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Abstract

The list of marine alien species in Hellenic waters is updated taking into account new findings (published and unpublished data). According to the present work, the number of these species has increased from 90 (known until end 2003) to 128. Most of them are zoobenthic species followed by fish and macroalgae. An interannual analysis revealed an important increase of alien species during the last years. The study of their geographic distribution showed that their majority is present in the southeastern Aegean. More than 55% of them are well established, while about 40% are casual records. Their main pathway of introduction seems to be the Suez Canal followed by shipping, whereas the Straits of Gibraltar, aquaculture and the Straits of Dardanelles appear to play a less important role in their invasion of Hellenic waters. These findings are discussed considering environmental and anthropogenic factors.

Keywords: Alien marine species; Greece; Ionian; Aegean; Mediterranean; Lessepsian migration.

Introduction

It is now accepted that during the last decades the marine biota of the Eastern Mediterranean Sea is experiencing severe changes, due to the introduction of alien species. Even though biotic invasion via ballast waters, fouling, aquaculture, accidental introduction etc. play a significant role in the Eastern Basin, the main pathway of alien species' spreading remains the Suez Canal. Despite impediments such as the canal's length, shallowness, current regime, temperature and salinity extremes, hundreds of species of Indo-Pacific origin (the so-called "Lessepsian immigrants") have traversed the canal and settled in the Eastern Mediterranean, an ongoing phenomenon well documented by POR (1978), ZIBROWIUS (1992), STREFTARIS *et al*. (2005). After a series of scattered publications dealing with single species or groups (KEVREKIDES & GALIL, 2003; CORSINI *et al*., 2005; ZENETOS *et al*., 2005; SIMBOURA & ZENETOS, 2005), the first attempt to compile available information on alien species recorded in Hellenic waters is an inventory prepared by PANCUCCI-PAPADOPOULOU *et al.* (2005) which takes into account records up to 2003. Two years later, with a plethora of new findings and the contribution of more experts in the field, it is considered necessary to revise the previous inventory.

The present effort comes to elucidate any discrepancy with the previous inventory, adding new records and discussing questionable cases.

Methods

The basis of the present work is the checklist of alien species in Hellenic waters reported by PANCUCCI *et al.* (2005). However, this has been revised on the basis of the annotated list of ZENETOS *et al*. (this volume), according to which some species in the checklist have been classified by Mediterranean experts as "questionable" or "excluded", while some others previously excluded, have been added. Additional records of species sighted in the period 2004-2005, published or recorded in the grey literature, as well as species belonging to taxonomic groups not considered previously and unpublished records are included. Grey literature includes HCMR and EU technical reports, 2005 Scientific Congresses, personal communication by specialists, website (seaslug forum, algaebase).

The distribution of each taxon in the Hellenic Seas was established from the scrutiny of more than 100 references. Only some references of interest plus the more recent are cited due to space limitations.

All calculations are based on species' records up to December 2005. Alien species have been grouped into five broad categories covering ecofunctional groups: phytoplankton (PP), phytobenthos (PB), zooplankton (ZP), zoobenthos (ZB) and fish (F). Cryptogenic species are not included in our compiled list.

According to their establishment success alien species have been classified into four main categories, namely established, casual, questionable and excluded, in the sense described in ZENETOS *et al*. (this volume). Excluded species are not counted in calculations, while questionable which may turn out to be established, are taken into account.

Results

A. Diversity of Alien Taxa

The total number of aliens recorded/brought to our attention until December 2005 reaches 140 species (Table 1) of which 7 are questionable and 13 excluded, according to the screening procedure described in detail in ZENETOS *et al*. (this volume). The majority of aliens is represented by zoobenthos (63 species) followed by fish (32 species) and macroalgae (16 species) (Fig. 1).

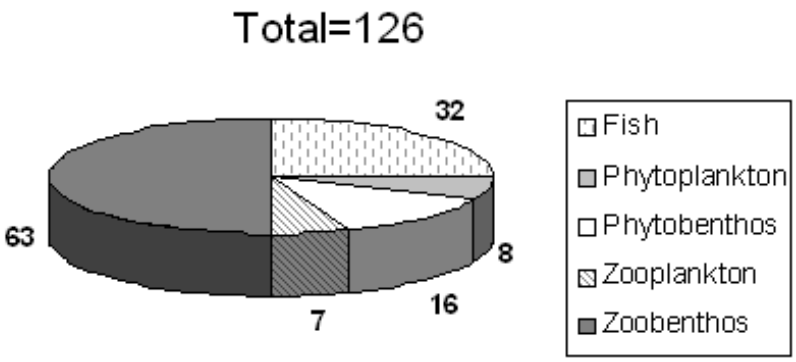

Fig. 1: The contribution of main marine groups of aliens in Hellenic waters**.**

Table 1
List of aliens per group.
Asterisk denotes new entries
ES: Establishment success (E: Established, C: Casual, Q: Questionable, Ex: Excluded)

Fish	**ES**
**Etrumeus teres*	E
**Iniistius pavo*	C
**Lagocephalus sceleratus*	E
**Lagocephalus suezensis*	E
**Petroscirtes ancylodon*	C
**Seriola fasciata*	C
**Tylerius spinosissimus*	C
**Tylosyrus crocodilus*	C
**Upeneus pori*	C
Alepes djedaba	C
Apogon pharaonis	E
Atherinomorus lacunosus	C
Callionymus filamentosus	C
Enchelycore anatina	C
Fistularia commersonii	E
Gaidropsarus granti	Q
Hemiramphus far	E
Lagocephalus spadiceus	E
Leiognathus klunzingeri	E
Mugil soiuy = Liza haematocheila	C
Parexocoetus mento	E
Pempheris vanicolensis	E
Pteragogus pelycus	E
Sargocentron rubrum	E
Saurida undosquamis	E
Siganus luridus	E
Siganus rivulatus	E
Sphoeroides pachygaster	E
Sphyraena chrysotaenia	E
Sphyraena flavicauda	C
Stephanolepis diaspros	E
Upeneus moluccensis	E
Phytobenthos (PB)	
**Acanthophora nayadiformis*	C
**Acrothamnion preissii*	**Ex**
Asparagopsis armata	E
**Caulerpa racemosa*	E
**Ceramium bisporum*	**Ex**
**Chondria collinsiana*	C
**Chondria polyrhiza*	C
Codium fragile tomentosoides	E
Colpomenia peregrina	C
**Grateloupia subpectinata* (=*G. filicina* var. *luxurians*)	C
Halophila stipulacea	E
**Hypnea esperi*	**Ex**
**Hypnea spinella* (=*H. cervicornis*)	C
**Hypnea valentiae*	C
**Laurencia okamurae* (= *L. coronopus*)	**Ex**
**Lophocladia lallemandii*	C
**Neosiphonia sphaerocarpa*	C
**Polysiphonia fucoides* (= *P. nigrescens)*	**Ex**
**Sarconema filiforme*	**Ex**
Sarconema scinaioides	E
Stypopodium schimperi	E
**Womersleyella setacea*	E
Phytoplankton (PP)	
**Alexandrium insuetum*	E
**Alexandrium taylori*	E
Alexandrium tamarense	**Ex**
**Histioneis detonii*	C
**Gymnodinium mikimotoi*	E
**Gymnodinium (= Karenia) breve*	E
**Gymnodinium catenatum*	E
**Gymnodinium fusus*	**Ex**
**Phaeocystis pouchettii*	E
**Prorocentrum mexicanum*	E
**Rhizosolenia alata*	**Ex**

(continued)

(continued)

Zoobenthos (ZB)	
Crustacea	
**Balanus trigonus*	E
**Calappa pelii*	C
**Leucosia signata*	C
**Megabalanus tintinnabulum*	Q
**Myra subgranulata*	C
**Percnon gibbesi*	E
**Stenothoe gallensis*	E
Alpheus rapacida	C
Callinectes sapidus	E
Charybdis longicollis	E
Erugosquilla massavensis	E
Ixa monodi	C
Marsupenaeus japonicus	E
Metapenaeopsis aegyptia	E
Metapenaeopsis mogiensis consobrina	E
Portunus pelagicus	E
Thalamita poissonii	E
Trachysalambria palaestinensis	E
Mollusca	
**Aplysia dactylomeda*	E
Acteocina mucronata	C
Anadara demiri	E
Brachidontes pharaonis	E
Bulla ampulla	E
Bursatella leachi	E
Cellana rota	C
Crassostrea gigas	E
Crepidula fornicata	E
Cylichna girardi	C
Fulvia fragilis	E
Gastrochaena cymbium	C
Haminoea cyanomarginata	C
Malvufundus regulus	C
Melibe fimbriata	E
Murex forskoehli	Q
Mya arenaria	C
Nerita sanguinolenta	C
Petricola pholadiformis	C
Pinctada radiata	E
Pleurobranchus forskali	C
Polycerella emertoni	C
Pseudochama corbieri	C
Rapana rapiformis	Q
Rapana venosa	C
Smaragdia souverbiana	Q
Strombus persicus	E
Trochus erythraeus	E
Polychaeta	
**Desdemona ornata*	E
**Ficopomatus enigmaticus*	E
**Hydroides dianthus*	E
Branchiosyllis exilis	**Ex**
Cossura coasta	Q
Hydroides elegans	E
Lysidice collaris	Q
Metasychis gotoi	E
Notomastus aberans	C
Paradyte cf. crinoidicola	C
Prionospio pulchra	C
Prionospio salzi	**Ex**
Scoloplos chevalieri candiensis	**Ex**
Spirobranchus tetraceros	C
Spirorbis marioni	C
Timarete anchylochaeta	**Ex**
Miscellanea	
**Oculina patagonica*	E
**Synaptula reciprocans*	C
Aspidoshiphon mexicanus	C
Hippopodina feegeensis	C
Ophiactis savignyi	C
Zooplankton (ZP)	
**Paracartia grani*	E
**Arietellus pavoninus*	E
Calanopia elliptica	C
Centropages furcatus	C
Mnemiopsis leidyi	E
Pseudocalanus elongatus	E
Cassiopeia andromeda	C

Table 2
Alien species sighted since 2003.

Group	Species latin name	Year of intro-duction	Area	Reference
Fish	*Etrumeus teres*	2003	Kyklades: Paros, Naxos, Ios, N.Kriti	CORSINI *et al*., 2005 KALLIANIOTIS & LEKKAS, 2005
	Lagocephalus suezensis	2003	Rodos	CORSINI *et al*., in press
	Tylosyrus crocodilus	2003	Chalkidiki	SINIS, 2005
	Upeneus pori	2003	Rodos	CORSINI *et al*., 2005
	Iniistius pavo	2004	Rodos	CORSINI *et al*., in press
	Petroscirtes ancylodon	2004	Rodos	CORSINI *et al*., 2005
	Seriola fasciata	2004	Rodos	CORSINI *et al*., in press
	Tylerius spinosissimus	2004	Rodos	CORSINI *et al*., 2005
	Lagocephalus sceleratus	2005	Rodos, Symi, N. Kriti	CORSINI *et al*., 2005
Zoobenthos				
Crustaceans	*Myra subgranulata*	2004	Rodos	CORSINI & KONDILATOS, in press
	Percnon gibbesi	2004	Messiniakos, Kriti, Rodos	KAMBOUROGLOU *et al*., in press
	Leucosia signata	2005	Rodos	CORSINI *et al*., in press
	Calappa pelii	2005	Saronikos, N. Ionian	POLITOU, unpublished
Molluscs	*Aplysia dactylomeda*	*2005*	Messiniakos	*Sea slug website*
Cnidaria	*Oculina patagonica*	2005	Saronikos	SALOMIDI *et al*., in press
Echino-derms	*Synaptula reciprocans*	2005	Rodos	ZIBROWIUS, unpublished

Thirty eight new records are added to the inventory of PANCUCCI *et al*. (2005), 16 of which were sighted in the period 2003-2005 (Table 2) and published within 2005 or are as yet unpublished. Among the remaining 22 species, 14 are earlier records hidden in grey literature or previously excluded because of some uncertainties. These include: the copepods *Paracartia grani, Arietellus pavoninus*, the polychaetes *Desdemona ornata, Ficopomatus enigmaticus* and *Hydroides dianthus* and many macroalgae (phytobenthos). The remaining 8 are species of phytoplankton, which was not treated in the previous inventory. These are: *Alexandrium insuetum, Alexandrium taylori, Gymnodinium (=Karenia) breve, Gymnodinium mikimotoi, Histioneis detonii, Phaeocystis pouchettii, Prorocentrum mexicanum* and *Gymnodinium catenatum.*

As seen in Table 2, the additional records belong mostly to fish (9) and zoobenthos (7) which indicate that they are the most studied groups, as opposed to phytobenthos and zooplankton that are studied less.

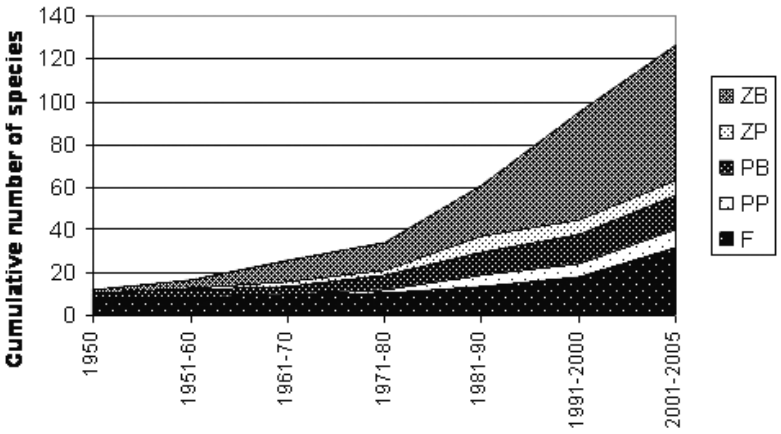

Fig. 2: Chronological trends of aliens in Hellenic waters (ZB: zoobenthos, ZP: zooplankton, PB: phytobenthos, PP: phytoplankton and F: fish).

B. Chronological trends

Compared to the 17 species reported by POR (1978) in Hellenic waters about 100 years after the opening of the Suez Canal, a vast increase of alien species during the last two decades is noted. An increasing trend in the occurrence of aliens (Fig. 2) that started in the decade 1980-1990 coincides with the revival of Hellenic taxonomists mainly in zooplanktonic and zoobenthic groups. This continues in the next decade, when not only Hellenic but the world scientific interest is increased in aliens, and culminates in the present decade. It is worth noticing that intensive research during the last three years has revealed 16 new entries (Table 2).

C. Geographic distribution

Figure 3 shows aliens' zoogeographical patterns in Hellenic waters. The bulk is present in the southeastern Aegean, their presence decreasing significantly northwards and westwards. Ninety eight out of 126 alien species nowadays accepted as casual or established have been reported from the South-Central Aegean Sea (south of 38^{o} parallel). Indeed, 69 aliens are known from the eastern part of the South Aegean (Dodekanisos Islands), with a peak of 63 along the NW coast of Rodos Island, while only 34 have been recorded from the rest of the South Aegean. This testifies the importance of the area as the main pathway of lessepsian immigrants spreading within the Mediterranean. Particular notice should be given to the 34 species found in the restricted area of the Saronikos and Argolikos Gulfs, closely related to the route of ships towards Peiraias, the biggest Hellenic port. A marked decrease of the aliens appears northwards, with only 36 species recorded in the North Aegean, 14 of them present in the Bay of Thessaloniki, where the second major port of Hellas is located. In Thessaloniki Bay the majority of species are those coming from the Black Sea or transported in ballasts, as opposed to the dominance of lessepsian immigrants observed in the South Aegean. Distribution of alien species in the Ionian coasts is even more restricted (30 species), mostly introduced via ballasts or fouling, with only a few, mainly fishes, being of Indo-Pacific origin.

D. Establishment success

Twenty species are considered as "questionable" or "excluded" in Table 1, mainly due to the uncertainty of their real taxonomical status

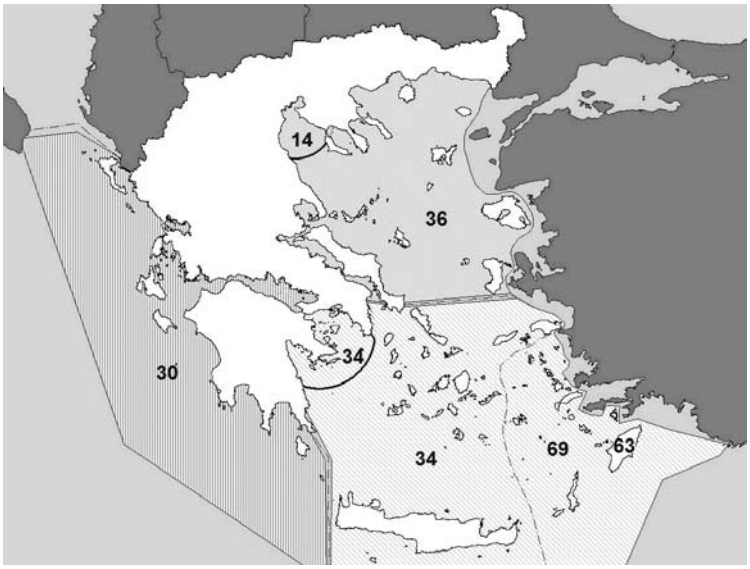

Fig. 3: Patterns of alien species distribution in Hellenic waters.

and distributional patterns. Of the 126 species (including 7 questionable records), 69 (55%) are well established, being locally abundant and even exploited in Hellenic waters and 50 (40.3%) consist of casual records reported sporadically from one or two locations. The worst invasive species in terms of spread and impact are encountered among molluscs (*Pinctada radiata, Strombus persicus*), crustaceans (*Marsupenaeus japonicus, Charybdis longicollis, Erugosquilla massavensis*), fish (*Siganus luridus, Siganus rivulatus, Sphyraena chrysotaenia, Fistularia commersonii*) and macroalgae (*Asparagopsis armata, Caulerpa racemosa, Codium fragile*).

E. Pathways of introduction

Figure 4 shows the percentage of invasion pathways in Hellenic waters. The most important way appears to be the Suez Canal opening (60%), while the second is the accidental transportation via shipping (25%). The gradual introduction from the western Mediterranean is also significant (5%), while the introduction from the Black Sea via Dardanelles) is very limited.

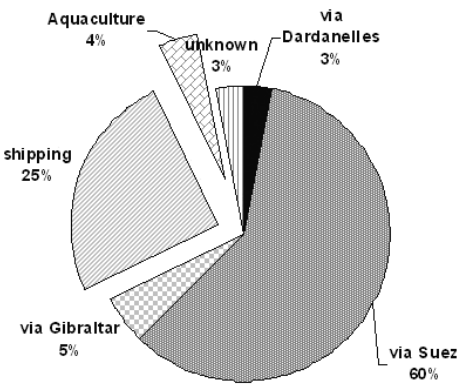

Fig. 4: Pathways of introduction of alien species into Hellenic waters.

E1. Introduction of alien species in ballasts/fouling

Thirtyfour species are assumed to have been transferred via shipping. Ship borne invaders are represented by phytoplankton (5 species), zooplankton (2 species), phytobenthos (7), and zoobenthos (19) [Cnidaria (1), Cirripedia (2),

Mollusca (8), Polychaeta (4), Amphipoda (1), Decapoda (2), Hydrozoa (1)].

A review of the alien biota recorded in the broader area of the major Hellenic ports (Peiraias, Thessaloniki) that is, in the inner Saronikos and Thermaikos Gulfs (HCMR technical reports, SIOKOU-FRANGOU, 1999; VARDALA-THEODOROU, 1999; ZENETOS, 1994; ZENETOS *et al*., 2002) has revealed the presence of 32 and 14 species, respectively, of which only 5 are common. These are: the dinoflagellate *Gymnodinium mikimotoi,* the nanoflagellate *Phaeocystis pouchettii*, the copepod *Paracartia grani,* the polychaete *Metasychis gotoi* and the mollusc *Crepidula fornicata.*

The presence of *Strombus persicus*, which was earlier attributed to shipping in the eastern Mediterranean (Iskenderun) (ZENETOS *et al*., 2003) and subsequently in Hellas, is now argued. Its wide expansion in Rodos and many Hellenic areas including the Saronikos Gulf (the Peiraias port broader area) is rather due to its invasive character. Therefore, Lessepsian migration appears to be its means of transportation. Similarly, molecular studies of *Pinctada radiata* populations in the Saronikos (ZENETOS *et al*., 2004) have rather excluded shipping as mode of transportation.

E2. Introduction of alien species through fish/shellfish imports

It is unknown when the Pacific oyster *Crassostrea gigas* was imported for mariculture in Hellas. Although it is not currently cultured, self maintained populations have been recorded in the Ionian Sea. Similarly, the pearl oyster *Pinctada radiata* was imported as early as 1963, but its cultivation did not prove prosperous and was thus abandoned. However, the species was naturalised and expanded in the Hellenic Seas. (ZENETOS *et al*., 2003).

The So-iuy mullet *(Mugil soiuy)* has been introduced for exploitation in the Northern Aegean Sea and is commercially exploited.

The following three species, which are encountered in mariculture areas, are considered accidental introductions: *Grateloupia subpectinata, Prionospio pulchra* and *Hydroides dianthus*.

Discussion

Intensive research and data mining the last years have increased the number of aliens in Hellenic waters from 90 (end 2003, PANCUCCI-PAPADOPOULOU *et al*., 2005) to 126 (present work) and in particular from 15 records of ship transported species reported in 2002 (ZENETOS *et al*., 2002), to 34. Intensive work in Hellenic ports, currently in progress, has brought to light more species carried among hull fouling (unpublished data).

Introductions of alien species are still going on and a global increase in the number of successful colonisation events is being observed (GRUSZKA, 1999). This is certainly true for the biological invasion in Hellenic waters. After a period of "gradual" spread of alien species via the Suez Canal to the eastern basin, it seems that during the last years a significant increase has been occurring, which reflects a new order of things in the area. This can be related to the adaptation time of "invaders" to their new habitat or, more simply, to the increased interest of the scientific community during the two last decades. It is, however, undeniable that Indo-Pacific biota records are continuously increasing along Hellenic coasts. The significant increase observed in the rate of introduction in the South Aegean could be related to the sampling depth, as it is known that settlement of Erythrean species is favoured in shallow areas with warm waters and the attention of Hellenic scientists has only recently been turned to very shallow coastal benthos. On the other hand, we cannot exclude the possibility of a gradual 'colonisation' of this 'hotspot' region due to climatic changes.

POR (1990) predicted that the distribution of Erythrean immigrants "will certainly expand or shrink according to the climatic evolution in the area" and that "immigrants will expand further

west if the climate warms up further". Moreover, the occurrence and spread of thermophilic species in the Mediterranean, either indigenous or alien, the so-called tropicalization of the Mediterranean has been attributed to the combination of four factors, namely: the Atlantic flux, lessepsian migration, human action and present climate warming (BIANCHI & MORRI, 2003).

Regarding the South Aegean, during 1988-1992 anomalies in meteorological parameters (very cold winters; dry years) were observed, in association with changes in the water mass pathways and a 1-4 fold increase in salt transport from the Levantine into the Aegean in the upper 200 m layer between 1987 and 1994 (THEOCHARIS *et al*., 1999). The increased outflow of the newly formed denser water through the Cretan Arc straits into the eastern Mediterranean was compensated for by inflowing Levantine surface and intermediate waters (WU *et al*., 2000). Significant changes resulted in the south Aegean water mass characteristics, which considerably influenced the thermohaline circulation of the eastern Mediterranean, termed the Eastern Mediterranean climatic Transient (EMT).

Although there is no documentation of direct competition between Erythrean and indigenous species, there are many instances of sudden changes in abundance where competition is suspected. Thus, if the present characteristics of the south Aegean hydrography persist, a modification of the composition and structure of the fauna is entirely possible.

The geographic distribution of alien species in the three major subareas of Hellenic waters (South, North Aegean, Ionian) clearly reflects the main hydrographic features of the subareas and shows that with the exception of those brought by shipping, the percentage of alien species in the North Aegean is almost negligible. This indicates that some natural "frontiers" still exist and may prevent the invasion/establishment of undesirable species. All that is needed is effective legislation considering all pathways associated. Because, although it is unrealistic to stop a physical (or man-mediated phenomenon like Lessepsian migration), it is feasible to stop invasion from other sources.

In conclusion, it seems that, apart from the increasing interest of the scientific community in the phenomenon, a gradual warming of the area is occurring over the last years, resulting in more favourable climatic conditions for the establishment of new invaders.

Addendum

While this paper was accepted for publication two more species were recorded bringing the total number of marine aliens to 128. The new findings are: the polychaete *Pseudonereis anomala* (KAMBOUROGLOU & NICOLAIDOU, 2006) and the decapod *Charybdis helleri* (KIRMITZOGLOU *et al.*, 2006).

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