

ACID SULFATE SOILS IN INTERTIDAL MOSQUITO BREEDING HABITATS AND IMPLICATIONS FOR HABITAT MODIFICATION

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ABSTRACT. Public concern about the use of chemicals for mosquito control in coastal Australia has led to the development of physical habitat modification methods that aim to reduce mosquito populations to acceptable levels. Habitat modification methods include runnels (depth < 0.30 m) and ditches (depth > 0.50 m). During excavation for habitat modification, a risk of exposure of acid sulfate soils may exist. Acid sulfate soils are soils that contain iron sulfides, in particular pyrite (FeS₂), and produce sulfuric acid when exposed to air. These soils occur predominantly in coastal lowland areas that are also prime mosquito breeding habitats. The paper discusses the problem and illustrates the application of survey methods that facilitate wise decision making and management of intertidal wetlands.

KEY WORDS Salt marsh, iron sulfides, sulfuric acid, runnelling, ditching

INTRODUCTION

The human population in Australia is concentrated around the coast, particularly along the eastern seaboard. These areas contain large expanses of intertidal wetlands, including salt marshes that breed large populations of mosquitoes, including the vectors of arbovirus diseases such as Ross River virus. In recent years, the mosquito problem in Australia has become of increasing concern because the incidence of Ross River virus disease is increasing (Curran et al. 1997) and the growing population is placing higher demands for residential and tourism development near coastal mosquito breeding habitats.

Traditionally, mosquito control in Australia has relied on chemical treatment, mainly the application of larvicides to breeding areas. Concern exists over the long-term and indirect effects of this form of control. Runnelling is an alternative method developed in the mid-1980s as a simple form of open marsh water management (Hulsman et al. 1989; Dale et al. 1993, 1996). Runnelling modifies the habitat via a network of very shallow, broad, spoon-shaped (parabolic) channels or runnels with a maximum depth of 0.30 m connecting otherwise isolated pools to each other and to a tidal source. The impacts are relatively minor, compared to other forms of habitat modification (Dale and Hulsman 1991; Dale et al. 1993, 1996). Another form of habitat modification method is ditching, as part of open marsh water management. Ditches are larger structures than runnels. Ditches may be up to 1.65 m deep, and are narrow and steep sided. In Australia ditching is only contemplated in areas that are not suited to runnelling.

One ground for concern in habitat modification that involves digging runnels or ditches is that a risk of exposing acid sulfate soils may occur during excavation. Acid sulfate soils are soils that contain iron sulfides (in particular pyrite [FeS₂]) and pro-

duce sulfuric acid when exposed to air (Melville et al. 1991; Pons et al. 1982). They may be potential acid sulfate soils (PASS) or actual acid sulfate soils (AASS). Potential acid sulfate soils contain iron sulfides (FeS₂) and have the potential to generate sulfuric acid when exposed to air. They have a soil pH of less than 3 when treated with 30% hydrogen peroxide (Powell et al. 1996), and/or pyrite S >0.01% to >0.05%, depending on soil texture (Blunden and Naylor 1995), and/or pH decrease > 2 units after oxidation with 30% hydrogen peroxide ($\Delta\text{pH} = \text{pH}_w - \text{pH}_{ox}$, where pH_w = soil pH in water and pH_{ox} = soil pH after treatment with 30% hydrogen peroxide) (Ahern and Blunden 1997). Actual acid sulfate soils have already been disturbed or exposed to the air, allowing the pyrite to oxidize to form sulfuric acid. That is, AASS already have a soil pH in water of less than 4 (Dent 1986, Isbell 1996). These soils may still have potential to produce further acid if left exposed. Potential acid sulfate soils and AASS are widespread in the coastal eastern Australia, at elevations <10 m Australian height datum (approximately sea level) (Willet and Walker 1982; Saffigna et al. 1996, 1997), and this includes prime mosquito breeding habitats. Rey et al. (1992) reported pore-water sulfide concentrations ranging from 0 to 1,640 µg/liter in salt marshes in east-central Florida. The associated pH of water in these systems was usually above pH 5.5, suggesting no acidity problems. Acidity may be influenced not only by the inherent nature of the substrate, especially if composed of marine sediments, but also by vegetation processes, particularly in mangrove habitats (Carlson et al. 1983). Acid sulfate soils are widely distributed throughout the world (Dent 1986, Dent and Pons 1995).

The impact of acid sulfate waters in estuarine systems is likely to be adverse (Soukup and Portnoy 1986, Greene and Van Handel 1992). The acid and associated toxic by-products may lead to fish kills, damage to vegetation, and destruction of steel pipe and concrete infrastructure. Acid sulfate waters represent a major environmental risk if managed inappropriately (Blunden and Naylor 1995;

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Naylor et al. 1995). In the Northern Hemisphere, acid sulfate soils have already caused the demise of local fisheries while not providing effective mosquito control because the mosquitoes were tolerant of the low pH levels that followed ditching (Soukop and Portnoy 1986). In contrast to the findings of Soukop and Portnoy, Wolfe (1996) noted that surface pH increased in some ditching projects. Relatively little research seems to have been reported on the impact of water management in tidal marshes on pH levels in Australia.

Nevertheless, the findings are a cause for concern when applied to the Australian situation in which large areas of mosquito breeding wetlands overlying acid sulfate soils are close to human populations as well as being linked to important commercial fisheries resources. A risk is perceived that habitat modification may disturb currently benign PASS, creating environmentally damaging AASS and adversely affecting fisheries resources if acid sulfate soils are unmanaged (Sammut et al. 1996).

The aim of the research was to characterize the horizontal and vertical distributions of AASS and PASS in part of southeastern Queensland and discuss their implications for habitat modification.

MATERIALS AND METHODS

Study areas

The 2 main study areas, Noosa and Maroochy, represented a range of locations over a distance of approximately 50 km of coastline on the Sunshine Coast of Queensland (Fig. 1).

Noosa

Experimental area: The experimental area was situated in a tidal marsh-mangrove ecosystem near Tewantin, approximately 6 km west of Noosa and 112 km north of Brisbane, in coastal southeastern Queensland. On October 16, 1996, a field sampling program was initiated at 2 sites and on May 7, 1997, at 1 site, to characterize the horizontal and vertical distributions of AASS and PASS. The study area is characterized by predominantly summer rainfall.

Site 1 was a tidal marsh-mangrove ecosystem, with an approximately 500-m transect adjacent to a selective ditch constructed for mosquito control. The ditch traversed the site in a northeasterly direction from the elevated portion of the marsh, where the dominant vegetation was marine couch (*Sporobolus* spp.) and *Casuarina* spp., toward Lake Cooroibah where the dominant vegetation was mangroves.

Site 2 was an approximately 50-m transect along a 1-m high, 17-year-old, stockpile of marine sediment adjacent to a drain that had been excavated in 1979 to form a channel through part of the mangrove ecosystem. The drain was not part of any

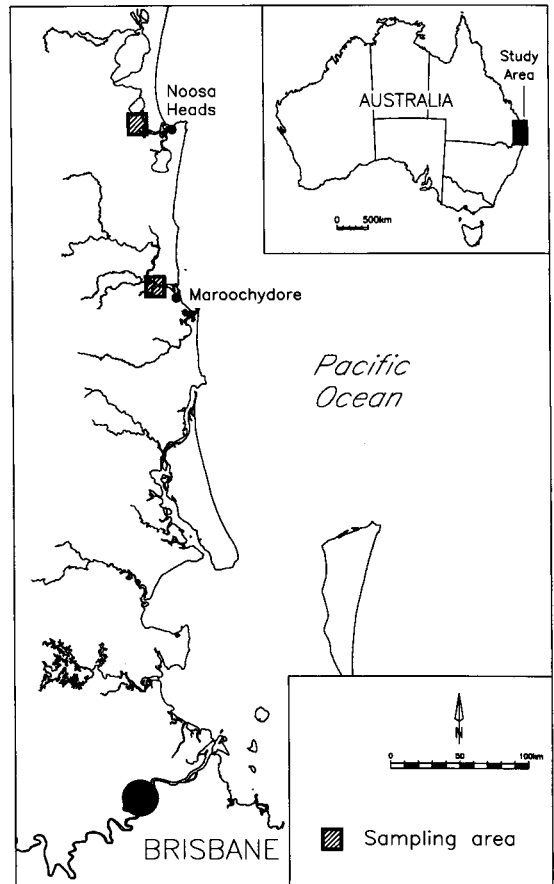


Fig. 1. Map showing the main study areas (Noosa and Maroochy) on the Sunshine Coast of Queensland, Australia.

mosquito control strategy. However, it represented an opportunity for us to assess the potential for acid generation associated with major disturbance of estuarine sediments in tidal marsh-mangrove ecosystems. Site 2 was located approximately 200 m from site 1.

Site 3 was several kilometers away from sites 1 and 2 on the shores of Lake Doonella, with sampling in the salt marsh adjacent to the mangrove fringe.

Sampling methodology and analysis: Samples of soils were taken from a number of locations at the 3 sites, using a spade or an auger. Soil was excavated in layers or soil horizons to 120 cm or until an impenetrable layer of coffee rock (indurated sand) was reached.

Observations were made of soil profile morphology, soil color, texture, moisture content, and indicators of acid sulfate soil (e.g., jarosite or goethite mottling, color variations, gypsum nodules, and so on) and root distribution. Representative 1-kg subsamples of the soil were stored under refrigerated conditions before analysis.

Maroochy

Experimental area: The experimental area was located within Maroochy Shire and included a number of ecosystems. On April 10 and 11, 1997, a field sampling program was initiated at 4 sites to characterize the horizontal and vertical distributions of AASS and PASS.

Site 1 was located off Godfrey's Road near the Maroochy River. The area was ca. 6 ha, with less than 20% to be runnelled, with a transect length of ca. 100 m. The 3 sampling locations in site 1 were across an extratidal saltwater couch-mangrove ecosystem. The dominant species of mangrove in this area was *Avicennia marina*, and marine couch (*Sporobolus virginicus*) was the predominant ground cover vegetation.

Site 2 was located between cane land and the Maroochy River near Bli Bli. The ca. 95-ha area consisted of 90% cane fields, with proposed runnels covering 5% maximum and existing drains covering 5%. The 7 sampling locations in site 2 were located across a supratidal saltwater couch-*Casuarina* marsh, according to the planned placement of runnels for mosquito control. The area also supported mangroves, mostly *Avicennia* sp., and numerous small depressions were also present.

Site 3 was located adjacent to site 2 between cane land and the Maroochy River. The ca. 112-ha area consisted of 85% cane fields, with proposed runnels covering 5% maximum and existing drains covering 10%. The 6 sampling locations in site 3 were located along a transect across a supratidal saltwater couch-*Casuarina* marsh ecosystem. Site 3 had similar vegetative cover to site 2 but with fewer mangroves and pools present.

Site 4 was located near Diddillibah across Eudlo Creek and access was gained via boat. The area was ca. 24 ha (transect length less than 100 m). Three sampling locations were included in site 4 along a transect in an extratidal *Sporobolus-Phragmites-Casuarina* ecosystem. The vegetation here was quite different from that of the previous 3 areas with dense stands of *Casuarina* trees and *Phragmites* almost 2 m tall. Marine couch (*Sporobolus*), more than 0.30 m high, was also much taller than in the previous 3 areas.

Sampling methodology and analysis: A core sample was taken at each site to a depth of 90 cm. This was done using a 1-m-long 5-cm-diameter tapered open-faced gouge auger. This was pushed into the ground and then twisted as it was removed to retain the core sample within the cylindrical tube. The tapered tube prevents the soil from falling out of the auger. Soil samples were taken from the core sample at depths of 30, 60, and 90 cm. Each of these were tested for pH in water and pH in hydrogen peroxide in the field and the remainder of the samples were taken back to the laboratory to be further analyzed.

Laboratory analysis

In the laboratory, the samples were oven dried for 48 h at 85°C and ground to <0.5 mm in a Christy Hunt (Christy Hunt Engineering, Atlas Works, Earls Colne, U.K.) Cross Beater Mill fitted with a stainless steel BS mesh of 0.5 mm (Christy Hunt Engineering). This final grind followed an initial grind to <2.0 mm and then subsequently to <1.0 mm. Subsamples were analyzed for pH in water (pH_w , 1:5 soil: water), pH after treatment with 30% hydrogen peroxide (pH_{ox}), and peroxide oxidizable sulfuric acid acidity as an index of pyrite S (Ahern et al. 1996). If pH_w is <4, the presence of actual acid sulfate soil is indicated; if pH_{ox} is <3 or if the difference between pH_w and pH_{ox} is >2, the presence of potential acid sulfate soil is indicated.

Data analysis

Data analysis involved simple descriptive statistics and analysis of variance to test for between-site differences and for relationships between the indicators and depth.

RESULTS

No AASS was found except where the sediment had been disturbed (at the 17-year-old ditch site in Noosa). No significant differences were found between the sites in pH_{ox} and the difference between pH_w and pH_{ox} ($P < 0.001$), although both were indicative of acid sulfate soils, with a mean value of 2.97 (SD = 1.20) and 2.92 (SD = 1.56), respectively. Significant differences were found between sites in terms of pH_w , but overall the mean, at 5.89 (SD = 0.96), was well above the level of 4, which defines AASS.

Highly significant relationships were found between depth and the 3 measures ($P < 0.001$), as shown in Table 1. The relationship is illustrated in Figs. 2-4. The pH_w tended to increase with depth; a strong inverse relationship existed for pH_{ox} with a marked decrease in pH with increasing depth. Conversely, the difference between pH_w and pH_{ox} increased with depth. The last 2 results indicated that the risk of encountering PASS increased as depth increased.

DISCUSSION

At all sites where the ditches had been planned or installed for mosquito control to increase tidal flushing, no AASS were present. However, AASS were present where a drain had been excavated to a depth of 1 m (not for mosquito control purposes) and the spoil had been stockpiled on the bank.

These findings have major implications for the sustainable management of the coastal ecosystems. With respect to runnelling, because the runnels are shallow and generally maintain the wetness of the

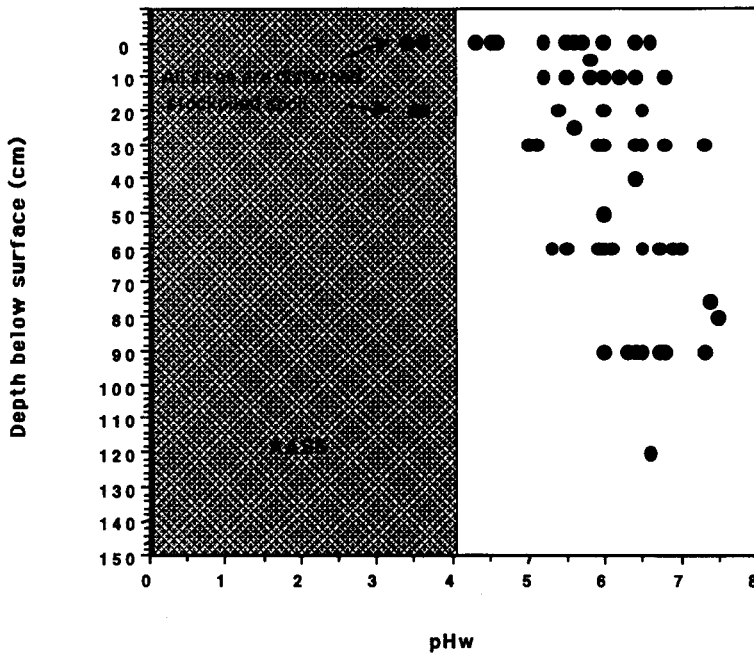


Fig. 2. Distribution of actual acid sulfate soils at study sites, as indicated by soil pH in water (pH_w) ($pH_w < 4$).

site (Dale et al. 1993), the acid sulfate problem should not be a major one. Nevertheless, if PASS are close to the surface, special care would need to be taken to avoid problems, such as monitoring pH and using lime as a neutralizing agent or ensuring access of seawater as a buffer.

Analysis of the results also indicated that to rely on the pH_w would be misleading, because most places with acceptable levels did have potential acid sulfate problems when the more rigorous tests were done for pH_{ox} and the difference between pH_w and pH_{ox} . In addition, the results for measurement

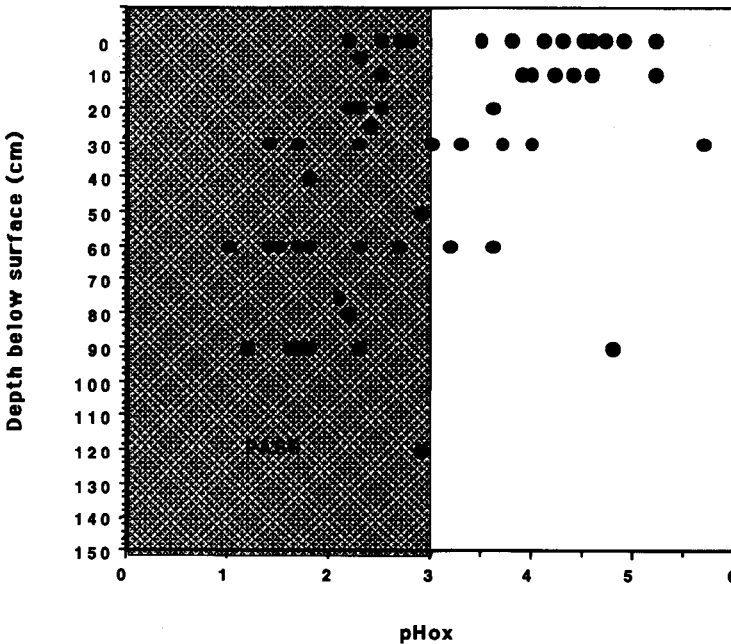


Fig. 3. Distribution of potential acid sulfate soils at study sites as indicated by soil pH after treatment with 30% hydrogen peroxide (pH_{ox}) ($pH_{ox} < 3$).

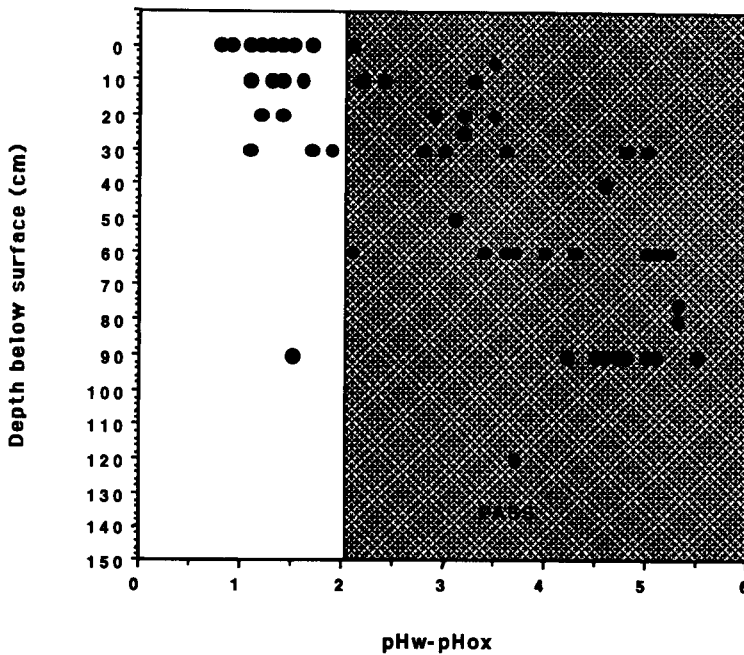


Fig. 4. Distribution of potential acid sulfate soils at study sites as indicated by the change in soil pH after treatment with 30% hydrogen peroxide ($\text{pH}_w - \text{pH}_{ox} > 2$).

of pyrite S confirmed that PASS were present, as indicated by the other measurements.

Analysis of the results also indicated that, for the sites tested, the risk of acid sulfate soil problems increases with depth. However, this is not necessarily likely to be true in all instances because no generally applicable reason exists for why a particular pattern of PASS distribution should occur with depth, because many factors influence PASS formation. Of course, as a general rule in intertidal areas, the regular wetting and drying cycles would be expected to result in oxidation of pyrite in the surface soils, whereas the deeper soils would remain anaerobic. For this reason, a general pattern of increasing PASS with depth may occur in intertidal areas.

Implications exist for the type of mosquito control structures that would be acceptable in areas that have PASS increasing with depth. Runnelling, with its shallow channels (depth < 0.30 m), will generally not disturb acid sulfate soil at levels found

in the study area. However, ditches may well disturb pyritic sediments and care would need to be taken to avoid problems. Avoidance would be achieved by a design that retains water, for example, one with shallow sills to the tidal source that would hold water in the deeper ditches, or alternatively by continuing with chemical treatment. Mitigation could be achieved by monitoring pH and adding lime or other neutralizing agents to the ditches if pH falls to some threshold level (e.g., 5). It must also be borne in mind that seawater with a relatively high pH is a natural buffer to acidity and the problem may be of less concern than, for example, in freshwater environments. Relevant too are the findings of Rey et al. (1992). They found that acid sulfide concentrations were higher in managed systems than in natural ones and that concentrations varied by season and stage of water management. Applying their findings as relevant to the Australian case, opening up newly constructed ditches during high tides to minimize oxidation by exposure to air and to maximize dilution of any acid waters with seawater would be wise.

Table 1. Analysis of variance results showing the relationship between pH_w , pH_{ox} , $\text{pH}_w - \text{pH}_{ox}$, and depth at all sites.¹

Variable	F	df	P
pH_w	22.1563	1,62	<0.001
pH_{ox}	27.4456	1,62	<0.001
$\text{pH}_w - \text{pH}_{ox}$	76.4896	1,62	<0.001

¹ pH_w soil pH in water; pH_{ox} , soil pH after treatment with 30% hydrogen peroxide.

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REFERENCES

- Ahern, C. R. and B. Blunden. 1997. Sampling and analysis procedure for lowland acid sulfate soils (ASS) in Queensland. Draft Version 3.47. October 15, 1997. Department of Natural Resources, Indooroopilly, Queensland, Australia.
- Ahern, C. R., A. McElnea, W. Hicks and D. E. Baker. 1996. A combined routine peroxide method for analysing acid sulfate soils. Proc. 2nd Nat. Conf. on Acid Sulfate Soils. 1996 September 5-6; Coffs Harbour, NSW, Australia. Australia: Robert J. Smith and Associates and ASSMAC. p. 82-87.
- Blunden, B. and S. Naylor. 1995. Assessing and management of acid sulfate soils. Guidelines for land management in New South Wales coastal areas. EPA 95/41. Environmental Protection Authority, Chatswood, New South Wales. Australia.
- Carlson, P. R., L. A. Yarbro, C. F. Zimmermann and J. R. Montgomery. 1983. Pore water chemistry of an overwash mangrove island. *Fl. Sci.* 46:239-249.
- Curran, M., B. Harvey, S. Crerar, G. Oliver, R. D'Souza, H. Myint, C. Rann and R. Andrews. 1997. Australia's notifiable diseases status. 1996 annual report of the National Notifiable Diseases Surveillance system. *Commun. Dis. Intell. (Aust.)* 21:281-307.
- Dale, P. E. R. and K. Hulsman. 1991. A critical review of salt marsh management methods for mosquito control. *Crit. Rev. Aquat. Sci.* 3:281-311.
- Dale, P. E. R., A. L. Chandica and M. Evans. 1996. Using image subtraction and classification to evaluate change in subtropical intertidal wetlands. *Int. J. Remote Sens.* 17(4):703-719.
- Dale, P. E. R., P. T. Dale, K. Hulsman and B. H. Kay. 1993. Runnelling to control saltmarsh mosquitoes: long-term efficacy and environmental impacts. *J. Am. Mosq. Control Assoc.* 9:174-181.
- Dent, D. 1986. Acid sulfate soils: a baseline for research and development. ICRI Publication 39. ICRI, Wageningen, The Netherlands.
- Dent, D. L. and L. J. Pons. 1995. A world perspective on acid sulphate soils. *Geoderma* 67:263-276.
- Greene, L. E. and E. Van Handel. 1992. Sulfide sensitivity in fishes of the Indian River Lagoon, Florida. *J. Am. Mosq. Control Assoc.* 8:95-96.
- Hulsman, K., P. E. R. Dale and B. H. Kay. 1989. The runnelling method of habitat modification: an environment focussed tool for salt marsh management. *J. Am. Mosq. Control Assoc.* 5:226-234.
- Isbell, R. F. 1996. The Australian soil classification series: Australian soil and land survey handbook series, Volume 4. CSIRO Publishing, Melbourne, Australia.
- Melville, M. D., I. White and I. R. Willett. 1991. Problems of acid sulfate soils and water degradation in Holocene pyritic systems, pp. 89-94. In: G. Brierley and J. Chappell (eds.). *Applied Quaternary studies*. Department of Biogeography and Geomorphology, Australian National University, Canberra, Australia.
- Naylor, S. D., G. A. Chapman, G. Atkinson, C. L. Murphy, M. J. Tulau, T. C. Flewin, H. B. Milford and D. T. Morand. 1995. Guidelines for the use of acid sulfate soil risk maps. Soil Conservation Service of New South Wales, Sydney, Australia.
- Pons, L. J., N. van Breeman and P. M. Driessen. 1982. Physiography of coastal sediments and development of potential acidity, pp. 1-18. In: *Acid sulfate weathering—part 1*. Special Publication 10, Soil Science Society of America, Madison, WI.
- Powell, B., C. R. Ahern and C. D. Smith. 1996. Mapping acid sulfate soils in Queensland. Proc. 2nd Nat. Conf. Acid Sulfate Soils. 1996 September 5-6; Coffs Harbour, NSW, Australia. Australia: Robert J. Smith and Associates and ASSMAC. p. 33-37.
- Rey, J. R., J. Shaffer, T. Kain, R. Stahl and R. Crossman. 1992. Sulfide variation in the pore and surface waters of artificial salt-marsh ditches and a natural tidal creek. *Estuaries* 15:257-269.
- Saffigna, P. G., K. M. Hey and P. E. R. Dale. 1997. Acid sulfate soils and mosquito control in coastal Australia, pp. 252-257. In: B. H. Kay, M. D. Brown and J. G. Aaskov (eds.). *Arbovirus research in Australia*, Volume 7.
- Saffigna, P. G., G. L. Holland, A. S. Joyce, B. A. Cordwell and N. R. Covey. 1996. Distribution of pyrite in silt, sand, gravel, soil and wood in a soil profile near Yandina, Queensland. Proc. 2nd Nat. Conf. Acid Sulfate Soils. 1996 September 5-6; Coffs Harbour, NSW, Australia. Australia: Robert J. Smith and Associates and ASSMAC. p. 59-60.
- Sammut, J., R. B. Callinan and G. C. Fraser. 1996. An overview of the ecological impacts of acid sulfate soils in Australia. Proc. 2nd Nat. Conf. Acid Sulfate Soils. 1996 September 5-6; Coffs Harbour, NSW, Australia. Australia: Robert J. Smith and Associates and ASSMAC. p. 140-145.
- Soukup, M. A. and J. W. Portnoy. 1986. Impacts from mosquito control-induced sulfur mobilisation in a Cape Cod Estuary. *Environ. Conserv.* 13:47-50.
- Willett, I. R. and P. H. Walker. 1982. Soil morphology and distribution of iron and sulfur fractions in a coastal floodplain toposequence. *Aust. J. Soil Res.* 20:283-294.
- Wolfe, R. J. 1996. Effects of open marsh water management on selected tidal marsh resources: a review. *J. Am. Mosq. Control Assoc.* 12:701-712.