x l_x ur + WGM\phi &= K_0 \end{aligned} \quad \textbf{(20)}$$

where m_x y m_y are added mass in the surge and yaw directions, J_x and J_z the added inertia about roll and axes respectively. The centre of added mass for m_y is denoted by α_y (x-coordinate), while lx and ly are the added mass coordinates of m_x and m_y respectively.

The origin of the fixed coordinates of the ship is described as $[x_G, 0, 0]$. The terms for added mass and inertias are expressly included with their corresponding radius of rotation rather than including them by means of their hydrodynamic coefficients, as was the case in equation (19). The metacentric restoring moment in roll was added in the K expression, where W is the weight of the water displaced by the ship hull and GM is the transverse metacentric height. The term x_G appears in the equation since the hydrodynamic motion of yaw N is defined around the geometrical centre of the ship. The hydrodynamic forces and motions are developed using the hydrodynamic derivatives of equations (20).

$$= X(u) + (1-t)T(J) + X_{vr}\, vr + X_{vv} v^2 + + X_{rr}\, r^2 + X_{\varphi\varphi}\varphi^2 + c_{RX}\, F_N \operatorname{sen}\delta \quad \textbf{(21)}$$

$$\begin{aligned} Y = {} & Y_v\, v + Y_r\, r + Y_{\dot{\phi}}\dot{\phi} + Y_{\phi}\phi + Y_{vvv}\, v^3 + Y_{rrr} r^3 + Y_{vvr} v^2 r + Y_{vrr} vr^2 + \\ & + Y_{vv\phi} v^2\phi + Y_{v\phi\phi} v\phi^2 + Y_{rr\phi} r^2\phi + Y_{r\phi\phi} r\phi^2 + (1 + a_H) F_N \cos\delta \end{aligned} \quad \textbf{(22)}$$

$$N = N_v v + N_r r + N_{\dot{\phi}} \dot{\phi} + N_\phi \phi + N_{vvv} v^3 + N_{rrr} r^3 + N_{vvr} v^2 r + N_{vrr} v r^2 + \\ + N_{vv\phi} v^2 \phi + N_{v\phi\phi} v \phi^2 + N_{rr\phi} r^2 \phi + N_{r\phi\phi} r \phi^2 + (x_R + a_H x_H) F_N \cos\delta \quad (23)$$

$$K = K_v v + K_r r + K_{\dot{\phi}} \dot{\phi} + K_\phi \phi + K_{vvv} v^3 + K_{rrr} r^3 + K_{vvr} v^2 r + K_{vrr} v r^2 + \\ + K_{vv\phi} v^2 \phi + K_{v\phi\phi} v \phi^2 + K_{rr\phi} r^2 \phi + K_{r\phi\phi} r \phi^2 - (1 + a_H) z_R F_N \cos\delta \quad (24)$$

The forces produced by the rudder are represented by the last terms of each equation. The force of the rudder F_N is expressed as:

$$F_N = -\frac{6{,}13\Lambda}{\Lambda + 2{,}25} \cdot \frac{A_R}{L^2} \left(u_R^2 + v_R^2\right) sen\alpha_R \quad (25)$$

where α_R is the incidence flow angle, u_R and v_R are the surge and sway components of the incident flow velocity in the rudder defined by equations 26, 27 and 28, respectively:

$$\alpha_R = \delta + \arctan\left(v_R / u_R\right) \quad (26)$$

$$v_R = \gamma v + c_{Rr} r + c_{Rrrr} r^3 + c_{Rrrv} r^2 v \quad (27)$$

$$u_R = u_p \varepsilon \sqrt{1 + 8kK_T / (\pi J^2)} \quad (28)$$

$$J = u_p V / (nD) \quad (29)$$

$$u_p = \cos v \left[(1 - w_p) + r \left\{ (v + x_p r)^2 + c_{pv} v + c_{pr} r \right\} \right] \quad (30)$$

Table 2 shows the main features of the ship identified by Son and Nomoto in their research.

Table 2: Container Ship SR 108 Main Features

Description		Symbol	Value	units
Length		L	175,00	m
Breadth		B	25,40	m
Draft	fore	d_F	8	m
	aft	d_A	9	m
	mean	d	8,5	m
Displacement volume		∇	21.222	m^3
Height from keel to transverse metacenter		KM	10,39	m
Height from keel to centre of buoyancy		KB	4,6154	m
Block coefficient		C_B	0,559	
Prismatic coefficient		C_p	0,580	
Rudder Area		A_R	33,0376	m^2
Aspect Ratio		Λ	1,8219	
Propeller Diameter		D	6,533	m

Table 3 shows the hydrodynamic coefficients and other parameters of the model

Table 3: Hydrodynamic derivatives and coefficients

a) Only hull parameters

m	0,00792	Yp	0,0	Nvvφ		-0,019058
mx	0,000238	Yφ	-0,000063	Nvφφ		-0,0053766
my	0,007049	Yvvv	-0,109	Nrrφ		-0,0038592
Ix	0,0000176	Yrrr	0,00177	Nrφφ		0,0024195
Jx	0,0000034	Yrvv	0,0214	Kv		0,0003026
Iz	0,000456	Yrrv	-0,0405	Kr		-0,0003026
Jz	0,000419	Yvvφ	0,04605	κφ	0,1	($Fn \leq 0,1$)
αy	0,05	Yvφφ	0,0034		0,2	($Fn \geq 0,2$)
lx	0,0313	Yrrφ	0,009325		Fn	($0,1<Fn<0,2$)
ly	0,0313	Yrφφ	-0,001368	Kφ		-0,000021
KT	0,527-0,455J	Nv	-0,0038545	Kvvv		0,002843
Xuu	-0,0004226	Nr	-0,00222	Krrr		-0,0000462
Xuu	-0,00311	Np	0,000213	Krvv		-000558
Xuu	0,00386	Nφ	-0,0001424	Krrv		0,0010565
Xuu	0,00020	Nvvv	0,001492	Kvvφ		-0,0012012
Xuu	-0,00020	Nrrr	-0,00229	Kvφφ		-0,0000793
Yv	-0,0116	Nrvv	-0,0424	Krrφ		-0,000243
Yr	0,00242	Nrrv	0,00156	Krφφ		0,00003569

b) Propeller and rudder parameters

Np	79,10 (Fn 0,2)	αH	0,237	ε	0,921
(rpm)	118,64 (Fn 0,3)	xH	-0,48	k	0,631
	158,19 (Fn 0,4)	cRX	0,71	γ	0,088 ($v > 0$)
(1- t)	0,825	zR	0,033		0,193 ($v \leq 0$)
(1-ωp)	0,816	cpv	0,0	cRr	-0,156
xR	-0,5	cpr	0,0	cRrrr	-0,275
xp	-0,526	τ	1,09	cRrrv	1,96

Motion equation (19) can be described as:

$$\begin{bmatrix} (m+m_x) & 0 & 0 & 0 \\ 0 & (m+m_y) & m_y\alpha_y & -m_y l_y \\ 0 & -m_y I_y & (I_x+J_x) & 0 \\ 0 & m_y\alpha_y & 0 & (I_z+J_z) \end{bmatrix} \begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{p} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} X \\ Y \\ K \\ N \end{bmatrix} + \begin{bmatrix} (m+m_y)vr \\ (m+m_x)ur \\ m_x l_x ur - WGM\phi \\ -Yx_G \end{bmatrix} \quad \textbf{(31)}$$

Blanke and Jensen's Model

Blanke and Jensen presented a non-linear mathematical model of a high-speed container ship (Blanke and Jensen, 1997) obtained using a roll planar motion mechanism (RPMM) with four degrees of freedom. The model was developed in order to predict the manoeuvring characteristics with more accuracy than that obtained previously in order to study the coupled motions of yaw, sway and roll. The basic equations of motion with four degrees of freedom of equation (19) were formulated as follows:

$$\begin{aligned} & m(\dot{u} - vr - x_G r^2 + z_G pr\cos\phi) = X \\ & m(\dot{v} - ur - z_G \dot{p}\cos\phi + x_G \dot{r}) = Y \\ & I_x \dot{p} - m z_G (ur + \dot{v})\cos\phi = K - \rho g \nabla G_z(\phi) \\ & I_z \dot{r} + m x_G (ur + \dot{v}) = N \end{aligned} \quad \textbf{(32)}$$

where ∇ indicates the displacement of the ship, g the gravity constant, δ the density of the water, I_x and I_z are the inertia motions of the ship with respect to the axes x_B and z_B, m is the ship's mass and the centre of gravity is assumed to be in the position (x_G, 0, z_G).

The results of the experiments with the RPMM were formulated with a full adimensional hydrodynamic model using the prime system:

$$U = \sqrt{(u_0 + u)^2 + v^2} \tag{33}$$

In the RPMM model, the relative velocity of adimensional advance in hydrodynamic terms is used:

$$u'_{\mathrm{a}} = \frac{U - U_{norm}}{U} \tag{34}$$

In the reference, it is noticeable that u'_{a} is different from the relative velocity of adimensional advance $u'=u/U$ which is included when the accelerations of equation (32) are calculated. The terms X, Y, N and K of the hydrodynamic forces were:

$$\begin{aligned} X' = {} & X'_0 + X'_u u'_{\mathrm{a}} + X'_{uu} u'^2_{\mathrm{a}} + X'_{uuu} u'^3_{\mathrm{a}} + X'_{vr} v'r' + X'_{rr} r'^2 + X'_\delta \delta' + X'_{\delta\delta} \delta'^2 \\ & + X'_{\delta u} \delta' u'_{\mathrm{a}} + X'_{\delta\delta u} \delta'^2 + X'_{\delta uu} \delta' u'^2_{\mathrm{a}} + X'_v v' + X'_{vv} v'^2 + X'_{\delta v} \delta' v' + X'_{\delta vv} \delta' v'^2 \\ & + X'_{v\phi} v'\phi' + X'_{v\phi\phi} v'\phi'^2 + X'_\phi \phi' + X'_{\phi\phi} \phi'^2 + X'_{\phi vv} \phi' v'^2 + X'_r r' + X'_{pp} p'^2 \\ & + X'_{ppu} p'^2 u'^2_{\mathrm{a}} + X'_{ext} \end{aligned} \tag{35}$$

$$\begin{aligned} Y' = {} & Y'_0 + Y'_{0u} u'_{\mathrm{a}} + Y'_{\dot v} \dot v' + Y'_{\dot r} \dot r' + Y'_{\dot p} \dot p' + Y'_v v' + Y'_{vv} v'^2 + Y'_{v|v|} v'|v'| + Y'_\delta \delta' \\ & + Y'_{\delta\delta} \delta'^2 + Y'_{\delta\delta\delta} \delta'^3 + Y'_{\delta u} \delta' u'_{\mathrm{a}} + Y_{\delta\delta u} \delta'^2 u'_{\mathrm{a}} + Y_u u'_{\mathrm{a}} + Y'_{uu} u'^2_{\mathrm{a}} + Y'_{uuu} u'^3_{\mathrm{a}} + Y'_{\delta u} \delta' u'_{\mathrm{a}} \\ & + Y'_{\delta\delta u} \delta'^2 u' + Y'_{\delta\delta\delta u} \delta'^3 u'_{\mathrm{a}} + Y'_{\delta v} v'\delta' + Y'_{\delta vv} \delta' v'^2 + Y'_\phi \phi' + Y'_{\phi\phi} \phi'^2 + Y'_{v\phi} v'\phi' \\ & + Y'_{v\phi\phi} v'\phi'^2 + Y'_{\phi vv} \phi' v'^2 + Y'_r r' + Y'_{rrr} r'^3 + Y'_{r|v|} r'|v'| + Y'_{v|r|} v'|r'| + Y'_{vrr} v' r'^2 \\ & + Y'_p p' + Y'_{p|p|} p'|p'| + Y'_{ppp} p'^3 + Y'_{pu} p' u'_{\mathrm{a}} + Y'_{pu|pu|} p' u'_{\mathrm{a}} |p' u'_{\mathrm{a}}| + Y'_{ext} \end{aligned} \tag{36}$$

$$\begin{aligned} K' = {} & K'_0 + K'_{0u} u'_{\mathrm{a}} + K'_{\dot v} \dot v' + K'_{\dot r} \dot r' + K'_{\dot p} \dot p' + K'_v v' + K'_{vv} v'^2 + K'_{v|v|} v'|v'| + K'_\delta \delta' \\ & + K'_{\delta\delta\delta} \delta'^3 + K'_{\delta u} \delta' u'_{\mathrm{a}} + K'_{\delta\delta u} \delta'^2 u'_{\mathrm{a}} + K'_u u'_{\mathrm{a}} + K'_{uu} u'^2_{\mathrm{a}} + K'_{uuu} u'^3_{\mathrm{a}} + K'_{\delta u} \delta' u'_{\mathrm{a}} \\ & + K'_{\delta\delta u} \delta'^2 u'_{\mathrm{a}} + K'_{\delta\delta\delta u} \delta'^3 u'_{\mathrm{a}} + K'_{\delta v} v'\delta' + K'_{\delta vv} \delta'' v'^2 + K'_\phi \phi' + K_{\phi\phi} \phi'^2 + K'_{v\phi} v'\phi' \\ & + K_{v\phi\phi} v'\phi'^2 + K'_{\phi vv} \phi' v'^2 + K'_r r' + K'_{rrr} r'^3 + K'_{r|v|} r'|v'| + K'_{v|r|} v'|r'| + K'_{vrr} v' r'^2 \\ & + K'_p p' + K'_{p|p|} p'|p'| + K'_{ppp} p'^3 + K'_{pu} p' u'_{\mathrm{a}} + K'_{pu|pu|} p' u'_{\mathrm{a}} |p' u'_{\mathrm{a}}| + K'_{ext} \end{aligned} \tag{37}$$

$$\begin{aligned} N' = {} & N'_0 + N'_{0u} u'_{\mathrm{a}} + N'_{\dot v} \dot v' + N'_{\dot r} \dot r' + N'_{\dot p} \dot p' + N'_v v' + N'_{vv} v' v' + N'_{v|v|} v'|v'| + N'_\delta \delta' \\ & + N'_{\delta\delta} \delta'^2 + N'_{\delta\delta\delta} \delta'^3 + N'_{\delta u} \delta' u'_{\mathrm{a}} + N'_{\delta\delta u} \delta'^2 u'_{\mathrm{a}} + N'_u u'_{\mathrm{a}} + N'_{uu} u'^2_{\mathrm{a}} + N'_{uuu} u'^3_{\mathrm{a}} + N'_{\delta u} \delta u'_{\mathrm{a}} \\ & + N'_{\delta\delta u} \delta'^2 u'_{\mathrm{a}} + N'_{\delta\delta\delta u} \delta'^3 u'_{\mathrm{a}} + N'_{\delta v} \delta' v' + N'_{\delta vv} \delta' v'^2 + N'_\phi \phi' + N'_{\phi\phi} \phi'^2 + N'_{v\phi} v'\phi' \\ & + N'_{v\phi\phi} v'\phi'^2 + N'_{\phi vv} \phi' v'^2 + N'_r r' + N'_{rrr} r'^3 + N'_{r|v|} r'|v'| + N'_{v|r|} v'|r'| + N'_{vrr} v' r'^2 \\ & + N'_{pu} p' u'_{\mathrm{a}} + N'_p p' + N'_{p|p|} p'|p'| + N'_{ppp} p'^3 + N'_{pu|pu|} p' u'_{\mathrm{a}} |p' u'_{\mathrm{a}}| + N'_{ext} \end{aligned} \tag{38}$$

where X'_0 is the force in direction x_B in the equilibrium condition $U = u_0$ and N'_0, K'_0 and Y'_0 the motions N, K and the force Y for $v = r = p = \delta = 0$. The terms represent the effects of wind, waves and currents.

For the design of the controllers, it is difficult to use the non-linear model directly. For this reason, the non-linear model must be replaced by a linear model, since most theorems have been obtained using linear theory. It is easy to obtain a linear model from the non-linear model by eliminating all of the terms whose orders are greater than one in equation (32).

For the study of the motions of roll and yaw the surge equation is not considered due to the small coupling between the motions of yaw, sway and roll with the surge motion. Thus, the linear model has only five states $\mathbf{x} = [v \ p \ r \ \phi \ \psi]^T$ and, if the rudder angle $\mathbf{u} = [\delta]$ is defined as input, the linear model can be expressed as:

$$\dot{\mathbf{x}} = \mathbf{A}\,\mathbf{x} + \mathbf{B}\,\mathbf{u} \tag{39}$$

where the matrixes **A** and **B** are defined by:

$$\mathbf{A} = \mathbf{M}^{-1}\,\mathbf{F} \qquad \mathbf{B} = \mathbf{M}^{-1}\,\mathbf{G} \tag{40}$$

with

$$\mathbf{F} = \begin{bmatrix} Y'_v + Y'_{uv}\Delta u' & Y'_p + Y'_{up}\Delta u' & Y'_r - m'\Delta u' & Y'_\phi & 0 \\ K'_v + K'_{uv}\Delta u' & K'_p + K'_{up}\Delta u' & K'_r + m'z'_G\Delta u' & K'_\phi - \rho' g' \nabla' GM' & 0 \\ N'_v + N'_{uv}\Delta u' & N'_p + N'_{up}\Delta u' & N'_r + m'x'_G\Delta u' & N'_\phi & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{41}$$

$$\mathbf{G} = \begin{bmatrix} Y'_\delta + Y'_{\delta u}\Delta u' \\ K'_\delta + K'_{\delta u}\Delta u' \\ N'_\delta + N'_{\delta u}\Delta u' \\ 0 \\ 0 \end{bmatrix} \tag{42}$$

CONCLUSIONS

Mathematical models of ships are used both in the simulation and in the design of control systems in applications such as ship steering control or the study of sea vessels which act cooperatively.

A review has been made of several models of four degrees of freedom which take into account the yaw, sway and roll couplings. These models are useful in some types of ships such as warships, container ships, fast ferries, etc. These models obtain a better agreement between the results predicted in simulation and those obtained experimentally.

ACKNOWLEDGEMENTS

This work has been partially financed by the MCYT through project DPI2003-09745-C04-03.

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APENDICE: MODELOS MATEMATICOS DE BUQUES PARA SIMULACIÓN Y CONTROL DE MANIOBRA

RESUMEN

En este artículo se revisan modelos con cuatro grados de libertad, que incluyen el movimiento de balance, para describir el movimiento de un buque. Así, se tienen en cuenta los acoplamientos de guiñada, abatimiento (desplazamiento lateral) y balance. Estos modelos se utilizan en aplicaciones como la simulación y control del gobierno de un buque, o el estudio de vehículos marinos que actúan cooperativamente.

Palabras clave: Modelos matemáticos. Movimiento del buque. Maniobra. Simulación.

INTRODUCCIÓN

El conocimiento de las dinámicas relacionadas con la guiñada, el desplazamiento lateral del buque y el balance, es útil tanto para mejorar los modelos de maniobra como también, por ejemplo, esencial para desarrollar aplicaciones de control de amortiguamiento de balance en las que los acoplamientos dinámicos entre dichos movimientos son muy importantes. En este artículo se describen modelos de buques de cuatro grados de libertad que se pueden utilizar para la simulación del comportamiento de maniobra y en aplicaciones de control. Se han incluido los modelos hidrodinámicos de dos buques contenedores (Son and Nomoto, 1981) and (Blanke and Jensen, 1997) obtenidos utilizando modelos cautivos en un canal de ensayos hidrodinámicos que incluyen el movimiento de balance.

METODOLOGÍA: MODELOS MATEMÁTICOS DE BUQUES

En primer lugar se presenta la notación estándar utilizada en la descripción del movimiento de vehículos marinos en seis grados de libertad (GDL) y que se muestran en la tabla 1.

Tabla 1: Notación y descripción de los GDL

GDL	Traslaciones	Fuerzas	Velocidades lineales	Posiciones
1	avance	X	u	x
2	abatimiento	Y	v	y
3	arfada	Z	w	z
	Rotaciones	**Momentos**	**Velocidades angulares**	**Ángulos**
4	balanceo	K	p	ϕ
5	cabeceo	M	q	θ
6	guiñada	N	r	ψ

Así, el movimiento de un buque en seis GDL se puede describir con los vectores:

$$\mathbf{v}=\left[u,\ v,\ w,\ p,\ q,\ r\right]^T,\quad \boldsymbol{\tau}=\left[X,\ Y,\ Z,\ K,\ M,\ N\right]^T,\quad \boldsymbol{\eta}=\left[x,\ y,\ z,\ \phi,\ \theta,\ \psi\right]^T \qquad (1)$$

y las ecuaciones del movimiento que se definen de forma vectorial por las ecuaciones:

$$\begin{aligned} \boldsymbol{M}\,\dot{\boldsymbol{v}}+\boldsymbol{C}(\boldsymbol{v})\boldsymbol{v}+\boldsymbol{D}(\boldsymbol{v})\boldsymbol{v}+\boldsymbol{g}(\boldsymbol{\eta})&=\boldsymbol{\tau} \\ \dot{\boldsymbol{\eta}}&=\boldsymbol{J}(\boldsymbol{\eta})\boldsymbol{v} \end{aligned} \qquad (2)$$

donde M es la matriz de inercia y $C(v)$ la matriz de Coriolis y términos centrípetos (incluyendo en ambas las matrices de masas añadidas). $\boldsymbol{D(v)}$ es la matriz de amortiguamiento, $\boldsymbol{g(\eta)}$ un vector de fuerzas y momentos debidos a la gravedad y el empuje y τ un vector de las fuerzas y momentos de la propulsión, superficies de control y perturbaciones ambientales. Las masas añadidas (virtuales) deben entenderse como las fuerzas inducidas de presión y los momentos debidos a un movimiento armónico forzado del casco que es proporcional a su aceleración. El término $\boldsymbol{J(\eta)}$ es la matriz de transformación utilizada para representar el vector η de posición y orientación.

Las fuerzas y momentos hidrodinámicos se suelen representar como una función no lineal de las aceleraciones $\dot{\nu}$, velocidades ν, y los ángulos de Euler incluidos en η:

$$\boldsymbol{\tau}_H=\mathbf{f}(\dot{\mathbf{v}},\ \mathbf{v},\ \boldsymbol{\eta}) \qquad (3)$$

donde la función **f** se calcula mediante el desarrollo de Taylor de las funciones X, Y, Z, K, M y N y las derivadas parciales del desarrollo, denominadas *derivadas* o *coeficientes hidrodinámicos*, están evaluadas con el buque navegando en avante a una velocidad constante ($u = u_0$ and $\nu = \dot{\nu} = 0_{6x1}$).

Las derivadas hidrodinámicas pueden determinarse de forma aproximada a partir de la teoría hidrodinámica, por experimentos con modelos a escala o mediante identificación de sistemas realizando experimentos en los buques. Para obtener un buen modelo del buque hay que determinarlos con una exactitud razonable. Para incluir en el modelo la acción del timón, se ha utilizado el modelo simplificado sugerido por Van Amerongen.

En algunos buques como por ejemplo buques contenedores, de guerra o en los ferries de alta velocidad, se debe incluir también el movimiento de balance en el modelo matemático. La ecuación del movimiento en cuatro grados de libertad es:

$$\begin{aligned} &\text{Avance:} && m(\dot{u}-vr-x_G r^2+z_G pr)=X \\ &\text{Desp. lateral:} && m(\dot{v}-ur-z_G\dot{p}+x_G\dot{r})=Y \\ &\text{Balanceo:} && I_x\dot{p}-mz_G(ur+\dot{v})=K \\ &\text{Guiñada:} && I_z\dot{r}+mx_G(ur+\dot{v})=N \end{aligned} \qquad (4)$$

En este trabajo se realiza una revisión de algunos de los modelos, que se pueden utilizar para simular el comportamiento dinámico de un buque. En primer lugar se presenta el *modelo de Son y Nomoto* expresado por la ecuación (5) que es un modelo matemático no lineal con cuatro GDL. El modelo incluye el desarrollo de las fuerzas y momentos hidrodinámicos, la fuerza del timón, las principales características del buque y los valores de los coeficientes hidrodinámicos y otros parámetros del modelo.

$$\begin{aligned}(m+m_x)\dot{u}-(m+m_y)vr &= X\\ (m+m_y)\dot{v}-(m+m_x)ur+m_y\alpha_y\dot{r}-m_y l_y\dot{p} &= Y\\ (I_z+J_z)\dot{r}+m_y\alpha_y\dot{v} &= N-Yx_G\\ (I_x+J_x)\dot{p}-m_y l_y\dot{v}-m_x l_x ur+WGM\phi &= K_0\end{aligned} \quad \mathbf{(5)}$$

El segundo modelo presentado corresponde al *modelo de Blanke y Jensen* que corresponde al modelo matemático no lineal de un buque contenedor de alta velocidad. El modelo se desarrolló con el objeto de predecir las características de maniobra con una mayor precisión que la obtenida anteriormente, con el fin de investigar los movimientos acoplados de guiñada, desplazamiento lateral y balance. Las ecuaciones básicas del movimiento con cuatro GDL de la ecuación (4) las formularon como sigue:

$$\begin{aligned}&m(\dot{u}-vr-x_G r^2+z_G pr\cos\phi)=X\\ &m(\dot{v}-ur-z_G\dot{p}\cos\phi+x_G\dot{r})=Y\\ &I_x\dot{p}-m z_G(ur+\dot{v})\cos\phi=K-\rho g\nabla G_z(\phi)\\ &I_z\dot{r}+m x_G(ur+\dot{v})=N\end{aligned} \quad \mathbf{(6)}$$

Para el diseño de controladores es difícil utilizar directamente el modelo no lineal. Por esta razón, debe reemplazarse por un modelo lineal. Es fácil obtener un modelo lineal a partir del modelo no lineal eliminando todos los términos cuyos órdenes sean mayores que uno en la ecuación (6). Para el estudio de los movimientos de balance y guiñada, la ecuación de avance no se considera debido al pequeño acoplamiento entre los movimientos de guiñada, desplazamiento lateral y balance con el movimiento de avance. Por lo tanto, el modelo lineal tiene sólo cinco estados $[v\ p\ r\ \phi\ \psi]^T$

CONCLUSIONES

Los modelos matemáticos de buques se emplean tanto en simulación como en el diseño de sistemas de control en aplicaciones tales como el control del gobierno de un buque, o el estudio de vehículos marinos que actúan cooperativamente.

Se ha efectuado una revisión de diferentes modelos de cuatro grados de libertad, que tienen en cuenta los acoplamientos de guiñada, desplazamiento lateral y balance. Estos modelos están indicados en algunos tipos de buques tales como buques de guerra, contenedores, ferries de alta velocidad, etc. Con ellos se obtiene una mejor adecuación entre los resultados previstos en simulación, y los obtenidos experimentalmente.

Journal of Maritime Research, Vol. I. No. 2, pp. 21-32, 2004

ISSN: 1697-4840

A NEW RECURSIVE IDENTIFICATION PROCEDURE OF THE NONLINEAR MODEL SHIP BASED ON THE TURNING TEST MANOEUVRING AND THE NORRBIN EQUATION

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ABSTRACT

In this paper has been carried out an identification procedure based on the adaptive backstepping design. The process depart of the experimental results obtained for a particular ship in the turning circle test. The ship's dynamics has been adjusted according to the Norrbin model being the coefficients of the nonlinear manoeuvring characteristics determined by the described procedure.

Key words: Modelling, nonlinear systems, ship's dynamics, adaptive backstepping.

1. INTRODUCTION

Several trial test for marine vehicles has been proposed, namely, the Turning, the Z-Manoeuvre (Kempf), Modified Z-Maneuver, Direct Spiral (Dieudonné), Reverse Spiral (Bech), Pull-Out, Stopping, Stopping Inertia, New Course Keeping, Man-Overboard, Parallel Course Manoeuver, Inertial Turning, Z-Maneuver Test at Low Speed, Accelerating Turning, Acceleration /Deceleration, Thruster, Minimum Revolution, Crash Ahead Test, though there are no definitive international standards for conducting manoeuvring trials with ships. Many shipyards have developed their own procedures driven by their experience and with consideration to the efforts made by the International Towing Tank Conference (ITTC, Proceedings 1963-1975) and other organizations or institutes, Journée and Pinkster (2001). The society of Naval Architects and Marine Engineers (SNAME) has produced three guidelines: "Code on manoeuvring and Special Trials and Tests" (1950), "Code for Sea Trials" (1973) and "Guide for Sea Trials" (1989). The Norwegian Standard Organization has produced "Testing of New Ship, Norsk Standard" (1985). The Japan Ship Research Association (JSRA) has produced a "Sea Trial Code for Giant Ships (1972). IMO Resolution A.601 (1987) and IMO Resolution A.751 (1993), were adopted by the IMO Assemblies to address ship manoeuvrability. The last Resolution adopted by this organization was the MSC 137(76) on 4 December 2002. The Z - Maneuver Test (Kemf) jointly with the Spiral Manoeuvre give some indication of control effectiveness (yaw- angle rate versus rudder angle) are recommended for all organisations and let us to carry out a compare the manoeuvring properties and control characteristic of a ship with those of other ships.

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Experimental results of trial tests can be to meet in the references showed in Principles of Manoeuvring and Control (Crane, 1999).

The backstepping designs (Krstić, et al., 1995) has been applied with considerable success in: Throttle valve and bleed valve, Banaszuk and Krener (1997) and the air injection, Behnken and Murray (1997), Protz and Paduano (1997), aeronautic systems, Monahemi and Krstić (1996), electric machines (Marino, et al., 1999), ship control, route planning, Haro and Velasco (2003), and in optimality problems (Fossen, 1994), electric generator systems based on the wind energy (Haro, et al.,2003).

The purpose of this paper is to carry out the identification process of the nonlinear dynamics of a ship supposing that its dynamics verify the Norrbin model (1963). El procedure based on the adaptive backstepping theory and the Turning Test manoeuvre let us the calculus of the coefficients that defines the nonlinear equation of the ship steering dynamics. A only measurement, the temporal variation of the yaw rate, it is necessary for this purpose. This measurement is available from relatively inexpensive measurement devices based on GPS/INS, that is, the satellite based on the Global Positioning System (GPS), aided with an Inertial Navigation System (INS). The four phases of the turning test, Fig.1, are distinguishable by the conditions shown in Table 1, where v, r , represents the sway velocity of the ship and the angular one about the a perpendicular axis, while $\dot{v}$, $\dot{r} = \alpha$ are the corresponding linear and angular accelerations, respectively.

2. SHIP MODEL

The ship movement is described in the Norrbin's model by the following equation,

Figure 1. Turning path of a ship.

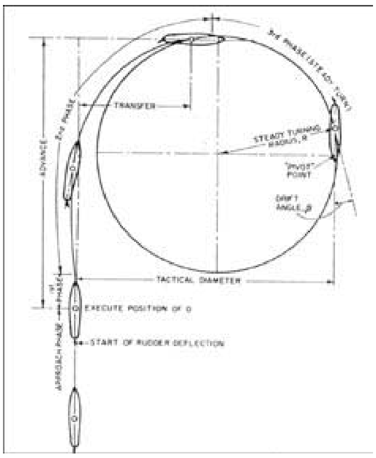


Table 1. Characteristics of the transient phases of a turn.

Phase	$\dot{v}$	$\dot{r}$	v	r
Approach	0	0	0	0
First	≠ 0	≠0	0	0
Second	≠ 0	≠ 0	≠ 0	≠ 0
Third	=0	=0	≠ 0	≠ 0

$$T \cdot \ddot{\varnothing} + H_N(\dot{\varnothing}) = K \cdot \ddot{a} \qquad \textbf{(1)}$$

where ψ is the course, $r=\dot{\psi}$ the yaw rate, δ the rudder angle, governed by a linear first order dynamics with a time constant τ, K the Nomoto gain constant, and T an equivalent time constant

$$\frac{\delta(s)}{U(s)} = \frac{1}{1 + s \cdot \tau} \tag{2}$$

U represents to the control and $H_N(\dot{\psi})$ the nonlinear manoeuvring characteristic usually represented by a third order polynomial as

$$H_N(\dot{\psi}) = n_3 \cdot \dot{\psi}^3 + n_2 \cdot \dot{\psi}^2 + n_1 \cdot \dot{\psi} + n_C \tag{3}$$

The steering dynamic with the equations (1) and (3) can be expressed as

$$\ddot{\psi} = a_3 \cdot \dot{\psi}^3 + a_2 \cdot \dot{\psi}^2 + a_1 \cdot \dot{\psi} + a_0 + b \cdot \delta \tag{4}$$

being

$$a_i = -\frac{n_i}{T} \qquad (i = 0 \cdots 3) \tag{5.a}$$

$$b = \frac{K}{T} \tag{5.b}$$

The state equations with the state variables r and $\alpha = \dot{r}$ (angular acceleration) are,

$$\dot{r} = \alpha \tag{6.a}$$

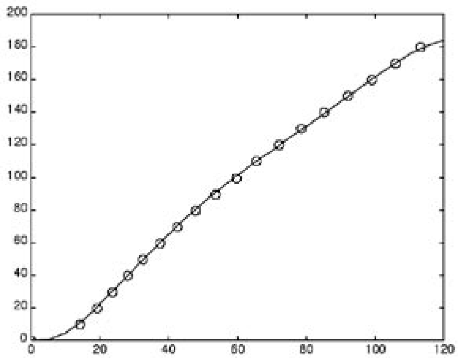
$$\dot{\alpha} = a_3 \cdot r^3 + a_2 \cdot r^2 + a_1 \cdot r + a_0 + b \cdot \delta \tag{6.b}$$

In the former equation an asymmetry in the hull is considered ($a_2 \uparrow 0$), also the procedure let us compute the term (a_0) due to environmental disturbances (wind, waves and currents) that they can act on the ship.

The roll-on/roll-off ship (Figure 2), whose characteristics are shown in the Table 2, has the following variation of the yaw angle with the time (Figure 3, equation 7) obtained

Figure 2. Ship whose characteristics has been tested in this paper.

Figure 3. Variation of the yaw angle vs time. Continuous line (fit obtained), circles (experimental points).



by means of fitting by least squares procedure of the experimental points of the yaw angle obtained by the realisation of the first three phases of the turning test to a polynomial of fourth order. The test was carried out in normal ballast condition, maximum ahead speed with a rudder angle of the 35 degrees. The turn causes a reduction in the speed of the ship like it is indicated in Table 3.

$$r_d = -0.22815 \cdot 10^{-6} \cdot t^4 + 7.433 \cdot 10^{-5} \cdot t^3 - 6.7401 \cdot 10^{-3} \cdot t^2 + 0.2319 \cdot t - 0.4611 \quad \textbf{(7)}$$

Figure 4. Variation of the yaw rate vs time.

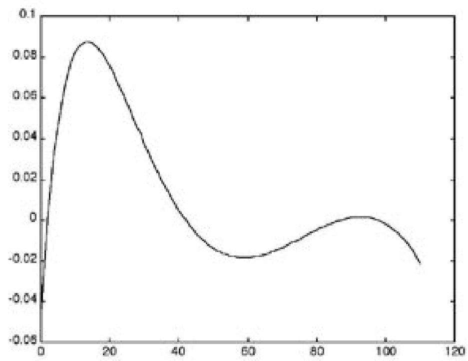
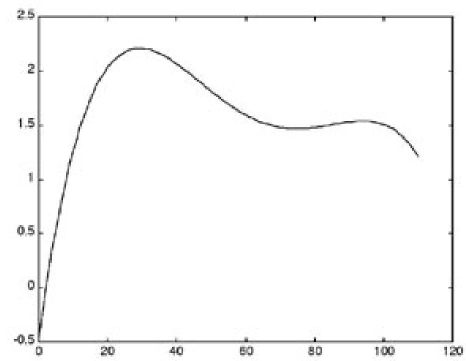


Figure 5. Variation of angular acceleration.



where r_d is the desired temporal variation of yaw rate in deg.s^{-1}.

Table 2. Main characteristics of the ship tested (Izar, 2001).

Draught forward (full load condition)	6m
Deadweight	7456 metric tonnes
Max. displacement	19949 metric tonnes
Length overall	188.3 m
Breadth (moulded)	28.7 m
Bulbous bow	Yes
Type of rudder	Becker
Number of units	2
Maximum angle of rudder	65 degrees
Time of hard–over to hard over	56 s
Propellers	2
Type	Controllable pitch
Engine (2 per shaft) Maximum power	4 x 6000 kW
Speed loaded (maximum full ahead)	22.68 knots
Speed ballast (maximum full ahead)	23.14 knots

Table 3. Reduction on the ship's speed from the initial value (22.68 knots) during the test.

Change of heading (deg)	Ship's speed (knots)	Change of heading (deg)	Ship's speed (knots)
10	19.24	100	9.07
20	18.27	110	8.18
30	17.22	120	7.37
40	16.08	130	6.69
50	14.89	140	6.15
60	13.64	150	5.69
70	12.41	160	5.30
80	11.22	170	5.00
90	10.09	180	4.74

3. ADAPTIVE BACKSTEPPING PROCEDURE

In order to get the identification of the parameters a_i (i=0...3) in equation (6.b) by the adaptive backstepping procedure it is convenient to define the new state variables,

$$z_1 = r - r_d \quad \textbf{(8.a)}$$

$$z_2 = \alpha - \beta(z_1) \quad \textbf{(8.b)}$$

where $\beta(z_1)$ represents a stabilizing function.

In the first step of the backstepping it is necessary to derive the equation (8.a) and with the aid of the (8.b) to obtain

$$\dot{z}_1 = z_2 + \beta(z_1) - \dot{r}_d \qquad \textbf{(9)}$$

and choosing the stabilizing function as

$$\beta(z_1) = \dot{r}_d - K_1 \cdot z_1 - \beta_1(z_1) \cdot z_1 \qquad \textbf{(10)}$$

being $K_1>0$, $\beta(z_1) \geq 0$, $\forall z_1$. In this step a Liapunov's function candidate is,

$$V_1 = \frac{1}{2} \cdot z_1^2 \qquad \textbf{(11)}$$

whose derivative is

$$\dot{V}_1 = -[K_1 + \beta_1(z_1)] \cdot z_1^2 + z_1 \cdot z_2 \qquad \textbf{(12)}$$

The second step of the backstepping depart of the equation (8.b) where the variation of the second backstepping state is,

$$\dot{z}_2 = \dot{\alpha} - \dot{\beta}(z_1) = \sum_{i=0}^{3} a_i + b \cdot \delta - \dot{\beta}(z_1) \qquad \textbf{(13)}$$

As consequence of the uncertainties in the parameters a_i (i=0..3) it cannot be cancelled by the control. For the principle of certain equivalence, each one of the parameters are substituted for its estimate $\hat{a}_i$(i=0..3) , the made error is $\tilde{a}_i$(i=0..3)

$$\tilde{a}_i = a_i - \hat{a}_i \qquad (i = 0..3) \qquad \textbf{(14)}$$

The second Liapunov function proposed is,

$$V_2 = V_1 + \frac{1}{2} \cdot z_2^2 + \frac{1}{2} \cdot \left[\sum_{i=0}^{3} \frac{1}{\gamma_i} \cdot \tilde{a}_i^2 \right] \qquad \textbf{(15)}$$

its derivative is

$$\dot{V}_2 = \dot{V}_1 + z_2 \cdot \dot{z}_2 + \sum_{i=0}^{3} \frac{1}{\gamma_i} \cdot \tilde{a}_i \cdot \dot{\tilde{a}}_i \qquad \textbf{(16)}$$

after of considering (12,13,14) the equation (16) can be transformed in

$$\dot{V}_2 = -[K_1 + \beta_1(z_1)] \cdot z_1^2 + z_1 \cdot z_2 + z_2 \cdot \left[\sum_{i=0}^{3} \hat{a}_i \cdot r^i + b \cdot \delta - \dot{\beta} \right] + \sum_{i=0}^{3} \tilde{a}_i \cdot \left[r^i \cdot z_2 + \frac{1}{\gamma_i} \cdot \dot{\tilde{a}}_i \right] \qquad \textbf{(17)}$$

in a real situation it is predictable that $\sum_{i=0}^{3} \tilde{a}_i \neq 0$, that it to say, always there is an error in the parameter estimations, in consequence to eliminate the last term in (17), two solutions can be adopted,

- solution less restrictive

$$\sum_{i=0}^{3} r^i \cdot z_2 = -\sum_{i=0}^{3} \frac{1}{\gamma_i} \cdot \dot{\tilde{a}}_i \tag{18.a}$$

- solution more restrictive,

$$r^i \cdot z_2 = -\frac{1}{\gamma_i} \cdot \dot{\tilde{a}}_i \qquad (i = 0 \cdots 3) \tag{18.b}$$

If someone of the conditions (18.a) or (18.b) are match, then of the (17)

$$\dot{V}_2 = -[K_1 + \beta_1(z_1)] \cdot \sum_{i=0}^{3} \hat{a}_i \cdot r^i + b \cdot \delta - \dot{\beta} \;]z_1^2 + z_1 \cdot z_2 + z_2 \cdot \left[\sum_{i=0}^{3} \hat{a}_i \cdot r^i + b \cdot \delta - \dot{\beta} \; \right] \tag{19}$$

If the rudder angle is chosen as,

$$\delta = \frac{1}{b} \left\{ -z_1 - \sum_{i=0}^{3} \hat{a}_i \cdot r^i + \dot{\beta} - [K_2 + \beta_2(z_2)] \cdot z_2 \right\} \tag{20}$$

the derivative of the Liapunov function (19) is now

$$\dot{V}_2 = -[K_1 + \beta_1(z_1)] \cdot z_1^2 - [K_2 + \beta_2(z_2)] \cdot z_2^2 \tag{21}$$

if $\beta_1(z_1) \geq 0, \beta_2(z_2) \geq 0, K_1 > 0, K_2 > 0$, by direct method of the Liapunov or by the theorem of LaSalle (Khalil, 1996) the system is global asymptotically stable.

The dynamics of the first error state can be obtained from (9) and considering (10). The result is

$$\dot{z}_1 = -[K_1 + \beta_1(z_1)] \cdot z_1 + z_2 \tag{22}$$

the corresponding variation of the state z_2, is obtained to depart of (8.b) and considering (6.b) with the rudder value chosen (20)

$$\dot{z}_2 = -z_1 - [K_2 + \beta_2(z_2)] \cdot z_2 + \sum_{i=0}^{3} \tilde{a}_i \cdot r^i \tag{23}$$

in matrix form after of taking into account (8.a)

$$\begin{bmatrix}\dot z_1\\ \dot z_2\end{bmatrix}=\begin{bmatrix}-[K_1+\beta_1(z_1)] & 1\\ -1 & -[K_2+\beta_2(z_2)]\end{bmatrix}\cdot\begin{bmatrix}z_1\\ z_2\end{bmatrix}+\begin{bmatrix}0\\ \sum_{i=0}^{3}\tilde a_i\cdot(z_1+r^d)^i\end{bmatrix} \quad \textbf{(24)}$$

the block diagram is show in Figure 6.

For the implementation of the control rudder angle (20) it is necessary to express the derivative of the β function in terms of the variables. It is easy to show that this is defined by the equation,

$$\dot\beta=\ddot r_d-\left[K_1+\frac{\partial\,[\beta_1(z_1)\cdot z_1]}{\partial\, z_1}\right]\cdot\dot z_1 \quad \textbf{(25)}$$

the simplest form for the β_i(i = 12) that verifies the imposed conditions are

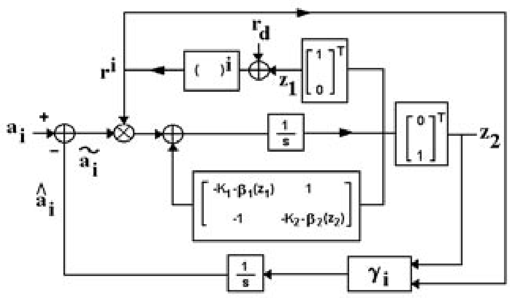
$$\beta_1(z_1)=z_1^2 \quad \textbf{(26.a)}$$

$$\beta_2(z_2)=z_2^2 \quad \textbf{(26.b)}$$

with this choice,

$$\dot\beta=\ddot r_d-[K_1+3\cdot z_1^2]\,\dot z_1=\ddot r_d-[K_1+3\cdot z_1^2]\,[-(K_1+z_1^2)\,z_1+z_2] \quad \textbf{(27)}$$

Figure 6. Implementation of the identification algorithm designed.



4. SIMULATION OF THE SYSTEM

According to block diagram showed in Figure 6, the simulation of the system has been carried out. By means of the algorithm of integration of Backward- Euler with a step-size of 0.1 s. The optimisation one that allows the reduction of the error between the parameters estimates and its true values was of the Fletcher Reeves, that requires few iterations to convergence (Flannery, et al., 1989). For this purpose the experimental results of the yaw rate variation versus time obtained in the turning test manoeuvring for the ship (K=1,T=97 s) whose characteristics are shown in Table 4.

Table 4. Coefficients of the nonlinear manoeuvring characteristics when the_procedure of identification more restrictive (18.b) is adopted.

Coefficient	Estimated value (p.u)
a_0	$1.155.10^{-2}$
a_1	$-2.673.10^{-2}$
a_2	$2.648.10^{-2}$
a_3	$-3.719.10^{-2}$

Table 5. Values of the different gains in the analysed system.

Constant	Value (p.u)
γ_0	$-5.199.10^{-3}$
γ_1	$-5.440.10^{-4}$
γ_2	$-9.986.10^{-5}$
γ_3	$-8.830.10^{-5}$
K_1	57.09
K_2	50.00

Figure 7. Variation of the heading angle vs time. Continuous line (values obtained from of the identified model), circles (adjust show in Figure 3).

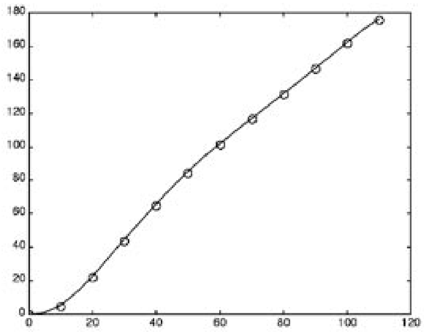


Figure 8. Variation of the error state variable (z_1).

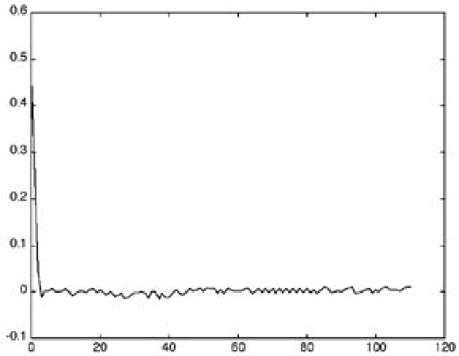


Figure 9. Variation of the error state (z_2).

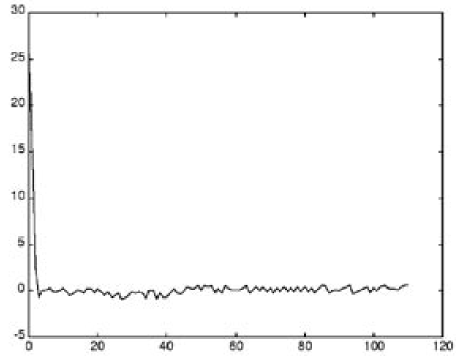


Figure 10. Variation of the yaw angle vs time. Continuous line (values obtained from the identified model), circles (adjust show in Figure 3).

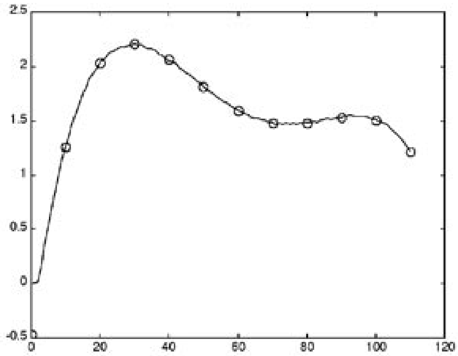
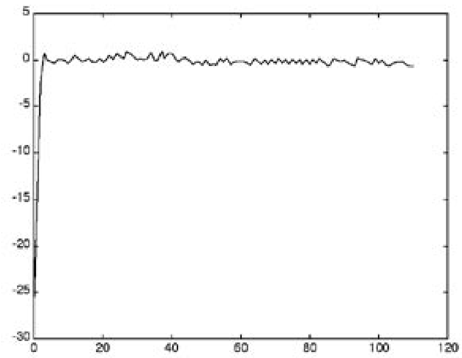


Figure 11. Variation of the stabilizing function.



4. CONCLUSIONS

A identification procedure based on the recursive backstepping procedure and the tuning functions design has been developed with the purpose of determining the coefficients of the polynomial that defines the manoeuvring characteristics. The procedure only takes into account the experimental results of the yaw variation in the particular test of the turning circle. The procedure overcomes the difficulty of the meet a solution of the a nonlinear differential equation of second order that should be necessary to resolve with the purpose of matching the experimental results of the yaw angle with the dynamics equation that represents the Norrbin model. The results show a fast convergence of the initial estimates of the parameters of the model toward their true values (Figs.8,9), in addition an excellent agreement between the experimental values and the theoretical ones (Figs.7,10).

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APENDICE: UN NOVEDOSO PROCEDIMIENTO DE IDENTIFICACIÓN DEL MODELO NO LINEAL DE UN BUQUE BASADO EN LA PRUEBA DEL CÍRCULO Y EN LA ECUACIÓN DE NORRBIN.

RESUMEN

En este artículo se ha implementado un procedimiento de identificación de la dinámica de un buque basado en el diseño del backstepping adaptativo. El procedimiento parte de los resultados experimentales obtenidos en un buque determinado durante la realización del test del círculo. La dinámica del buque ha sido ajustada a un modelo de Norrbin en donde los coeficientes de la ecuación no lineal que describen sus características de maniobra han podido ser determinados mediante el procedimiento descrito.

Palabras Clave: Modelado, sistemas no lineales, dinámica del buque, backstepping adaptativo.

INTRODUCCIÓN

En el trabajo se ha realizado un diseño de un procedimiento recursivo de identificación de la dinámica no lineal de un buque basado en la teoría del backstepping.

El procedimiento parte de los resultados de las pruebas de mar obtenidos en la realización del test del círculo de un buque roll-on/roll-off construido en el año 2001 en la factoría de IZAR de Puerto Real (Cádiz). La dinámica del buque ha sido ajustada según el modelo no lineal de Norrbin de tercer orden en donde los coeficientes de esta dinámica se han determinado mediante el procedimiento descrito. Asimismo se ha considerado la dinámica del timón representada por un sistema de primer orden. Para la realización del procedimiento de identificación solamente es necesario conocer la variación temporal del ángulo de rumbo.

METOLOGÍA

El procedimiento de identificación está basado en la teoría del backstepping introducida en el año 1995 por Krestić, Kanellakopulos y Kokotovic.

Fundamentalmente consiste en escribir la dinámica no lineal del sistema como una cadena de integradores en donde en las realimentaciones de cada uno de los subsistemas aparecen los términos de incertidumbre cuyos términos se pueden determinar a partir de las leyes de actualización de parámetros y las funciones sintonizadoras. En cada uno de los subsistemas los estados se consideran como entradas ficticias, lográndose la estabilización asintótica de los errores cometidos mediante la introducción de las funciones estabilizadoras y una elección adecuada de las funciones de Liapunov.

CONCLUSIONES

En el artículo se ha desarrollado un procedimiento de identificación recursivo basado en la teoría del backstepping y en las funciones sintonizadoras con el propósito de determinar los coeficientes del polinomio que definen la dinámica de un buque según el modelo de Norrbin. El procedimiento únicamente considera los resultados experimentales de la variación temporal del ángulo de rumbo obtenidos durante las pruebas del mar del buque durante la realización de la prueba del círculo. La sistemática desarrollada permite soslayar la dificultad de resolver una ecuación diferencial no lineal de segundo orden que sería necesario resolver si se desea ajustar los resultados experimentales a los previstos según el modelo de Norrbin. El procedimiento revela una rápida convergencia de los valores estimados de los parámetros hacia sus verdaderos valores así como la excelente concordancia entre los resultados experimentales obtenidos con los previstos por la teoría.

Journal of Maritime Research, Vol. I. No. 2, pp. 33-48, 2004

ISSN: 1697-4840

DYNAMIC FAIRLEAD FOR TOWING WINCH

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ABSRACT

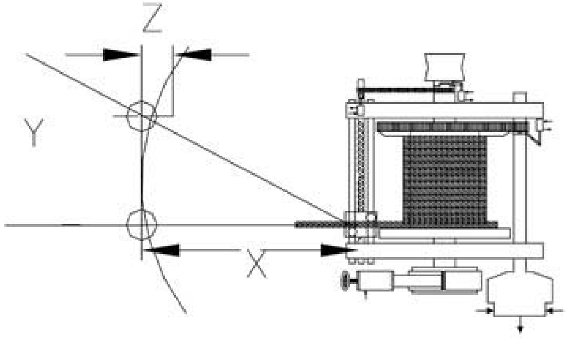
The patent deals with the problems existing between the towline and the fairlead and presents a dynamic variety of the last to compensate the lengthening of the towline and, therefore, reduce and even eliminate rope wear on abrasive surfaces. Tug stability will increase during tow operations. The system is composed of structural elements as well as hydraulic components.

Key words: Tug, fairlead, winch, stability, towing hook.

1. - INTRODUCTION

The fairlead dynamic in winch and towing hook *is* a system rail track. Rail track systems cause smaller heeling angles so higher athwartships towline forces can be applied, resulting in a increase in tug performance.

Figure 1.- Winch



The escort tugs for assistance and escort of potentially dangerous vessels are provided with several appliances which are currently under research and development.

It is well known that a great percentage of incidents during tug operations are due to the failure of the towing line, which forces rope and cable manufacturers to research to improve the quality of their products so that tug operations may be safer.

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Tug design has improved greatly. Usually, tug safety relies on systems duplication; their propellers can be azimuthal or cycloidal and tow power can be as three times greater when they use indirect pull. This variety uses engine power combined with hydrodynamic effects on the tug hull to increase pull. In this case, relative speed of water to the tug hull produces hydrodynamic forces which increase nearly as the square of the speed.

In practice, this pull increase during tow operations works much harder over the towline than with direct pull.

This capacity to produce greatly improved pull forces has lead to the development of different and modern varieties of an old device known as fairlead.

Let's analyze recent developments in towage equipment, which has focused mainly in tow winches and towlines, keeping the rest under minimal evolution. Such equipment comprises bitts, different types of fairleads, rollers, roller-heads, cat holes, bollards, tow pins, hold-down block, etc. which allow the tugboat to apply the pull force from a fixed point on the tug deck.

Therefore, the tug transmits all the required force to the assisted vessel via the towline – which as has been said can be a rope or a cable– and, when the pull is indirect, the towline goes trough a fairlead. This fairlead is the forced way between the winch or the hook and the towed vessel. This is the most critical point of the towline, since it supports there the greatest forces during towing operations.

This type of fairleads, also known as towing staples, serve several purposes: to maintain a fixed geometrical distance between the propeller and the towing point, to guide the towline to / from the winch so that its drum can stow the wire properly and to make sure that the towed ship doesn't tow the tug as result of a human error or an inadequate manoeuvre, avoiding therefore the risk of capsizing.

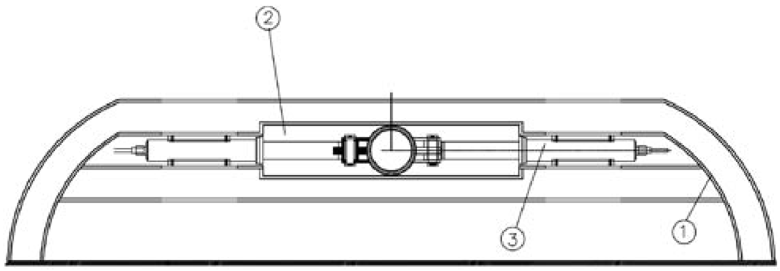
Current tug fairleads are fixed structures, usually formed by a stand welded to the deck with a couple of vertical or tilted cylinders which form a closed arch in their upper part. They are made of steel and located amidships, some times forward and some times aft, or even in both places. Their precise longitudinal positioning depends upon the shape of the hull, the deck and even propeller location. They can also be fixed to the deck with a variety of intermediate devices.

The stress produced over the towline can lead to its eventual failure, but even if it doesn't, it certainly produces a premature tensile stress and life shortening. The problem is that the lengthening produced between the winch and the staple is not balanced with that of the rest of the towline and, when it does, it produces sudden and violent slipping which frequently leads to towline failure.

We are proposing a new variety of dynamic fairlead between the winch and the tow, as we can see in Figure 1, which will compensate the above lengthening and protect the towline from unwanted and violent counter effects.

Up to now, we have usually found static towing gear. At most, we find rotating fair-leads or ancillary elements to stabilize the path of the towline, but no one has proposed a dynamic device which will automatically adjust its movement as the pull changes, to avoid violent counter effects which can lead to towline failure.

Figure 2.- Fairlead



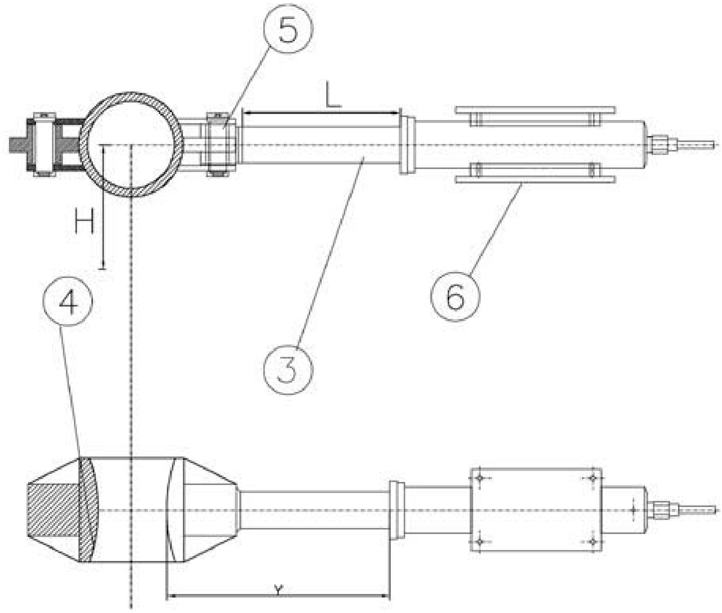
2. DESCRIPTION

The fairlead see figure 2. Usually, towing staples are fixed and welded to the deck, with a hole through which the towline goes. Our patent consists of the implementation of an auxiliary device which moves the fairlead to compensate the towline lengthening. Such movement equals the lengthening produced in the towline between the winch and the fairlead when it is under heavy stress. The movement of the fairlead bed is produced and controlled by a hydraulic system which can be seen in figures 3. The system regulation depends on the elasticity module of the working towline.

This device consists of the following parts, which are marked in the figure with the numbers shown below:

1. Arch structure.
2. Rail track
3. Two hydraulic cylinders.
4. Fairlead.
5. Crosshead
6. Bed.
7. Regulating valve.
8. Safety valves.
9. No-return valves.
10. Isolating valve.
11. Reversible pump.
12. Pump control.
13. Control box.
14. Oil tank.

Figure 3.- Two Hydraulic Cylinders



Hydraulic cylinders (3) are connected by pipes through the regulating valve (7), which limits oil flow depending on the characteristics of the towline. Therefore, this valve will be regulated as the lengthening expected in the towline. In figure 2, we can see opposite balanced cylinders with the fairlead in its resting position, amidships.

The hydraulic system which moves the basic fairlead is shown with greater detail in figure 2. We can see how the system recovers its resting position by means of two springs and a reversible engine.

This circuit is composed by a reversible hydraulic pump, two safety valves, two no-return valves, pump control and two isolating valves.

3. SYSTEM OPERATION

The patent system is aimed to be applied to any existing tug, no matter her size or power. The device can be accordingly dimensioned. Distances L and H in fig. 3 vary with the winch level and the expected lengthening of the towline.

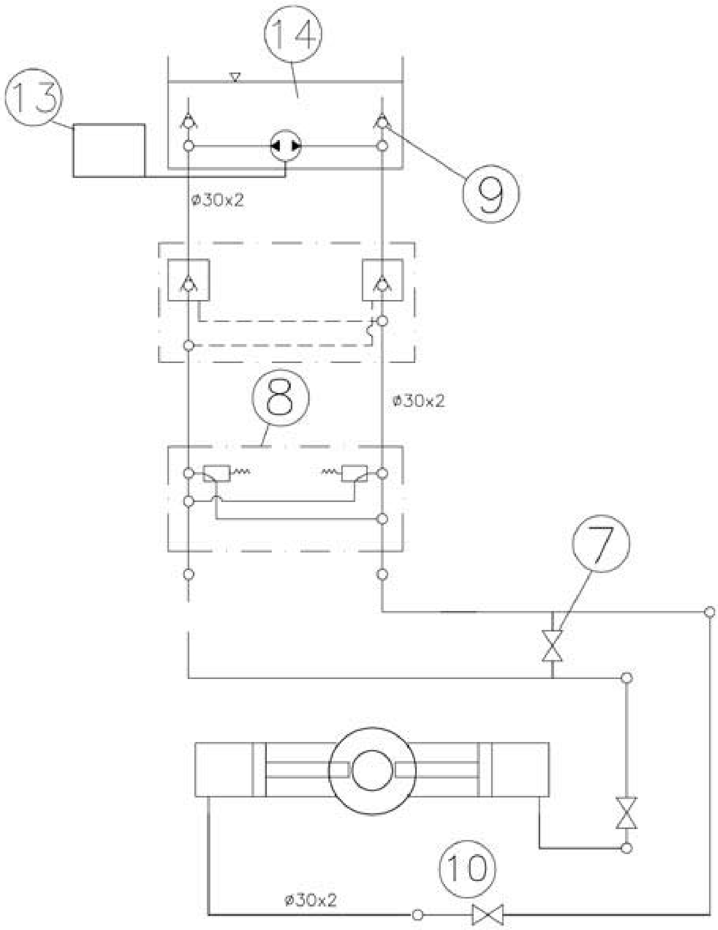
As we can see in figure 4, the device consists of two opposite cylinders with inner springs to recover the resting position. The towline goes from the winch through the hole in the lead up to the tow. When ordered to pull, the tug will manoeuvre as usual until the pull reaches higher values than those for which the control valve has been adjusted, the system will begin to operate moving the fairlead abeam to compensate the lengthening of the towline. Once the pull decreases below the calculated value, the system will come to a rest, with the fairlead amidships.

This abeam displacement of the fairlead has an additional benefit. As the fairlead pivot point moves abeam, the pulling forces work against the heeling moment, increasing tug stability.

When the system is intended for a tug of over 2.000 kW we propose a different design, which is shown in figure 5, where the resting position is reached by means of a hydraulic pump. This hydraulic equipment permits a better control of the fairlead displacement as the manoeuvre requires.

The system in designed to withstand failures, since the fairlead moves safely inside a track with a limited travel.

Figure 4.- Hydraulic System



4. APPLICATION

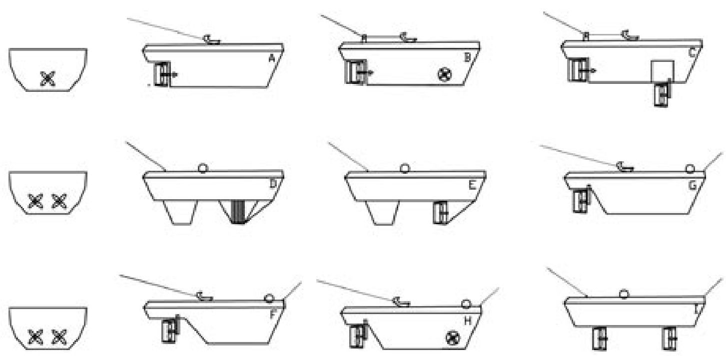
A study would be carried out for each tug, taking into consideration the need of specific manoeuvre capabilities, type of operations and pull required to determine the proper amount of displacement of the fairlead to compensate the expected lengthening and the overall design of the system. After the study is finished, the tug company can order the making of the device to any mechanical workshop in their area.

The device is compact and can integrate most of its elements, so that the fitting onboard can be achieved in a couple of working days. Figure 5 shows its position relative to the propellers. The types of tug for dynamic fairlead are: conventional tug, Azimuth Stern Tug, Combi-Tugs, Tractor-tugs and Reverse-Tractor Tugs and Rotor tug.

5. CONCLUSIONS

1. Indirect pull evolution creates the need of towing staples.
2. Combi-tugs, tractor-tugs and reverse-tractor tugs use fixed towing staples.
3. Failure usually takes place at the contact point between the towlines and the fairleads.
4. The use of bearings or grease doesn't reduce enough the risk of towline failure.
5. The dynamic fairlead proposed in this paper compensates the lengthening of the towline.
6. The dynamic fairlead avoids violent counter effects, minimizing the risk of breaking the towline.
7. Using dynamic fairleads increases safety in towing operations, especially during critical moments when towline lengthening can provoke its failure.
8. Dynamic fairlead fitting will increase towline life.
9. The device proposed is quite economically efficient. Its cost is moderate.
10. Tug stability will increase during tow operations when fitted with a dynamic fairlead.

Figure 5.- Tugs Types



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APENDICE: BITA GUÍA DINÁMICA PARA CHIGRES DE REMOLCADORES

RESUMEN

En los remolcadores tractor y acimutales, este mecanismo directamente, amortigua y compensa el alargamiento de la línea de remolque entre la maquinilla y la bita-guía, para evitar los estrincones, proteger la línea de remolque y aumentar sus horas de trabajo.

A su vez indirectamente aumenta la estabilidad del remolcador, durante las operaciones de remolque, cuando el tiro es de traves.

Este sistema esta compuesto por unos elementos hidráulicos.

Palabras clave: Remolcador, Bita, Chigre, Maquinilla, Gancho y Estabilidad.

INTRODUCCIÓN

Consiste en una máquina compuesta por dos cilindros situada en una estructura de arcos y con una pista por donde se desliza la guía, por la que pasará la línea de remolque del remolcador al buque remolcado, ésta guía permite trabajar a la línea de remolque sin problemas en las situaciones en que el tiro se eleva por encima de valores superiores al tiro a punto fijo del remolcador.

Las ventajas son:

- Compensar el alargamiento producido en las líneas de remolque entre el chigre y la bita-guía
- Amortiguar los efectos de la estrepada y reducir los estrincones.
- Aumentar la seguridad durante los remolques realizados con tiro indirecto
- Alarga la vida de las líneas de remolque
- Reducir el efecto de la fatiga a la que está sometida la línea de remolque.

INVESTIGACION DEL PROBLEMA

La bita-guía, también denominada bitón, está situada en la cubierta del remolcador y su trabajo esta reservado para las peores situaciones de tiro.

Conocido es, que entre el buque remolcado y el remolcador, como elemento de unión y transmisión de esfuerzos, está la línea de remolque que sale del chigre del remolcador hasta el buque remolcado, y que en los nuevos remolcadores, en caso de llegar el tiro a sobrepasar la carga de rotura del cable, del chigre se desvira para que el remolque no falte, pero cuando el trabajo obliga a que el remolque trabaje sobre la bita-guía, el rozamiento al desvirarse la maquinilla produce en la línea de remolque sobre la bita-guía un aumento de temperatura que produce la rotura.

La capacidad de desarrollar en los remolcadores actuales, un tiro muy superior a los obtenidos con tiro directo y que, dependiendo de la velocidad del buque remolcado, puede llegar a superar el doble del tiro realizado a punto fijo, hace que en la línea de remolque se produzcan solicitaciones en los cables o estachas de remolque como:

Tracción, Abrasión, Temperatura, Giro, Aplastamiento, Golpes, Efectos de Alargamiento y de Rozamiento, y Esfuerzos de Tracción y Flexión.

METODOLOGÍA DE LA INVESTIGACION

Varios métodos se han utilizado para reducir los efectos del contacto entre las líneas de remolque y las guías. Se usan los alavantes, las gateras, las guías de retorno, las guías panamá, los bitones y las bitas-guía, otros métodos son la lubricación de los elementos en contacto a base de grasas.

Las patentes relacionadas son:

- Sistemas de estibado de cadenas de maniobra, 435314
- Dispositivo para enganchar y desenganchar un cable 268143 - U2698143
- Mecanismo de retención y soltado rápido de cable y/o cadena, 547728.
- Mejoras de bitas giratorias con un mecanismo de bloqueo y frenado, 3555617
- Aparejo para maniobra y freno de embarcaciones, 950084
- Guía cabos en forma de cuadrante auto deslizante, US 904573, Europa87104203.2
- Bita telescópica para guiado de líneas de tipo de amarre en buques, 271.349
- Hasta ahora nos hemos encontrado que todos los sistemas de alavantes, guías, gateras, guías de retorno, guías panamá, bitas-guía y bitones son estáticos y sus desarrollos han llegado a hacerlos giratorios, otros han diseñado los elementos para que los cables sigan rutas fijas definidas, pero ninguno ha desarrollado una guía dinámica que se encuentra construida sobre una máquina que la moverá de acuerdo con el esfuerzo al que sea sometido la línea de remolque para evitar los estrincones sobre ella y la rotura por su efecto.

SISTEMA DE BITA GUIA DINÁMICA PARA CHIGRES DE REMOLCADORES

Las bitas-guía en los remolcadores son fijas y soldadas a la cubierta, tienen un orificio por donde pasa la línea de remolque, con la característica principal que este invento introduce una máquina que mueve la guía para compensar el alargamiento de la línea de remolque. El trabajo de la guía dinámica consiste en realizar un desplazamiento de la guía en dirección transversal, como demuestra la figura 1, cuya magnitud es igual al alargamiento sufrido por la línea de remolque entre la maquinilla y la guía, cuando ésta esté sometida a elevados esfuerzos.

El movimiento de la bancada de la guía es efectuado por medio de una máquina hidráulica, según las figuras 1, 2, 3 y 4, regulada de acuerdo con el módulo de elasticidad de la línea de remolque que esté trabajando.

Está máquina esta compuesta por los siguientes elementos, representados en las figuras por los números:

- Estructura de arcos (1)
- Pista con limitación de recorrido (2)
- Dos cilindros hidráulicos (3)
- Guía (4)
- Articulación de montaje rápido (5)
- Bancada (6)
- Válvula reguladora (7)
- Válvulas de seguridad (8)
- Válvulas anti-retorno (9)
- Válvula de incomunicación (10)
- Bomba reversible (11)
- Maniobra de la bomba (12)
- Caja de conexiones (13)
- Tanque de aceite (14)

- Los cilindros hidráulicos (3) están comunicados por unas tuberías a través de la válvula reguladora (7) que limita el paso del aceite en función de las características del material de la línea de remolque, por lo que la válvula se regulará de acuerdo al alargamiento que se produce en la línea de remolque, de acuerdo con el recorrido que deba realizar.

- En la figura están representados los dos cilindros opuestos compensados y la bita guía situada en posición de reposo, en la línea de crujía.

- En la figura (3) se aprecia el esquema hidráulico que maniobra la bita-guía básica, con unos resortes para recuperar la guía la posición de reposo o de la crujía.

- En la figura (4) tenemos el esquema hidráulico del equipo con recuperación de la posición de reposo por un motor reversible.

- Los elementos que componen este circuito son: una Bomba hidráulica reversible, dos válvulas de seguridad, dos válvulas anti-retorno, el cuadro de maniobra del motor hidráulico y dos válvulas de incomunicación.

DESCRIPCIÓN DE LOS DIBUJOS

Figura 1.- Principio básico del chigre

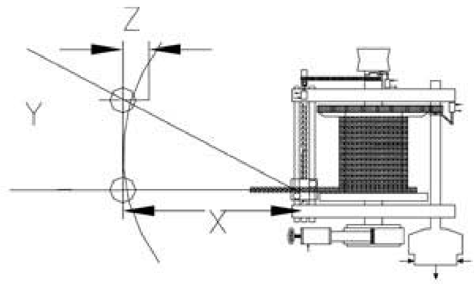


Figura 2.- Disposición Bita Dinámica

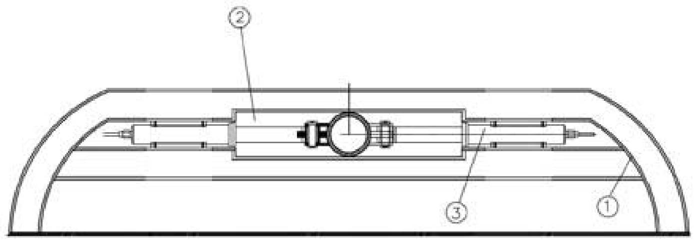


Figura 3.- Guía y Servomotor

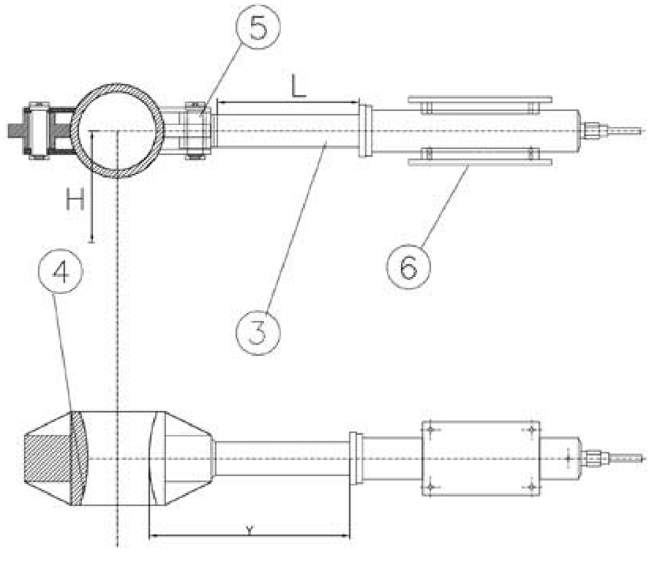


Figura 4.- Esquema hidráulico

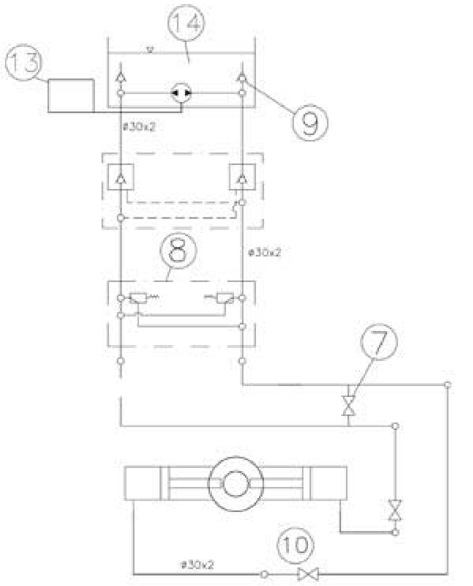
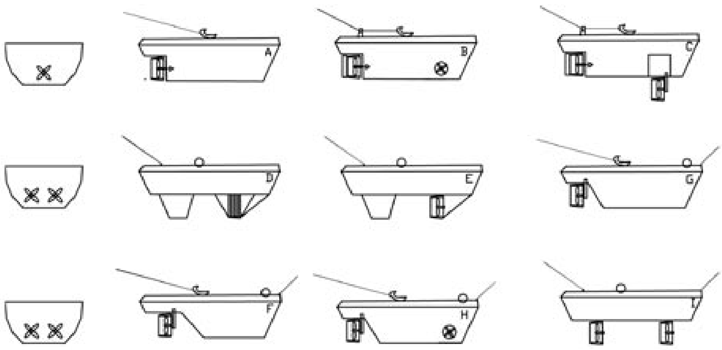


Figura 5.- Tipos de buques para la instalación de la Bita Dinámica



CONCLUSIONES

1.- El tiro indirecto necesita una guía sujeta a una estructura fija a la cubierta.
2.- Los remolcadores acimutales, tractor, combi y convencionales utilizan estas guías.
3.- Las roturas en las líneas de remolque se producen en el punto de contacto con la guía.
4.- La utilización de grasas y otros sistemas desarrollados no solucionan el problema.
5.- La Bita Dinámica, soluciona el problema de estrepada de las líneas de remolque.
6.- La Bita Dinámica amortigua los golpes del remolque.
7.- La Bita Dinámica, reduce el rozamiento de la línea del remolque con la guía.
8.- La Bita Dinámica incrementa el tiempo de utilización de la línea de remolque.
9.- La Bita Dinámica no supone un costo elevado entre la maquinaria del remolcador.
10.- Incremento de la estabilidad durante el tiro indirecto.

JMR

Journal of Maritime Research, Vol. I. No. 2, pp. 45-64, 2004

ISSN: 1697-4840

ASSIGNATION OF RESOURCES FOR SEA RESCUE. AN APPLICATION TO THE BASQUE COUNTRY

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ABSTRACT

The problem of the location of sea rescue resources generates certain controversies which are generally revived after accidents which have had a great social impact. The aim of the present paper is to formulate a methodology based on gravity models allowing sea rescue resources to be assigned. To this end, a study has been made of the problems of accident assessment, of ports and airports and their relation with the above and of zonification. Finally, an empirical application of this methodology to the Basque Country has been made.

KEYWORDS

1. INTRODUCTION

The concept of sea rescue has varied considerably over the last two decades. The boom in communications, the advances in the field of navigation, the use of elements of aerial intervention, the increase in sea traffic and especially in sports crafts has substantially modified traditional sea rescue models.

But what is sea rescue? Much was said over the course of the last century about the meaning of this term and its repercussions and its legal comparisons with aid. For some specialists in marine law, these are similar concepts. For others, in contrast, the difference is quite clear. Without going into the legal smallprint, and adhering to the dictionary of the Spanish Academy, 'sea rescue' is defined as 'action and effect of saving' and 'aid' as 'help, succour, assistance'. However, on examining the matter further, our dictionary would seem to make it clear that these are two distinct concepts. Taking all of this into consideration, and looking at the matter more from a technical than a legal viewpoint, sea rescue may be defined as the external action aimed at rescuing persons, crafts or objects in immediate and irreversible danger should no intervention be made. Aid means help to anyone in a difficult situation. The aid given to persons or to a craft does not always mean that without that aid, the person or craft could not have got out of that difficult situation. Finally, 'sea rescue' also has a legal acceptance when a great ecological or economic tragedy is avoided by such action.

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Nowadays, rescue organisations are costly and complex and are no longer locally based, but rather are of an interregional or even global nature. Much time has passed now since May 5th 1879, when, probably precipitated by the great gales of the spring of the previous year which left the Cantabrian coast with heavy human and material losses, the Project was drawn up in the Ateneo of San Sebastian for what would later become the Humanitarian Society for Sea Rescue of Guipúzcoa, the predecessor of the Spanish Society of Sea Rescue of 1880. Not to mention the English, pioneers in everything related to safety at sea, who took us forward by a century, as well as several other European countries at the forefront in this age.

Our country, thanks to the International Convention on Search and Rescue of 1979, has fulfilled its commitments efficiently since over a decade ago, through the development of the National Sea Rescue Plan and Fight aginst Pollution Plan and by creating a geographical network of Rescue Centres to which can be added specialist units such as tow-boats, speedboats and helicopters and agreements and contracts are made with several organisms for an effective coordination of the resources. And thus, almost overnight, we are now on a par with the most advanced countries in the world in matters of coastal protection.

In this paper, we interpret accidents at sea to be any event which affects a craft, implying grave danger to the craft itself, the persons or the load. This may be due to human error, materials or bad weather and may cause damage involving the loss of the craft, faults in the hull, human loss, etc. These are classified in categories such as sinking, collision, fire, explosion, etc.

In Spain, from 1992 to 1999 there were 3,006 accidents involving 3,235 crafts, meaning that there is an average of just over one accident per day (1.3). Our country, because of its strategic position, is a crossroads for several important sea routes, such as those of The Straits of Gibraltar and the North-West peninsular. This means that Andalucía and Galicia are the most significant and conflictive regions from the point of view of marine safety. Although the accident figures are clearly the most important, the rescue services also undertake other activities, such as various incidents related with navigation (accidents at work, activation of radio buoys, medical evacuations, etc). The number of these incidents is almost twice that of accidents: 674 in 1992, 812 in 1993 and 1,116, 929 and 1085 in the years 1994, 1995 and 1996, respectively. This is without taking into account other services not related with crafts which are very numerous, such as the removal of floating objects dangerous for navigation, service of supervision of oil slicks, recovery of bodies of victims of fatal accidents, etc.

Let us, however, continue with accidents. Table 1 shows the pattern of accidents in the Basque Country, the object of our study: 122 accidents with 127 crafts affected. It is not an area in which accidents are particularly frequent: it is not a crossroads for any major routes and the sea traffic can be considered to be around average.

Total number of accidents occurring 1992-99 in the SAR zone under Spanish liability:

Table 1

Year	Total	Merc.	Other	Fish.	Tug.	SD.	Yacht	Fail.	Disap	Inj.	Resc.
1992	328	61	29	138	3	1	96	47	117	70	1268
1993	486	68	20	159	2	1	236	65	53	35	1301
1994	457	89	17	177	3	0	171	27	48	53	831
1995	435	71	34	143	6	0	181	34	27	31	660
1996	507	76	11	190	5	0	225	44	48	27	666
1997	506	56	16	183	4	0	247	49	83	36	868
1998	516	59	22	163	2	0	270	50	89	24	684
	3235	480	149	1153	25	2	1426	316	465	276	6278

Table 2 – Basque Country

	Total	Merc.	Fish.	Yacht	Tug	Others	SD	Fail.	Disap.	Inj.	Resc.
1992	3	1	1	1	0	0	0	0	0	1	11
1993	19	7	6	4	1	1	0	3	2	1	27
1994	17	4	7	4	0	2	0	1	0	3	27
1995	17	1	11	3	0	2	0	2	0	0	37
1996	20	3	12	5	0	0	0	0	0	1	21
1997	22	1	10	10	0	1	0	1	3	8	43
1998	29	1	12	16	0	0	0	0	0	1	17
Total	127	18	59	43	1	6	0	7	5	15	183

Tables 1 and 2 above show the statistics to be used for the present work.

Regarding the data shown in these tables, we shall now outline some aspects relating to the generation of the information contained therein. When an accident occurs, the authorities in charge send all of the reports corresponding to that accident to the Government Board for Maritime Affairs. The gravity of the accident can be deduced from the number of documents or reports. The functionaries of the Government Board draw up the official statistics from the data sent, using numerous variables such as the region where the accident took place, the name of the craft, day and time, age of craft, nationality, GRT, type of craft, type of accident, cause, damage, persons affected, contamination and mediums used. We have added to this information other aspects related to the geographical location of the accident, the metereological conditions of the moment, etc., which we considered essential for the present work.

2. METHODOLOGY: AN APPROACH TO GRAVITY MODELS

2.1. GENERAL APPROACH

In order to build our model, we have taken as a reference the works of Hansen (1959), Catenese and Steiss (1968) and Quade Boucher (1968). In keeping with these, the proposed model aims to redistribute or locate the rescue resources efficiently.

The assessment of a location is to be undertaken taking into account the gravity or weight of the accidents,number, distance and capacity or appropriacy of the place of evacuation, be this a port or an airport. On weighing things up, it must be borne in mind that the gravity of an event will have preference over other aspects, always considering that any accident must be attended to immediately. This is the typical pattern of a gravity model.

As regards the appropriacy factor, a gravity model has to consider the available installations, medical care and technical aspects. This work studies each of the mediums (launch, tow-boat, helicopter) separately. This approach is logical since the locations of each of these do not necessarily coincide. An accident may require the presence of one, two or more than two of the above resources.

In view of this approach, it can be observed that the model may be applied accident by accident, and the expression relating the variables to consider is:

$$Coef = f \sum_{i=1}^{i=n} \frac{P_i}{d_i}$$

Coef is a coefficient which measures the value of a rescue medium located at a specific point.
f is the factor of appropriacy for the location in question.
n is the number of accidents in the data base located within the radius of action of the rescue means under study.
P_i is the weight of each of the accidents.
d_i is the distance between the location and the accident.

However, the clarity of the calculations is greater if, as shall be seen below, the waters under study are divided into zones.

The accidents have been divided into four groups, assigning to each of them an evaluation to establish a hierarchical number of 5, 3, 2 and 1 points, respectively for most serious, serious, moderate and slight. In the terms of the gravity models, we are assigning 'weight' to the accidents. The accident classification procedure is a decisive factor.

The distribution of the accidents in groups has been made according to the following procedure: first, the records corresponding to the accident in question are selected from the data base. The data appearing in the data base obtained directly from the Government Board or in the files are evaluated: place of accident, type of accident, consequences for the craft, number of injured persons, deaths or disappearances, number of persons on board, type of craft, age, tonnage, time of day, month of year to calibrate the temperature of the water, state of the weather and the sea. The situation of the accidents on the Nautical Map will serve as a perfect complement to the above: whether the wind or the sea were or not favourable, whether the place where the accident occurs is sandy or rocky, whether the beach is flat, etc. Thus, the accidents were grouped in logical categories valid for any type of study.

The classification is:

Very serious accidents: When there have been deaths or disappearances, or the rescue of various injured or uninjured persons in such a way that if no external action had been taken the result would heve been death for these persons. In these accidents, there is total loss or serious damage to the craft or substantial contamination. Apart from the above questions, very serious accidents are characterised by the difficulty of the rescue operation since, generally, the external agents (weather, season, time) act as negative factors.

Serious accidents: When there are deaths, disappearances, injured or rescued parties. It is different from the above in that if no external help had been provided, the risk of death for the crew would, in many cases, have been evident, but the external agents did not act exclusively against the resolution of the problem. Typical accidents in this category are stranding and the subsequent loss of the craft, water entering the craft, heeling and persons falling into the water with little or no possibility of recovery, as well as quite substantial contamination.

Moderate: When the accident may constitute a certain danger for the crew. These produce damage to the craft and the external elements do not act against the resolution of the problem.

Slight: When the accident does not constitute a serious risk to the crew. They are accidnets with little personal or material damage. Their common denominator is mechanical or human failure which give rise to towing or to small collisions and stranding. It is the classical accident of estuaries and their surroundings with non-damaging external elements.

2.2. PROCEDURE FOR THE ASSIGNATION OF SEA RESCUE RESOURCES

In order to study which medium should go out in aid of the damaged craft, the following is available:

1. Information provided by the data base (gravity of accident, type of craft, type of accident, weather conditions, time and season) distance, winds, currents, etc.

2. Operability and functionality of each of the rescue mediums.

With the results of the analysis described in the above paragraphs, the logic fields are filled in the form: 'require medium X'. Making use of these fields, an automatic selection can be made of the accidents in which each of the rescue mediums are to be used.

New fields or rows will be added to the data base: need for helicopters, tow-boat, launch or other elements, etc. The operative process for sending a medium to the zone will be similar to that used for the assignation of categories and bearing in mind the following considerations:

Rescue Helicopters:

Essential elements in current rescue systems. Autonomy of the best types: maximum radius of action, 150 miles; maximum capcacity, 25 personas; highest speed, 120-130 miles/hour. These can act in almost all situations.

It has been verified that these perform very fast. According to the files of the Government Board, after an average of 11 minutes after receiving the order to leave, they are taking off from the airport. They are used in all cases of immediate rescue and whenever there is a possibility of sinking or imminent danger. They are also used for pursuits and tracking or to provide any information necessary to the services in charge.

Rescue tow-boats:

These can act in all weather conditions, with a great radius of action, great capacity for taking on shipwrecked persons, as landing grounds for helicopters, can carry the leaders of a rescue operation, tow, have fireproof systems, bailing and the means to fight contamination. Their drawbacks are their relative slowness, draught and lack of manoeuvrability in some cases. Normal radius of action: 100 miles.

Rescue launches:

Great speed, reach 30-35 knots in good weather, serve for the open sea or offshore. They are not operative in rouge seas and their autonomy is 400 miles. Whenever aid is to be given to a small craft with some damage, or it is to be pulled out of a stranded situation, or tossed or any other attention and for rescuing persons, this medium is selected. Radius of action: 50 miles.

We shall describe the assessment of locations, the problem of zonification, the formulation of the model and its application.

a) Evaluation of locations

Any rescue medium, such as a launch, can be located at a specific point near a place where accidents proliferate. Thus, the port in question will be will be a clear candidate for locating a rescue medium when a gravity model is applied. However, this port may have certain conditions which prevent the launch from taking to sea in bad weather, which will reduce its possibilities. In fact, this model evaluates the capacity of the locations and develops from this evaluation 'indicators of appropriacy'.

The 'indicators of appropriacy' are numerical assignations ranking from 1 to 0. An optimal port has an assignation of 1, a good one up to 0.8, and so on, decreasing when considered regular, bad or very bad. The assignation of a factor of appropriacy to each of the locations is performed in accordance with the following considerations:

Access: access to the port from the sea is evaluated; whether it is possible to continue operating in storms or to what proportion its docks are closed and with what seas; capacity for medical care; infrastructure of the port itself; capacity for making repairs; fuel supply system; cranes, etc; innovative elements: new docks with more room for sports crafts, etc.

There will be one factor for the launches and another for the two-boats. Airports are all valued equally, since all of the airports selected are close to hospital infrastructures and dispose of the necessary technical means.

b) The problem of zonification and formulation of the model

The gravity model could be applied accident by accident as stated previously. However, this approach involves the calculation of the distance between each accident and the different locations. These calculations can be simplified if the water zones under study are divided. Also, the specific case that may arise when an accident affects a marine medium in its own base is eliminated.

The accidents that occur in each of the zones are grouped into one 'superaccident'. The weight of this is obtained by adding up that of the respective accidents. The situation of 'superaccident' is obtained from the mathematical average of the latitudes and longitudes corresponding to the accidents arising in the zone in question

The greatest problem with zonification is to determine the size of the zones. Zones which are too small lead to unnecessary calculations, while those which are too big induce all accidents to be treated equally, though these clearly require different operating procedures.

The size of the zone depends on the rescue medium. The zone must be a sea region whose size means that the conditions of access to any of its points are quite similar. In other words, the size of the zone must be small in comparison with the radius of action of the rescue medium, so that the criteria followed has been to use zones whose size guarantees that access can be made to any of its points practically homogenously. Thus the coast of the Cantabrian Sea and Galicia has been divided in zones, 207 for the two-boats and 34 for the helicopters.

Once the accidents have been distributed in zones, the calculation is made of the 'superaccident' corresponding to each of them. This 'superaccident' represents the zone in question and is determined by a situation (latitude and longitude) and a weight.

Once the sample is zonified, we select those 'superaccidents' which take place in the radius of action of the rescue medium found in the location under study. The coefficient which evaluates the location is obtained with the expression mentioned above with slight variations:

$$Coef = f \sum_{i=1}^{i=n} \frac{P_i}{d_i}$$

Coef is a coefficient which measures the value of a rescue medium situated in a specific location.

f is the factor of appropriacy for the location in question.
n is the number of zones situated within the radius of action of the rescue medium whose base is the location under study.
P_i is the weight of the 'superaccident' which represents the zone.
d_i is the distance between the location evaluated and the 'superaccident'.

Below the method followed is explained using an example.

The figure below shows a series of accidents in a specific zone and the distance between these and three ports located in the surrounding area.

The coefficient of each port in relation to zone A will be the result of dividing the total of the weights in zone A (PA=22, the largest circle in the schema) by the distance in miles from the centre (average distance of all of the accidents in the zone) to each port. This for the port on the left of the schema, 22 will be divided by 40 giving 0.55. This number will have to be multiplied by the appropriacy of the port (access by sea and land, infrastructure, hospital care, geographical situation, etc.). An ideal port has a maximum value of 1. Assume that the port represented has 0.6. Then, the coefficient of that port in relation to zone A will be: 0.55*0.6= 0.33. A similar operation is performed for all ports within less than 50 miles for the launches, 100 for the tow-boats and 150 for the helicopters.

The port on the right in relation to zone A will have the best coefficient for two reasons: firstly because it is the closest (24 miles) and because it has better performance characteristics than the others (the corresponding circle is the biggest). In other words:

It can be observed from the schema that the power of attraction between the accidents occuring in zone A (represented by PA) and P´ is greater than that between the same and d. The formula which measures the attraction between P´ and zone A is:

$$CoefP'_A = \frac{P_A}{d_A} = \frac{\sum P_{accA}}{d_A}$$

in which *dA* is the average distance to all of the accidents of the zone. As stated above, in gravity models the distance factor is elevated or not to one power depending on the experimental comparison. In this case, it is not elevated although, if this were done, the results would not change substantially.

In our paper, we will use the function of distance rather than that of weather as this would vary for each accident for any small variation in metereological conditions.

The formula will now be developed considering mainly four zones: A, B, C, D:

$$CoefP' = CoefP'_A + CoefP'_B + CoefP'_C + CoefP'_D$$

It can also be stated that:

$$CoefP' = \sum_{zona=1}^{4} \frac{P_{zona}}{d_{zona}}$$

Considering the capacity of the port,

$$Coef\ P' = \left(\frac{P_A}{d_{A,X}} + \frac{P_B}{d_{B,X}} + \frac{P_C}{d_{C,X}} + \frac{P_D}{d_{C,X}} \right) * Idoneidad_{puerto}\ P'$$

When the number of zones is greater, the final coefficient (Coeff puertox) will take into account the n zones and the formula will be:

$$Coeff_{puerto\ X} = \left(\sum_{zona=1}^{n} \frac{P_{zona}}{d_{zona,\ puerto\ X}} \right) * Idoneidad_{puerto\ X}$$

c) Application of model and interpretation of results.

The coefficient is a numerical value which establishes a hierarchy of port or airport in relation to the accidents. This depends on their number, gravity, the distance at which they occur and the appropriacy of the port or the airport. For the calculation of the coefficients of the helicopters, tow-boats and launches, the gravity model formula outlined above has been used and we have used the data base for this. It goes without saying that through the study of the coefficients over several stages, the evolution of accidents in a zone can be studied.

Although the coefficients lead us to the almost total resolution of the location of the mediums, it must be borne in mind that there are other aspects that allow us to situate these mediums appropriately along the coastline.

The work equlibrium centres are those points on the coast which establish the distances to be covered by each rescue medium and their mission is to share out the work appropriately, taking into account the capacity of each medium. And what are these distances? For the Basque-Cantabrian coast with its geographical characteristics, metereological conditions and volume of traffic, the ideal distance, bearing in mind the opinions of several experts and their studies (captains, pilots and owners of launches, tow-boats and helicopters) as well as those that exist in other countries such as France and England, these will be:

For rescue launches, the maximum radius of action should not exceed 25 miles (50 miles between them) 50 for tow-boats (100 maximum distance between them) and 75 (150) as the crow flies for helicopters.

3. APPLICATION TO THE BASQUE COUNTRY

3.1. RESCUE LAUNCHES IN THE BASQUE COUNTRY

The zone studied takes in the area from the border with France to the eastern limit of Cantabria.

Accidents requiring launches in the Basque Country 1992-1999: 82. Total weight: 164. average: 2.0. Four were very serious, 18 serious, 30 moderate, and 30 slight. In the proximities of Pasajes there were 25 (with a weight of 49), around Orio 11 (with a weight of 11), in the area of Deva 14 (with 26), Elanchove 10 (with 15), Bakio 5 (with 17) and Bilbao 23 (with 46).

Zonification: the coast under study is divided into 17 zones (207 for all of the North-Galicia) of around 10*10 miles and a northern boundary whcih coincides with that of the area of responsibility of the Spanish SAR

The launches assist preferably fishing boats and sports crafts rescuing persons in places not too far from the coast. They also act as a complement to helicopters or tow-boats in very serious cases.

Evaluation of accidents and locations: this is done according to the criteria described above, that is with 5 for serious accidents, 3 for serious ones, 2 moderate and 1 slight, and for locations, those shown in the table below in the column 'appropriacy of port'.

Ports studied: the main ports of the whole area: Fuenterrabía, Pasajes, San Sebastián, Guetaria, Lequeitio, Bermeo y Bilbao.

For the calculation of the distances from the ports to the 'superaccident' (orthodromic distance) a correction by outputs has been performed, whenever these existed.

The coefficients obtained for the Basque coast are:

Basque Country	Initial Coef.	Appropriacy of port	Final Coef.	Weight	Total Distance	Average Distance	Between L= 1° 45,0W and	Betweee L=2° 27,2W y 3° 09,1W
Fuenterrabía	**10,86**	0,75	**8,15**	164	2483	30,3	14,6	
Pasajes	**27,37**	0,82	**22,41**	164	2111	25,7	**10,3**	
San Sebastián	**14,64**	0,82	**12,05**	164	2039	24,9	10,7	
Guetaria	**10,72**	0,75	**8,05**	164	1810	22,1	12,9	
Lequeitio	**14,29**	0,75	**10,72**	164	1653	20,2	20,4	19,9
Bermeo	**11,56**	0,82	**9,48**	164	1842	22,5		13,9
Bilbao	**29,11**	0,92	**26,78**	164	2546	31,1		**11,9**

If a single launch had to be positioned in The Basque Country to attend to such a great area of coast, the most suitable point would be at Longitude = 2º 25.0 W which coincides with the area around Ondárroa. But it has already been pointed out that a single launch in the Basque Country is insufficient since, from the nearest port which is Lekeitio, it would have to travel an average of 20.9 miles, a figure which is too high for a single launch. It is necessary to determine which ports are best placed to cover all of the coast with average distances of less than 15 miles. In the same table, it can be clearly observed which ports do this: Bilbao and Pasajes, which have the highest coefficients and the shortest distances.

For a correct distribution of work, one will cover from the French border to the area around Ondárroa and the other from there to the border with Cantabria.

As an example of other northern ports, the corrected coefficients and average distances to all the accidents in the area are for Cantabria: Castro 13.28 and 17.46; Santoña 9.57 and 21.00; Santander 34.85 and 13.8; Suances 5.63 and 20.6 and San Vicente 4.67 and 34.4.

3.2 INTERZONAL ANALYSIS OF LAUNCHES IN THE BASQUE COUNTRY

The maximum radius of action is 50 miles which means that the Basque ports take coefficients for accidents occurring in Cantabrian waters and Cantabrian ports take them for the bordering communities. Operating with the data base and spreadsheets gives the results shown in the table below. It can be observed that Lekeitio, Bermeo and Bilbao have higher coefficients while the other ports maintain their previous values since their bases are more than 50 miles away.

Basque Country	Coefficient	Appropri-acy of Port	Total Dis-tance	Average Distance
Fuenterrabía	10,01	0,75	Farther	
Pasajes	27,24	0,82	656,4	**13,4**
San Sebast.	14,61	0,82	631,4	12,9
Guetaria	11,15	0,75	656,6	13,4
Lequeitio	15,44	0,75	Farther	
Bermeo	14,52	0,82	942,5	18,8
Arminza			689,1	13,8
Bilbao	33,15	0,92	654,5	**13,1**

It has always been maintained that the oragnisation of rescue operations needs to be global, so that once the launches are located in the Basque Country, bearing in mind that the Community of Cantabria is to the east, and analysing the situation there, it becomes clear that the launch at Bilbao could cover part of this Community without any inconvenience for Bilbao. The launch at Santander would also benefit from this as it would not have to cover such great distances. If this were the case, the launch at Pasajes would have to cover 5.5 miles to the west, so that it would cover from the French border to the Cape of Santa Catalina in Lequeitio. This study shows the places where accidents proliferate. The launch at Bilbao will have responsibility for almost 11 miles more to the west, clearly reducing the load on the launch at Santander. The Bilbao launch will establish this point to the east and Mount Buciero in Santoña to the west. Thus, the launches in the Basque Country will be located thus:

One launch in Pasajes which will cover from the French border to Longitude = 2° 30,5 W; that is to the Cape of Santa Catalina in Lequeitio. Number of accidents in the last 7 years: 49. Two very serious, 11 serious, 13 moderate and 23 slight. Weight: 92. Average 1.88. 29 occurred in the open sea. Distance to cover between capes: 36 miles.

One launch in Bilbao which will cover from the cape of Santa Catalina to the mount of Santoña, that is from Longitude = 2º 30,5 W to Longitude = 3º 27,2 W. Thus the 17 accidents occurred in the waters of eastern Cantabria would be attended to by the Bilbao launch, since the distance is shorter. Total accidents in 7 years: 50. Very serious 3, serious 12, moderate 19 and slight 16. Weight: 105. Average: 2.1. 29 took place in the open sea.

Distance to the nearest launch: 55 miles. Distance between capes: 42. A Red Cross launch may be located at an intermediate point.

Thus, the Santander launch, should it not have the assisatnace of the Bilbao launch, would have to cover from the border with Vizcaya to Tina Mayor. As the Bilbao launch covers up to Buciero, the reduction would be of 20% of the accidents in Cantabria requiring a launch. It would thus attend to 68 accidents with an average distance of 10.8 instead of the 13.8 in the case of acting without this coordination.

3.3. AUTONOMOUS AND INTERREGIONAL ANALYSIS OF HELICOPTERS IN THE BASQUE COUNTRY

Maximum radius of action of helicopters: all of the Basque Country. Zones in the Basque Country: 6. Airports evaluated, all the existing ones: Fuenterrabía, Bilbao and Vitoria.

Evaluation of the locations: all of the airports have been assigned the same evaluation (factor of appropriacy: 1).

Zonification: the coast under study is divided into 6 zones, bordered by the coastline in the longitudinal direction. In the part which goes from east to west, each zone has an extension of 20 miles and a Northern border which coincides with the zone of responsibility of the Spanish SAR, although 3 accidents are evaluated whcih, though they took place in areas under French responsibilty, are normally assisted by the Spanish rescue service.

Accidents occurring 1992-99 requiring helicopter: 44. Putting the above method into practice and taking as reference the data base and the columns of latitudes and longitudes gives:

From the French border to the border with Cantabria. Number of crafts suffering accidnets: 44. Total weight: 122. Very serious: 5. serious: 21. moderate: 16. slight: 2. Average per accident: 2.77, including moderate and serious.

Coefficient for Fuenterrabía: 6.678. Total distance of all accidents requiring helicopter in The Basque Country: 1,486.3 miles. Average distance: 33.7 miles.

Bilbao coefficient: 6.672. Total distance of all accidents requiring helicopter in the Basque country: 1,398.8. Average distance: 31.8 miles.

Ídem Vitoria: 2.543. Total distance: 2,165.7. Average Distance: 49.2 miles.

Conclusion: if the aerial mediums of the Basque Country acted autonomously and only one single helicopter were to be located, the coefficients of Fuenterrabía and Bilbao are almost identical. This means that the accidents which take place to the east are, on average, slightly more serious than those of the western zone. Thus, the location selected must be Bilbao. In short, the gravity of the accidents is widely distributed all along the Basque coast. Logically, Vitoria is badly situated on all counts.

Now, from which part of the coast could a more efficient service be made? The place whose weight is equivalent for both the east and the west corresponds to a point on the coast at Longitude = 2º 22,3 W, which is at Punta Alcolea, near the port of Motrico. This point is obtained from the data base by interpolation of longitudes until the weights are equal, since The Basque Country extends approximately on a parallel. If the rescue operations were not coordinated between communities, this would be the ideal place to locate a helicopter. Distance from the point mentioned to all accidents: 1,131 miles; average distance: 25. 7 miles.

But maintaining that accidnets must be attended to on an interregional or international level and bearing in mind that the maximum radius of action from the bases of Fuenterrabía, Bilbao and the other airports of the north will be 150 miles, the situation is as follows.

Coefficient for Fuenterrabía (its radius of action would be up to Tazones): 8.2029. Coefficient for Bilbao (up to Vidio): 9.0075.

Table summarising use of Basque airports.

Airport (1)	Weight (2)	Coefficient (3)	All D. (4)	E-Bars (5)	Lim. Bars (6)	Limit Ribadeo (7)	Distance (8)
Fuenterrabía	247	8,2029	91313	18903	128,6	12905	104,9
Bilbao	334	9,0075	75484	14095	95,9	9209	74,8
Santander	356	9,2447	64613	11956	81,4	8004	65,1

Column 3 shows the coefficients, and Column 4 gives the total distance from all accidents requiring helicopter assistance occurring in the north, including Galicia, for all bases. Columns 5 and 6 show the distances from the French border to Estaca de Bares and distances to Cantabrian airports. Coumn 7 gives distances with respect to the border at Ribadeo and 8 gives average distances with this border.

3.4. TOW-BOATS IN THE BASQUE COUNTRY: AUTONOMOUS AND INTERREGIONAL ANALYSIS

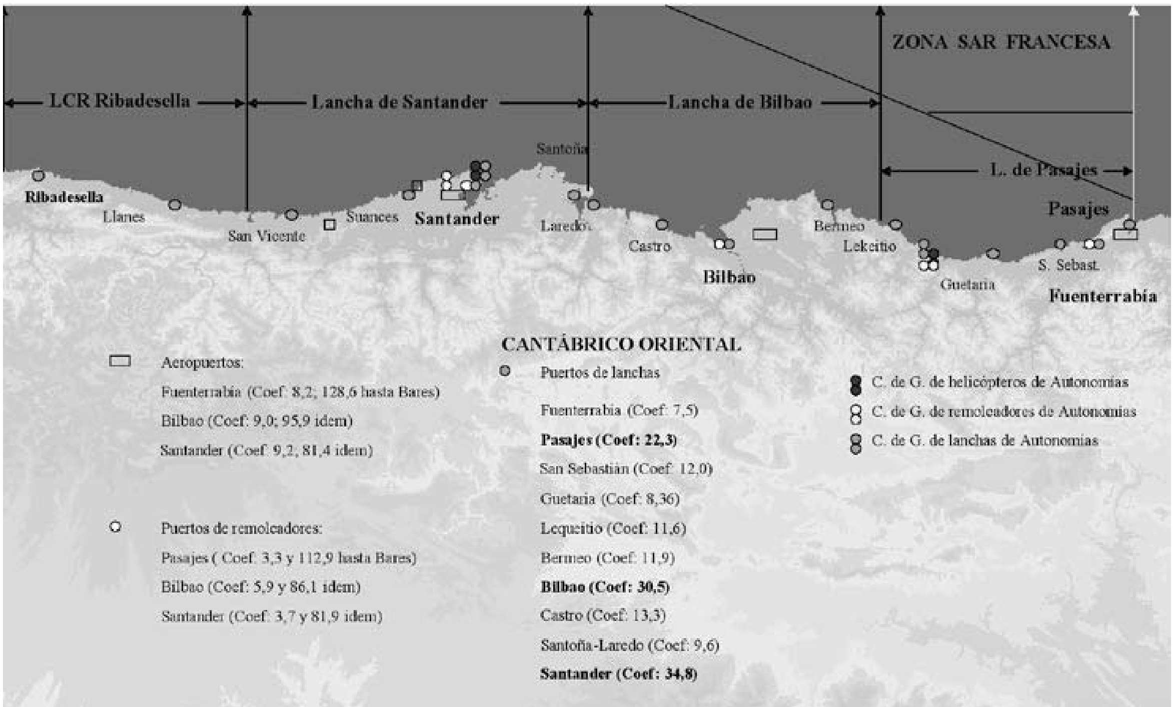
Radius of action of tow-boats: 100 miles. Ports studied: Bilbao and Pasajes, since they fulfil the basic conditions for accommodating this type of crafts. The main services of the tow-boats are: assistance, preferably for freight crafts and fishing boats in cases of collision, strandings or failures of materials or mechanics, towing or fighting contamination and fire. They are not characterised by a high level of assistance for persons. All of the other parameters are based on the aspects considered above.

Borders: from the French border to the border with Cantabria. Number of accidents requirng tow-boats: 38. Total weight: 78. Average: 2.05.

Coefficient for Pasajes for accidents in the Basque Country requiring tow-boats: 3.51 for 0.82 appropriacy of port: 2.88. Total distance to Pasajes for all accidents: 1338.7. average distance: 35.2. Coefficient for Bilbao: 4.01 for 0.96: 3.84. Total distance: 1295.5. average distance: 34.1. The most suitable port would be Bilbao, although the presence of a smaller tow-boat is desirable in Pasajes for the rescue service, since this is a zone of moderate risk.

For all of the Basque Country, the location closest to all acidents would be at Longitude = 2° 23,5 W. Centre of gravity between Motrico and Ondárroa.

Finally, and with a radius of action of 100 miles, the following table shows the coefficients for the two main Basque ports and for Santander.



CONCLUSIONS

1. The launches in the Basque Country should be located in Pasajes and in Bilbao with a smaller one in an intermediate port. The Bilbao launch will attend to 20% of the services of eastern Cantabria.

2. In the Basque Country, with an interregional analysis, there should be a helicopter located in Bilbao with similar characteristics to the Galician 'pesca' in order to improve the coverage of eastern Cantabria (for the year 2004 there is the following prediction of work: accidents-year Basque Country and Cantabria requiring helicopter: 16, incidents on crafts 32, incidentes not on crafts 64). There would thus be a good coverage provided for the ferries which arrive in Bilbao and Santander with up to 3,000 passengers per trip and for the fishing fleet. All of this without considering the foreseeable increase in accidents, since governments have undertaken measures to increase the number of moorings for sports crafts. Their coverage would be at sea but could also cover specific cases on land. The paper also summarises the location of the maritime and aerial mediums all along the northern Spanish coast

3. The two Basque ports with freight traffic should dispose of the service of a two-boat. The policy of providing private tow-boats in important ports by the authorities in charge of the rescue service is a good one.

4. Coefficients are given throughout this work of other places on the northern Spanish coast serving to establish comparisons with those obtained for the Basque Country.

5. The variation in the coefficients is valid for establishing the evolution of accidents.

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Capitanías Marítimas de Pasajes, Bilbao y Santander.

APENDICE: ASIGNACIÓN DE RECURSOS PARA EL SALVAMENTO MARÍTIMO. UNA APLICACIÓN AL PAÍS VASCO

RESUMEN

La problemática en la ubicación de los medios de salvamento marítimo genera algunas controversias que suelen reavivarse con posterioridad a los accidentes que ocasionan gran impacto social. El objetivo del presente trabajo es formular una metodología -que permite asignar recursos a los salvamentos marítimos- basada en los modelos de gravedad. Con tal finalidad, hemos procedido a abordar la problemática de la valoración de los accidentes, de los puertos y aeropuertos y su interrelación con los anteriores, y de la zonificación. Finalmente, se ha realizado una aplicación empírica de dicha metodología al País Vasco.

PALABRAS CLAVES

1. INTRODUCCIÓN

El salvamento marítimo se puede definir como la acción externa dirigida a sacar a personas, a buques o a cosas de un peligro inmediato e irreversible si no se ayuda. Últimamente también tiene la consideración legal de salvamento cuando con una acción se evita una gran tragedia ecológica o económica.

Nuestro país, en virtud del Convenio Internacional sobre Búsqueda y Salvamento de 1979, da una respuesta eficaz a sus compromisos internacionales desde hace más de una década mediante el desarrollo de los Planes Nacionales de Salvamento Marítimo y Lucha contra la Contaminación al crearse una red geográfica de Centros de Salvamento a los que se agregan unidades especializadas como remolcadores, lanchas rápidas y helicópteros y se firman acuerdos y convenios con diversos organismos para la adecuada coordinación de los medios.

Un accidente marítimo es todo suceso que afecta al buque en su materialidad suponiendo un grave peligro para el mismo, las personas o la carga. Puede deberse a fallos humanos, materiales o al mal tiempo y puede causar un daño que suponga la pérdida del buque, averías en el casco, pérdidas humanas, etc. Se clasifican en categorías: hundimiento, colisión, incendio-explosión, etc.

En España desde iniciado el año 1992 hasta 1999 sucedieron 3.006 accidentes con 3.235 buques implicados, es decir, significa que hay una media de poco más de un accidente diario (1,3). Nuestro país por su situación estratégica es zona de confluencias de las grandes rutas marítimas como son la Zona del Estrecho de Gibraltar y el Noroeste peninsular.

En el País Vasco, objeto de nuestro estudio, sucedieron según se refleja en la tabla 1, 122 accidentes con 127 barcos afectados. No es una zona en la cual los accidentes proliferen de manera especial: no está dentro de confluencias de grandes rutas y el movimiento marítimo de la zona puede considerarse de tipo medio.

Tabla 1 País Vasco.

	Total	Merc.	Pesq.	Yates	Reml.	Otros	SD	Fall.	Desp.	Her.	Resc.
1992	3	1	1	1	0	0	0	0	0	1	11
1993	19	7	6	4	1	1	0	3	2	1	27
1994	17	4	7	4	0	2	0	1	0	3	27
1995	17	1	11	3	0	2	0	2	0	0	37
1996	20	3	12	5	0	0	0	0	0	1	21
1997	22	1	10	10	0	1	0	1	3	8	43
1998	29	1	12	16	0	0	0	0	0	1	17
Total	127	18	59	43	1	6	0	7	5	15	183

Cuando ocurre un accidente son enviados a la Dirección General de la Marina Mercante por las autoridades competentes, todos los informes correspondientes a ese accidente. Del número de documentos o informes se puede deducir la importancia o gravedad del mismo. Con los datos enviados, el personal funcionario de la Dirección General elabora estadísticas utilizando diversas variables como la región donde se ha producido el siniestro, nombre del buque, edad, día y hora, nacionalidad, TRB, tipo de buque, tipo de accidente, causa, daños materiales, personas afectadas, contaminaciones y medios utilizados. A dicha información hemos añadido otros aspectos relativos a situación geográfica del accidente, condiciones meteorológicas del momento, etc, que hemos considerado indispensables para la realización del presente trabajo.

2. METODOLOGÍA

Para construir nuestro modelo matemático hemos tomado como referencia los trabajos sobre modelos de gravedad de Hansen (1959). De acuerdo con los mismos, el modelo que proponemos pretende redistribuir o ubicar los medios de salvamento de forma eficiente. La evaluación de una ubicación se ha de efectuar teniendo en cuenta, por un lado, los accidentes: gravedad o peso de los mismos, número, y distancia a los posibles puertos o aeropuertos receptores de medios específicos de salvamento y por otro lado la capacidad o idoneidad de estos puertos o aeropuertos como accesos desde la mar, capacidad hospitalaria, accesos terrestres, infraestructura del puerto, etc.

Los accidentes los hemos dividido en cuatro grupos, asignándole a cada uno de ellos una valoración para establecer una jerarquía numérica de 5, 3, 2 y 1 puntos, respectivamente para los muy graves, los graves, los moderados y los leves. En términos de los modelos de gravedad, estamos asignando "peso" a los accidentes. El procedimiento de clasificación de los accidentes es un factor determinante.

Accidentes muy graves: Cuando ha habido fallecidos o desaparecidos, o rescate de diversas personas heridas o ilesas, de tal manera que si no se hubiese actuado externamente, el resultado habría sido de muerte para ellas. En estos accidentes hubo pérdida total o se produjo gran daño al buque o una muy importante contaminación.

Accidentes graves: Se denominan así cuando hay algún muerto o desaparecido, heridos o rescatados y daños importantes.

Moderados: Se han seleccionado como moderados aquellos accidentes que pueden constituir un cierto peligro para los tripulantes. Producen daños moderados al buque.

Leves: No constituyen un peligro razonable para los tripulantes. Son accidentes con pocos daños personales o materiales.

En el procedimiento de asignación de los medios (lanchas de salvamento, remolcadores y helicópteros principalmente) se ha tenido en cuenta la autonomía de los mismos, cabida, velocidad, calados, maniobrabilidad, medios técnicos y operatividad en diversas situaciones meteorológicas.

Para la elaboración del presente trabajo se ha dividido la zona de responsabilidad marítima asignada por los organismos internacionales en áreas geográficas de aproximadamente 10 por 10 millas. En el País Vasco se han establecido 17 áreas o zonas para el estudio de las lanchas de salvamento y 8 para remolcadores y helicópteros. Teniendo en cuenta todos los factores mencionados se ha elaborado una fórmula basada en los modelos de gravedad que establece la interrelación entre los accidentes y los puertos o aeropuertos de las inmediaciones que nos proporcionan unos coeficientes de acuerdo a la fórmula siguiente y apoyados en la base de datos de la que se ha hecho mención:

$$Coeff_{\,puerto\ X} = \left(\sum_{zona=1}^{n} \frac{P_{zona}}{d_{zona,\ puerto\ X}} \right) * Idoneidad_{\,puerto\ X}$$

El coeficiente es un valor numérico que establece una jerarquía de puerto o aeropuerto con relación a los accidentes. Depende del número de ellos, de su gravedad, de la distancia a la que se producen y de la idoneidad del puerto o aeropuerto. Por descontado que mediante el estudio de coeficientes entre diversas etapas se puede estudiar la evolución de los accidentes.

Si bien los coeficientes nos resuelven la resolución de las ubicaciones de medios, debemos tener en cuenta otros aspectos que nos permitirán situar dichos medios de manera adecuada a lo largo de la costa.

Los centros de equilibrio de trabajo son aquellos puntos de la costa que establecen las distancias que debe cubrir cada medio de salvamento y tienen como misión repartir el trabajo de manera adecuada, teniendo en cuenta la capacidad de cada medio. Y ¿cuáles son esas distancias? Para la costa vasco-cántabra con sus características geográficas, condiciones meteorológicas y volumen de tráfico las distancias serán: para lanchas de salvamento el radio máximo de actuación no debe sobrepasar las 25 millas, de 50 para remolcadores y 75 para helicópteros en línea recta.

En el presente trabajo se analizan los coeficientes en el País Vasco referentes a lanchas remolcadores y helicópteros que nos han de servir de guía para la correcta ubicación de los medios desde los aspectos autónomo e interregional.

CONCLUSIONES

6. Las lanchas en el País Vasco han de situarse en Pasajes y en Bilbao con una menor en un puerto intermedio. La de Bilbao asistirá el 20% de los servicios de Cantabria oriental.

7. En el País Vasco y visto interregionalmente debería haber un helicóptero que se situaría en Bilbao con características parecidas a los "Pesca gallegos" para que la cobertura aérea del Cantábrico oriental fuese mejor. Su cobertura sería la marítima pero podría cubrir casos muy específicos en tierra.

8. Los dos puertos vascos con tráfico mercante deben contar con servicio de remolcador de salvamento. La política de habilitar remolcadores privados en puertos importantes por parte de los responsables marítimos para el servicio de salvamento es acertada.

9. La variación de los coeficientes es válida para establecer la evolución de los accidentes.

Journal of Maritime Research, Vol. I. No. 2, pp. 65-84, 2004

ISSN: 1697-4840

ANTHROPIC PRESSURE ON THE CANTABRIAN COAST

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ABSTRACT

The Autonomous Community of Cantabria is in the north of Spain, its northern border formed by the shores of the Cantabrian Sea. During the last few decades, socio-economic development has centred around the coastline, endangering natural ecosystems of great ecological value and renewable resources, as well as cultural values and traditional uses of land.

Cantabria has lost around 50 % of its estuary ecosystems, taking land from the sea for agrofishing, residential and industrial uses and for transport infrastructures, ignoring the values of biological productivity of these areas and their importance for the maintenance of traditional fishing grounds.

Today, fishing constitutes a secondary economic activity, with negative average annual rates in the catches of the main fisheries. These days, fishing ports are being transformed to house mainly recreational nautical activities.

The sediments of the Bay of Santander, San Martín de la Arena Estuary (Suances) and the Bay of Santoña have accumulated high concentrations of heavy metals.

In Cantabria, in the period between the year 2001 and the second term of 2003, 33828 new housing units have been built, 94.2 % on the coastal strip.

As for the transformation of the vegetation, the number of eucalyptus trees increased in the period from 1972 to 2000 by 72 %.

Key words: anthropic pressure, coastal management, contamination, overfishing, urban development.

1. INTRODUCTION

Cantabria is an Autonomous Community of the State of Spain of around 5300 km^2, situated in the north and bordered by the Cantabrian Sea, between 42º 46' and 43º 31' latitude north and 3º 9' and 4º 52' longitude west (see Figure 1).

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Figure 1. Location of Cantabrian Community. The population of around 500000 inhabitants, is

concentrated on the coastal strip, this being the area which, in recent years, has undergone the most intense socioeconomic dynamism in the Community.

The absence of the environmental variable in the process of occupation and use of the coastal strip, of an integral coastal management and of any specific criteria for the planning of the coastal municipalities are seriously compromising the possibilities of sustainability of this coastal area.

This work describes: a) the heavy imbalance in the region of Cantabria between the coastal strip and the mountains inland, the two great natural areas which integrate and define this Autonomous Community and b) the consequences of the strong anthropic pressure placed on the coast as the socioeconomic space of the greatest interest for the development of Cantabria.

2. METHODOLOGY

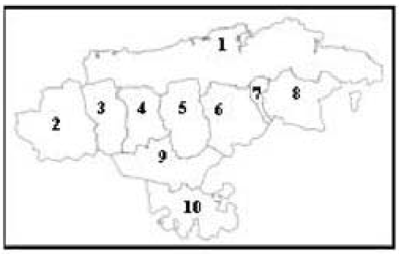
The socioeconomic development of Cantabria has been analysed and compared by means of a Principal Components Analysis (PCA). The ten natural local regions that integrate the Community of Cantabria have been considered as well as a set of 19 socioeconomic and demographic variables, as shown in Table 1, the data for which are drawn from the following sources:

- Municipal Statistical Indicators. Government of Cantabria. 1997.
- Economic Annual of Spain. 2003. La Caixa Studies Service.
- Economic Annual of Spain. 2004. La Caixa Studies Service.
- Socioeconomic and Labour Records of Cantabria 2002. Economic and Social Board of Cantabria.

The data handling has been carried out in keeping with the following steps: 1) obtaining the correlation matrix between all the variables, 2) calculating the eigenvalues of this matrix, their corresponding eigenvectors and Principal components (applying the *varimax* rotation) and , 3) extracting the coordinates or values for the observations, or local regions, in the axes or components obtained.

The anthropic pressure on the coastline was analysed using the following indicators: management of coastal areas, overexploitation of resources, contamination of estuaries by discharges, planning pressure and transformation of vegetation.

Table 1. Natural regions and variables considered in this study.



LOCAL AREAS

1. La Marina (Coastal Strip)
2. Liébana
3. Valley of Nansa
4. Valley of Saja
5. Valley of Besaya
6. Valley of Pas
7. Valley of Miera
8. Valley of Asón
9. Campoo
10. Valleys of South

VARIABLES

Average value of the area's municipalities:

1. Unemployment rate in 2003.
2. Percentage of housing units as first residence in 2001.
3. Percentage of empty housing units in 2001.
4. Population density in 2002.
5. Youth index in 1991.
6. Percentage of illiterates in 2001.
7. Percentage of university graduates in 2001.
8. Number of educational centres in 2001.
9. Growth rate in 2003
10. Number of bank branches in 2002.
11. Municipal budget in 2002.
12. Gross family income per inhabitant in 2002.

Mean comparative index of the importance of industry/commerce/hostelry in each local area, as a function of the tax on economic activities of the sector considered:

13. Mean industrial index in 2001.
14. Mean commercial index in 2001
15. Mean hostelry trade index in 2001.
16. Mean economic activity index in 2001, with respect to the total number of business and professional economic activities.

With respect to each local area:

17. Average distance from Santander airport.
18. Average smallest distance to a hospital centre.
19. Percentage of population in 2002.

3. RESULTS AND DISCUSSION

3.1 Regional Imbalance

The PCA performed reduces the information provided by the set of the 19 variables used to 3 axes or principal components which absorb 89.7 % of the total variance. Table 2 presents the load values of each variable for each of the three components. These values express the correlation of the variable with each component. Thus, variables with high values, close to 1, will have greater weight and will serve to interpret the significance of the principal components.

The first axis or component accounts for 50.66 % of the total variance and expresses the most important direction of the underlying variation in the set of information studied. The variables of most weight in this axis are as follows: bank branches, industrialisation index, commercialisation index, hostelry trade index, economic activities index and municipal budget.

All of these are variables which express or indicate aspects related with the economy of the local areas. A further two variables, population density and percentage distribution of the population per local area also have substantial weight in this axis, since the economy is more active in areas where the population is concentrated.

Table 2. Load values of the variables in each principal component.

Variables	Axis I	Axis II	Axis III
1. Unemployment rate	-0.485	-0.001	0.743
2. Percentage of housing units as first residence	-0.195	0.566	-0.741
3. Percentage of empty housing units	0.130	-0.661	0.128
4. Population density	0.942	0.302	-0.057
5. Youth index	0.391	0.822	-0.287
6. Percentage of illiterates	-0.278	0.182	-0.884
7. Percentage of university graduates	0.836	-0.234	0.349
8. Educational centres	0.703	0.340	-0.564
9. Growth rate	0.306	0.898	-0.021
10. Bank branches	0.967	0.129	0.078
11. Municipal budget	0.977	0.203	0.005
12. Gross family income	0.645	-0.234	0.717
13. Industrial index	0.915	-0.274	-0.024
14. Commercial index	0.964	0.241	0.016
15. Hostelry trade index	0.968	0.140	0.081
16. Economic activity index	0.977	0.154	0.035
17. Distance from Santander airport	-0.293	-0.708	0.412
18. Distance to a hospital centre	-0.079	-0.942	0.103
19. Percentage of population	0.936	0.271	-0.060

The first component thus allows the planning of the local areas of Cantabria as a function of their economic strength. Relative coordinates have been used, so that each axis comprises 100 percentage units, enabling the cartographic representation of the local areas, indicating with different shades the intervals of 10 percent. Thus, the first position corresponds to the interval between 90 and 100 % and the last position, the tenth, to the interval between 0 and 10 %.

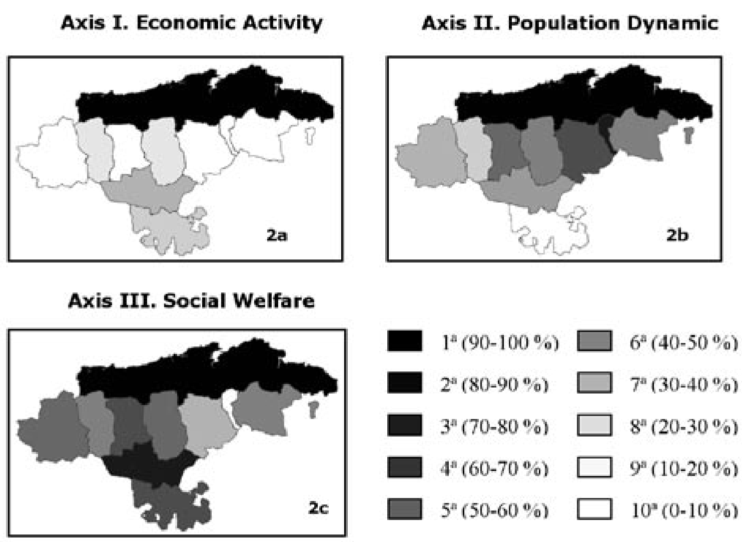
Using this system, Figure 2a shows the local regions of the Community of Cantabria as a function of their economic activity. The natural space of the coastal strip, or la Marina, stands out clearly from the rest of Cantabria, being the only one in the range between 90 and 100 %. The region of Campoo and that of the Valleys of the South are the next in economic importance, though at a considerable distance, Campoo being in seventh position, range 30 – 40 %, and the Valleys of the South in eighth position, range 20 – 30 %. The least favourable outlook is found in the set of regions which make up the intermediate valleys, Nansa and Besaya, occupying the ninth position, range 10 – 20 %, and the regions of Saja, Miera, Asón, Liébana and Pas are in the last position, in the range between 0 and 10 %.

The next axis or component accounts for 22.56 % of the total variance, outlining the second trend of variation in the set of natural areas of Cantabria. The variables which define this trend are of a dynamic demographic nature, such as the growth rate and the youth index. Two geographical variables also have some weight in this axis: that which represents the average distance from each region to Santander Airport (Parayas) and the distance to the closest hospital centre, variables which maintain a high negative correlation with demographics, since the older sector of the population is often found in the municipalities which are furthest from both the airport and the hospitals.

Figure 2b shows the cartographic representation of the regions of Cantabria in relation to the second axis or principal component which may be interpreted as demographic dynamics. The regions of la Marina and Miera are the most dynamic, the first being found in the range of 90 to 100 % and the second in the following range of 80 to 90 %, occupying respectively the first and the second position. The regions of Pas and Saja occupy the third position, range 70 – 80 %, and the fourth position, range 60 – 70 %, respectively. In an intermediate situation are the regions of Besaya and Asón, in fifth position (range 50 – 60 %) and Campoo, sixth (range 40 – 50 %). The last positions are occupied by Liébana, Nansa and the Valleys of the South, in positions seven (range 30 – 40 %), eight (range 20 – 30 %) and ten (range 0 – 10 %).

The third axis accounts for 16.52 % of the total variance. The variation tendency indicated by this axis is related with variables which point to degrees of social welfare: unemployment rate, percentage of housing units of first residence, percentage of illiterates and gross family income. The cartographic representation of the regions according to this axis of sociological variation is shown in Figure 2c. The best relative situation corresponds to the region of la Marina which ocupies the first position in the range of 90 – 100 %. The second position is occupied by Campoo, in the range of 80 – 90 %, followed by the regions of Saja, Valleys of the South, Besaya and Liébana, the first two occupying the third position, range 70 – 80 %, and the second two occupying the fourth position, range 60 – 70 %. In an intermediate situation of social welfare are the regions of Asón and Nansa which occupy the fifth position, range 50 – 60 %. The region of Pas is in seventh position, range 30 – 40 %, and the last position corresponds to the region of the Valley of Miera, in the interval between 0 and 10 %.

Figure 2. Cartographic representation of local regions of Cantabria according to the axes or principal components obtained from the PCA: axis I of economic activity (2a), axis II of population dynamics (2b) and axis III of social welfare (3c).



3.2 Main pressures on the coastline

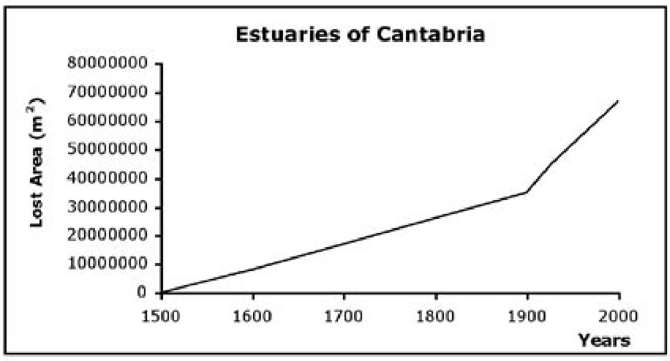
3.2.1 Management of coastal areas

The origin of the estuaries of Cantabria dates back to the last glaciation (Würm). During the Flandrian transgression, the surface area of the estuaries amounted to almost 112980500 m^2, lowering to 99305000 m^2 as a consequence of the fall in the sea level during the Postflandrian transgression. At present, the total surface area of the estuaries is 52082000 m^2, 52.4 % of the Postflandrian level, 89.4% of this reduction being due to anthropic causes and 10.6 % to the natural effects of sedimentation. (Rivas, 1991).

The human actions responsible for this occupation of areas of high ecological value have been landfills and barriers. According to data gathered by Rivas (1991), this process of occupation began in the 16^{th} century, though most of the actions took place in the 18^{th} and 19^{th} centuries, with an average occupation rate of 173000 m^2/year (see Figure 3). This rate increased significantly until it reached a maximum value of 522000 m^2/year in the period between 1900 and 1925. After this date, the occupation rate fell slowly, though maintaining values greater than 300000 m^2/year.

The processes of landfilling and barrier-building have affected all of the estuaries of Cantabria, though with varying intensities. The greatest occupations in absolute terms have taken place in the Bays of Santander and Santoña, 21183000 m^2 and 11571000 m^2, while the most affected in percentage terms with respect to the original Postflandrian extension have been the estuaries of Brazomar, 91.3 %, Merón, 89.1 %, Tina Menor, 75.2 % and las Llamas, 73.9 %. The Bay of Santander has lost around 47.6 % and the Bay of Santoña around 37.8 %.

Figure 3. Lost area in the stuaries of Cantabria due to anthropic causes.



Land gained from the sea with these practices has been used for several purposes, the most important of which are agrofishing, urban expansion and those related with transport and communication.

The occupation rate of the estuaries is directly related with the demophoric development, a concept which takes in both demographic and economic development.

Thus, in the Bay of Santander, the Bay of Santoña and in the San Martín de la Arena Estuary (Suances), the occupation of sea areas has been very closely linked to the development and expansion of their ports.

The occupation and transformation of the Bay of Santander is a good example of the management of the estuary areas of Cantabria towards the end of the 20th century.

The first actions in the 20th century were related with barrier works connected with the installation of tide mill locks which exploited wave energy to transform primary materials.

The increasing activity of the port during the 18th and 19th centuries necessitated new docks and quays. The port thus became a key player in the urban development taking place around it. (Pozueta, 1984; Ureña y Gómez, 1984), requiring space for warehouses, offices, premises, commerces and housing. However, the various town planning projects which were implanted during this period were of limited spatial effect. At the end of the 19th century, only 398000 m^2 of the Bay (1.9 % of the total lost up to date) had been occupied.

The intensive processes of occupation of the Bay take place towards the end of the 19th century and the beginning of the 20th century, during which time 14470000 m^2 (65% of the total lost) were affected. The export of minerals to Europe during this period led to an economic boom which required space for the development of port activities, as well as urban and industrial land and land for communication infrastructures. The urban and industrial expansion took place mainly towards the west, while the southern part was used as a huge pot of iron mineral.

Industrial activity came to the fore in response to the crisis in mining, during the first quarter of the 19th century, establishing the pattern of occupation of sea lands in the bay up to the 1970s. During the second quarter of this century, the Albareda docks were built, the Raos docks were commenced and the new fishing port was completed, Puerto Chico being used henceforth for leisure boats. Thus, the eastward expansion of the port was finalised.

In the middle of the 20th century, the Santander regional development plan promoted the use of the bay as a communications node. The extension of the installations was continued (Maliaño and Raos docks) and Parayas airport was built on land claimed from the bay.

The industrial crisis of the 1970s led to the generation of leisure activity infrastructures (marinas) and the construction of great public works: the Santander – Torrelavega motorway, the amplification of Parayas airport and the Raos industrial estate, etc.

The lands claimed from the sea have been put to various uses (Rivas,1991). The largest space is occupied by grazing land (9162000 m^2; 41 %). The origin of this occupation lies in the huge landfills performed by the discharge of mineral in the Solia, Tijero, Boo and Cubas estuaries.

Transport infrastructures (4132500 m^2; 18.73 %) are represented by Parayas Airport, RENFE and the Raos docks. Industrial installations (3287000 m^2; 14.89 %) were located in the north-western arch of the bay, between 1883 and 1929. The land dedicated to housing is also of considerable magnitude (1153000 m^2; 5.22 %) and is located in the urban nucleus of Santander, Santiago district, Nueva Montaña and Somo.

It should be noted that 10.35 % of the area occupied by the bay is not the object of any use today, most of this being isolated areas with restricted tidal change. This area should be recovered.

The bay has lost around 50 % of its original space, being divided into two clearly differentiated areas as regards use and conservation, a direct consequence of the different degrees of development experienced by the surrounding municipalities. There is, on the one hand, the western end and the back of the bay, areas with the greatest concentration of mining activity and later of the most substantial industrial installations, with the consequent demand for labour, giving rise to the most densely populated urban nuclei (Camargo, Astillero, Santander) and a heavy deterioration in the landscape. On the other hand, there is the eastern end, in the part closest to the mouth which maintains, in contrast, a high degree of its original nature thanks to its lesser demographic and economic development.

3.2.2 Overexploitation of fishing resources

The evolution of the fishing sector in Cantabria is marked by the successive transformations that this activity has undergone on a nacional scale. Towards the end of the 1950s, the model of fishing exploitation in all of the Iberian Peninsula was that of a coastal and artisanal fisheries, and it was not until the end of the next decade when, thanks to the incorporation of industrial refrigeration in sea vessels, the process of change favouring the development of an industrial-scale fishing activity began. This new model of exploitation, sanctioned by the enactment of Law 147/1961, of December 23, on the renewal and protection of the fishing fleet, led to a substantial increase in the fishing effort, reflected in the greater number of vessels, the introduction of new more productive fishing techniques and the possibility of access to fishing grounds further from the coast (Ortega, 1996).

During the boom period of the modern fisheries between 1940 and 1965, the annual landings in the Cantabrian fishing ports were well over thirty million kilograms. In contrast with these good results, the excessive increase in activity together with the modern technologies incorporated in the sector led to problems of overexploitation of the traditional coastal fishing grounds.

These circumstances meant that fishing in Cantabria slipped into a period of decline, beginning in 1966 with up to a 50% reduction in the catches of the principal target species, the anchovy, and lasting up to the present.

The variations registered in the last years in the structure of the fishing catches in Cantabria's ports are a true reflection of this situation of exhaustion of the coastal fishing grounds. Thus, it can be observed that in the 1990s, none of the canning species comprised more than 30% of the total catch. This tendency continues at present, only the anchovy being among the most caught species, with a contribution to the total catch of only around 10 %.

As a representative example of the situation of overexploitation to which several of the main fishing grounds of Cantabria are subjected, the evolution in the catches of the following species will now be outlined: hake (*Merluccius merluccius*), bream (*Pagellus bogaraveo*), anchovy (*Engraulis encrasicholus*), and horse mackerel (*Trachurus trachurus*), according to the data provided by the Department of Cattle, Agriculture and Fishery of the Government of Cantabria.

Hake (*Merluccius merluccius***)**

The hake landed in Cantabria comes from trawlers, longliners and gillnetters working in Community waters off the coast of France (subareas VIIIa and VIIIb of the International Council for the Exploration of the Sea, ICES), and from fishing carried out in the Spanish continental shelf (subarea VIIIc of the ISEB). The main port for unloading is Santander.

The catches are few due to the overfishing. Several studies performed on the hake population of the Cantabrian Sea point out that this species is subjected to heavy overexploitation (see Figure 4).

Sea Bream (*Pagellus bogaraveo***)**

The catches come mainly from subarea VIIIc. The ports of San Vicente de la Barquera and Santander are those that handle most of the sea bream.

Sea bream fishing plays an important role thanks both to its high economic interest and the seasonality of the fishing, since it allows the fleet to remain active during the winter months, until the anchovy and tunny-fish season begins.

The catches of this especies have decreased gradually, practically since the first records were taken, coinciding with the change in the fishing gear from pole and handline to the longliner, which is more efficient (see Figure 4). This great decline shows a clear syndrome of overfishing, since the effort of the fleet to catch this species has not diminished, while it may be said that bream fishing no longer exists in the Cantabrian Sea.

Anchovy (*Engraulis encrasicholus***)**

This is a clearly seasonal fishery taking place between the months of March and July. Most of the anchovy landing is done in Santoña which boasts an important canning industry. The catches of this species come from the Gulf of Biscay (Subarea VIIIb and VIIIc of the ICES).

The largest catch was registered in 1965, with a total of 27000 tonnes (see Figure 4). Since this year, catches have fallen sharply coinciding with the increase in the number of vessels.

There was an increase in the fishing effort after 1975 with the incorporation of sonar to the fleet, which led to a rise in catches, though to a far lower degree than the great catches of 1965. This fact coincided, some years later, with a new fall in catches, registering in 1982 the minimum of the whole historic series, which led to a parallel reduction in the fleet and a reduction in the fishing area which, for all of the Cantabrian Sea, was limited to the inner part of the Gulf of Biscay (Junquera, 1986; 1991).

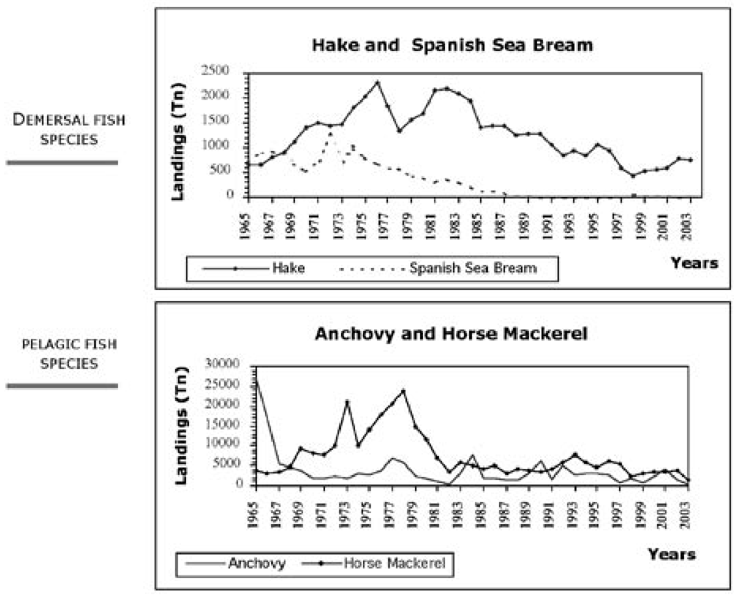
This series has been followed by reasonable catches, with averages of 7000 tonnes, with other clearly unsatisfactory ones, of 2000 tonnes, in almost regular cycles until 1991. Since then the intakes have fallen gradually, with the exception of the year 2001 with almost 4500 tonnes. These low catches are originated by low recruitments.

Horse mackerel (*Trachurus trachurus*)

The biggest catches come from division VIIIc though they are also present in subareas VIIIa and VIIIb.

The initial series show poor data on horse mackerel catches as regards landings, while a tendency to increase is noted after 1968, reaching a maximum in 1978 of around 24000 tonnes, then followed by a sharp fall until establishing an average balance of below 5000 tonnes (see Figure 3). This fall is probably due to the fish discarded by the trawlers on their return to the ports of disembarkment, to economic factors or to the abundance of the target species, hake.

Figure 4. Evolution of catches of fishing species in situation of overexploitation.



The biggest catches of this species are those obtained by purse-seines making up 90% of the total caught, while hook-fishing and gillnets account for the remaining 10 %. The ports of Santander and Santoña are the main ports of disembarkment.

Horse mackerel is, after the anchovy, the species with the biggest catches of all of the fleet of the Cantabrian coast, but in recent years, the widespread decline in numbers indicates that this is an overexploited species.

3.2.3 Discharges in Estuaries

The concentration of the population and of industry in the region of la Marina, together with the fact that the rivers are used for the evacuation of wastewaters, means that liquid discharges reach the coast through the estuaries.

One indication of the pressure borne by the coast can be observed in Table 3, where the total number of equivalent inhabitants per basin in the Community of Cantabria is shown. The coastal zones most affected are the Suances Estuary and the Bays of Santander and Santoña, in which the contamination of waters and sediments is critical in certain areas.

Table 3. Equivalent inhabitants per basin.

Basins	Population inhabitants	Industry Equivalent inhabitants	Total equivalent inhabitants
Agüera-Castro Urdiales	24151	26674	50825
Asón-bahía de Santoña	75324	36448	111772
Miera-bahía Santander	313298	362647	675945
Pas-Pisueña	39937	33218	73155
Saja-Besaya	124705	262201	386906
San Vicente de la Barquera	19891	4225	24116
Nansa	3639	0	3639
Deva	9142	1583	10725
Ebro	21053	29703	50756
Duero	1626	3560	5186

Source: Consejería de Medio Ambiente, Gobierno de Cantabria.

Estuary of Suances

The basin of the Saja-Besaya system concentrates a total of 386906 equivalent inhabitants, mainly in the area of Torrelavega, of which 68% is attributed to industrial activity. Most of these wastewaters are finally gathered by the flow network and are taken out to sea through the San Martín de la Arena Estuary (Suances).

The indicators which best reflect the state of quality of the estuary are the concentration of oxygen dissolved in water and the concentration of heavy metals in sediment. The demand for oxygen, both chemical and biological, of the discharges received exceeds the capacity for reoxygenisation, leading to situations of anoxy in the area of la Punta del Hornillo, where the entrance of seawater with oxygen saturation values relieves the critical situation, Figure 5. (Infrastructure and Ecology, 2000).

Industrial discharges have caused heavy metals to accumulate in the estuary sediments, especially lead, zinc, mercury and cadmium. Figure 5 shows the concentration of these metals in various areas of the estuary. In order to evaluate this data, Table 4 presents the levels of action, as threshold values, of the CEDEX (1994) corresponding to non-contaminated, moderately contaminated and highly contaminated sediments. The stretch of the estuary between the Hinojedo dock and the fishing port of Suances shows sediments which fit into the category of highly contaminated, with concentrations of mercury, cadmium, zinc and lead of over 28 ppm, 90 ppm,1600 ppm and 3400ppm. (Infrastructure and Ecology, 2000).

Figure 5. Environmental quality of Suances estuary through two indicators: the first one relative to the mass of water [concentration of dissolved oxygen (mg/l)] and the second sediment [concentration of heavy metals (ppm)].

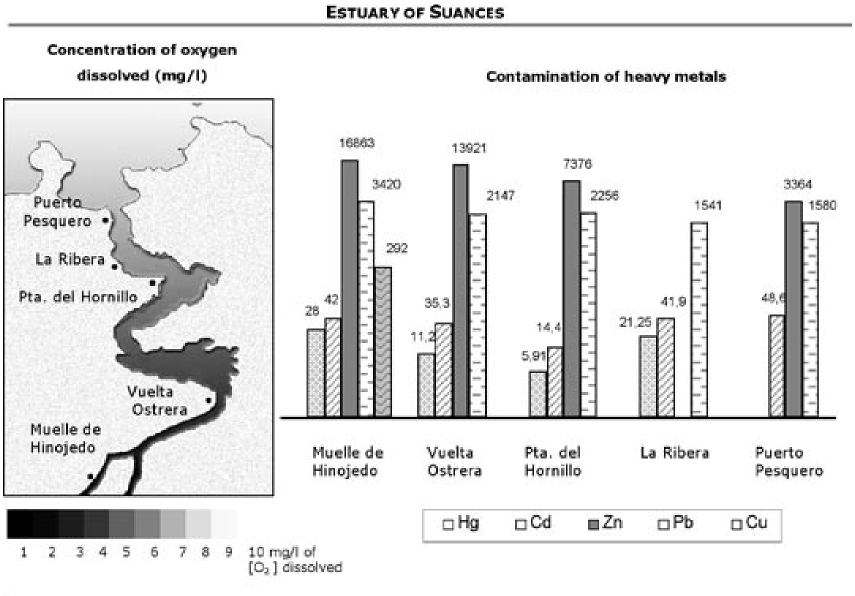


Table 4. Threshold values of heavy metal concentration for the characterisation of marine sediments.

marine sediments.

	Sediments		
Metal, ppm	No contaminated Action level 1	Moderately contaminated	Highly contaminated Action level 2
Mercury	< 0.6	Entre 0.6 y 3.0	> 3.0
Cadmium	< 1.0	Entre 1.0 y 5.0	> 5.0
Lead	< 120	Entre 120 y 600	> 600
Copper	< 100	Entre 100 y 400	> 400
Zinc	< 500	Entre 500 y 3000	> 3000
Chrome	< 200	Entre 200 y 1000	> 1000
Arsenic	< 80	Entre 80 y 200	> 200
Nickel	< 100	Entre 100 y 400	> 400

Bay of Santander

The Miera basin contains 675945 equivalent inhabitants, concentrated in the Bay of Santander, industrial activity being responsible for 54 % of the wastewater discharge.

The Integrated Sewage Plan for the Bay of Santander initiated in 2002 deals with most of the wastewater, which is taken to the sewage plant of San Román de la Llanilla to be later discharged into the neritic medium in the area of Virgen del Mar. The most appropriate indicator of the quality of the bay at this point has been considered to be the concentration of heavy metals in the sediments.

Table 5 shows the average values recorded in the area of Raos, mainly intertidal. The concentrations of zinc and lead exceed action level 1 and that of mercury even surpasses action level 2, highlighting the high levels of contamination of the sediments of the Bay of Santander. (Revilla et al., 2000).

Table 5. Concentration of heavy metals in the area of Raos, Bay of Santander.

marine sediments.

	Sediments		
Metal, ppm	No contaminated Action level 1	Moderately contaminated	Highly contaminated Action level 2
Mercury	< 0.6	Entre 0.6 y 3.0	> 3.0
Cadmium	< 1.0	Entre 1.0 y 5.0	> 5.0
Lead	< 120	Entre 120 y 600	> 600
Copper	< 100	Entre 100 y 400	> 400
Zinc	< 500	Entre 500 y 3000	> 3000
Chrome	< 200	Entre 200 y 1000	> 1000
Arsenic	< 80	Entre 80 y 200	> 200
Nickel	< 100	Entre 100 y 400	> 400

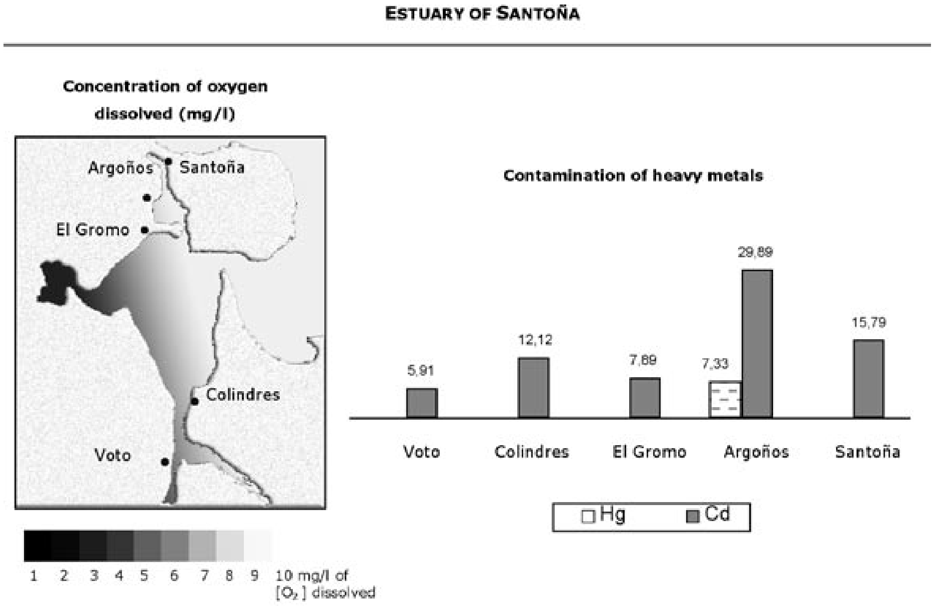
Estuary of Santoña

The Asón basin has a total of 111772 equivalent inhabitants, 32 % of which are due to industrial activity. The concentration of oxygen dissolved in water and the concentration of heavy metals in the Bay of Santoña synthesise the anthropic pressure on this area of the coast.

The concentration of oxygen shows a marked zonal distribution (see figure 5) with average annual values of under 3.9 mg/l in the innermost areas and values between 4 and 5.9 mg/l in the main channels. The highest values are obtained in the wetland marshes of the Dueso due to an intense photosynthetic activity. In the Escalante Estuary, values of under a 1 mg/l of oxygen are obtained in summer, Pérez et al. (2000).

The concentration of heavy metals in sediment shows zones in the estuary contaminated by mercury and cadmium, Figure 6. The Boo Estuary (Argoños) presents average mercury concentration values of 7.33 ppm, exceeding action level 2 and reveals sediments highly contaminated by this metal. The cadmium concentrations exceed action level 1 in all of the zones analysed, and action level 2 in the following zones: Voto, Colindres, El Gromo, Boo Estuary (Argoños) and Santoña. (Villasante, 1996; Canteras et al., 2000).

Figure 6. Environmental quality of Santoña's estuary through two indicators: the first one relative to the mass of water [concentration of dissolved oxygen (mg/l)] and the second sediment [concentration of heavy metals (ppm)].



3.2.4 Urban development pressure and modification of the landscape

In the last few decades, the increasing spread of tourism, the Cantabrian motorway, the policies of the European Union in agriculture sector and the greater socioeconomic expectations of the region of la Marina have meant that the use of land has tended to move towards residential purposes. This developmental pressure and the transformation of the vegetation through massive plantations of eucalyptus and pine trees, have given rise to a true transformation of the landscape of the coastal strip.

Due to their adjacency to both urban and rural nuclei, the traditional spaces formed by meadows and hill terraces have been the lands most affected by building processes either in the form of single housing units or housing estates. In some areas, land has also been occupied for industrial use and for infrastructures. The result is that three different zones can be distinguished in la Marina according to the different type of anthropic pressure:

1. Very high pressure coastline: axis Santander-Camargo-Astillero in the north and west of the Bay of Santander and the Santander-Torrelavega corridor.

2. High presure coastline: in the eastern zone, municipalities of Castro Urdiales, Laredo, Colindres, Santoña and Noja.

3. Medium pressure coastline: in the western zone, municipalities of Santillana de Mar, Comillas, San Vicente de la Barquera.

An indicator of the city-plaining pressure is the evolution of urban land in coastal municipalities such as Noja and Piélagos.

The municipality of Noja covers 9.2 km^2. The urban land detailed in the Urban Development Plan of 1990 occupies a surface of 40.9 %, constituting an increase with respect to that described in the previous plan of 1979 of 113 %.

The municipality of Piélagos covers a surface of 88.6 km^2. In the Urban Development Plan of 1985 the percentage of urban land was 6.08 %, increasing to 7.29 in the Plan of 1993, but distributed extremely unevenly. The greatest proportion corresponds to nuclei on the coastal fringe, especially in Puente Arce, Liencres and Mortera, where urban land has increased by 144 %, 85.5 % and 72.8 % respectively.

The number of new housing units built is another indicator of the strong pressure of urban development on la Marina with respect to the other regions of the Community of Cantabria. From the year 2001 to the second term of 2004, the number of new housing units built in Cantabria has been 33828, of which 31857 have been erected in la Marina, that is 94.2 %. (Colegio Oficial de Aparejadores y Arquitectos de Cantabria, 2004). The region of the Valley of the Besaya ocuppies the second place with 2.2 % and la Liébana is in third place with 1.5 % of the housing units built in this period of time.

As for the transformation of the forests, the surface occupied by single-species masses of repopulation corresponding to eucalyptus and radiata pine trees is 9.6 % of the total forested area of Cantabria, concentrated almost completely in la Marina, the increase in the number of eucalyptus tress in the period from 1972 to 2000 being 72 %. (Cantabria Forestry Plan, 2003).

4. CONCLUSIONS

The Community of Cantabria presents a pronounced regional imbalance. The region of la Marina constitutes the most important economic and demographic area.

This unequal regional development has led to a strong anthropic pressure on the coastal strip which has led to:

- The loss of natural spaces of a high ecological value such as estuaries, which have been reduced by 50 %.

- The contamination of the coast, especially in areas where the population and industry are concentrated: Bay of Santander, Bay of Santoña and San Martín de la Arena Estuary. The heavy metals accumulated in the sediments give high concentrations of mercury, cadmium and lead in certain areas.

- The overexploitation of fishing resources, fishing being at present a secondary activity.

- A modification of the coastal landscape, as a consequence of an accelerated process of urban development on traditional meadow and hill terrace lands, and the substitution of mixed autochthonous woods by single-species plantations of rapid growth.

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APENDICE: LA PRESIÓN ANTRÓPICA EN EL LITORAL DE CANTABRIA

RESUMEN

La Comunidad Autónoma de Cantabria se sitúa en el norte de España, limitando con el mar Cantábrico. En las últimas décadas el desarrollo socioeconómico se ha polarizado hacia la costa, poniendo en riesgo ecosistemas naturales de alto valor ecológico, recursos renovables, así como, valores culturales y tradicionales de utilización del suelo.

Cantabria ha perdido aproximadamente el 50 % de sus ecosistemas de estuarios, ganándose suelo al mar para usos agropecuarios, residenciales, industriales y para infraestructuras de transporte, ignorando los valores de productividad biológica de estos espacios y su vinculación con el mantenimiento de las pesquerías tradicionales.

La pesca constituye hoy una actividad económica residual, con tasas anuales medias negativas en las capturas de las principales pesquerías. Los puertos pesqueros son transformados para albergar esencialmente actividades náutico-recreativas.

Los sedimentos de la bahía de Santander, ría de San Martín de la Arena (Suances) y de la bahía de Santoña han acumulado altas concentraciones de metales pesados.

En Cantabria, en el período comprendido entre el año 2001 y el segundo trimestre de 2003, se han construido 33828 viviendas nuevas, el 94,2 % de las mismas se han llevado a cabo en la franja costera.

En cuanto a la transformación del tapiz vegetal, el incremento del número de ejemplares de eucaliptos en el período entre 1972 y 2000 ha sido del 72 %.

Palabras clave: presión antrópica, gestión costera, contaminación, sobrepesca, desarrollo urbano.

INTRODUCCIÓN

Cantabria es una Comunidad Autónoma del Estado Español de unos 5300 km2, localizada al norte y limítrofe con el mar Cantábrico, entre los 42º 46' y los 43º 31' de latitud norte y los 3º 9' y 4º 52' de longitud Oeste. Su población, de algo más de 500000 habitantes, se concentra en la franja costera, siendo esta zona la que en las últimas décadas ha experimentado el mayor dinamismo socioeconómico dentro de la Comunidad.

La ausencia de la variable ambiental en el proceso de ocupación y utilización de la franja costera, de un enfoque de gestión integral de la costa y de unos criterios específicos de ordenación para los municipios costeros están poniendo en riesgo las posibilidades de sostenibilidad de este espacio litoral.

Se presenta en este trabajo: a) el fuerte desequilibrio regional existente en Cantabria entre la Franja Litoral y la Montaña, las dos grandes comarcas naturales que integran y definen a esta Comunidad Autónoma y, b) las consecuencias de la fuerte presión antrópica que recibe el litoral como espacio socioeconómico de mayor interés para el desarrollo de Cantabria.

METODOLOGÍA

El diferente grado de desarrollo de las diez comarcas naturales que integran la Comunidad de Cantabria ha sido estudiado a través de 19 variables sociales, mediante la obtención de los valores propios de la matriz de correlación entre todas las variables y su análisis en componentes principales. Las representaciones cartográficas se han realizado obteniendo las coordenadas relativas sobre cada componente extraído.

La presión antrópica sobre el litoral fue analizada mediante los siguientes indicadores: gestión de espacios litorales, sobreexplotación de recursos, contaminación de rías y modificación del paisaje costero por la presión urbanística y modificación del tapiz vegetal por plantaciones monoespecífica de rápido crecimiento.

CONCLUSIONES

La información aportada por el conjunto de las variables estudiadas se puede reducir a tres componentes o ejes que marcan las tendencias principales de variación en el desarrollo social de las comarcas de la Comunidad de Cantabria. La primera tendencia se refiere al desarrollo económico, la segundo se asocia a la dinámica poblacional y la tercera al grado de bienestar social.

Cada eje da lugar a una ordenación de las comarcas, obteniéndose de esta manera las diferencias relativas según las tendencias de variación. La ordenación según la pujanza económica sitúa a la Marina como el espacio geográfico de mejor valor por los indicadores económicos. Hay un marcado desequilibrio regional entre la Marina y las restantes comarcas. La zona costera es la de mayor densidad de población, concentra al 86,68 % de la misma, proporciona mayores oportunidades y dispone de las mejores infraestructuras de comunicación, mayor número de oficinas bancarias y donde se ubica las principales industrias de la Comunidad. Actúa como foco de atracción del resto de las comarcas, especialmente de la de los valles intermedios, Nansa, Saja, Besaya, Pas Miera y Asón.

El segundo eje se relaciona con la dinámica poblacional, ordenando las comarcas según la tasa de crecimiento y el índice de juventud. Esta ordenación marca diferencias menos acusadas entre las comarcas. El mayor dinamismo demográfico coincide con la zona donde hay mayor actividad económica y mayores posibilidades de desarrollo, la Marina. Los Valles del Sur y las comarcas del Nansa y de la Liébana ocupan las últimas posiciones, consecuencia de las tasas negativas de crecimiento y de su población envejecida.

Por último, el tercer eje vuelve a situar a la Marina como el espacio geográfico de la Comunidad de Cantabria con los mejores índices en cuanto a bienestar social. Las mayores perspectivas económicas determinan que la media de la tasa de paro de sus municipios sea la menor de toda la Comunidad. En la Marina se tiene también el nivel de instrucción más alto, y la mayor renta bruta familiar disponible por habitante.

Este desigual desarrollo regional ha supuesto una fuerte presión antrópica sobre la franja costera que se ha traducido en:

• La pérdida de espacios naturales de alto valor ecológico como los estuarios, reducidos a su 50 %.

• La contaminación del litoral, especialmente en las zonas donde se ha concentrado la población y las industrias: bahía de Santander, Bahía de Santoña y ría de San Martín de la Arena. Los metales pesados acumulados en los sedimentos alcanzan, en determinadas zonas, elevadas concentraciones de mercurio, cadmio, zinc y plomo.

• La sobre explotación de recursos pesqueros, constituyendo hoy la pesca una actividad económica residual.

• Una modificación del paisaje costero, consecuencia de un acelerado proceso de urbanización sobre suelos tradicionales de mieses y terrazgos de monte, así como de la sustitución de los bosques mixtos autóctonos por plantaciones monoespecíficas de rápido crecimiento.

Journal of Maritime Research, Vol. I. No. 2, pp. 85-93, 2004

ISSN: 1697-4840

THE SEA AND ITS CONTAMINANTS

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ABSTRACT

Man produces a diversity of contaminants that, directly or indirectly, reach the ocean. Some are of organic origin and are absorbed by normal biological processes, but others such as insecticides resist decomposition and remain for long periods of time in the environment causing different prejudicial effects on both marine and human life.

Key words: toxicity, persistence, bioaccumulation,

1. INTRODUCTION

The misunderstanding in the past with respect to the sea led to the belief that due to it's immense dimensions and auto depuration capacity it could be used as an unlimited receptor of all kinds of contaminants, for which reason it is not surprising that our seas and oceans have deteriorated enormously for not taking into account its limitations both physical and biological.

2. TYPES OF CONTAMINANTS

It has to be emphasized that the contamination itself does not refer to the purity of the seas but to the modifications in its characteristics, the fact is that natural waters present variable grades of purity and also we must not forget that chemically pure water does not favour the development of life.

2.1 MICROBIOLOGICAL CONTAMINATION

Caused by domestic residual waters carried by urban effluents. These waters carry an elevated concentration of microorganisms and pathogens that reach the sea contaminating beaches and fishing banks.

Not al sewage is purified before reaching the sea, and in cases where the sewage is treated in order to eliminate part of the contaminants, the microorganisms are not completely eliminated (In the Canaries 9 out of 10 emissaries pour onto the sea unspecified or partly un purified waters in different stages; study carried out by Richard Haroun, biologist of the ULPGC, on behalf of the local Ministry of Environment). In these waters Bacteria, Viruses, fungus and other opportune microorganisms can be found.

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The risks of infectious illnesses can occur simply by contact with the skin or mucous by bathing in contaminated areas (Otitis, dermatitis, gastric infections, salmonella…) by the consumption of water, seafood and fish from infected areas. (Hepatitis, cólera, polio etc).

The seas and oceans elevated capacity to purify and dissolve contaminants, together with the environmental stress (changes in temperature, salinity, PH currents..) to which the microorganisms are subjected once they reach the sea, explain the low rate of survival and the disappearance of bacteria's and viruses.

The human being has as an indicator certain bacteria commonly known as, intestinal flora, which acts as an indicator to this type of contamination called facial coli forms and streptococcus, which although are not in themselves prejudicial to health, their presence indicates the existence of microorganisms dangerous (pseudomonas, staphylococcus..).

The fundamental factor that contributes to the reduction of this type of contamination is the correct treatment of wastewaters in the purifying stations (EDARS) before emptied to the sea, as well as effective dilution of the effluent in order to favour and not hinder the natural phenomena of purification and auto depuration of the marine environment.

2.2. CONTAMINATION BY NUTRITIOUS SUBSTANCES. EUTROFIZACION.

Once the waste produced by industries, agriculture and sewage reaches the sea these are chemically unfurled by bacteria, originating inorganic substances known as nutrients (remineralization process).

The key nutrients are nitrogen and phosphorus, although both silica and oligoelements are also important (Mn, Co, Ca, K). These are considered as contaminants when their concentration is sufficient to allow the elevated growth of algae, which provoke the exhaustion of the dissolved oxygen due to the biodegradation of the organic material created (CH20 + 02 $\rightarrow$ H20 + C02). Also the exhaustion favours the process of decomposition of the organic material via anaerobia (CH20 $\rightarrow$ H2S + CH4 + NH3), with the production of sulphuric hydrogen, highly toxic for the life of the sea and foul smelling volatile substances and a significant modification to the ecosystem.

The rapid growth of algae and phytoplankton due to over fertilization of the waters is known as Eutrofization, and can cause great danger to marine life due to the lack of oxygen resulting in, obstruction of the fish's gills and the increase in the growth of toxic algae (red tides).

The aquiculture that is being developed as an alternative to the problem of over fishing produces elevated levels of nutrients. The marine cages float in semi-closed areas with deficient hydric interchanges (which deteriorate the situation) converting the area sensible to the discharges of nutrients and antibiotics etc.

2.3. CONTAMINATION BY HYDROCARBONS

Although hydro carbides are of natural origin, those that are found in the seas and oceans are from human sources (refineries, ships, industries etc...).

Petroleum has become one of the most important contaminants in oceans and seas, deteriorating beaches and the quality of the water, damaging the production of fish and seafood, becoming a serious problem to the world fishing industries. Its adverse effects are due to:

Toxicity

The aromatic polycyclic hydro carbides are the most toxic followed by olefinicos, naftenicos and parafinicos. Those of less molecular weight are, apart from being the most toxic, are also the most volatile, evaporating in just a few days where others persist in the column of water or sediments.

The hydro carbides are highly toxic for marine life when absorbed through the gills and skin of fish, interfering in the nervous system, blocking organs and causing asphyxia in the marine communities, in general destroying their natural habitat

Synergy

The combination with other substances produces far superior effects compared to the effects of individual substances. It has been proven that synergy together with organoclo-ride pesticides and the facility they have to dissolve in the hydro carbides and other ten-soactive products, which favour the emulsion and dispersion of the layer of petroleum.

Direct physical action

Certain ecosystems are highly vulnerable to this type of contamination, such as coral reefs, swamps and mangroves. Oil slicks cause damage by covering the fauna and flora, complicating the interchange of oxygen.

Contrary to what public opinion can believe, the spectacular oil spillage of tankers is only responsible for 10 % of the total volume of petroleum found in the marine environ-ment, the rest is due to the contamination caused during the normal operations of loading and unloading at refineries, the cleaning of the ships tanks in harbours and at sea, etc. Also it must be emphasized that the treatments that can be used to eliminate petroleum from the coast line often result more aggressive and devastating than the contaminant in its self.

2.4. CONTAMINATION BY ACUMULATIVE SUBSTANCES

There exist a series of substances created by industries or elaborated as sub products of industrial processes, of difficult degradation, that get to the marine environment, accu-mulating in the organisms exposed to low or moderate concentrations, passing eventually to the trophic chain and possibly finally to man.

We refer to radioactive substances, persistent organic compositions (POC) and heavy metals. The common characteristics on which its prejudicial effects depend are:

Toxicity
Any substance that is "toxic" has an adverse effect on health, due to the concentration of the compound and exposure time (acute, chronic or teratogenic toxicity). Toxicologist often assure that "there is no toxic complex, but high or low toxic concentrations"

Persistence
It's the easiest or hardest capacity of degradation of an element. When a substance offers a high resistance to chemical and biological degradation it has greater probability to becoming lethal or a nearly lethal concentration.

Bioaccumulation: bioconcentration and biomagnifications
We talk about bio concentration when the substance tends to accumulate in the organic tissue, due to its lipofilic character (affinity to oily tissues) and the impossibility of the organism of keeping the required levels of excretion. The trophic relations in the ecosystems make possible the concentration of contaminants through the trophic chain. This enlargement of the toxicity in the upper levels of the chain is known as bio magnification. Also we have to take into account that when the contaminants of this kind are accumulated on fish or aquatic birds, it's not only dangerous to the local trophic chain, but the toxins can travel long distances with animals and end up in non contaminated areas.

2.4.1. RADIOACTIVE SUBSTANCES

Radioactivity is introduced through military tests, Activities performed by nuclear power stations, radio-isotopes usage in laboratories and medicine, by industrial processes, reactors used in the propulsion of ships, wastes submerged in containers in graves on the sea bed.

The most dangerous radio-isotopes are those stable elements strange to the environment, that tend to accumulate in the sediments of live matter, with an even greater facility in those elements with a lower level of evolution such as marine algae. Often these algae are used as bio indicators and radio-isotopes, for example, calcareous algae for the Stronicio-90, Laminaria digitata for Rutenio-106, different phanerogamous for Magnesium -54 or Cerio -144…

Radioactive contamination is very dangerous, not only for the reason that long periods of exposure damage live organisms causing changes in their somatic order (leukaemia) and genetic order (mutations), but also because this type of waste remains in the environment for longer periods of time.

2.4.2. PERSISTENT ORGANIC COMPOUNDS

These are organic compounds, the majority of which are synthetic and are produced by man, such as, refrigerants, pesticides, solvents, and whiteners from the paper industry.. The most extended are: polyclorated bifenilos (PBBs), pesticides (DDT, TBT), aromatic polycyclic hydro carbides (PHAs).

We are talking here of products that are highly resistant to biochemical degradation and are almost chemically inalterable, they remain for long periods of time in the environment. The aquatic organisms receive these compounds through their environment, incorporating them in their diet, absorbed principally through the gills of the fish and other marine life. The fact is that man has created these contaminants over the past century, and as yet marine life has not developed methods to metabolize. The effects on these organisms are produced on a molecular level, inducing changes in the permeability of the cellular membrane.

The high toxicity of these substances gives way to: insecticides such as DDT that destroy the phytoplankton (causing a descent in the organic material needed to feed other marine organisms), causing mutational effects, the evolution of immunological malfunctions, it also reduces the levels of reproduction; in humans, causes certain types of cancer, mutations in reproduction and evolution, suppression of the immunological system and also decontrol of the endocrine system.

Certain areas of the seas and oceans already have an alarming level of contamination, for example: the North Sea, where the Dieldrin industry is to be found, The Baltic Sea, a sea surrounded by seven industrialized countries that spill into the sea their waste products; the meridional coast of California due to the use of DDT in the control of plagues.

2.4.3. HEAVY METALS

We refer to all metallic chemical elements that have a high density (above a 5) and are not toxic o poisonous in low concentrations. Their presence in the marine environment is due mainly to metallurgic processes, mining explorations, and the production of chemical compounds and dredging operations.. The principal metals considered in having the highest danger levels are, mercury, cadmium, lead, chrome and arsenic.

We refer to natural elements that cannot be degraded and are dangerous because that tend to bio-cumulate. The toxicity of these metals depend on their individual characteristics, the organism in question and their state of development, the environmental conditions and chemical form (organic compounds Hg and Cd are 10 - 100 more toxic than those which are inorganic) and even the level of oxidation (the Cr^{3+} is an essential element, on the other hand the Cr^{6+} is highly cancerous) in which the metal intervenes.

Once incorporated in the organic tissue, heavy metals are capable of reacting (forming stable compounds), with sulphydric groups, rooted animus, carboxyl, and phosphorus.

Which belong to enzymes and other essential proteins inactivating them. The damage caused by these elements can be globalized as follows: genetic mutations, chromosomal alterations, changes in synthesis and repairing of nucleic acids and cellular transformations.

The disaster in Minamata Bay (Japan in the decade 40-50) created worldwide public alarm and gave mercury the worst reputation of all heavy metals. Of all the types of mercury the most dangerous is without doubt Methymercury (CH3Hg) it can be absorbed rapidly by the phytoplankton and from there to superior organisms. The damages caused by the said substance are: affection of the immunological system, the nervous system, produces abnormal growth of embryos and the alteration in genetic enzyme systems.

Also cadmium is subject to the most severe legislation due to its extreme toxicity, as it is very harmful even in low concentrations, basically for the effect it causes to enzymes. It accumulates in the liver, kidney and the gastrointestinal tract with the following consequences: poor mineralization of the bones, retarded growth, anaemia, problems in tonsils and kidneys.

Finally reference also has to be made to lead, as its size and weight can substitute calcium, being an area of accumulation of osseous tissue. Causing the following damage: the development and growth of foetus, the nervous system, disorders in behaviour and neurological deficits.

2.5. CONTAMINACION BY GARBAGE

We refer here to solid waste such as, paper, tins, bottles, plastics, tires …, which threaten marine life provoking death by asphyxia, ingestion, or being entangled in them. These are persistent materials that are abandoned near the coastline destroying natural habitats and affecting coastal biological production for this reason investigation is vital to find ways and means of eliminating this type of contamination and how to stop the seas and oceans becoming the final destination of our waste.

2.6. CONTAMINATION BY RESUDUAL HEAT

Thermal contamination due to the heat produced as a sub product from many industrial processes, for example power stations, waters used as refrigerants that can reach as much as 12º C higher than the environmental temperature of the water.

Heat as a contaminant when it reaches the aquatic environment causes alterations in seasonal variations in the temperature of the water, changing the natural reproductive cycle of the organisms and therefore producing a higher number of individuals than food, causing death. The increase in the superficial temperature of the water can reach vital limits or induce changes in solubility of dissolved oxygen, diminishing its concentration with the consequent modification of the ecosystem.

3. CONCLUSIONS

We do not pretend to create a catastrophic picture of this problem, but make the point that the anthropic pressure to which our populated coast lines are submitted are extremely excessive. It is only our intention to open people's eyes before a problem that exists and whose results are obvious. There must be an immediate change in the attitude that governments and the world's population in general manifest towards our seas and oceans. We have to minimize the environmental risks, protect as many natural areas as possible, create effective policies to protect our coastline, demand efficient purifying systems for sewage and waste together with a long etc etc… *in environmental material there is still a lot to do.*

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APENDICE: EL MAR Y SUS CONTAMINANTES

RESUMEN

El hombre produce diversidad de contaminantes que, directa o indirectamente, llegan al océano. Algunos de origen orgánico se desintegran por procesos biológicos normales, pero otros como plaguicidas, resisten la descomposición y subsisten largo tiempo en el ambiente, ocasionando distintos efectos perjudiciales sobre la vida marina y salud humana.

Palabras claves: toxicidad, persistencia, bioacumulación.

1. INTRODUCCIÓN

El desconocimiento del medio marino de tiempos atrás, propiciaron que se viera en el océano un depósito favorable que por inmensas dimensiones y capacidad de autodepuración podría utilizarse como receptor ilimitado de todo tipo de contaminantes, por lo que no es de extrañar que la salud de nuestros mares se vea mermada por un uso indiscriminado que no tuvo en cuenta las limitaciones del medio físico y biológico.

2. METODOLOGÍA: TIPOS DE CONTAMINACIÓN

Cabe destacar que la contaminación no se refiere a la “ pureza “ de las aguas, sino a las modificaciones de sus características, pues las aguas naturales presentan un grado de pureza variable y además, no hay que olvidar que el agua químicamente pura no es favorable para el desarrollo de los seres vivos.

2.1. CONTAMINACIÓN MICROBIOLÓGICA

Ocasionada por aguas residuales domésticas que portan los efluentes urbanos. Son aguas que contienen una elevada concentración de microorganismos, muchos patógenos, que al llegar al mar contaminan playas y pesquerías.

2.2. CONTAMINACION POR SUSTANCIAS NUTRITIVAS EUTROFIZACIÓN

Los desechos procedentes de la industria, agricultura y aguas residuales al llegar al mar son desdoblados químicamente por las bacterias, originando sustancias inorgánicas que denominamos nutrientes (proceso de remineralización).

2.3. CONTAMINACIÓN POR HIDROCARBUROS

Aunque los hidrocarburos son de origen natural, los que se encuentran en el medio marino costero provienen de fuentes antrópicas (refinerías, transporte marítimo, escorrentía industrial y urbana…).

El petróleo, convertido en uno de los contaminantes más extendidos en los océanos, deteriora playas y la calidad del agua, daña la producción de peces y crustáceos, llegando a ser un problema de gran importancia para las pesquerías mundiales.

2.4. CONTAMINACIÓN POR SUSTANCIAS ACUMULATIVAS

Existen una serie de sustancias creadas por la industria o elaboradas como subproductos de procesos industriales, de difícil degradación, que llegan al medio marino acumulándose en los organismos expuestos a concentraciones bajas o moderadas, pasando posteriormente a la cadena trófica y pudiendo llegar así hasta el hombre.

Nos referimos a sustancias radioactivas, compuestos orgánicos persistentes (COP) y metales pesados.

2.5. CONTAMINACIÓN POR BASURAS

Hace referencia a desechos sólidos, tipo papel, latas, botellas, plásticos, neumáticos..., que amenazan la vida marina al provocar la muerte por asfixia, ingestión o enredándose en ellos. Son materiales persistentes que se abandonan en el medio costero destruyendo habitats y afectando a la producción biológica costera, por lo que se hace necesario investigar, cómo eliminarlos y cómo frenar la dinámica de convertir al océano en el depósito final de los residuos.

2.6. CONTAMINACIÓN POR CALOR RESIDUAL

Contaminación térmica debida al calor desprendido como subproducto de muchos procesos industriales, como el de la energía eléctrica, y aguas usadas como refrigerantes que pueden llegar a alcanzar hasta 12 ºC de diferencia con las del medio.

3. CONCLUSIONES

No pretendemos crear una idea catastrofista del problema, sólo dejar constancia de que la presión antrópica que reciben los litorales más poblados es excesiva. Nuestra intención no es otra que abrir los ojos ante un problema que existe y que resulta ineludible. Debe cambiar de manera inmediata, las actitudes que gobernantes y ciudadanos manifestamos hacia el mar. Hay que minimizar los riesgos ambientales, proteger amplias zonas naturales, crear políticas efectivas de gestión del litoral, exigir sistemas eficientes de depuración de desechos y un largo etcétera… *en materia ambiental queda mucho por hacer.*

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