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► To cite this version:

B. Austin. Vibrios as causal agents of zoonoses. *Veterinary Microbiology*, 2010, 140 (3-4), pp.310. 10.1016/j.vetmic.2009.03.015 . hal-00556049

HAL Id: hal-00556049

<https://hal.science/hal-00556049>

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Accepted Manuscript

Title: Vibrios as causal agents of zoonoses

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PII: S0378-1135(09)00119-9
DOI: doi:10.1016/j.vetmic.2009.03.015
Reference: VETMIC 4385

To appear in: *VETMIC*

Received date: 9-1-2009
Revised date: 9-2-2009
Accepted date: 2-3-2009



Please cite this article as: Austin, B., Vibrios as causal agents of zoonoses, *Veterinary Microbiology* (2008), doi:10.1016/j.vetmic.2009.03.015

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Vibrios as causal agents of zoonoses

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23 **Abstract**

24 Vibrios are Gram-negative rod shaped bacteria that are widespread in the coastal
25 and estuarine environments. Some species, e.g. *Vibrio anguillarum* and *V. tapetis*,
26 comprise serious pathogens of aquatic vertebrates or invertebrates. Other groups,
27 including *Grimontia* (= *Vibrio*) *hollisae*, *Photobacterium* (= *Vibrio*) *damselae*
28 subsp. *damselae*, *V. alginolyticus*, *V. carchariae* (= *V. harveyi*), *V. cholerae*, *V.*
29 *fluvialis*, *V. furnissii*, *V. metschnikovii*, *V. mimicus*, *V. parahaemolyticus* and *V.*
30 *vulnificus*, may cause disease in both aquatic animals and humans. The human
31 outbreaks, although low in number, typically involve wound infections and gastro-
32 intestinal disease often with watery diarrhoea. In a minority of cases, for example
33 *V. vulnificus*, there is good evidence to actually associate human infections with
34 diseased animals. In other cases, the link is certainly feasible but hard evidence is
35 mostly lacking.

36

37 *Keywords:* Vibrios; Fish; Invertebrates; Wound infections; Gastro-enteritis

38

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60 1. Introduction

61 The vibrios are Gram-negative rod shaped bacteria that are fermentative,
62 catalase and oxidase positive, motile by polar flagella, are usually sensitive to the
63 vibriostatic agent, O/129, and mostly have a requirement for sodium chloride
64 (Farmer et al., 2005). Taxonomic improvements have resulted in some vibrios
65 transferred to new genera, e.g. *Vibrio hollisae* which was re-classified to the newly
66 created genus *Grimontia* as *G. hollisae*, or moved to other genera, e.g. *V. damsela*
67 which was transferred to *Photobacterium* as *P. damsela* (Farmer et al., 2005).
68 The organisms are generally widespread in the coastal and estuarine environments;
69 some species, e.g. *V. parahaemolyticus*, are commonplace in/on aquatic animals,
70 notably invertebrates (Farmer et al., 2005). Certainly, a steadily increasing
71 number of taxa, e.g. *V. anguillarum* and *V. tapetis*, have been associated with
72 diseases of aquatic animals, whereas other species, e.g. *V. cholerae*, comprise
73 serious pathogens of humans (Farmer et al., 2005; Austin and Austin, 2007). A
74 comparatively small number of species, e.g. *V. parahaemolyticus* and *V.*
75 *vulnificus*, cause disease in both aquatic animals and humans. However, there is a
76 dilemma that because an organism occurs in an aquatic animal, it does not
77 necessarily mean that this is the source of human infections. Indeed, the evidence
78 linking vibrios with zoonoses is at best incomplete and sometimes the subject of
79 conjecture. Fortunately, the number of cases of human diseases that may be traced
80 to animals is small, although comprehensive official statistics are missing. The
81 candidates for discussion include *G. hollisae*, *P. damsela* subsp. *damsela*, *V.*
82 *alginolyticus*, *V. harveyi* (= *V. carchariae*), *V. cholerae*, *V. fluvialis*, *V. furnissii*,
83 *V. metschnikovii*, *V. mimicus*, *V. parahaemolyticus* and *V. vulnificus* (Table 1). It
84 should be emphasized that the source of most of the organisms causing human

85 disease cannot be linked definitively to animals. Indeed, the origin of some of
86 these bacteria may well be the waters in which the aquatic animals are found.
87 Transmission to humans is inevitably via wound or may be food/water borne and
88 involving direct entry into the digestive tract. Certainly, all the taxa included in
89 this review have the potential to cause human disease although the evidence for a
90 definite link between animals and humans is not always proven. The narrative
91 will be divided into those organisms, e.g. *V. vulnificus*, for which there is a higher
92 risk and good evidence linking them with zoonoses, and those for which the risk is
93 lower and the data may be more uncertain.

94

95 **2. Higher risk organisms**

96 Three taxa, namely *V. cholerae*, *V. parahaemolyticus* and *V. vulnificus*, have been
97 either repeatedly involved in disease outbreaks or have the potential to do so.

98

99 **2.1. *Vibrio cholerae***

100 An epizootic, attributed to *V. cholerae* occurred in a wild population of ayu
101 (*Plecoglossus altivelis*) in the River Amano, Japan, with disease signs including
102 petechial haemorrhages on the body surface and congestion of the organs (Austin
103 and Austin, 2007). A similar organism was recovered from septicemic goldfish
104 in Australia and from sharks (see Austin and Austin, 2007). Also, there is some
105 indication that *V. cholerae* (non-O1 and O139) may be involved in shrimp disease,
106 specifically of *Penaeus monodon* (Haldari et al., 2007) and ornamental fish
107 (Swaminathan et al., 2007) in India. Infectivity experiments suggested that *V.*
108 *cholerae* was highly virulent to ayu and eels following immersion in 1.26×10^4
109 cells ml⁻¹ and 1.26×10^2 cells ml⁻¹, respectively. Yamanoi et al. (1980) reported

110 that with ayu, mortalities began in 2-7 days at water temperatures of 21 and 26°C,
111 but deaths did not occur if the water temperature was at only 16°C. Only 10%
112 mortalities occurred in eels within 5 days at a water temperature of 21°C, and 30%
113 deaths in 3-7 days at 26°C.

114

115 *V. cholerae* is the cause of the human pandemics of cholerae, which is caused
116 by cholera-toxin producing strains, and develop into extreme gastro-enteritis with
117 copious quantities of watery diarrhoea leading to dehydration (Morris, 2003).
118 Historically, cholera has been associated with toxigenic serogroup O1 strains, but
119 subsequently there was the emergence of cholera-toxin producing ability in other
120 groups, i.e. serogroup O139/non-O1. The question of relevance to the current
121 context is whether or not strains from aquatic animals carry the toxin gene?
122 Unfortunately, there is indeed evidence that some of the environmental isolates
123 have been associated with toxigenicity. Toxin-gene (*ctxA* and *zot*) carrying
124 strains have most certainly been recovered from marine waters off the west coast
125 of USA (Jiang et al., 2003).

126

127 The source of some outbreaks has been linked with contaminated shellfish,
128 including raw oysters (Morris, 2003) and crabs (CDC, 1991), and involves non-O1
129 and non-O139 strains (Farama et al., 2008). An outbreak of cholera in Louisiana,
130 USA in 1978 was associated with shellfish caught in the Gulf of Mexico (Blake et
131 al., 1980). Crabs, which had been transported from Ecuador to New York in 1991,
132 resulted in three individuals developing cholera. These people and samples of
133 crab meat revealed the presence of the pathogen (CDC, 1991). Also, cells have
134 been transferred in the water used to transport ornamental fish from countries in

135 which cholera occurs (Manfrin et al., 2001). In one study between 1997 and 1998,
136 34 out of 420 water samples (= 8.09% of the total) revealed the presence of *V.*
137 *cholerae* non-O1, and it was considered that their enterotoxins could pose a
138 potential risk of gastro-enteritis in humans especially those operating aquaria or
139 keeping pet fish (Manfrin et al., 2001).

140

141 **2.2. *Vibrio parahaemolyticus***

142 The organism has been associated with mortalities in Iberian toothcarp
143 (*Aphanius iberus*) with the signs centering on external haemorrhages, and tail rot
144 (Austin and Austin, 2007). Cultures regarded as intermediate between *V.*
145 *alginoliticus* and *V. parahaemolyticus* were recovered from diseased milkfish
146 (*Chanos chanos*) in the Philippines (Austin and Austin, 2007). Certainly, *V.*
147 *parahaemolyticus* is a well-recognized pathogen of invertebrates, including
148 abalone, *Haliotis diversicolor supertexta* (e.g. Cai et al., 2007) and shrimp (e.g.
149 Jayasree et al., 2006). Disease signs in abalone include a change in colour to white
150 and a detachment from the diatom films on which they are cultured (Cai et al.,
151 2007). In *Penaeus monodon*, the organism has been implicated as a cause of red
152 disease in India (Jayasree et al., 2006). Pathogenicity has been established in tiger
153 prawns with the LD₅₀ dose of 1×10^5 CFU shrimp⁻¹ (Sudheesh and Xu, 2001).
154 The corresponding value in abalone post-larvae was 3.5×10^5 CFU ml⁻¹ with the
155 disease mirroring that of natural infections (Cai et al., 2007).

156

157 *V. parahaemolyticus* may spread into humans orally via contaminated food,
158 particularly molluscs such as oysters (DePaola et al., 2003; Drake et al., 2007)
159 leading to the development of acute gastro-enteritis with diarrhoea (Cho et al.,

2008). In Denmark during 1987-1992, the organism was recovered from 13 patients of whom 3 and 10 displayed wound and ear infections, respectively. With many cases, there was a prior association with the marine environment (Hornstrup and Gahrnhansen, 1993). A seasonality in diarrhoeal cases, which was not linked to age, was reported in Korea between 2004-2006 (Cho et al., 2008). Virulence factors centre on proteases, β -haemolysins, notably the thermostable direct haemolysin (tdh) and the tdh-related haemolysin (trh), adhesins and the expression of *V. cholerae* virulence genes including the *toxR* operons (DePaola et al., 2003; Snoussi et al., 2008).

2.3. *Vibrio vulnificus*

The organism was recognized as a serious pathogen of eels in Japan during the 1970's with subsequent cases in Spain and Denmark (Austin and Austin, 2007). In addition, *V. vulnificus* has been mentioned as a cause of disease in *Penaeus monodon* in India (Jayasree et al., 2006). Overall, the disease is characterized by haemorrhaging seen as redness on the body surface, and later as involvement of the gastro-intestinal tract, gills, heart, liver and spleen (Austin and Austin, 2007). In 2005, the pathogen caused substantial mortality in farmed ovate pompano (*Trachinotus ovatus*) in P.R.C., with signs including external haemorrhaging and ulcers, and haemorrhaging of the gills, intestine and liver (Li et al., 2006). A new serogroup, i.e. *V. vulnificus* biotype 2 serovar A was recognized in Spain in 2000 and Denmark by 2004; the affected eels demonstrated extensive haemorrhaging and necrosis (Fouz et al., 2006). *V. vulnificus* has been recovered from fish caught in the US Gulf Coast (DePaola et al., 1994), with minimum and maximum numbers occurring in winter and April to October, respectively DePaola et al.

185 (1994). The highest levels, i.e. 10^8 bacteria 100 g^{-1} , were associated with the gut
186 contents of bottom-feeding fish, which ate molluscs and crustacea. Lower
187 populations were recovered from plankton-feeding fish, i.e. 10^5 *V. vulnificus* cells
188 100 g^{-1} .

189

190 A vaccine, named Vulnivaccine, which inactivated whole cells, comprises
191 capsular antigens and toxoids of serovar E was administered by immersion for 1 h
192 in three doses at 12 day intervals, and led to good protection in eels (RPS = 60-
193 90%) (Esteve-Gassent et al., 2003). During field trials by prolonged immersion
194 and boosting after 14 and 24-28 days of 9.5 million glass eels in Spain and with
195 parallel work in Denmark, Vulnivaccine led to an RPS of 62-86% (Fouz et al.,
196 2001). With the appearance of a second serotype of *V. vulnificus*, i.e. A, a bivalent
197 vaccine was formulated, and determined to be protective following oral
198 application, by anal and oral intubation, and by intraperitoneal injection (RPS =
199 80-100%) (Esteve-Gassent et al., 2004).

200

201 In human, *V. vulnificus* has been associated with a small but increasing number
202 of serious life-threatening conditions, many stemming from wound infections
203 which become septicaemic (e.g. Mouzopoulos et al., 2008). The onset of
204 symptoms is often abrupt, with a rapid progression to septic shock and thus death
205 despite the intervention of antibiotics, typically doxycycline (Haq and Dayal,
206 2005). In the USA, *V. vulnificus* has been regarded as being responsible for most
207 of the seafood-related deaths since the first report in 1979 (e.g. Oliver, 2005).
208 Indeed, a regular source of infection with the pathogen is the consumption of
209 contaminated raw seafood, notably molluscs (e.g. Drake et al., 2007). Specifically

210 within Louisiana, USA during 1980-2004, 252 cases of *V. vulnificus* infection
211 were reported of which 116 cases followed consumption of crabs (Barton and
212 Ratard, 2006). In Japan between 1999 and 2003, 94 cases were reported in June to
213 November but not at all in winter among 1045 hospitals, albeit with a mortality
214 rate of 75% among those with sepsis (Inoue et al., 2008). With the more serious
215 cases, patients often have underlying problems such as lymphocytic leukaemia and
216 hypogammaglobulinaemia (Barton and Ratard, 2006), immunosuppression,
217 diabetes and kidney disease (Kuo et al., 2007), liver disease (including alcohol
218 related cirrhosis) and secondary skin lesions (cellulitis, oedema and haemorrhagic
219 bulla) (e.g. Miyoshi, 2006). One outcome may be the need for amputation. Thus
220 in the case of some patients who developed necrotizing fasciitis, which is a soft
221 tissue infection, leg amputation proceeded when the excision of diseased tissue
222 failed to halt the infection (Mouzopoulos et al., 2008). Another patient developed
223 osteomyelitis after excision of necrotic soft tissue failed (Mouzopoulos et al.,
224 2008).

225

226 A link between human infections and fish developed as a result of cases in The
227 Netherlands and Israel. However, genetic differences have been identified
228 between eel and human isolates (Wang et al., 2008). In one case in The
229 Netherlands, a 63-year old man was hospitalized with severe pain in his right arm,
230 which became progressively swollen (Veenstra et al., 1992). Also, there were
231 small wounds on his hands. In hospital, the patient deteriorated with widespread
232 skin and muscle necrosis, leading to surgery, which removed the diseased tissue.
233 *V. vulnificus* was isolated from the blood, and determined to resemble a culture
234 recovered previously from eels in a Dutch eel farm (Veenstra et al., 1992).

235 Eventually the patient recovered. Apparently, the day before the onset of
236 symptoms, he had cleaned eels, which had been purchased from a local market. It
237 was thought likely that the man became infected from the eels through open
238 wounds on his hand. The second example concerns a major outbreak that
239 developed in Israeli fish market workers in 1996, and was considered to reflect
240 possible climate change insofar as the period coincided with the hottest ever
241 recorded summer, temperatures (Paz et al., 2007). In fact, the outbreak started 25-
242 30 days after the hottest temperatures had occurred, and concern was expressed
243 that high water temperatures might have led to the emergence of the disease (Paz
244 et al., 2007).

245

246 Because of the serious nature of human disease attributed to *V. vulnificus*, a
247 great deal of attention has focused on understanding the pathogenicity
248 mechanisms. It has been determined that isolates produce a range of pathogenicity
249 factors including a polysaccharide capsule, haemolysin, type IV pili and various
250 proteases, principally a serine protease (Wang et al., 2008) and a 45 kDa
251 metalloprotease, which is regulated through quorum sensing more efficiently at
252 25°C rather than 37°C [this protease may therefore be produced mostly in
253 interstitial tissues in the limbs which have lower temperature than the rest of the
254 body], may well be responsible for skin lesions (Shinoda, 2005; Miyoshi, 2006).
255 Purified preparations of the metalloprotease enhance vascular permeability and
256 induces haemorrhaging through digestion of vascular basement membranes
257 (Miyoshi, 2006). The metalloprotease degrades a number of complex
258 macromolecules, including elastin, fibrinogen and plasma proteinase inhibitors of
259 complement (Shinoda, 2005). Compared to an environmental isolate, a

260 pathogenic culture led to higher cytotoxicity and a concomitant reduction in the
261 number of macrophages in mice during the early stage of infection (Tsuchiya et
262 al., 2007).

263

264 **3. Lower risk organisms**

265 **3.1. *Grimontia hollisae***

266 There is limited information pointing to a role for *G. hollisae* in fish pathology.
267 Specifically, the organism has been recovered from amberjack (*Seriola dumerili*)
268 with vibriosis, i.e. haemorrhagic septicaemia (Ji et al., 2008). Moreover, the
269 organism is occasionally associated in humans with moderate to severe gastro-
270 enteritis linked to the consumption of raw shellfish (Abbott and Janda, 1994). One
271 case led to hypotension and acute kidney failure (Hinestrosa et al., 2007). An
272 even less common occurrence in humans is sepsis (Abbott and Janda, 1994).
273 There is scant information on the pathogenicity mechanism in humans, with the
274 data emphasizing aerobactin which is produced in response to iron starvation
275 (Suzuki et al., 2006)

276

277 **3.2. *Photobacterium damsela* subsp. *damsela***

278 *P. damsela* subsp. *damsela* (= *V. damsela*) was recovered initially from
279 ulcers on the pectoral fin and caudal peduncle of the damselfish, blacksmith
280 (*Chromis punctipinnis*) (Love et al., 1981). The fish were caught in the coastal
281 waters of southern California, USA during August to October, and at Ship Rock,
282 Catalina Island during June to October (Love et al., 1981). This suggests a
283 seasonal distribution in the disease, possibly coinciding with warmer water
284 temperatures and lowered resistance resulting from physiological changes in the

285 host during sexual maturity. The ulcers, which occur particularly in the region of
286 the pectoral fin and caudal peduncle, may reach 5-20 mm in diameter (Love et al.,
287 1981). Histopathology points to the presence of granulomatous ulcerative
288 dermatitis. Subsequently, the organism was recovered from a wide range of other
289 marine animals, including sharks, turbot (*Scophthalmus maximus*), yellowtail
290 (*Seriola quinqueradiata*) and red banded sea bream (*Pagrus auriga*) (see Austin
291 and Austin, 2007). Pathogenicity was confirmed with infectivity experiments
292 using blacksmith in which 4-6 scales were removed, the dermis scarified, and the
293 wound swabbed with 10^7 - 10^8 viable cells of *P. damsela* subsp. *damsela*. At
294 water temperatures of 16.0-16.5°C, the infected fish developed large ulcers within
295 3 days, with death following one day later (Love et al., 1981). In terms of
296 pathogenic mechanisms, a neurotoxic acetylcholinesterase has been described
297 (Pérez et al., 1998). Also, extracellular products (ECPs) with low proteolytic
298 activity have been implicated with cytotoxicity, with the LD₅₀ dose ranging from
299 0.02-0.43 µg of protein g⁻¹ of fish with mortalities occurring 4 and 72 h later (Fouz
300 et al., 1993). In addition, a siderophore-mediated iron sequestering system is
301 thought to be involved in pathogenicity (Fouz et al., 1997).

302

303 The role in human disease stems from the recovery of the organism from
304 wound infections (Love et al., 1981).

305

306 **3.3 *Vibrio alginolyticus***

307 *V. alginolyticus* is pathogenic to fin- and shellfish. In finfish, the organism
308 causes septicaemia in sea bream (*Sparus aurata*), exophthalmia and corneal
309 opaqueness in grouper (*Epinephelus malabaricus*), ascites, lethargy and melanosis

310 in cobia (*Rachycentrib canadum*), and ulcers (see Austin and Austin, 2007). Also,
311 *V. alginolyticus* has caused large-scale mortalities in silver sea bream (*Sparus*
312 *sarba*) in Hong Kong, gilt-head sea bream (*Sparus aurata*) in Spain, cultured
313 black sea bream (*Mylio macrocephalus*) fry in Japan and cobia (se Austin and
314 Austin, 2007). Indeed, Liu et al. (2004) calculated the LD₅₀ as 3.28 x 10⁴ for
315 cobia, and Lee (1995) described an ECP, which was lethal at 0.52 µg g⁻¹ of fish,
316 and contained a 44 kDa toxic protease with a minimum lethal dose of 0.17 µg g⁻¹
317 of fish. ECP, with haemolytic and proteolytic activity, led to an effect on hepatic
318 heat shock protein (Deane et al., 2004). A divalent vaccine containing formalized
319 cells and ECP of *V. alginolyticus* has been developed (Moriñigo et al., 2002).

320

321 *V. alginolyticus* has been associated with shell disease and white spot in shrimp,
322 *Penaeus monodon*, in India and Taiwan, with necrosis in *Macrobrachium*
323 *rosenbergii* larvae in India, and with mass mortalities in carpet shell clam
324 (*Ruditapes decussates*) larvae in Spain (e.g. Lee et al., 1996; Selvin and Lipton,
325 2003). With white spot, the diseased shrimp developed a reddish colour and
326 displayed white spots in the cuticle (Selvin and Lipton, 2003). Isolates have been
327 reported to cause mortalities when administered to shrimp, with the LD₅₀
328 calculated variously as 1.13 x 10⁵ g⁻¹ (Lee et al., 1996) and 5 x 10⁶ colony forming
329 units (CFU) animal⁻¹ (Selvin and Lipton, 2003).

330

331 In humans, *V. alginolyticus* has been implicated with ear, soft tissue and wound
332 infections, of which antibiotic-resistance has been cited as a major issue (Horii et
333 al., 2005). In Denmark from 1987-1992, *V. alginolyticus* was recovered from 17

334 patients with mild ear infections, all of whom had been exposed previously to
335 seawater (Hornstrup and Gahrnhansen, 1993).

336

337 **3.4. *Vibrio fluvialis***

338 *V. fluvialis*-like bacteria, which were identified biochemically and by pulsed
339 field gel electrophoresis, have been implicated as the cause of limp lobster disease
340 of the American lobster, *Homarus americanus* (Tall et al., 2003) and pustule
341 disease of abalone (*Haliotis discus hannai* Ino) in P.R. China (Dalian coast) (Li et
342 al., 1998). With this condition, several sites and different growth stages of the
343 animals were affected with 50-60% mortalities (Li et al., 1998). Experimental
344 infectivity experiments pointed to transmission through lesions in the abalone foot
345 with disease developing rapidly after intramuscular injection (Li et al., 1998).

346

347 An outbreak of food poisoning in India leading to gastro-enteritis during 1981
348 has been blamed on *V. fluvialis* insofar as the stools of 9/14 stool samples revealed
349 the presence of the organism (Thekdi et al., 1990). Also, the taxon has been
350 reported as a cause of wound infection leading to haemorrhagic cellulitis and
351 cerebritis with the source considered being multiple fire-ant stings and wading in
352 brackish water (Huang and Hsu, 2005).

353

354 **3.5. *Vibrio furnissii***

355 *V. furnissii* has been associated albeit tenuously with eel disease in Spain
356 (Austin and Austin, 2007) and with mortalities in tiger shrimp (*Penaeus monodon*)
357 (Sung et al., 2001).

358

359 There has been uncertainty about a role for this organism in human disease.
360 Certainly, it has been recovered from stool specimens, and has been implicated
361 with infantile diarrhoea, and diarrhoeal disease from 16 patients in Brazil (e.g.
362 Magalhaes et al., 1993) and during a cholera surveillance programme in Peru
363 during 1994 (Dalsgaard et al., 1997). The Brazilian isolates were haemolytic and
364 ECPs damaged HeLa cells pointing to the presence of cytotoxins (Magalhaes et al.,
365 1993). Phosphomannomutase (PPM) has been linked to significant intestinal
366 damage within 3-days in mice following oral uptake. In contrast, PPM deficient
367 mutants led to reduced virulence, loss of O-antigen and reduced serum resistance
368 (Kim et al., 2003).

369

370 **3.6. *Vibrio harveyi* (= *V. carchariae*)**

371 An organism named as *V. carchariae* was originally recovered from a dead
372 sandbar shark (*Carcharhinus plumbeus*) with vasculitis, which died at the National
373 Aquarium in Baltimore, USA, in 1982 (Grimes et al., 1984). Infected animals
374 became lethargic, inappetent, were disorientated, and developed necrotic
375 subdermal cysts. Postmortem examination revealed encephalitis, meningitis,
376 kidney necrosis, vasculitis, and unspecified liver and spleen damage. Other
377 isolations were from lemon sharks (*Negaprion brevirostris*) and from gastro-
378 enteritis and heavy mortalities in grouper (*Epinephelus coioides*). A similar
379 organism was isolated from a chronic skin ulcer on a shark (see Austin and Austin,
380 2007).

381

382 In a separate development, *V. harveyi* was recovered from opaque white
383 corneas leading to blindness in common snook (*Centropomus undecimalis*) within

24 h of capture in Florida, USA (Kraxberger-Beatty et al., 1990). In jack crevalle (*Caranx hippos*), deep dermal lesions but not any internal damage were observed in wild specimens also from Florida (Kraxberger-Beatty et al., 1990). Meanwhile, Saeed (1995) attributed *V. harveyi* with mortalities in cultured brown spotted grouper (*Epinephelus tauvina*) and silvery black porgy (*Acanthopagrus cuvieri*) in Kuwait. Then, DNA:DNA hybridization led Ishimaru and Muroga (1997) to realize that pathogenic vibrios recovered from milkfish in Japan were also *V. harveyi*. Moreover, the organism was recovered from eye lesions in the short sunfish (*Mola mola*) in Spain (Hispano et al., 1997), with the reason attributed to the biting behaviour of other fish. In addition, *V. harveyi* has been involved with flounder infectious necrotizing enteritis, in which the abdomen becomes distended and filled with opaque fluid. There was necrosis of the posterior intestine, reddening around the anus, lethargy and inappetance in farmed summer flounder in Rhode Island, USA (Gauger et al., 2006). Also, skin ulcers and haemorrhaging around the mouth and fins was noted in sole (*Solea senegalensis*) in Spain (Zorrilla et al., 2003). The organism has been linked with infectious gastroenteritis (swollen intestine containing yellow fluid) in cultured red drum (*Sciaenops ocelatus*) from Taiwan (Liu et al., 2003).

V. harveyi has developed into a serious pathogen of penaeids, being associated with luminous vibriosis, in which the affected shrimp glow in the dark, and *Bolitas negricans* involving the blockage of the digestive gland with balls of tissue (Austin and Zhang, 2006). The organism has been reported to be a factor in loose shell syndrome and white gut disease in *Penaeus monodon* in India (Jayasree et al., 2006).

409

410 Pedersen et al. (1998) deduced that *V. carchariae* was a junior synonym of *V.*
411 *harveyi*, which was confirmed by Gauger and Gómez-Chairri (2002) from the
412 results of 16S rDNA sequencing. Moreover, a disease, resembling vibriosis and
413 equated to a new species, i.e. *V. trachuri*, occurred in Japanese horse mackerel
414 (*Trachurus japonicus*) especially during summer when the seawater temperature
415 exceeded 25°C (Iwamoto et al., 1995). Infected fish swam erratically, developed
416 melanosis, and developed bilateral exophthalmia and internal haemorrhages.
417 However, the organism is now recognised as synonym of *V. harveyi* (Thompson et
418 al., 2002).

419

420 Certainly because of its importance in aquaculture, emphasis has been placed
421 on improving diagnostics. In this connection, a polymerase chain reaction (PCR)
422 using the *toxR* gene enabled detection of 4.0×10^3 cells ml⁻¹ (including cells
423 within diseased tissues) in <5 h, but not of other vibrios (Pang et al., 2006).

424

425 Prevention of *V. harveyi* infections by vaccination has met with some success.
426 Thus, a bivalent vaccine (with *P. damsela* subsp. *piscicida*) comprising
427 formalized cells and ECP administered by immersion with booster by
428 intraperitoneal injection led to high levels of protection (relative percent protection
429 [RPS] = ~88%) for 4 months (Arijo et al., 2005).

430

431 In terms of human disease, *V. harveyi* (= *V. carchariae*) has been recovered
432 from wound infections, specifically from a leg wound resulting from a shark bite
433 in South Carolina, USA (Pavia et al., 1989).

434

435 **3.7. *Vibrio metschnikovii***

436 *V. metschnikovii* is regarded as potentially pathogenic to larval giant clams,
437 *Tridacna gigas* with infection leading to general disintegration of the tissues and
438 total mortality after exposure to 10^7 bacteria ml^{-1} (Sutton and Garrick, 1993). The
439 organism has been recovered from raw fish and shellfish in markets and shops,
440 and is deemed to pose a risk to human health (Buck, 1991) with pathogenic factors
441 reflecting the presence of haemolysins and verotoxins (Matte et al., 2007).

442

443 **3.8. *Vibrio mimicus***

444 *V. mimicus* has been considered as a secondary invader of red claw crayfish
445 (*Cherax quadricarinatus*), which were weakened by poor management,
446 overcrowding and/or adverse water quality (Eaves and Ketterer, 1994). The
447 association with human illness is in connection with food borne infections leading
448 to gastro-enteritis and diarrhoea in which an enterotoxic haemolysin is produced
449 that targets intestinal epithelia cells effecting ion transport (Takahashi et al., 2007;
450 Mizuno et al., 2009).

451

452 **4. Future perspectives**

453 New pathogenic *Vibrio* species are frequently described. Therefore, the range
454 of zoonotic organisms may well increase. Diagnosticians need to be vigilant and
455 aware of this possibility. Certainly, the seriousness of *V. vulnificus* as a pathogen
456 of both aquatic animals and humans cannot be overstated, and the number of cases
457 of disease attributed to this organism seems likely to grow. The involvement of
458 vibrios with disease has prompted excellent work particularly in the realms of

ecology, pathogenicity and disease control strategies; this trend may be expected to continue.

5. Conflict of Interest Statement

The author does not have any conflict of interest. The views expressed in the article are those of the author, and they have not been influenced by any external interest.

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Table 1

Differential characteristics of zoonotic vibrios and their association with human and animal diseases (based on Farmer et al., 2005).

Characteristic:	<i>G. hollisae</i>	<i>P. damsela</i> subsp. <i>damsela</i>	<i>V. alginolyticus</i>	<i>V. harveyi</i>	<i>V. cholerae</i>	<i>V. fluvialis</i>	<i>V. furnissii</i>	<i>V. metschnikovii</i>	<i>V. mimicus</i>	<i>V. parahaemolyticus</i>	<i>V. vulnificus</i>
Oxidase production	+	+	+	+	+	+	+	-	+	+	(+)
Arginine dihydrolase	-	+	-	-	-	+	+	D	-	-	-
Lysine decarboxylase	-	D	+	+	+	-	-	-	+	+	+
Gas from glucose	-	+	-	-	-	-	+	-	-	-	-
Indole production	+	-	+	+	+	D	-	-	+	+	+
Voges	-	(+)	(+)	-	+	-	-	+	-	-	-

Proskauer
reaction

Utilization of cellobiose	-	-	-	+	-	D	D	-	-	-	(+)
Growth in 0% NaCl	-	-	-	-	+	+	+	-	+	-	-
Growth in 0.3% NaCl	-	D	-	-	+	+	+	+	+	-	+
Growth in 12% NaCl	-	-	+	-	-	-	(-)	-	-	-	-
Cause of wound infections in humans		+	+	+		+					+
Cause of gastro- intestinal	+				+	+	+	+	+	+	+

disease in
humans

Cause of fish disease	+	+	+	+	+		+			+	+
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Cause of invertebrate disease			+	+	(+)	+		+	+	+	+
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+, - and D correspond to 100%, 0% and 21-79% of positive results, respectively. (+) and (-) correspond to $\geq 80\%$ and $\leq 20\%$ of positive results.